MARINE ECOSYSTEM OVERVIEW OF THE BEAUFORT SEA LARGE OCEAN MANAGEMENT AREA (LOMA)

Cover Photos: photographs provided by Bob Fudge, Department of Fisheries and Oceans.

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OF THE BEAUFORT SEA
LARGE OCEAN MANAGEMENT AREA (LOMA)**

Prepared for
Department of Fisheries and Oceans

by

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Executive Summary

This marine ecosystem overview of the Beaufort Sea Large Ocean Management Area (LOMA) encompasses the Inuvialuit Settlement Region (ISR), and is intended to provide a description of the biological, chemical, and physical characteristics of the area as background towards the development of a marine area planning, protection, and monitoring plan. The geographic scope of the overview comprises the Canadian waters of the Beaufort Sea, associated islands, estuaries and freshwater influences, and major interconnections between important marine and terrestrial ecosystems within the ISR. The ISR is bounded by the 110th meridian to the east and the 140th meridian to the west, extending north from approximately the 67th to the 80th parallel.

Ultimately, this overview is intended to provide information for the development of a Department of Fisheries and Oceans (DFO) web-site and a management plan for the region of interest, in accordance with Canada's Oceans Act (1997). Under the Ocean's Act agenda, DFO's mandate includes: (1) the development of an ocean governance model; and, (2) expansion of existing Beluga Management Plan and community conservation plans. Towards meeting these objectives, DFO is currently developing a framework for resource management in nearshore and offshore areas in the western Arctic. The ultimate goal of this undertaking is the development of a broader Integrated Management Project.

The current report consists of an update and expansion of the geographic scope of the physical, chemical and biological environments of a report prepared in 2001 for the Oceans Sector of the Department of Fisheries and Oceans (DFO), which provided an ecosystem overview of the southeastern Beaufort Sea, including a description of the physical, chemical and biological environment, a discussion of ecosystem stressors, monitoring initiatives and knowledge gap analysis. DFO subsequently requested the inclusion of traditional knowledge, which has been reproduced in full in the current report and is highlighted.

At the request of the Beaufort Sea Integrated Management Planning Initiative Committee Inuvialuit traditional knowledge has been integrated into the overview. However, few studies have been conducted with the objective of documenting traditional knowledge of the subjects dealt with in this report, or that present their results in a form that is easily integrated into this report.

The environmental descriptions include the geology and permafrost of the coastal region, coastal processes and physical oceanography, and biology. The biology of the area that is of interest is discussed with respect to plankton, bacterial production, benthic invertebrates, aquatic macrophytes, fish, marine mammals, coastal waterfowl and seabirds, and energy flow and food webs. Within each group, topics discussed include descriptions of major taxa present in the area, species distribution, abundance/productivity, habitat use, reproduction, and migration, where applicable.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMAP	Arctic Monitoring and Assessment Programme
B[a]P	benzo[a]pyrene
CHL	chlordane-related compounds
DDE	dichlorodiphenyldichloroethane
DDT	dichlorodiphenyltrichloroethane
DFO	Fisheries and Oceans Canada
EMAN	Ecological Monitoring and Assessment Network
FJMC	Fisheries Joint Management Committee
GSC	Geological Survey of Canada
HCB	hexachlorobenzene
HCH	hexachlorocyclohexane
ICRC	Inuvialuit Cultural Resource Centre
IGC	Inuvialuit Game Council
IRC	Inuvialuit Regional Corporation
OC	organochlorine
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyls
PCC	polychlorinated camphene
POP	persistent organic pollutant
ppt	parts per thousand
TBT	tributyltin

1.0 INTRODUCTION

In 2001, the Oceans Sector of the Department of Fisheries and Oceans (DFO) undertook the completion of an ecosystem overview of the southeastern Beaufort Sea and contracted North/Suth Consultants Inc. to produce a draft report. Subsequent to this, DFO requested the inclusion of traditional knowledge in the draft document.

Currently, DFO has adopted a framework for integrated Oceans management, which is based on the examination of Large Ocean Management Areas (LOMA's) in each of Canada's oceans. Within this framework, the Beaufort Sea is considered a LOMA. In recognition of this new approach and framework for Oceans management, DFO requested that the ecosystem overview produced for the southeastern Beaufort Sea be expanded to include a larger geographical area, including the Inuvialuit Settlement Region (ISR), and to undertake an update of scientific literature produced since production of the draft report in 2001. The present document represents this expansion and is intended to position DFO to move forward with its Integrated Management Framework in the western arctic.

The marine ecosystem overview of the Beaufort Sea LOMA, which encompasses the Inuvialuit Settlement Region (ISR), presented herein, is intended to provide a description of the biological, chemical, and physical characteristics of the area as background towards the development of marine area planning, protection, and monitoring initiatives. The geographic scope of the overview comprises the Canadian waters of the Beaufort Sea, its associated islands, estuaries and freshwater influences, and major interconnections between important marine and terrestrial ecosystems within the ISR. The ISR is bounded between the 110^{th} and 140^{th} meridian, north from the 67^{th} to the 80^{th} parallel, and includes the Mackenzie River Delta (Figure 1).

Specifically, this overview provides an indication of the ecological significance of the Beaufort Sea and nearshore areas, including the Mackenzie River Delta, in a local context (i.e., within the Beaufort Sea, within the Canadian Arctic). Inuvialuit traditional knowledge has been integrated into the overview from available written sources so that local expertise can be utilized. Potential indicators for monitoring the condition of the region are discussed, knowledge gaps are identified, and a framework for the development of a community-based monitoring program is presented.

Ultimately, this overview is intended to provide the ecological context for the development of coastal management plans for the region of interest, in accordance with Canada's Oceans Act (1997). Under the Ocean's Act, DFO's mandate includes: (1) the development of an ocean governance model; and, (2) expansion of existing Beluga Management Plan and community conservation plans. Towards meeting these objectives, DFO is currently developing a framework for resource management in nearshore and offshore areas in the western Arctic. This document will also assist in developing ecosystem objectives and indicators for future monitoring in the region.

1.1 DESCRIPTION OF THE LITERATURE REVIEWED

This document integrates both published scientific literature, and traditional knowledge. These knowledge sources compliment each other, providing "two ways of knowing". The Beaufort Sea Integrated Management Planning Initiative (BSIMPI) Working Group believed that in spite of the difficulties of integrating these sources of knowledge, it was important to provide the most comprehensive understanding of the Beaufort Sea ecosystem in one document. In addition to published literature, this overview also incorporates observations of experts as personal communication.

Although expanding geographic scope of the study area implies inclusion of the entire Canadian basin of the Beaufort Sea, many of the references within the updated document continue to pertain to the eastern and southeastern Beaufort. Much of the research resulting in published literature has, and continues to be conducted in association with the nearshore (eastern and southeastern) environment of the Beaufort, rather than its main body. Many of the marine biota, especially in the upper trohpic levels, is simply not adapted to the unbroken ice environment of polar pack ice. Additionally, research in the severe ice environment of the Beaufort Sea main body is a daunting task that presents difficult and expensive logistics. The recent use of remote sensing, satellite-linked transmitters, and ice-breaking research vessels for studies of oceanic water exchange, sea ice dynamics, and marine mammal movements are examples of the methods required to overcome the difficulties of study in the polar ice environment.

This document and the literature cited within reflects an expansion to include information pertaining to the physical systems (geological, atmospheric, oceanographic) and the biological components associated with the larger study area of the Beaufort Sea Large Ocean Management Area (broadly defined by the borders of the Inuvialuit Settlement Region). In light of the increased interest in oil, gas, and mineral exploration and development in the Beaufort Sea area, there is, and will continue to be a constant flow of new information pertinent to this LOMA. Several national and international scientific studies related to climate change (e.g., Canadian Arctic Shelf Exchange Study) are currently underway and will provide new and valuable information on the ecosystem of the Beaufort Sea. Recently, marine mammal and fish studies have been initiated within the ISR, often in a government/non-government partnership, reflecting shared responsibility in resource management. As well, the Community Conservation Plans which have been drafted for the Inuvialuit Settlement Region are intended to be reviewed and updated regularly. As a result, there will always be opportunities to update the information contained within the Ecosystem Overview Report for the Beaufort Sea Large Ocean Management Area.

1.1.1 Integrating Inuvialuit Knowledge into this Report

The Inuvialuit Cultural Resource Centre (ICRC) was asked to integrate previously documented sources of Inuvialuit traditional knowledge into this ecosystem overview. The request came from the Beaufort Sea Integrated Management Planning Initiative (BSIMPI) Working Group which also consists of a Traditional Knowledge Sub-Group composed of three Inuvialuit members. The latter group reviewed an initial list of resources to be reviewed. ICRC suggested that traditional knowledge would be most effectively placed in a separate section of the report. However, the BSIMPI Working Group requested that this material be incorporated directly into the body of the report. This approach has the advantage of ensuring that traditional knowledge is assessed directly with the scientific information, but can present difficulties in context and summarization.

The definition of traditional knowledge used here is "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission" (Berkes 1999:8). By the time the literature review and integration were completed, it was clear that we had integrated a combination of both traditional and non-traditional knowledge that could collectively be referred to as "Inuvialuit knowledge".

This review suggests that Inuvialuit have contributed much knowledge over the years to numerous researchers, such as those working on land use, conservation and wildlife management. Researchers have integrated this information in the design and corroboration of their projects which have led to a better understanding of the environment and use of the Inuvialuit Settlement Region. Although Inuvialuit knowledge has often been integral to these studies, little of it has been reported as a separate body of knowledge. In fact, we found few studies focussing specifically on the topics of interest.

The Resources Reviewed

The review included a number of oral history and oral traditions reports and transcripts relevant to the area (Cockney 1997, Hart and Cockney 1998, Hart 2002, 2003, Nagy 1994, Nasogaluak and Cockney 1996). Although these resources present interesting and valuable insights into aspects of Inuvialuit life, land use and history, they yielded little specific information for this overview. For example, questions about animals were often dealt with using general terms like *iqaluit* for any kind of fish, or *tingmiluit* for geese, rather than specific words like *iqalukpiit* for Dolly Varden or *tingmiat* for white-fronted geese (yellow-legs). Also, the information presented is primarily historical and does not fit easily into a state-of-knowledge-type report.

A number of published and unpublished reports are included in the overview (Byers 1993, Byers and Roberts 1995, Dressler et al. 2001, Freeman 1976, 1997, Freeman and Stevenson 1995, Usher et al. 1995). A study by Byers (1993) included interviews with Gwich'in, so it was impossible to identify what information was specific to Inuvialuit.

A number of consulting companies working in the area were contacted to see if they had any reports including traditional knowledge that could be reviewed. A report on vegetation classification and wildlife habitat suitability modelling conducted for the purpose of impact assessment, included a summary of traditional knowledge collected through community consultations (IEG 2000). Although useful the results were not easily integrated into this overview.

A study of Inuvialuit perceptions of climate change conducted with residents of Sachs Harbour was included even though that community is out of the area of interest. The study is useful in showing the type of information on the environment that can be obtained through traditional knowledge research (Riedlinger and Berkes 2001).

In addition to searching various library catalogues and databases, a number of researchers working in the area were asked if they knew of any resources on traditional knowledge that may not be widely known, or of studies or reports in progress. Although not presented in the overview the studies are mention here to make readers aware of the research. A study by the West Side Working Group has documented both Gwich'in and Inuvialuit traditional knowledge relevant to developing a fish management plan for the area between Big Fish River west to Fish Creek near the Alaskan border (FJMC 2002). Work is ongoing with Dene and Inuvialuit to develop an integrated management plan for inconnu (Stephenson and Moshenko 2000). A monitoring program of the tundra swan that includes a traditional knowledge component is being conducted by the Canadian Wildlife Service and the University of Northern British Columbia (Swyston 2003).

Although out of the area of interest the results of two traditional knowledge studies will soon be available. One will present the results of a study on the impacts of chemical pollutants on the human ecology of the residents of Holman (Kassam No date.). The other is on the traditional knowledge of the king and pacific eiders, black brant and some other birds near Holman and Sachs Harbour (Kay et al. in Hines and Wiebe in progress).

Quotes Presented in the Overview

A number of quotes from traditional knowledge studies are presented in the Overview. In some cases individuals providing responses are identified by a number rather than by their name (eg. [121]). That reflects the method used by the researchers to protect the confidentiality of the participants.

2.0 PHYSICAL SYSTEMS OF THE BEAUFORT SEA LOMA

2.1 GEOLOGY

The geology within the Inuvialuit Settlement Region varies considerably, from west to east on the mainland, as well as to the north on its large arctic islands. The Beaufort-Mackenzie Basin is formed on a post-rift continental margin. Rifting began in the Jurassic period and continued to the end of the Albian, eventually resulting in the opening of Canada Basin (Dixon et al. 2001).

Much of the Inuvialuit Settlement Region land mass located west of the Mackenzie Delta is associated with Canada's Western Cordillera, a series of mountain ranges consisting of folded and faulted Palaeozoic sedimentary rocks, with local igneous intrusions, volcanic flows, and enclaves of earlier Proterozoic and later Mesozoic rocks. The fold belts continue into Alaska where they exist as the Brooks Range. The bedrock geology on the west side of the ISR consists mainly of folded sedimentary rocks, punctured by crystalline blocks and affected variously by metamorphism. Mesozoic rocks occur in relatively undeformed sedimentary basins, separated by tectonic arches, uplifts and fold belts; some older Proterozoic rocks are exposed and there are granitic intrusions forming the core of the Old Crow Range and Mount Sedgwick. Along a narrow geological strip bordering the Beaufort Sea known as the Arctic Coastal Plain, Tertiary and Cretaceous strata exist, blanketed by unconsolidated moraines, glaciofluvial and fluvial deposits of the Quaternary Period (Welch in Ivvavik RDA 1993).

The land mass located east of the Mackenzie is typical of the nearly level strata of the Mesozoic Era. Parent materials are derived from dolomites and quartzite. In glaciated areas, mixing of parent materials by glacial transport has resulted in relatively uniform till of dolomitic parent material with a loamy texture. On the central portion of the Melville Hills, where recent glacial activity appears to have been absent, the parent material reflects the local bedrock of quartzite or dolomite. Most soils in the area belong to the Turbic Cryosol group, reflecting the intense frost churning prevalent in the area. Static Cryosols are found mainly on glaciofluvial parent materials. Rocklands include exposed bedrock and rock rubble (BMMDA 2001).

The land mass in the immediate Mackenzie River Delta area is based upon argillite, a metamorphic rock a little more than one billion years old, forming the core of an elongated dome that may have begun growing hundreds of millions of years ago. The dome has gradually been leveled by weathering and erosion so that the oldest rocks are exposed in the center, and younger, overlying rocks crop out on the flanks. These younger rocks are the Devonian (400 – 345 million years ago) carbonates, which form the Campbell Uplift, and Cretaceous (135 – 65 million years ago) sandstones and shales which are the ancestors of the modern Mackenzie Delta. A major fault, the Donna River, runs along the west side of the Delta, the length of the Aklavik range. This is an active fault. There is also an inactive fault just south of Inuvik at Dolomite Lake, adjacent to an outcropping of argillite. In the Inuvik area, Precambrian rocks are mostly covered by the sedimentary rocks, limestone and dolostone, from the Devonian period. The large sedimentary basin that is preserved under the Mackenzie Delta is evident only by a few exposures of shale that cover limestone throughout the area. The continuous deposition of sediments over the last 65 million years has built up to a thickness of about 15 kilometers. Unlike much of the region west of the Mackenzie Delta, this area was heavily influenced by glacial activity during the Wisconsin Ice Age, 18,000 to 20,000 years age (BMMDA 2001).

With reference to the geology of the large arctic islands within the ISR, Victoria Island lies on a stable Paleozoic platform that includes portions of the Canadian Shield and the Arctic Platform, attached to the North American Tectonic plate. Bedrock is comprised of carbonate sedimentary rocks of different ages, and deposited in various marine environments. Most of Victoria Island, the northeastern portion of Banks Island, and the Dundas Peninsula on Melville Island are composed of Ordovician and Silurian sediments which are 400-500 million years old. These rocks lie on Precambrian sediments and older, deformed rocks which are exposed in many areas. A large, uplifted area of Precambrian rocks is present on Victoria Island (the Minto Inlier or Arch) and forms the Shaler Mountains, which are sedimentary and igneous in origin. Igneous intrusions into the Precambrian rocks occurred 675 million years ago as a result of an upwelling in the earth's mantle.

A large amount of uplift has occurred since Devonian times, less than 345 million years ago. This uplift along the fault lines is responsible for the steep, high cliffs which are characteristic of the region. A series of uplift and subsidence events has created a series of broad basins, platforms and highs. The ancient sediments are overlain by a cover of Quaternary sediments left by the last glaciation, which retreated 10,000 years ago. Sediment deposition was controlled largely by topography, where thick glacial drift was deposited on scarps, and thinner deposition occurred on the lowlands. Ice margin deposits consist of till and lateral and end moraines above sea level, while stratified sediments were deposited below sea level. Outcrops of exposed bedrock are common on lowland areas heavily scoured by ice (BMMDA 2001).

2.2 GEMORPHOLOGY

The ISR is situated in the Arctic Archipelago and the Arctic Basin marine ecozones associated with the Beaufort Sea in Canada's western Arctic region. The ISR was created as a result of signing the Inuvialuit Final Agreement (IFA) in 1984. It covers 906,430 km^2 and includes two distinct geographic regions: the Beaufort Sea and the Mackenzie River Delta. The landscape associated with the Mackenzie River and east is characterized by extensive tablelands, rolling hills, broad valleys and deep river canyons. The landscape to the west of the Mackenzie is more typical of the mountainous areas of British Columbia and Alaska. .

The Beaufort Sea area includes marine, as well as coastal areas, Banks Island, and portions of Victoria and Melville islands. Prominent land forms associated with the arctic islands include glacial features such as drumlins, moraines, and raised beaches (BMMDA 2001). The major communities of the area are Paulatuk, Tuktoyaktuk, Sachs Harbour and Holman. The marine environment includes a permanently ice-covered region, a seasonally ice-covered region, and a coastal area influenced by the mixing of saltwater and freshwater from the Mackenzie River, and to a lesser extent, freshwater from much smaller rivers discharging directly to the coast. Because of the Mackenzie River's considerably greater size and prominent influence on the Beaufort Sea, relative to the numerous smaller rivers, discussion of its geomorphology is relatively expanded.

Offshore Geomorphology

A significant geomorphologic feature of the southern Beaufort Sea is the continental (Beaufort) shelf, which extends offshore into the marine environment. The shelf is bounded by Amundsen Gulf to the east, Mackenzie Canyon to the west, the Mackenzie River Delta to the south, and the Beaufort Sea to the north. In recent geological history, the shelf has experienced much influence from sea level fluctuations. Approximately 20,000 years ago, it was largely dry land, and it was at this time that permafrost first formed. As the sea level rose, the shelf gradually became covered in fine-grained sediments, supplied by the Mackenzie River (Dome et al. 1982). The Beaufort shelf is relatively narrow, no greater than 150 km offshore at any point. The component within Canadian waters is approximately 120 km in width and 530 km in length. Average depth is less than 65 m, and as shallow as 10 m off the Mackenzie Delta. The Amundson Gulf and Prince of Wales Strait are relatively shallow channels within the ISR, not exceeding 200 m in depth, and typically less than 100 m deep. M'Clure Strait, which connects Viscount Melville Sound to the Beaufort Sea, is over 400 m deep (BMMDA 2001).

Beyond the shelf, the continental (Beaufort) slope begins a sharp drop to depths of approximately 1,000 m (Dome et al. 1982). Two major submarine canyons cut through the shelf; they are the wide Mackenzie Canyon, and the narrow Kugmallit Canyon, both of which are potential sites of upwelling water (Macdonald et al. 1987).

Nearshore Geomorphology

Formation of the Mackenzie River Delta occurred during the retreat of the continental glaciers, approximately 12,000 to 13,000 years ago (BMMDA 2001). The Delta includes wetlands, river channels and lakes, encompassing over 13,000 km^2 (Hirst et al. 1987). The major communities of the area are Aklavik and Inuvik. Evidence indicates that sea level is increasing at a relatively rapid rate, as it has been for more than 15,000 years, and the delta front is retreating.

The Mackenzie delta has been classified into three basic units: (1) channel system; (2) basin system; and, (3) delta plain (Hirst et al. 1987). The channel system covers approximately 15 to 20% of the total delta surface area. The basin system, which covers approximately 40 to 50% of the delta, is composed primarily of lakes and ponds. As many as 24,000 lakes have been estimated to be present in the Mackenzie Delta. The delta plain is comprised of portions of the floodplain that are high enough above flood level to support a mature spruce forest. The delta plain is not as dynamic as the channel or basin systems and it receives little sediment deposition.

The terrestrial environment is generally of deltaic origin and character (Slaney 1976). There are several offshore barrier islands of moderate size, a number of deltaic islands, and the large Richards Island. Eskers and kames are fairly abundant on Richards Island (e.g., Ya Ya esker complex) (Dome et al. 1982). There are mainly two general physiographic types in the delta: (1) low-lying, floodplains with poor drainage and vegetative cover consisting mainly of sedges and willows; and, (2) upland areas with good drainage and vegetative cover consisting mainly of shrubby ericaceous (i.e., heather-like) species.

In the floodplain regions, substrate consists primarily of recently deposited fine-grained materials (i.e., silts and clays) from rivers. Floodplains are distributed along all river channels that discharge to Mackenzie Bay and on some Barrier Islands. The relief is generally flat but also contains landforms such as pingos and polygonal ridging (Slaney 1976).

Upland areas, which are underlain by pleistocene fluvial, estuarine, and morainal materials, are not typically flooded and are not affected by erosion from the Mackenzie River. Substrate composition is inconsistent and may be fine-grained or coarse gravel. The relief ranges from gently sloping hills to steep banks created by thermokarst slumping (Slaney 1976).

In the channels, substrates are typically fine-grained although more coarse-grained sediments occur in areas of eroded pleistocene island materials. Island shorelines are a reflection of on-going erosion through wave and current action, spits and mudflats are formed on most offshore islands (Slaney 1976). Spits and barriers are particularly common on the Tuktoyaktuk Peninsula (Lewis and Forbes 1975). Sediments along most of the Mackenzie Shelf consist of clays and silts, originating from the Mackenzie River (Dome et al. 1982).

There are several areas lying within the southeastern Beaufort Sea/Mackenzie Delta area with potential to generate earthquakes: (1) the Beaufort Sea seismicity cluster; (2) the Husky Lakes fault zone; (3) the Martin Point seismicity cluster; and, (4) a projection of the Rapid Fault Array/Kaltag fault (Dome et al. 1982). The first area is outside of the region of interest, lying in deep waters off of the Mackenzie Shelf. Of the remaining three areas, only the Husky Lakes fault zone and the Martin Point seismicity cluster appear to be significant potential sites of earthquakes.
The coastal geology of the Canadian Beaufort Sea is influenced by storm events and the effects of fluvial, thermo-erosional, and ice pressure processes (Dome et al. 1982). High rates of coastal erosion may occur during storm events (Dome et al. 1982). The coastline is comprised of barrier beaches, ice-rich or unconsolidated coastal cliffs, and deltas. Due to the speed of coastal recession, the coastline has become highly indented in regions with numerous lakes (Lawrence et al. 1984).

Watersheds

The watersheds associated with the Inuvialuit Settlement Region occupy two extremes in scale, from the relatively small, isolated drainage areas of numerous small rivers discharging directly into the Beaufort Sea, to the huge drainage area known as the Mackenzie River Basin. Due to the latter's uniquely large freshwater, sediment and nutrient contribution to the Beaufort Sea, emphasis will be given to describing the Mackenzie River watershed.

The Mackenzie River drains approximately 18 million km^2, and is the largest North American river bringing freshwater to the Arctic Ocean. The Mackenzie River contributes considerable freshwater background flow to the Beaufort Sea (Macdonald et al. 1999). This freshwater flow maintains the strong thermohaline gradient in the southern Beaufort Sea that is responsible for the basin's surface water stratification. The Mackenzie's watershed extends from central Alberta in the south to the Beaufort Sea coast in the north, and from the continental divide of the Western Cordillera to the

Canadian Shield at the eastern border of the Northwest Territories. Tje watershed involves four physiographical regions, which include the mountains, valleys and plateaus of the Western Cordillera (west), the rolling terrain, lakes and wetlands of the Canadian Shield (east), prairie grassland, boreal and subarctic forest, and tundra of the Interior Plains (south), and the Mackenzie Delta itself, with its assemblage of tributaries, levees, wetlands, and lakes (north).

The Mackenzie drainage is divided into seven major drainage areas, distinguished by hydrological characteristics and discharge values. These areas include the Athabasca, located in the cold, temperate zone of the southern Mackenzie Basin; the Peace, which is impounded by the Bennett Dam to form the Williston Reservoir; the Great Slave, which includes the drainage from the Canadian Shield, as well as several basins on the high plains (>1500 m); the Great Bear in the Shield region, dominated by the large Great Bear Lake; the low plains, with many basins draining wetlands, small lakes, and northern forests; the Liard, a large, mountainous basin; and the northern mountains, with a collection of smaller catchments in a subarctic, subalpine setting.

The flow of the Mackenzie River reflects the contributions from its major sub-basins at different times of the year. The seasonal flow exhibits a subarctic nival regime, with high flows occurring during the snowmelt and river ice breakup period, followed by a steady decline, periordically raised by summer and autumn rain events, until low flow prevails in the winter. Adding to the nearshore freshwater influence on the Beaufort are the numerous rivers on the mainland ISR which flow directly from the interior to the Sea. Most carve steep canyons deeply into the tundra before they discharge at the coast. They exhibit extreme variations in flow, which is largely determined by spring snow melt, and many bottom-freeze during the winter. Many of these rivers develop substantial deltaic formations, especially those discharging through the unconsolidated sediments along the ISR's western-most coastline (Ivvavik RDA 1993).

Geologic Resource potential

The Beaufort-Mackenzie Basin contains large volumes of discovered oil and natural gas resources, and has high potential for future discoveries. Petroleum exploration in the basin began in the mid 1960s, with the bulk of exploration drilling activity occurring in the 1970s and 1980s. A total of 183 exploration wells (and 66 development wells) have been drilled in the region, resulting in the discovery of 53 oil and/or gas fields, attesting to the basin's resource richness. The largest onshore discoveries include the Taglu field, and the Parsons Lake field. The largest offshore field is Amauligak. Total discovered resources are estimated at $255x10^9$ m^3 of recoverable gas and $161x10^6$ m^3 (1 billion barrels) of recoverable oil (National Energy Board 1998).

Oil and gas fields discovered in the Beaufort-Mackenzie Basin occur in a variety of stratigraphic and structural settings. Common reservoir units include Lower Cretaceous nonmarine and shoreline sandstones (Parsons Group), and highly porous Eocene and Oligocene deltaic sandstones (Taglu and Kugmallit sequences). Oligocene and Miocene shelf and turbidite sandstone reservoirs occur in the Kugmallit and Mackenzie Bay sequences in offshore parts of the basin. Common structural traps include basement-involved Cretaceous fault blocks along the basin rift margin, Tertiary deltaic growth-fault blocks in the central basin, and Tertiary thrust-cored anticlines in western areas. Identified petroleum source rocks include shales in the middle Eocene Richards Sequence and organic-rich shales in the Upper Cretaceous Boundary Creek and Smoking Hills sequences. The combination of thick and widespread reservoir intervals, abundant structures, and multiple phases of hydrocarbon generation provide the conditions for formation of abundant oil and gas accumulations (Dix et al. 1992, 1994).

Estimates of the total petroleum resources in the Beaufort-Mackenzie Basin (discovered and undiscovered) are $1.1x10^9$ m^3 (7 billion barrels) of recoverable oil and $1.9x10^{12}$ m^3 of recoverable gas (Dixon *et al*. 1992, 1994). Basin-wide appraisals indicate high potential for undiscovered petroleum resources, including the likelihood that several major fields (with recoverable volumes of greater than 100 million barrels of oil or 1 Trillion cubic feet of gas) remain to be discovered. Promising areas include the Oligocene Kugmallit sequence in shallow-shelf areas offshore the Mackenzie Delta, the Lower Tertiary sequences in the offshore west Beaufort fold belt, and Lower Cretaceous strata in the southern Mackenzie Delta area. The petroleum resources of the Beaufort-Mackenzie Basin represent about 25% of the total oil and 20% of the total gas resource potential in frontier basins in Canada. With the exception of local gas production from the onshore Ikhil field near Inuvik, no oil or gas fields have been developed in the Mackenzie Delta-Beaufort Sea region to date.

Considerable economic potential exists in the mineral deposits Darnley Bay's coastal waters. An exploration agreement was reached between Darnley Bay Resources Ltd. and the Inuvialuit in 1995, and exploration activities have continued into the present. An area referred to as the 'Anomaly' is suspected to contain rich deposits of copper, nickel, and Platinum group elements. As well, exploratory surveys have produced samples of kimberlite showing a high occurrence of diamonds (Darnley Bay Resources Ltd. 2005).

2.2 PERMAFROST

Victoria Island lies within the zone of continuous permafrost where the freeze-thaw layer ranges from 30-100 cm. Permafrost conditions are reflected in the widespread distribution of patterned ground, solifluction forms, thermokarst scars and lakes, and debris-flow lobes. All soils are cryosolic, but few show extensive frost churned development. Many sediments in hummocky moraine deposits undergoe redistribution when buried ground ice is exposed and melts to form thaw lakes, slump scars and sediment flows.

Inland of the Mackenzie River Delta, permafrost is extensive, thick, and is typically of high ice content; permafrost thicknesses may exceed 100 m at Inuvik (Dyke et al. 1997). However, in the Mackenzie Delta itself, permafrost is typically less than 100 m thick (Dyke et al. 1997, Solomon 2002). Although permafrost distribution beneath the Mackenzie Delta is dynamic, changing with channel migration, it may extend over the entire channel bed (Dyke et al. 1997). Ice wedges are common in the Mackenzie Delta and Inuvik areas (Young *in* LGL Limited 1982).

The offshore environment (i.e., the Mackenzie River estuary and southeastern Beaufort Sea) is covered by ice-rich sub-sea permafrost that is vulnerable to thermal disturbances (Hunter et al. 1976). Offshore permafrost tends to exist at considerably higher temperatures than onshore permafrost (Hunter et al. 1976). The permafrost that currently exists beneath the Beaufort Sea, which formed in the last glaciation event, is in disequilibrium and is degrading (GSC 2001).

Landslides, which occur when icy sediments thaw, are common occurrences in the Mackenzie Delta-Tuktoyaktuk Peninsula (Dyke et al. 1997). Fine grained sediments (i.e., silts and clays), which cover much of the Tuktoyaktuk Peninsula, are prone to slope failure due to the characteristically high ice contents (Aylsworth and Duk-Rodkin 1997). Severe meteorological events, such as heavy precipitation or an abnormally warm summer, may induce permafrost thaws and subsequent landslides (Aylsworth and Duk-Rodkin 1997).

The Mackenzie Delta channels are prone to erosion, due to high flow velocities and thermal niching (Dome et al. 1982). Warm river water thaws the ice-rich silty banks, causing erosion and substantive channel migration. Through this erosional process, substantive quantities of suspended sediments are introduced to the southeastern Beaufort Sea.

Pingos, conical to sub-conical hills with cores of massive ice, are distributed in various locations in the Mackenzie Delta, but are most numerous near Tuktoyaktuk and along the peninsula (Dome et al. 1982). Pingos are also located in clusters on Richards Island and on all sides of Husky Lakes (Pelletier 2000). Pingos are formed when lakes are rapidly drained, permafrost aggrades, and pore water undergoes a process of expulsion and freezing, associated with increasing hydrostatic pressure.

Pingo-like features (PLFs), named due to their similarity to pingos, are distributed along the seafloor of the southern Beaufort Sea (Dome et al. 1982). Although the origins of these structures are not known, they may have developed on land, in their present position under water, or due to mud slumps. Over 200 PLFs have been identified in the southeastern Beaufort Sea, ranging between 200 and 1,000 m in diameter.

Information on permafrost in the Mackenzie Delta/Beaufort Sea has been collected through a long-term monitoring program initiated by the Geological Survey of Canada (GSC), as part of climate change monitoring and research. The last permafrost map of Canada was produced in 1995 (Heginbottom et al. 1995) and the GSC maintains a long-term database of permafrost temperatures and thickness across Canada, which can be accessed through the GSC web-site (http://sts.gsc.nrcan.gc.ca/clf/geoserv_permafrost.asp). The Mackenzie Valley Integrated Research and Monitoring Area report, which summarizes data pertaining to permafrost in the Mackenzie Valley, is currently in press (Dyke and Brooks 2001). Studies, directed by the GSC, in the region of interest include assessments of the occurrence of ground ice, landslides and climate relationships, coastal processes, monitoring of regional active-layer and permafrost thermal state, and studies pertaining to carbon sources and sinks in the Mackenzie Delta/Beaufort Sea. For further details regarding monitoring locations and activities visit the GSC web-site at http//sts.gsc.nrcan.gc.ca/permafrost/suppdoc.htm

2.3 ATMOSPHERIC COMPONENTS

The climate of the Beaufort's southern coastal region is dry and cold, typical of the Marine Tundra Climatic Zone (Slaney 1976). Average annual mean daily air temperature is well below zero degrees celsius (Hirst et al. 1987). Mean monthly temperatures are above freezing from June to September, but extended periods of warm temperatures in summer are rare near the coast. Mean annual rainfall, snowfall, and precipitation (for the years 1961 - 1990) are 116 mm, 175.2 cm, and 257.4 mm, respectively (BMMDA 2001). The region's climate is stongly inflenced by pressure systems, storm tracks, latitude, topography, and the Beaufort Sea. Wahl et al. (1987), and Searby and Hunter (1971) provide an examination of the Beaufort's coastal climate.

Pressure systems over the Yukon coast are dominated by the Aleution Low, centred over the Bering Sea and Gulf of Alaska, is most influencial during late fall and early winter. A high pressure area fluctuates between the Arctic Ocean in summer and the Mackenzie Valley in the winter. The net result is an easterly pressure gradient prevailing along the Yukon coastal region which is stronger during the fall and winter than during the spring and summer.

Although the marine influence from the Beaufort Sea suppresses storm formation along of the Yukon coast, storms do track from Alaska to the Mackenzie Valley, in turn causing some of the heavier summer preceipitation events for the coast. Surges can be caused by winds blowing either parallel or perpendicular to the coastline, and can also establish as a result of storms occurring over the Beaufort Sea during the summer's open water season.

Due to the region's high latitudinal location, the sun is continually above the horizon from late May until mid-July, and below the horizon from the beginning of December until early January. Combined with the steeper sun angle of during summer versus winter, the high latitude has significant influence over the amount of radiation received, and therefore solar heating.

At mid-latitudes, air temperature normally decreases 1º C for every 100 m increase in elevation. However, at the high latitudes in which the Mackenzie River and Beaufort Sea are located, the normal influences of topography are altered. During the long polar night and extended absence of sun, heat is continuously lost from the surface, such that the coldest air is near the surface and warner air exists above. An inversion occurs, with the cold and warm air stratifying and limiting the circulation of air in the lower levels of the atmosphere. Inversions actually occur throughout the year; during the winter, they promote the formation of ice fog, and during the summer, they cause low cloud and haze along the coastline.

The coastal plain west of the Mackenzie Delta is very windy; wind velocities can be high and durations long. A velocity of 119 km/hr was recorded over a 10-minute interval at Babbage River in December, 1987; strong winds (i.e., exceeding 37 km/hr) averages 10 hours during the month of January and peak durations can be 40 hours. In confined area, and wind direction being influenced more by topography (e.g., confined valleys coming off of slopes) that by pressure patterns.

The Beaufort Sea influences climate in several ways. It has a humidifying effect during summer and fall, and is therefore a source of cloud and precipitation. It is both a heat sink and heat source.

During the spring, it is cooler than the land which is being rapidly warmed by intense solar heating, and therefore delays the progress of spring near the coast. During the winter, the ocean is warmer than the land, and therefore delays the progress of freeze-up near the coast. Additionally, onshore winds from the Beaufort usually result in low cloud over the coast, whereas offshore winds result in cloud dissipation.

Similar to the mainland climate, the Arctic Islands experience long cold winters, short summers and low precipitation. On average, western Victoria Island receives about 18 cm of precipitation annually, with rainfall peaks in summer and snowfall peaks in early fall. Lake ice usually remains on about 30% of the lakes until early August. July mean high temperature is 11.4°C, low 3.3°C, while the January mean high is -26.7°C, mean low -32.7°C (BMMDA 2001).

2.4 OCEANOGRAPHIC COMPONENTS

2.4.1 Physical Oceanography

2.4.1.1 Large-Scale Circulation

Large-scale movements of sea ice and surface water in the Beaufort Sea occur in a clockwise direction, due to the influence of the Beaufort Gyre. Circulation below the surface occurs in a counter-clockwise direction along the continental slope, and is known as the Beaufort Undercurrent. This flow results in the eastward movement of waters originating from both the Pacific and Atlantic oceans, as well as the transport of nutrients from offshore waters to areas on the Canadian Shelf (Aagaard 1984). Mesoscale eddies (circular currents up to several hundred kilometers in diameter, typically between 10 - 20 km in diameter and 50 - 300 m in depth in the Beaufort Sea) have been identified as important water transport mechanisms (Carmack and Macdonald 2002). Upwelling events associated with these eddies can be up to 400 m in amplitude (Aagaard 1984), implying that the interior Beaufort experiences significant flow and mixing.

2.4.1.2 Nearshore Currents

Circulation patterns in nearshore areas display considerable variability. Flows are often driven by high winds along coastal areas. In winter, ice cover reduces the effects of wind and flows may be influenced by differences in water mass densities related to salinity gradients formed by brine rejection during ice formation. The denser saline water that temporarily accumulates near the water surface can cause convective currents as it descends through the water column. The wide Mackenzie Canyon and narrow Kugmallit Canyon found on the Canadian Shelf are sites of potential upwelling (Carmack and Macdonald 2002).

2.4.1.3 Mackenzie River Discharge and Wind Driven Currents

Although the discharge of fresh water from the Mackenzie River is higher in the spring and summer, it exerts a substantial influence on the Beaufort Sea year-round. In the winter, fresh water from the Mackenzie pools beneath the landfast ice and forms a “floating freshwater lake” above brackish and marine water. This mass of fresh water covers an area of approximately 12,000 km^2 and has a volume of about 70 km^3. Due to differences in the freezing temperatures, the interface between the fresh water and marine water masses is a potential site for the production of frazil ice (small ice crystals formed in the water column that may adhere to each other to form larger masses, as well as lead to rapid cooling of water) (Carmack and Macdonald 2002). The dispersal of this mass of fresh water is certain to influence the stability of the water column, nutrient distribution, and dispersal of organisms, but the degree to which this occurs has not been studied (Carmack and Macdonald 2002).

Peak Mackenzie River discharge occurs between mid-May and June following the break-up of ice in the headwaters of the river in late April and the delta in late May. Landfast and bottomfast ice in the estuary and nearshore areas at this time can obstruct the movement of water under the ice and cause over-flooding, which often results in meter-high geysers of turbid water forming at cracks and holes in the surface ice. This warmer water causes ice cover in the delta to melt about two months earlier than it would otherwise occur, as well as accelerating the melting of ice cover in the areas further away from the river mouth, to a lesser degree (Carmack and Macdonald 2002).

During the summer months, large volumes of water continue to be discharged from the Mackenzie River and form plumes, fronts, and a strongly defined surface layer. Additional fresh water is also released over a large portion of this area from ice melt (Carmack and Macdonald 2002). The plume of fresh water from the Mackenzie River has a tendency to flow eastwards along the Tuktoyaktuk Peninsula, due to Coriolis force. However, the size, shape, and direction of this plume are strongly influenced by winds. Easterly winds cause upwelling and cause plume waters to extend into offshore areas, up to several hundred kilometres, whereas westerly winds typically force plume waters against the coast and enhance the flow of this water along the Tuktoyaktuk Peninsula (Carmack and Macdonald 2002). Mackenzie River plume waters are recognizable up to 400 km away from shore (Carmack and Macdonald 2002), 85 km west of Herschel Island, and as far north as Richards Island (Dome et al. 1982).

The general pattern of surface circulation on the inshore continental shelf of the southeastern Beaufort Sea is controlled primarily by wind direction and intensity, and modified to a lesser extent by the Mackenzie River discharge. Interactions with the underlying water layer and local bathymetry also affect circulation patterns in this area. Tidal amplitude in the Beaufort Sea is generally small (< 0.5 m) and tidal currents are weak (generally < 5 cm/s) (Dome et al. 1982).

2.4.1.4 Ice Dynamics

Winter ice cover in the southern Beaufort Sea is subdivided into three zones: (1) the landfast zone; (2) the seasonal ice or transition zone; and, (3) the pack ice or polar ice zone (Dome et al. 1982).

Landfast Ice Zone

Landfast ice is located along the coast and is attached to the shore. Ice begins to advance outward from shore over the continental shelf in late September or October, extending to about the 20 m depth contour. Maximum extent of landfast ice is reached between the middle of November and early March. Ice thickness increases throughout the winter, reaching a maximum thickness of approximately 2 m in late April. Break-up of ice in this zone typically begins in May and an ice-free corridor along the coast is found from July to October, reaching its maximum extent in early September (Dome et al. 1982). Ice break-up in the Mackenzie River Estuary and, to a lesser degree, nearshore waters is primarily influenced by the release of warmer water during high spring flows discharged from the Mackenzie River (Carmack and Macdonald 2002). To a lesser extent, coastal discharge from smaller freshwater systems located east and west of the Mackenzie also has a hastening effect on nearshore ice break-up.

The landfast ice zone can also be further subdivided into three zones: bottom fast, floating, and grounded. Bottom fast ice is generally smooth and featureless, but may contain some tidal ridges. The bottom fast ice zone contains ice that grows outward from shore to about the 2 m depth contour, where it contacts the floating ice zone. Floating ice contains piles of ice that are referred to as pressure ridges, which increase in frequency with increasing distance from shore. This zone extends out to the grounded ice zone at about the 13 m depth contour. Grounded ice contains pressure ridges that are grounded to the bottom and can be 10 m high and up to 20 m deep. The outer edge of this zone may also contain areas with continuous ridges or hummock fields that are formed when thinner ice at the edge is crushed against the thicker landfast ice. Attachment to shore and the sea floor bottom by grounded pressure ridges limits movement of landfast ice throughout the winter to less than 10 m; the majority of movements are less than 1.5 m (Dome et al. 1982).

Seasonal Ice Zone

The seasonal ice zone is located between the landfast ice and the polar pack ice. Movements in the vicinity of the polar pack ice edge cause the width of the seasonal ice zone to vary seasonally and annually from a few kilometres up to 300 km. Most ice in this zone is first year ice, but multi-year ice also occurs to a varying extent (Dome et al. 1982). Ice in this zone moves throughout the winter, generally in a westerly direction. Daily movements are most extensive in the Mackenzie Delta region and sometimes exceed 30 km/day (Dome et al. 1982). Areas of thin ice occur along the offshore edge of the landfast ice. This results in an active shear zone, which contains flaw leads that open with offshore winds and close with onshore winds. Polynyas (open water or thin ice areas surrounded by thicker ice) that are caused by currents, tidal fluctuations, wind, upwellings, or a combination of these factors (Stirling 1981), are also found in this area. The open water associated with polynyas exhibits enhanced primary productivity which ultimately results in higher, upper trophic level populations (Tremblay et al. 2002). Pressure ridges in the seasonal ice zone are masses of jumbled ice blocks composed of either first year ice or stronger ridges composed of multi-year ice. The most extensive ridging occurs when onshore winds compress the seasonal ice against landfast ice (Dome et al. 1982). Mid-shelf and outer shelf ice break-up occurs outward from existing areas of open water (polynyas and leads) (Carmack and Macdonald 2002).

Polar Ice Zone

The polar ice zone contains permanent multi-year ice, which moves slowly (ice near the edge of the Gyre drifts about 2 km per day) in a clockwise direction due to the Beaufort Gyre. During the winter, the multi-year ice, which ranges from 2 m to almost 4 m thick year-round, is surrounded by first year ice, which reaches a maximum thickness of about 2 m by the end of winter. In the summer months, some melting occurs along the edge of the polar pack ice and open water areas form around the ice floes (Dome et al. 1982).

Detected during the 1990's, an increase in the thinning and freshening of polar ice in the Beaufort Sea heightened concern over the effects of global warming on the polar ice sheet, and led to intensified study of sea ice dynamics under SIMI (Sea Ice Mechanics Initiative), SHEBA (Surface Heat Budget of the Arctic Ocean) and most recently, CASES (Canadian Arctic Shelf Exchange Study). A combination of thermodynamic and dynamic processes largely determines the thickness distribution of polar ice (Thorndike et al. 1975). The thermo-dynamic component dictates the growth and ablation of sea ice, whereas the motion of the ice, due to wind and current, results in the formation of leads and ridges, creating areas of thinner and thicker ice, respectively (Richter-Menge et al. 2002). Large shear fractures, greater than 100 km and running from the seasonal ice to the polar ice, are possible in the Beaufort Sea, but require several days of wind-forcing to create the necessary ice-motion stress (Perovich et al. 1999). Thermal ice-stress is relatively uniform, horizontal, and dominant during the fall, but as new ice builds over the winter, motion-induced ice-stress becomes dominant, and is relatively variable (spacially and temporally) and highly directional (Richter-Menge and Elder 1998).

2.4.1.5 Ice Scouring

Scouring from onshore and longshore movements of the keels of pressure ridges and glacial ice (ice that has formed on land and has broken off into the sea, such as icebergs or ice islands) is common along the Beaufort Sea continental shelf. Most scouring occurs in waters that are less than 50 m deep, with the most intensive scouring occurring at depths between about 20 and 25 m (Dome et al. 1982; Carmack and Macdonald 2002). Scour trenches are usually less than 2 m deep, but can reach depths of 7 m. The width of scours varies from a few metres to more than 300 m (Dome et al. 1982; Hequette et al. 1995). Scouring creates unique benthic habitats by disturbing sediments on a large-scale, and producing uneven sedimentation rates, which favour organisms capable of rapidly recolonizing scoured locations (Carmack and Macdonald 2002). Another outcome of ice scouring which has an effect of food-web structure is the creation of anoxic pockets. Brine rejected from sea ice can settle into scour depressions, causing a stratification which traps organic matter and limits oxygen renewal, leading to anoxic conditions (Carmack and Macdonald 2002).

2.4.1.6 Ploynyas

The open waters associated with polynyas generally exhibit enhanced primary production and higher upper trophic level populations. In typical Arctic waters, low winter irradiance and thick ice cover limit phytoplankton to a short period in summer (July-August) when diatom blooms respond to ice melt (Hsiao 1992) However, in Arctic polynyas such as the Northeast Water (NEW) and North Water (NOW) polynyas, diatoms bloom soon after the end of the polar night (April-May) (Tremblay et al. 2002) and extend the production season. The increased primary productivity cascades into greater production at higher trophic levels, such as copepods and appendicularians (Kosobokova et al. 1998), which are in turn preyed upon by larval and juvenile cod (Michaud et al. 1996). Essentially, polynya dynamics in the Arctic play a significant role in changing the productivity and food web structure of these high latitude marine environments (Arrigo and van Dijken 2004).

The Cape Bathurst polynya, located in the Amundsen Gulf (150 km east of the Mackenzie River mouth), is part of the circum-arctic system of flaw polynyas. This particular polynya is exceptional in that it is habitat for some of the highest densities of birds and mammals found anywhere in the Arctic (Harwood and Stirling 1992). Its formation begins as sea ice beings to form in shallow areas in October. By winter, drifting ice floes that raft against the edge of the landfast ice forms a zone of thick ice ridges (stamukhi) parallel to the coast. Beyond the stamukhi, but inshore of the pack ice, a flaw polynya stretches along the entire Arctic shelf, widening in the summer to form the Cape Bathurts polynya. Easterly winds dominate the ice cover dynamics in this region of the Beaufort Sea, and large flaw leads form near Cape Bathurst and of the west coast of Banks Island in respone to mesoscale storm or wind events (Fett et al, 1994).

The Cape Bathurst polynya exhibits marked interannnual variability in the dynamics of sea ice retreat and formation. Over a five-year study cycle, polynya size was found to begin a rapid and sustained increase in June, from 6000 km^2, to as large as 25000 km^2, with the exception of 1998 when expansion began two months earlier. During the same study cycle, sea ice began to re-freeze during the month of October, resulting in an average open water season of four months. Again, 1998 was the exception where refreezing did not occur until November, resulting in a total open water season of 7 months (Arrigo and van Dijken 2004). Maslanik et al (1999) attributed this unusual duration to the large positive anomaly in atmospheric temperature that occurred the same year.

Even greater interannaul variation has been exhibited in phytoplankton cholophyl *a* concentration. During May, 1998, mean Chl *a* concentration has been recorded as high as 8 mg/m^3, with local concentrations exceeding 20 mg/m^3. The year;s unually warmth and cloud-free conditions resulted in an early and productive bloom, but also an early and precipitous crash as nutrients were exhausted. Conversely, 1999 began with a small initial bloom in early June (1 mg/m3), with only a slightly higher, but short duration bloom in August of 3 mg/m^3. The Cape Bathurst polynya generally hosts two temporarily distinct phytoplankton blooms per year, with one peak occurring during sping or early summer, and a second occurring in late summer or fall. Typically, the late bloom is significantly larger than the early bloom (Arrigo and van Dijken 2004). Annual production (approximately 3.0 g C/m2/day) is slightly greater than the NEW polynya (at 1.1 g C/m2/day) and slightly lesss than the NOW polynya (at 6 g C/m2/day). Measured annual production has ranged from 90 g C/m2/yr to 175 g C/m2/yr. This compares favourably to the annual production in Lancaster Sound (60 g C/m2/yr) and Barents Sea (25-30 g C/m2/yr) (Welch et al. 1992), but is still well below that of the highly productive Bering Sea (720-840 g C/m2/year) (Springer and McRoy 1993). The intense blooms within the polynyas appear to depend on early stratification of surface waters to form a favourable light environment for phytoplankton production (Arrigo and van Dijken 2004).

2.4.2 Chemical Oceanography

2.4.2.1 Seasonal Changes in Salinity, Temperatures, and Stratification

End of Winter

In late winter, freshwater accumulates behind an ice dam near the mouth of the Mackenzie River. This results in the eventual formation of a large mass of fresh or brackish water, known locally as Lake Mackenzie, which floats above underlying marine water further out into the estuary. Winter ice production in the seasonal ice zone results in the release of dense brine, which convectively mixes the surface layer to a depth of 40 - 50 m as it sinks to the bottom. A mixed layer of water extends to a depth of 30 - 50 m under the polar pack ice, but generally does not intermix with the underlying nutrient-rich waters, which originate from the Pacific Ocean (Carmack and Macdonald 2002).

Spring

The mass of fresh water near the mouth of the Mackenzie River is displaced by turbid river water during spring flooding. Although sufficient nutrients are available, phytoplankton growth is restricted by lingering ice cover and high turbidity, which limit the amount of light available for photosynthesis (Carmack and Macdonald 2002).

Summer

In the summer fresh water from the Mackenzie River and runoff from ice melt form a well defined surface layer to a depth of 5 - 10 m (Carmack and Macdonald 2002). The Mackenzie River generally remains free of marine water intrusions landward of the transverse bar across Kittigazuit Bay. Seaward of this point, a 2 to 4 m thick layer of turbid, mostly fresh, water from the Mackenzie River spreads outwards for 5 to 10 km over the denser intruding mass of seawater. The exact size and location of these water masses are influenced by wind-driven currents (Carmack and Macdonald 2002).

Fall

In the middle of September, prior to the beginning of freeze-up, there is a 2 to 4 m layer of fresh water over the Canadian shelf, derived from ice melt and river runoff (Carmack and Macdonald 2002). The top 10 to 20 m of fresher water has been mixed by summer and early fall storms and typically overlies a cold, saline layer, found at depths below 20 m. As freeze-up occurs, the fresh water in the surface layer is rapidly withdrawn to form ice. With the exception of areas containing open water, the thickness of the ice increases as the rate of ice growth slows in most areas (e.g. flaw leads) (Carmack and Macdonald 2002).

2.4.2.2 Coastal Erosion

Generally, the coastline of the southern Beaufort Sea exhibits retreat rates greater than 1 m per year, although this rate may reach a maximum of 18 m per year (observed at Shallow Bay in the Mackenzie Delta). These high rates of shoreline erosion result in unstable and dynamic shoreline habitats. Cliffs located along the Beaufort Sea coast that are developed of unconsolidated frozen material are typically eroding at rates of 1 to 3 m per year (Solomon and Forbes 1994). Erosion due to coastal drowning results in the retreat of cliffs, melting of permafrost, and breaching of coastal lakes, all of which are accelerated by storms and storm surges (Solomon and Forbes 1994, Carmack and Macdonald 2002). Coastal erosion supplies an estimated 7×10^6 tonnes of sediment each year near shoreline areas. Although it is an important local source of sediments, the relative contribution of coastal erosion to sediment loading in the Beaufort Sea is minor in comparison to that originating from the Mackenzie River (Carmack and Macdonald 2002). However, the rate of coastal erosion is predicted to increase as a result of elevated temperatures resulting from climate change, which can destabilize frozen sediments and massive ice that are found in coastal cliffs (Solomon and Forbes 1994).

2.4.2.3 Sediment Loading of the Mackenzie River Estuary

The Mackenzie River transports about 130×10^6 tonnes of sediment each year into the Beaufort Sea, and is considered the most sediment-rich river in the Arctic (Carmack and Macdonald 2002). Sediments accumulating on the Canadian shelf consist predominantly of clay or silt, with relatively little gravel. Most gravel deposits probably originate from either ice rafting, or drowned beaches from which the finer sediments have been previously eroded (Carmack and Macdonald 2002). Shelf sediments are also resuspended and transported during storms, particularly in late fall (Carmack and Macdonald 2002).

2.4.2.4 Nutrients

Distribution of nutrients in the southern Beaufort Sea is dominated by the Mackenzie River discharge. Local variability in nutrient concentrations can vary greatly due to the presence of areas with greater volumes of ice-melt, which contains very little nitrate, phosphate, or silicate (Dome et al. 1982). The highest concentrations of nitrates in the southeastern Beaufort Sea are in the vicinity of the Mackenzie River outlets. Phosphate concentrations are also highest near the mouth of the Mackenzie River, but levels do not vary as greatly as for nitrates. Silicon availability can be an important limiting factor for the production of diatoms, which are generally the dominant members of the nearshore phytoplankton community. As with nitrates, the Mackenzie River plume is a major source of silicates (Dome et al. 1982). In the summer, vertical stratification results in the nutrient supply of surface waters becoming rapidly depleted by phytoplankton growth. Primary sources of nutrient replenishment are river discharges, which also create currents that entrain nutrient-rich deep water into the surface layer, and upwelling, due to the disruption of vertical stratification by wind driven currents. Additional nutrient replenishment of surface waters takes place in the winter when ice formation results in the release of cold, dense saline water. As this water descends it can cause convective currents that transport nutrient-rich deeper water upwards through the water column (Dome et al. 1982).

3.0 BIOLOGICAL COMPONENTS OF THE BEAUFORT SEA LOMA

3.1 PLANKTON COMMUNITIES

3.1.1 Phytoplankton

Primary producers (e.g., phytoplankton, benthic micro- and macroalgae, aquatic macrophytes) contribute to the basis of the aquatic food web upon which all other organisms depend. These organisms use energy provided by sunlight to convert carbon dioxide and water to organic compounds. Some of the primary producers are consumed directly by other organisms (herbivores), or indirectly by higher trophic levels (consumers).

The aquatic environment of the Beaufort Sea is characterized by the following:

- seasons with little or no sunlight;
- remineralization and rapid nutrient depletion (e.g., nitrogen, phosphorus, silicon);
- low to high freshwater discharge; and,
- vertical stratification (temperature and salinity) of the water column during summer months (Dome et al. 1982).

Seasonal variations in the composition, abundance, and productivity of the algal communities (planktonic, ice-associated, benthic) found within the Beaufort Sea environment are influenced to varying degrees by the above factors. Levels of phytoplankton chlorophyll *a*, abundance, and productivity are low throughout the winter months (Horner and Schrader 1982). Low winter irradiance and thick ice cover limit phytoplankton production to a short period in summer when diatom blooms respond to ice melt in July or August (Hsiao 1992). Ice algae are present in the sea ice from the time it forms in the fall; however, they become more concentrated during the spring (March-April) in response to increasing light levels (Horner and Schrader 1982). Growth of ice algae continues until late May-early June when maximum production and abundance occurs, consisting predominantly of microflagellates and pennate diatoms (Horner and Schrader 1982). Light penetration through ice is likely the limiting factor controlling primary production during spring, with the proximity of the ice algae to the ice surface influencing the level of primary production as light levels increase. As a result, this community effectively limits both phytoplankton and benthic algal production by shading these communities until the break up of ice in June and the subsequent decline of the ice algae community (Horner and Schrader 1982). Within the MacKenzie River Estuary, inputs of suspended sediments results in ice layers containing relatively high concentrations of sediments, thereby limiting the growth of ice algae as layers of sediment in ice likely inhibit the development of an ice community (Horner and Schrader 1982).

For the purposes of this overview, phytoplankton community structure, abundance, and productivity in the southern Beaufort Sea will be discussed.

Species Composition and Abundance

The phytoplankton of the southern Beaufort Sea were investigated during the summers of 1973, 1974, and 1975 by Hsiao (1976). Phytoplankton cell counts (standing stock) in the euphotic zone were found to decrease with increasing distance offshore; cell counts at inshore sampling locations were typically 10 times higher than those at offshore sites of comparable water depths. At ice covered stations, the standing stock was concentrated in the upper 1 m of the water column, while at open water stations it was in the upper 5 m. At both station types, phytoplankton cell counts decreased with increasing water depth.

Fifty-one genera and 87 phytoplankton species were identified from the southern Beaufort Sea and Husky Lakes (Hsiao 1976, Foy and Hsiao 1976). Hsiao (1976) observed a distinct difference between the lower salinity surface water layer (between 1 and 5 m) and the more saline water layer below; at depths shallower than 5 m, all species of phytoplankton were found to be relatively more abundant than at depths greater than 5 m.

The predominant groups of phytoplankton identified by Hsiao (1976) included diatoms, flagellates, dinoflagellates, chrysophytes, and blue-green algae (cyanobacteria). Diatoms and flagellates were most abundant, followed by dinoflagellates and chrysophytes. Distributions of these groups varied with sample location (inshore, offshore), water depth, and environmental conditions. Diatoms were found to dominate the phytoplankton community at inshore stations (warmer, more turbid water and higher nutrient concentrations) more strongly influenced by the turbid, freshwater plume originating from the Mackenzie River, accounting for 52.0 to 99.5 % of the population. However, flagellates predominated at offshore stations (colder, less turbid water and lower nutrient concentrations) where they formed up to 89.0 % of the population. Dinoflagellates and chrysophytes were observed in relatively lower numbers, except in a small number of instances when blooms of these particular phytoplankters occurred. Cyanobacteria were found in very low numbers on a few sampling occasions. Warmer water temperatures, higher nutrient concentrations, and lower light intensities likely favour the growth and reproduction of diatoms in nearshore areas, while the dominance of flagellates in offshore areas may be a reflection of poor growth conditions for other algal groups, in combination with the ability of flagellates to tolerate high light intensities and lower nutrient concentrations (Dome et al. 1982).

Hsiao (1976) believes that in the Mackenzie River Estuary, light penetration has a greater influence than nutrient availability on the growth and reproduction of phytoplankton during the summer months. Turbid conditions in nearshore waters due to sediments carried by the Mackenzie River may limit light availability during the summer (Grainger 1975). Also, nutrient concentrations are typically higher in nearshore areas due to constant renewal via the Mackenzie River inflow (Grainger 1975). Although water clarity is typically improved in the offshore area in comparison to sites nearer the mouth of the Mackenzie River, a thermocline that exists throughout the summer limits replenishment of nutrients in the euphotic zone of offshore regions by deeper, nutrient rich waters. As a result, nutrients depleted from the euphotic zone by phytoplankton will not be replenished and may become limiting (Hsiao 1976). In most instances, the limiting factor to phytoplankton growth in nearshore areas is light intensity and in offshore areas is nutrient availability, particularly nitrate (Dome et al. 1982).

Seasonal succession of phytoplankton species, resulting in temporal and spatial variation in species composition and abundance, is typical among phytoplankton communities. In nearshore areas of the southern Beaufort Sea, the following environmental factors have been identified as being most important for influencing phytoplankton growth and reproduction:

- high concentrations of suspended sediments (i.e., reduced light penetration into the water column);
- relatively low salinities;
- relatively warm water temperatures; and,
- an adequate supply of nitrate and silicate (associated with freshwater discharge) (Dome et al. 1982).

In offshore areas, the dominant factors identified are the following:

- the stratified nature of the water column (i.e., limited nutrient replenishment from deeper waters);
- low light intensities in areas of persistent ice cover; and,
- reduced nutrient availability subsequent to the initial uptake by spring phytoplankton blooms (Dome et al. 1982).

Primary Productivity

Primary production studies in the southern Beaufort Sea have been conducted by Hsiao (1976), Hsiao et al. (1977), Parsons et al. (1988), and Parsons et al. (1989). The average productivity rate for surface waters measured during the summers of 1973, 1974, and 1975 was 6.74 mg C/m^3/h for inshore sampling locations and 1.39 mg C/m^3/h for offshore stations (Hsiao 1976). Parsons et al. (1989) observed maximum surface primary productivity values of approximately 10 mg C/m^3/h during July and August in 1986 and 1987, similar to the maximum values reported by Subba Rao and Platt (1984) and Hsiao et al. (1977) for Arctic waters.

Diatoms were found to be primarily responsible for nearshore production and primary productivity decreasing with increasing distance from shore (Hsiao 1976, Hsiao et al. 1977). Studies conducted by Parsons et al. (1989) agreed with the above findings, except for the immediate inshore area where light attenuation due to high levels of suspended sediments severely inhibited photosynthetic activity. Higher primary productivity at nearshore locations is likely related to the discharge of relatively nutrient-rich waters by the Mackenzie River and remineralization of organic matter carried downstream by the river (Dome et al. 1982).

3.1.2 Bacterial Production

Bacteria play an important role in nutrient recycling within aquatic environments. Particular species, referred to as oleoclastic bacteria, are capable of degrading (metabolizing) certain petroleum hydrocarbons and contributing to the ‘weathering’ or break-down of oil. Aquatic bacteria are also important as food for some zooplankton and benthic invertebrates. They typically occur within the water column and bottom sediments of the Beaufort Sea in concentrations similar to those of more temperate coastal areas (Bunch and Harland 1976). The bacteria occurring throughout the water column of the southern Beaufort Sea will be considered for this overview.

Planktonic bacterial sampling was conducted in the southern Beaufort Sea during July, 1973, by Bunch (1974). The data from this investigation suggested that relatively large biomass of freshwater heterotrophic bacteria are discharged from the Mackenzie River. However, the bacteria discharged by the river were not observed to substantially alter the counts of marine bacteria in the area sampled. A relatively uniform abundance of marine heterotrophic bacteria was found to exist in the southern Beaufort Sea.

Bunch and Harland (1976) conducted bacterial sampling in the southern Beaufort Sea during the summers of 1973 and 1974. They reported total viable counts ranging from 1,000 to 30,000 cells/mL, with the maximum planktonic bacteria population observed coinciding with a phytoplankton bloom occurring after spring break-up; bacterial biomass and primary productivity simultaneously declined subsequent to the bloom. Generally, the viable counts of heterotrophic bacteria measured were in agreement with values observed by Bunch (1974). Bunch and Harland (1976) also found oleoclastic species to be common to both offshore and nearshore sampling locations.

Production studies carried out in the Mackenzie River Estuary during the summer of 1986 indicated the plankton community near the river mouth was characterized by high dissolved organic carbon (DOC) and high bacterial activity (Parsons et al. 1988). Parsons et al. (1988) suggested that the presence of considerable DOC near the mouth of the Mackenzie River where the greatest number of bacteria, and highest bacterial growth and heterotrophic activity were observed indicates a planktonic community based on energy supplied by riverine DOC. This is in contrast to the planktonic community associated with high phytoplankton production found at offshore sampling locations.

Following the 1986 observations by Parsons et al. (1988), a second study was conducted in July and August, 1987 (Parsons et al. 1989). The most pronounced difference between the two years was in the standing stock of bacteria and the measured heterotrophic activity; both were found to be substantially higher in 1987. In 1986, bacterial concentrations in the estuary were approximately 10×10^3 cells/mL, similar to levels encountered by Bunch and Harland (1976). In 1987, measurements of at least 5×10^6 cells/mL were obtained, much greater than in 1986. Parsons et al. (1989) suggested that this difference was primarily the result of advective processes due to on-shore winds in 1987.

3.1.3 Zooplankton

Zooplankton contribute to the secondary production that occurs in aquatic environments, as many species are herbivorous and feed directly on phytoplankton, thereby providing a critical linkage between the primary producers and higher trophic levels, particularly vertebrates (e.g., fish, whales).

Species Composition, Distribution, and Abundance

The zooplankton of the southern Beaufort Sea were investigated during the summers of 1973, 1974, and 1975 by Grainger (1975), with more than 95 species having been identified. Grainger (1975) reported spatial differences in zooplankton species composition, primarily attributable to the variable extent of the Mackenzie River freshwater plume and resultant localized differences in salinity and water temperature. Zooplankton abundance was highest at Mason Bay and Tuktoyaktuk Harbour (inshore sampling locations), however diversity was low, with only five species represented (four copepod species). The dominant species in the nearshore area were *Acartia clausi* and *Eurytemora herdmani*, followed by *Pseudocalanus minutus* and *Limnocalanus macrurus*; all copepods known to inhabit estuarine or brackish water habitats. Freshwater genera, including copepods, *Diaptomus* and *Cyclops*, and cladocerans, *Daphnia* and *Bosmina*, became much more abundant near and in the mouth of the Mackenzie River. A collection of zooplankton from Tuktoyuktuk Harbour in the summer of 1970 reported a small number of relatively widespread species characteristic of fresh to brackish waters, such as the copepod genera *Cyclops*, *Diaptomus*, and *Eurytemora* (Sutherland 1982).

The abundance and community structure of zooplankton also varies with water depth in virtually all aquatic environments; however information regarding the vertical distribution of zooplankton in this particular region is lacking. Grainger (1965) observed a preference by the copepod *Acartia longiremis* for waters of relatively low salinities and high temperatures.

Variability in the numbers and species of zooplankton present at any one time throughout the year is typical of aquatic systems. Seasonal succession of species results due to differences that exist among species with respect to timing of reproduction and development. For example, herbivorous zooplankton reproduction would coincide with the timing of maximum phytoplankton productivity and abundance, i.e., during the spring and early summer in this region. However, the relatively high variability in the spatial distributions of zooplankton species recorded in this area and the confined time periods of investigation, with respect to season, has diminished the resolution of any seasonal distribution patterns (Dome et al. 1982).

Feeding by Higher Trophic Levels

Factors which may affect bowhead whale (*Balaena mysticetus*) distribution in the southern Beaufort Sea were investigated by LGL Ltd. (1988). The focus of the study was on the distribution of zooplankton available to bowhead whales during their critical summer feeding period. In 1985 and 1986, the distribution of zooplankton biomass was related to the distribution of the Mackenzie River fresh water plume and other oceanographic characteristics; biomass was highest in water not influenced by the Mackenzie River plume. In both years, bowhead whales were observed feeding in areas where zooplankton biomass was high. The distribution of bowhead whales in 1986, in particular, supported the notion that these whales tend to avoid areas strongly influenced by the inflow of the Mackenzie River (LGL Ltd. 1988).

LGL Ltd. (1988) observed the dominant zooplankton in nearshore waters off the Yukon coastline to be *Limnocalanus macrurus*, a copepod species important to the feeding ecology of bowhead whales. The abundance of *L. macrurus* is correlated with water mass characteristics, which are in turn influenced by the degree of upwelling. Bowhead whales typically feed at nearshore locations where aggregations of *L. macrurus* occur.

Additional evidence from monitoring programs conducted in recent years supports the opinion that distribution of bowhead whales in the southeast Beaufort Sea is strongly influenced by numerous physical and biological factors that affect the distribution of their preferred food (Ford et al. 1987). Bowhead whales have been observed to congregate near areas experiencing thermal and/or turbidity gradients, discernible with satellite imagery (Harwood and Borstad 1985; Duval 1986). These gradients are indicative of localized oceanic fronts or upwelling, which may be associated with relatively high biomasses of zooplankton (Thomson et al. 1986).

3.2 BENTHIC INVERTEBRATES

Benthic organisms are typically grouped into two major categories:

- infauna - organisms living within soft bottom substrata (e.g., bivalves and polychaetes); and,
- epifauna - organisms living on the bottom substrata and may be either sessile or mobile (e.g., mysids, amphipods, isopods).

The spatial distribution of benthic invertebrates in the Arctic environment is typically influenced by the following parameters to varying degrees:

- bottom substrata suitability;
- water depth;
- ice scour (i.e., occurrence, frequency);
- oceanographic regimes (e.g., water temperature and salinity gradients); and,
- food availability (Dome et al. 1982).

3.2.1 Zonation

The largest-scale benthic survey conducted for the southern Beaufort Sea region was by Wacasey (1975). Benthic organisms were investigated in the Beaufort Sea between Herschel Island and Cape Dalhousie, NWT, from May to September over a four year period (1971, and1973-1975). The Mackenzie River releases a large volume of fresh water into this portion of the Beaufort Sea, where mixing occurs with saline (marine) waters to produce a relatively large estuarine region (Wacasey 1975). Four depth zones have been described for the southern Beaufort based upon physical parameters (water depth and temperature, salinity) and benthic invertebrate diversity and biomass. Table 1 provides a summary for the zones designated by Wacasey (1975).

Estuarine Zone

The nearshore, estuarine zone, extending from the shore to water depths of 10-15 m, is strongly influenced by fresh water input from the Mackenzie River (Wacasey 1975). As a result, salinities measured were typically less than 20 ppt. Salinities were initially low (0.1 ppt) in Mackenzie and Kugmallit bays and gradually increase with distance from the river outlets. Diversity was low in this zone, with stations bordering the transitional zone having a higher number of species. Wacasey (1975) attributes the low species diversity in the estuarine zone primarily to the reduced tolerance of many species (e.g., echinoderms) for low salinities over extended periods of time. Invertebrates characteristic of this zone were the polychaete, *Ampharete vega*, the amphipods *Boeckosimus affinis*, *Onisimus glacialis*, and *Pontopreia affinis*, the cumacean *Diastylis sulcata*, the isopod *Mesidotea entomon* (also known as *Saduria entomon*), the bivalves *Macoma balthica*, *Cyrtodaria kurriana*, and *Yoldiella intermedia*, and the mysids *Mysis femorata* and *M. relicta*. Echinoderms were not found in any samples collected from this zone. Average biomass was approximately 2 g/m^2, with the lowest biomass measured in Mackenzie and Kugmallit bays. Biomass values were found to be much higher in a protected embayment, Mason Bay, than in the remainder of the zone, perhaps reflecting the more stable conditions and nutrient enrichment that may occur in this relatively protected area.

Snow and Chang (1975) sampled the benthic invertebrates of the Mackenzie Delta to investigate the factors controlling their distribution and abundance. The shallow, inshore areas (e.g., Mackenzie Bay) were found to have very low densities of benthos, similar to the observations of Wacasey (1975).

Transitional Zone

Wacasey (1975) found this particular zone more difficult to delineate due to fluctuations in temperature and salinity of the bottom waters. Water of depths between 15 and 30 m demarcate the transitional zone. A high proportion of this zone is located within an area that experiences ice scouring, where ice keels mechanically disturb the bottom sediments. Diversity is higher than in the estuarine zone due to the presence of species observed in both the estuarine and further offshore marine zone. Examples of species that are representative of this zone are the polychaetes *Artacama proboscidea* and *Trochochaeta carica*, and the bivalve *Portlandia arctica*. Echinoderms are present in this zone. Average biomass was approximately 5 g/m^2, higher than the estuarine zone, but likely attenuated due to the effective removal of bottom substrate by the scouring activity of ice.

Marine Zone

The marine zone extends from water depths of 30 m up to 200 m, with salinities ranging from approximately 30 to 33 ppt (Wacasey 1975). Sampling locations in the eastern portion of this zone had the greatest number of species represented and the highest biomass of all areas investigated. Average biomass for the entire zone was 14 g/m^2. Wacasey (1975) suggests that nutrient enrichment of the deeper waters is a probable explanation for the observed higher diversity and biomass in this zone. Very few species sampled from this zone were also found in the estuarine zone, with salinity likely limiting their distribution. Species typical of the marine zone were the polychaetes *Maldane sarsi*, *Aricidea suecica*, *Paraonis gracilis*, *Onuphis conchylega*, and *Pectinaria hyperborea*, the amphipod *Haploops laevis*, the isopod *Mesidotea sabini*, and the bivalves *Astarte borealis*, *A. montagui*, *Macoma calcarea*, and *Macoma* spp.

Continental Slope Zone

Beyond water depths of 200 m, the continental slope zone is encountered (Wacasey 1975). Average biomass was 4 g/m^2, lower than for the marine zone, and diversity was comparable to that measured in the transitional and marine zones. Biomass typically decreases with increasing water depth. As in the marine zone, Wacasey (1975) regards nutrient availability as the primary parameter governing benthic invertebrate biomass and diversity. The benthic invertebrate community observed is distinguished by the occurrence of species absent or rare in the other zones. Examples of such species are the polychaetes *Onuphis quadricuspis* and *Laonice cirrata*, the amphipods *Haploops tubicola* and *Hippomedon abyssi*, and the isopod *Gnathia stygia*.

Tuktoyaktuk Harbour

Primary sources of information on the benthos of Tuktoyaktuk Harbour are Thomas et al. (1981), Thomas et al. (1983), and Hopky et al. (1994). The distributions of benthic invertebrates identified by Thomas et al. (1981) appeared to be most strongly influenced by water-depth related parameters (e.g., water temperature and salinity gradients). The community observed in water less than 6 m deep inhabited shallow areas subjected to relatively large and episodic variations in water temperature and salinity and was characterized by the bivalves *Cyrtodaria kurriana* and *Macoma incon spicula*, the amphipods *Pontoporeia femorata* and *Aceroides latipes*, and the polychaetes *Ampharete acutifrons* and *Spio filicornis*. Deeper areas of the harbour, where salinity is typically higher, but less variable, were characterized by the polychaetes *Prionospio cirrifera* and *Antinoella sarsi*, the gastropod *Cylichna alba*, and the priapulid *Halicriptus spinulosis*.

The species composition and abundance of benthic invertebrates in Tuktoyaktuk Harbour appear to be representative of nearshore areas, the estuarine and transitional zones demarcated by Wacasey (1975), which are more strongly influenced by the fresh water discharge of the Mackenzie River (Thomas 1988).

3.3 ARCTIC MARINE ISOPODS

The large marine isopods *Mesidotea entomon*, *M. sibirica*, and *M. sabini* are all common in the southern Beaufort Sea, adjacent to the Mackenzie River Delta (Percy 1983). Percy (1983) suspects that the occurrence of all three *Mesidotea* species in the southern Beaufort Sea is related to the spatial and temporal variability in water temperature and salinity regimes near the Mackenzie River.

Each of the isopod species tends to exploit one of the different zones described by Wacasey (1975). *M. entomon* appears to be limited to the nearshore, estuarine zone, as the majority were collected in less than 10 m of water and none were observed in samples collected in water deeper than 40 m (Percy 1983). However, after reviewing the available literature, Percy (1983) concludes that greater water depth, higher salinity, nor colder water temperature is sufficient to limit the seaward spread of this particular species.

M. sibirica occurred primarily in the transitional zone, most commonly in samples collected at depths from 5 to 25 m (Percy 1983). Percy (1983) suggested that *M. sibirica* may not occupy the estuarine zone due to the high water temperature or reduced salinity. Salinity has been identified as the principal factor influencing the distribution of this isopod where Percy and Fife (1980) observed significant mortalities during exposures of *M. sibirica* to salinities less than 15 ppt for a number of concurrent days.

M. sabini was the only one of these three isopod species commonly collected in the marine zone, up to water depths of 441 m, but was also observed in the transitional zone and the outer edge of the estuarine zone (Percy 1983).

Although the distribution of these isopods is related to the three distinct zones characterized by Wacasey (1975), there appears to be a considerable amount of overlap among them (Percy 1983). The distributions of *M. sibirica* and *M. sabini* appear to overlap more so than either do with *M. entomon*. Percy (1983) attributes this to the variable pattern of warm, fresh water input to the waters adjacent to the Mackenzie River, which results in areas being exposed to a cycle of different thermal and osmotic regimes within a short time period. Greater overlap among these three species was observed to the west of the Mackenzie River Delta (near Herschel Island) and to the east (in Liverpool Bay), as deeper water extends closer to shore (Percy 1983).

3.4 MACROALGAE AND MACROPHYTES

Much of the Arctic's macroalgal community is believed to have evolved from that of the Atlantic. Species diversity decreases westward through the Arctic, and is low in the Beaufort region, limited by lack of suitable substrate, low salinity, prolonged ice cover, water column stratification, and ice scouring (Lee 1980). Systematic surveys are lacking, but cursory sampling has occurred at Spy Island, Collinson Point, Kugmallit Bay, Herschel Island, Demarcation Bay, Tigvariak Island and the Tuktoyaktuk area. Species idendtified include Anabaena sp. (blue green algae phylum), several from the green algae phylum, including Chlorella marinus, Ulothrix pseudoflacca, U. flacca, Stichococcus marinus, Enteromorpha micrococca, E. percusa, E. prolifera, E. torta, Ilea fulvescens, Blidingia minima, and Rhizoclonium implexum. The red algaes include Phyllophora truncata and Ceratocolax hartzii, and the brown algaes include Pylaiella littoralis and Laminaria solidunga. Along the Alaskan coast, additional species include the kelps L. saccharina and Alaria esculenta, and the red algaes Phycodrys rubens, Neodilsea integra, Rhodomela confervoides and Odonthalia dentata (Dunton et al. 1982).

Arctic salt marshes are relatively unproductive in comparison to temperate salt marshes, or even to terrestrial Arctic vegetation (Jeffirs 1977). Taylor (1981) classified the coastal marine vegetation into five habitat types. They are tidal salt marshes, upper storm zone salt marshes, gravelly beaches, raised beaches, and coastal dunes. Vegetation dominance is determined by largely by substrate and level of disturbance by ice, waves and wind. Tidal salt marsh vegetation occurs on lagoons, and is dominated by dwarf grass (Puccinellia phryganodes), followed by Stellaria humifusa and Cochlearia officinalis at the seaward edge. Vegetation of upper storm zone salt marshes is indicative of begin beyond the influence of high tide, but periodically flooded by storm surgees. It is dominated by Dupontia psilosantha, followed by Arctagrostis latifolia, Arctophila fulva, Carex aquatilis var. stans, Eriophorum angustifolium, Salix ovalifolia, and S. arctica; mosses are also frequent and dense. The steeper and narrower gravelly beaches are more disturbed by waves and stranded ice. The ryegrass Elymus mollis is dominant, accompanied with sparse stands of Mertensia maritima, Honckenya peploides, Lathyrus japonica, Equisetum arvense, and Cochlearia officinalis. Raised beaches, are almost terrestrial, rarely flooded by storm surges and more often influenced by salt spray. This community is comprised of willows (Salix ovalifolia and S. arctica), and grasses Elymus mollis, Festuca brachyphylla, and Poa arctica. Coastal dunes are relatively unstable, with plant cover higher on the leeward slope and dominated by Elymus mollis, and acoompanied by Salix ovalifolia, Festuca brachyphylla, Artemisia borealis, and Chrysanthemum bipannata.

3.5 FISH

The diverse range of conditions present in the coastal areas of the southeastern Beaufort Sea in the vicinity of the Mackenzie River Estuary provide suitable habitat for a relatively distinct assemblage of fish species (Craig 1984). A list of families and species of fish, along with their scientific names and the general habitats in which they occur is presented in Table 2. A selection of words for fish in the Siglit dialect of Inuvialuktun is presented in Table A. The three principal aquatic habitat types in this region are freshwater drainages, nearshore coastal waters (relatively warm and brackish), and offshore waters (colder marine waters). Freshwater streams and rivers provide important habitat for anadromous fish stocks, as do brackish waters in the summer, while offshore waters are used throughout the year by marine species (Craig 1984). Overwintering habitat for species that are intolerant of high salinities is also provided in sheltered bays where water stratifies under winter ice cover. Tuktoyaktuk Harbour is an example of this type of bay. The shape and depth profile of the bay results in the formation of a surface layer of up to 6 m of freshwater over a bottom layer of salt water during periods of winter ice cover. The resulting range of conditions provide suitable habitat for a large number of species (Chang-Kue and Jessop 1991).

There are a number of species of fish in this area that are of cultural and/or economic importance to local residents. Some of the more important species in this regard are the coregonids (whitefishes, ciscoes, and inconnu), char (Dolly Varden), and to a lesser extent pacific herring. Other species, such as Arctic cod and possibly rainbow smelt provide links in the food chain, and may be important sources of food for other fish as well as beluga whales and other marine mammals.

Fishes captured in coastal areas are numerically dominated by anadromous fishes, such as Arctic cisco, Dolly Varden, rainbow smelt, and least cisco. Arctic cisco is usually the most abundant species in this area, generally followed by fourhorn sculpin and least cisco (Karasiuk et al 1993). In the summer months the band of brackish water along the Yukon coast and Kugmallit Bay coast is an important migration route for anadromous species. This habitat allows migration between the coastal lagoons and estuaries that many species use for foraging, and nursery areas. Species composition in nearshore habitats varies with seasonal changes in salinities, shifting from Dolly Varden, least cisco, broad whitefish, inconnu, and other anadromous fishes in the open water season to fourhorn sculpin, saffron cod, and other more marine species during the period of landfast ice cover (Karasiuk et al. 1993).

Arctic Lamprey

Arctic lamprey are near the eastern limit of their range in this area and are rarely seen in high numbers (Karasiuk et al. 1993). Adults are parasitic on many fish species, such as inconnu, northern pike, burbot, pacific herring, least cisco, Arctic cisco, Dolly Varden, smelt, starry flounder, broad whitefish and lake whitefish (Reist et al. 1987; Karasiuk et al. 1993). Spawning occurs in freshwater, probably in the Mackenzie River, in late May to July. Larvae (ammocetes) are filter feeders that live in mud or silt substrates for three or four years before metamorphosing into adults, which migrate to large lakes or the sea to feed. Sexually mature fish return to freshwater in as little as a year in order to spawn (Karasiuk et al. 1993).

Clupeidae

Pacific Herring

Pacific herring in the southeastern Beaufort Sea most commonly occur in the vicinity of Richards Island and the outer Mackenzie Delta, particularly Mason Bay, Mallik Bay, and Tuktoyaktuk Harbour, and are less commonly found east of McKinley Bay on the Tuktoyaktuk Peninsula and along the Yukon coast (Lawrence et al. 1984, Karasiuk et al. 1993). Prespawning adults become more abundant along the Tuktoyaktuk Peninsula in August and September and spawn under the ice in early June or early July (Lawrence et al. 1984, Karasiuk et al. 1993). Spawning has been observed in Liverpool Bay, Mason Bay, and McKinley Bay. Known overwintering sites consist of estuarine coastal habitats along the Tuktoyaktuk Peninsula, Tuktoyaktuk Harbour, and possibly Moose Channel of the lower Mackenzie River (Sekerak et al. 1992). This species has been captured in a wide range of salinities, from mildly brackish to nearly marine waters (Lawrence et al. 1984). Stomach samples indicate that the diet of pacific herring in the southeastern Beaufort Sea is relatively more diverse than in other waters. Organisms that are consumed include copepods, mysids, amphipods, plant material, and benthic organisms such as bivalves, water mites, nematodes and chironomid larvae (Percy 1975, Lawrence et al. 1984).

Salmonidae

Salmon and Dolly Varden

Very small numbers of Pink salmon and chum salmon spawn in the Mackenzie River system and migrate westward along the Beaufort Sea coast to Alaskan waters. Sexually mature sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) caught in the Sachs River estuary on Banks Island represent the furthest extension of their known distribution (Bablauk et al. 2000). All anadromous char that spawn in streams and rivers located west of the Mackenzie River are Dolly Varden (Reist et al. 1997). Dolly Varden stocks in the western Arctic are composed of two types, self-perpetuating non-anadromous isolated populations, and anadromous populations (Reist 1989). In some anadromous populations, such as the Big Fish River stock, a portion of the male fish mature at a smaller size and younger age without going to sea. These residual males utilize a "sneak spawning" strategy to spawn with anadromous pairs (Reist 1989).

A limiting factor for Dolly Varden in the western Arctic is the availability of accessible spawning and over-wintering habitat. The high gradient of rivers running off the Yukon North Slope allows them to bottom-freeze over much of their length, the exception being where groundwater springs discharge, sufficiently maintaining water tempertures for flow (Sandstrom et al. 2001). All anadromous Dolly Varden spawn and overwinter in sections of rivers or creeks that are fed by thermal springs, which provide areas of open water throughout the year. The limited size of these areas of open water results in the entire population of a river system, from egg to adult, occupying the same limited habitat for nine to ten months of the year. Dolly Varden in these streams comprise discrete stocks that are maintained by high site fidelity to natal streams by spawning fish (Reist 1989). In the Big Fish River all spawning and overwintering occurs in a single section of Cache Creek called the Fish Hole (Byers 1993, Sandstrom 1995).

Inuvialuit and Gwich'in respondents of a study on the Big Fish River char fishery said that the char enter the river during a run that lasts for two to three weeks, primarily between August and September. Two respondents thought it also took place in July. If conditions are bad for spawning, such as the water being silty or debris blocking the river mouth, then some respondents thought the char would go to the Rat River instead. Char lay eggs from late October to November. Juveniles leave the grounds when they are between 4 to 12 inches long, and the char leave the Fish Hole after break-up. Two interviewees noted that some char stay in the river all year down from Cache Creek Falls (Byers 1993).

Spawning and overwintering grounds for the Rat River stock, which may contain several sub-populations, appear to be in at least two locations in the spring-fed reaches of Fish Creek, a tributary of the upper Rat River. A separate and genetically distinct stock of Dolly Varden also occurs in the Vittrekwa River. There may also be several populations in tributaries of the Peel River, other than the Vittrekwa and Rat Rivers, but little information exists for these (Reist pers comm 2001).

During the summer months anadromous adult Dolly Varden migrate to the sea to feed, while juveniles and residual adults remain in freshwater. Adult fish undergo feeding migrations along the coast of Northwest Territories, Yukon and Alaska. Juvenile fish (three or four years of age) migrate to estuaries near the mouths of their natal streams to smoltify (undergo the physiological changes that allow them to tolerate marine waters), where they usually remain for the rest of the summer, migrating further along the coast the following year (Sandstrom 1995). Residual males and juvenile char in freshwater feed mainly on aquatic insect larvae, anadromous fish rarely feed while in rivers (Armstrong and Morrow 1980). Small char (<300 mm) in coastal waters feed on aquatic insects, such as chironomid larvae, char between 300 and 500 mm eat amphipods, small isopods, and some fish, and large char (>500 mm) feed mostly on fish such as fourhorn sculpin and Arctic cod, and smaller numbers of insects and crustaceans (Karasiuk et al. 1993).

Coregonidae

Inconnu

Inconnu are found in the Mackenzie River drainage and along the coast. Most inconnu that are located along the Yukon coast are immature or adult fish between spawning years (Karasiuk et al.

1993). The highest concentrations of inconnu in coastal waters occur east of Shingle Point, although some fish are found northwest to Stokes Point or Herschel Island. Overwintering fish have been located as far west as Sabine Point (Lawrence et al. 1984, Karasiuk et al. 1993). Inconnu have been known to migrate distances up to several hundred kilometres between freshwater spawning and brackish water overwintering areas and have been captured in waters with salinities ranging between <0.1 - 31 ppt (Lawrence et al. 1984). Upstream migrations in the Mackenzie River for feeding, followed by spawning, occur from June to September, and downstream migrations to overwintering habitats are in October, following freeze-up. Fry hatch in late February to April and are soon carried downstream by currents to the lower reaches of rivers and brackish waters. There is also a fully freshwater life history type, which does not migrate into coastal waters (Reist and Bond 1988). Deep embayments of the Mackenzie Estuary, such as Mallik Bay and Tuktoyaktuk Harbour, as well as Kugmallit Bay provide overwintering habitat (Lawrence et al. 1984). Additional overwintering areas include Shallow Bay and Shoalwater Bay and major channels and lakes of the inner Mackenzie Delta (Husky, Peel, Enoch, West, Aklavik, Reindeer, and East channels, as well as the Peel and Arctic Red rivers), which appear to contain some of the most important overwintering areas (Sekerak et al. 1992). Fry eat zooplankton and insect larvae, switching to fish within about one year. Adult fish in coastal waters feed on least and Arctic cisco, ninespine stickleback, boreal smelt, fourhorn sculpin, pacific herring, cod, lamprey ammocoetes, and occasionally on small numbers of isopods, mysids, amphipods, or other invertebrates (Stein et al. 1973, Lawrence et al. 1984, Karasiuk et al. 1993).

Broad Whitefish

Broad whitefish are found in the nearshore waters of the Mackenzie River Estuary, and in the streams and rivers in this coastal area as far west as Herschel Island. Inuvialuit recognize three kinds of broad whitefish. One is described as a large "jumbo" type. The second is dark coloured, lives in lakes and is said to have firmer flesh and is better tasting. The third is a silvery colour, lives in rivers and has waterier flesh. Some Inuvialuit report that there is a large fish which appears to be a cross between an inconnu (coney) and a broad whitefish (Freeman 1997).

Typical migration patterns involve summer feeding movements along the coast, and upstream migrations in the fall to spawn in mid-October to early November over gravel shoals in the mainstem of the Mackenzie River. Some Inuvialuit say that broad whitefish spawn in lakes primarily from September to October, while others say it is from November to December. Spawning is thought to take place in the cool, shallow waters of vegetated lakes, or ones with a sandy substrate. Some Inuvialuit recognize that whitefish can go far upstream and spawn in areas they don't know about (Freeman 1997).

The migratory movements and dispersal of broad whitefish in the area of Tuktoyaktuk Harbour have been described by Inuvialuit of Tuktoyaktuk as follows:

> When the ice begins to leave the harbour, so do the whitefish to feed on "little shrimp" in the ocean [202]. About a month later the whitefish return from the sea, with the smaller whitefish arriving before the larger ones; only after the ice leaves

> the harbour completely, do the bigger whitefish arrive [213]. In fact, most jumbo whitefish are caught in August after the dryfish-making season [214].
> When the water temperature drops, about the third week of August, many whitefish, especially the smaller, medium-sized fish, begin to head upstream. By early September, there are hardly any whitefish left in Tuk harbour [201] (Freeman and Stevenson 1995).

Non-spawning adult fish are known to overwinter in lakes deeper than about 3 m with access to coastal areas along the Tuktoyaktuk Peninsula. The lakes in the Kukjuktuk Creek drainage, Tuktoyaktuk Harbour, Whitefish Bay, and the East Channel of the Mackenzie Delta are thought to be important overwintering habitat. Spawning adult fish probably overwinter in the Mackenzie River or Delta (Chang-Kue and Jessop 1983, Lawrence et al. 1984, Reist and Bond 1988). Eggs hatch in late winter or early spring and young fish are swept downstream to the coast. Some young broad whitefish move westward along the coast as far as Philips Bay, but most migrate along the coast of the Tuktoyakyuk Peninsula. When these fish reach 50 mm in length they migrate into the peninsula's lakes, which provide major nursery habitat (Reist and Bond 1988, Chang-Kue and Jessop 1992). Broad whitefish may remain in coastal lakes for three to five years before returning to coastal waters to emigrate up rivers to spawn (Reist and Bond 1988). This pattern has been observed by Inuvialuit of Tuktoyaktuk who have noted that "only rarely are jumbos seen to head upstream to lakes of the Tuk peninsula in the fall" [201, 207, 214] and have suggested that smaller whitefish might stay in these lakes for a couple of years before coming back down [207], since big whitefish are often seen coming out of the lakes in the spring [211, 214] (Freeman and Stevenson 1995). This species feeds heavily on chironomid larvae and other aquatic insects, as well as other small crustaceans, molluscs, and annelids (Lawrence et al. 1984, Karasiuk et al. 1993).

Lake (or Humpback) Whitefish

Lake whitefish distribution in the southeastern Beaufort Sea is similar to that of broad whitefish; they can be found in the nearshore waters of the Mackenzie River Estuary, and in streams and rivers as far west as Herschel Island. Salinity of waters from which lake whitefish have been captured range from 0.06 - 30.0 ppt (Lawrence et al. 1984). Isolated, non-migratory populations of lake whitefish are also found in a number of upland lakes in the area (Sekerak et al. 1992). In the fall, adult fish migrate up the Mackenzie River to spawning locations. There is evidence that larger fish migrate upstream before smaller individuals. Following spawning over gravel shoals in lakes in the upper Mackenzie Delta or in the Mackenzie River, adult fish overwinter in the delta, or areas of the inner estuary, such as south Kugmallit Bay, as well as Tuktoyaktuk Harbour (Lawrence et al. 1984). Young-of-the-year lake whitefish do not appear to use the lakes of the Tuktoyaktuk Peninsula and have only rarely been found outside of the Mackenzie Delta, which contains major nursery areas (Reist and Bond 1988). Commonly found prey items in lake whitefish stomachs include gastropods, amphipods, bivalves, and chironomids in fish captured from lakes. The diets of coastal fish vary with timing and area. Some common diet items include isopods, amphipods, plant matter, mysids, bivalves, and aquatic insect larvae (Lawrence et al. 1984).

Least Cisco

There are several different life history types for least cisco in the southeastern Beaufort Sea and Mackenzie Delta region. Lacustrine forms are found in lakes along the coast, and dwarf and normal lacustrine forms are found in several lakes in the Mackenzie Delta. In comparison to anadromous fish, lacustrine least cisco appear to sexually ripen earlier, are larger and more deeply bellied, do not appear to enter coastal areas when migrating to other lakes, have a more darkly pigmented dorsal surface and ventral fins, have a less protruding lower jaw, and are heavier at a given fork length (which may be due to habitat differences) (Lawrence et al. 1984). Anadromous forms migrate and feed along the coast in the summer, spawning and overwintering in the Mackenzie River system, as far west as the area between Shingle and Sabine points (Karasiuk et al. 1993). The highest concentrations of this species in the summer are near the Mackenzie Delta, with abundance decreasing along the coastline to the Yukon/Alaska border. Coastal migrations occur within the band of warm, brackish water that forms in the summer. Least cisco rarely move further offshore, unless inshore waters become too rough, or the band of brackish water extends further out to sea (Craig 1984, Karasiuk et al. 1993). Migration to spawning and overwintering areas begins in August, with mature fish probably arriving on the spawning grounds first. Spawning occurs in late September or early October in shallow water over sand and gravel. Adult fish begin summer feeding migrations in June, which is about the same time that fry move downstream from spawning areas (Karasiuk et al. 1993). Young-of-the-year least cisco do not appear to migrate far from the mouth of the Mackenzie River. Most of these young fish remain in coastal areas with the Mackenzie Estuary, although some fish also enter lakes within the Tuktoyaktuk Peninsula (Bond and Erikson 1989).

Overwintering habitat consists of lakes in the Mackenzie Delta and Tuktoyaktuk Peninsula and sheltered coastal bays, such as Mallik Bay and Tuktoyaktuk Harbour (Chang-Kue and Jessop1992). Diet studies indicate that least cisco in coastal waters feed on copepods, amphipods, mysids, polychaetes, and fish, while lacustrine least cisco eat amphipods, snails, clams, ostracods, aquatic insect larvae, and small fish, such as ninespine stickleback (Lawrence et al. 1984). Adult fish (spawners) do not appear to feed as they migrate into the Mackenzie Delta (Karasiuk et al. 1993).

Arctic Cisco

Arctic cisco occur along the Yukon in brackish waters and the lower reaches of coastal rivers along the Yukon coast from the Mackenzie Delta to Prudhoe Bay. Fry and juveniles in this area are typically found along shallow shorelines, and in lagoons and estuaries. Despite higher salinity tolerances than least cisco, Arctic cisco tend to remain in nearshore areas, probably due to a preference for warmer water temperatures (Karasiuk et al. 1993), although age-0 fish in good condition have been captured offshore beyond brackish waters (Jarvela and Thorsteinson 1999). Spawning occurs at or near freeze-up.

Sexually mature fish migrate up spawning rivers (the Mackenzie River or its major tributaries) from July to September, well before spawning takes place, and spawn over gravel in fast water. Downstream migrations to overwintering areas in the Mackenzie Delta or along Tuktoyaktuk Peninsula, such as bays and lagoons along Richards Island, Kugmallit Bay, and Tuktoyaktuk Harbour, occur from October to December (Percy 1975, Lawrence et al. 1984, Karasiuk et al. 1993).

Young-of-the-year fish disperse west and east along the coast, depending on which channel of the Mackenzie River that they travel downstream in. Once in coastal water these fish disperse, with the aid of wind driven currents, well into Alaskan waters. Abundance of adult fish along the coast of Alaska appears to be related to increased or decreased recruitment levels resulting from the intensity of wind derived currents five years earlier (Fechhelm and Fissel 1988).

Arctic cisco feed primarily on benthic organisms, such as crustaceans, chironomids and other aquatic insects, as well as small fishes. Fry and juveniles eat copepods, chironomids and other dipterans, amphipods, mysids, and fourhorn sculpin. The diet of adult fish varies with location, but consists mostly of crustaceans (mysids, amphipods, copepods, and isopods), but chironomids and other insects, fishes, polychaetes, and clams are also eaten when available (Lawrence et al. 1984, Karasiuk et al. 1993).

Arctic Grayling

Arctic grayling are found in streams and lakes containing sui spawning and overwintering habitat, including some areas on Tuktoyaktuk Peninsula and Richards Island (Lawrence et al. 1984). Summer distributions along the North Slope appear to vary with life history stage. Young fry form large schools in warmer, low velocity, shallow water near spawning areas, moving to riffles and pools as they grow larger. Adult and juvenile fish are found in spawning streams in early summer, and move into the main channels of rivers and lakes as water temperatures increase. Overwintering areas consist of the lower reaches of larger tributaries, or the Mackenzie River. Fish in North Slope coastal rivers, such as Big Fish River, overwinter near thermal springs, as the remainder of the river freezes to the bottom. The grayling's low tolerance for salinities over 3.0 ppt renders estuaries unsuitable for overwintering habitat (Karasiuk et al. 1993). During spawning migrations, which begin in about mid-May to mid-July, grayling often travel considerable distance to upstream spawning grounds. The diet of fry consists of zooplankton, switching to aquatic insect larvae during their first summer. Adult fish feed primarily on terrestrial insects, followed by aquatic insect larvae, as well as some small fish and fish eggs (Karasiuk et al. 1993).

Osmeridae

Pond Smelt

Isolated populations of pond smelt are found in the lower Mackenzie River and the Tuktoyaktuk Peninsula, as well as a distinct, slow growing, long lived population in Roland Lake, near Stokes Point (Karasiuk et al. 1993). Catches of pond smelt in seine hauls along the coast of Richards Island in waters with salinities ranging from 0.4 to 5.5 ppt suggest that this species utilizes the nearshore band of brackish water to some extent (Lawrence et al. 1984). This species is primarily planktivorous and dominant food types vary with fish size and location. Rotifers, copepods, chironomids, and cladocerans are commonly found prey items in stomach samples (DeGraaf 1986).

Rainbow Smelt

The highest abundance of rainbow smelt in the Canadian Beaufort Sea occurs near the Mackenzie Delta. Distribution along the Yukon coast tends to vary between years, with the most western extent being Herschel Island (Karasiuk et al. 1993). This species is able to tolerate a wide range of salinities, at least 0.1 - 30 ppt (Lawrence et al. 1984). Rainbow smelt overwinter in the brackish and freshwater portions of the estuary and migrate upstream to spawning areas, particularly the upper Mackenzie Delta and the Arctic Red River, in the spring (Lawrence et al. 1984, Bond and Erikson 1989). After they emerge, smelt fry are carried downstream into the Mackenzie River Estuary with the spring flood. Coastal areas provide important feeding and nursery habitat for this species (Bond and Erikson 1989). Major prey items include mysids, isopods, copepods, and small fishes, such as Arctic cod (Karasiuk et al. 1993).

Capelin

Little is known about the distribution and status of capelin in the Beaufort Sea. Large numbers have been recorded in the past (1960), while few or none were captured in a number of coastal fisheries surveys conducted since that time (Karasiuk et al. 1993). Higher numbers of capelin are found along the northwestern coast of Alaska, which appears to be an important spawning and nursery area. Age-0 fish are present in high numbers in this area throughout the summer, but adult fish are only captured in high numbers periodically during summer months. These occasional high catches probably represent spawning runs (Jarvela and Thorsteinson 1999) and the infrequent catches of capelin near the Mackenzie Delta may be due to spawning runs that have strayed further east than usual. Distribution of capelin in the central Mackenzie River Estuary is sporadic.

Esocidae

Northern Pike

Northern pike are primarily found in freshwater and are only able to tolerate low levels of salinity. Some northern pike have been captured in coastal areas, but these were usually in channel mouths in areas of low salinities. Further inland, northern pike become much more numerous, and are frequently captured in freshwater catches from rivers and lakes of the Mackenzie Delta (Lawrence et al. 1984). Northern pike migrate into warm, low velocity areas that contain abundant aquatic or flooded terrestrial vegetation in the spring and spawn when water temperatures are about 6 - 9^{o}C. Young northern pike feed on zooplankton and aquatic insects, quickly switching to fish. Adult northern pike feed primarily on fishes, such as whitefish and cisco, although ducklings, rodents, and other prey are also consumed (Percy 1975, Karasiuk et al. 1993).

Catostomidae

Longnose Sucker

Longnose sucker is a freshwater species that is rarely found in the brackish waters of the Mackenzie Delta (Karasiuk et al. 1993). In coastal areas where this species has been captured salinities were low (0.02 - 1.66 ppt), which indicates that longnose sucker probably do not migrate very far into brackish waters (Lawrence et al. 1984).

Gadidae

Arctic Cod

Arctic cod have a circumpolar distribution, and have often been described as a key species in Arctic marine food webs. Young-of-the-year and juvenile Arctic cod are abundant in offshore marine waters of the southern Beaufort Sea, including polynyas where primary productivity is enhanced by higher water temperatures and extended open water period (Michaud et al. 1997), and can be the most abundant species in catches along the coast of Alaska or the Yukon North Slope (Jarvela and Thorsteinson 1999). However, only low numbers of this species have been captured in fish surveys along the coastal areas of the southern Beaufort Sea (Karasiuk et al. 1993). It has been suggested that the apparent low numbers of this fish in this area may be due to a combination of low catchability in gill nets, due to body shape, and its use of pelagic habitats confounding abundance estimates (Lawrence et al. 1984), as well as a preference for colder, higher salinity waters (Jarvela and Thorsteinson 1999). This species is probably less ecologically important in the Mackenzie Estuary than in more marine waters (Lawrence et al. 1984, Karasiuk et al. 1993). Stomach content analysis indicates that copepods are one of the most common types of food consumed. Other prey items that are common in the diet of Arctic cod are amphipods, mysids, other crustaceans, and fish larvae (Lacho 1986).

Saffron Cod

Saffron cod are more tolerant of low salinity waters than Arctic cod and are found in shallow coastal waters and river mouths. This species, which is distributed in Canada from the Yukon coast, east to Bathurst Inlet, shows a preference for cool waters, and ceases to feed at temperatures above 10^{o}C. Highest abundance of saffron cod along the coast appears to be in the vicinity of the outer Mackenzie Delta and Tuktoyaktuk Peninsula (Karasiuk et al. 1993). Distribution of saffron cod in nearshore areas of the Beaufort Sea, generally in depths of less than 50 m, appears to be related to water temperature and salinity, which may be due at least in part to their effect on prey species distribution (Johnson 1995). Spawning appears to occur in March or April in areas such as Kujuktuk Bay and Tuktoyaktuk Harbour (Lawrence et al. 1984). Known overwintering areas include coastal areas along the Tuktoyaktuk Peninsula and in Tuktoyaktuk Harbour (Sekerak et al. 1992). The diet of saffron cod appears to vary with the location and time of year that fish are sampled. Amphipods, isopods, fishes, mysids, polychaetes, priapulids, and plant material are frequently consumed items (Lawrence et al. 1984). In areas where this species is locally abundant (nearshore areas) it probably plays a greater role in food chains, by acting as the dominant piscivorous marine fish species, and as an important prey species for marine mammals (Johnson 1995).

Burbot

Burbot are a primarily freshwater species that is occasionally found in estuary waters of large rivers that flow into the Arctic Ocean. Catches of burbot in the coastal waters of the Yukon coast have been recorded at Shingle Point, Kay Point, and perhaps Herschel Island. Burbot have also been captured in streams and lakes of Richards Island and the Tuktoyaktuk Peninsula. Overwintering burbot have been captured from areas of Kugmallit and Tuktoyaktuk Harbour where there were reduced salinities in the upper 4 m of the water column (Lawrence et al. 1984). Burbot in the outer Mackenzie Delta have been found to feed on fishes, such as sculpins, smelts, other burbot, and ninespine stickleback, as well as invertebrates, such as notostracans, amphipods, molluscs, isopods, mysids, and fish eggs (Lawrence et al. 1984, Karasiuk et al. 1993).

Cottidae

Slimy Sculpin and Spoonhead Sculpin

Slimy sculpin and spoonhead sculpin are freshwater species that are commonly located in the lakes and streams in the inner Mackenzie Delta. Slimy sculpin have been recorded in Yukon coastal waters once (Karasiuk et al. 1993). Spoonhead sculpin stomachs from fish captured in streams and lakes of the Mackenzie Delta contained chironomids, ostracods, mysids, and plecopterans (Lawrence et al. 1984).

Fourhorn Sculpin

Fourhorn sculpin are very abundant in the coastal areas of the southern Beaufort Sea and are preyed on by a wide range of species. In nearshore waters the fourhorn sculpin may play a more important role in coastal food webs than Arctic cod (Karasiuk et al. 1993). This species is found in brackish and marine waters of the Yukon coast, including delta and estuary areas. Distribution is widespread, with greater abundance in areas with sufficiently high salinities. Fourhorn sculpin are among the most numerous species in catches along coastal areas such as, Herschel Island, the outer Mackenzie Delta, and the Tuktoyaktuk Peninsula (Lawrence et al. 1984, Karasiuk et al. 1993).

Fourhorn sculpins are tolerant of a wide range of salinities, from 0.04 to 27.0 ppt. and temperatures from about 0 - 7.3^{o}C (Lawrence et al. 1984). Migrations appear to be linked to changes in turbidity, temperature, and salinity, with fish moving to offshore areas during periods of high discharge, presumably to areas with more suitable conditions. Upstream movements generally do not exceed regions of tidal influence (Lawrence et al. 1984). Spawning occurs during the winter, with males defending territories and guarding young (Karasiuk et al. 1993). Known overwintering areas along the coast are Shingle Point, Mason and Mallik Bays, and Tuktoyaktuk Harbour. Offshore wintering areas are difficult to sample and their relative importance is not known (Lawrence et al. 1984, Karasiuk et al. 1993). Diet studies indicate that isopods are a key prey species of fourhorn sculpin. In different areas amphipods, mysids, and fishes are also important. Fish eggs, clams, insects, and plant matter are also consumed in lesser amounts (Lawrence et al. 1984, Karasiuk et al. 1993).

Gasterosteidae

Ninespine Stickleback

Ninespine stickleback, which is located in both freshwater and brackish coastal waters, is an important forage fish for a large number of species (Karasiuk et al. 1993). In the Beaufort Sea this species is distributed along the coast from the Mackenzie Delta and Tuktoyaktuk Peninsula to at least the Yukon/Alaska border. Ninespine stickleback occupy a diverse range of habitats, such as streams and rivers, coastal lagoons, estuaries, tundra ponds and lakes, and is capable of inhabiting waters with salinities up to 16 - 20 ppt. Downstream migrations often occur in the fall as fish move downstream to estuaries or lakes to overwinter. In the summer, ninespine stickleback migrate into freshwater to spawn (Lawrence et al. 1984, Karasiuk et al. 1993).

Pleuronectidae

Arctic Flounder

Arctic flounder range from the White Sea near Finland, east along the Siberian coast to the Beaufort Sea and Coronation Gulf. This species is generally widespread but not common along the Yukon coast, although it is more abundant along Tuktoyaktuk Peninsula, particularly where salinities are above about 10 ppt (Karasiuk et al. 1993). Arctic flounder tend to segregate into single-sex schools, possibly due to differences in the timing of male and female spawning and post-spawning migrations. The only reported spawning areas in the southern Beaufort Sea are Kujuktuk Bay and Mallik Bay (Percy 1975, Lawrence et al. 1984). Commonly found food items from stomach samples included plant material, amphipods, oligochaetes, priapulids, ascideans, and polychaetes (Lawrence et al. 1984).

Starry Flounder

Starry flounder are found in coastal waters from 0 - 150 m deep, are tolerant of low salinities, and sometimes enter river mouths. This species appears to be rare along the Yukon coast (Karasiuk et al. 1993). Higher abundances are found along the Tuktoyaktuk Peninsula, where they are about the third most abundant marine species, and have been captured from waters with salinities from 1 - 29 ppt (Lawrence et al. 1984). In the spring sexually mature fish in the vicinity of the Tuktoyaktuk Peninsula undergo spawning migrations into brackish waters ranging from salinities of 3.7 - 8.0 ppt. This is followed by an inshore migration of non-spawning adults. Most schools tend to be all the same sex. Starry flounder remain abundant in nearshore areas throughout the summer, migrating offshore by about September to overwintering areas, although overwintering probably also occurs in deeper bays, such as Mallik Bay (Percy 1975, Lawrence et al. 1984). No known spawning areas exist along the Yukon coast, but fry and juvenile fish have been captured from the lagoon at Stokes Point, and from Phillips Bay (Karasiuk et al. 1993). Clams, plant material, amphipods, isopods, priapulids, and polychaetes are the most commonly identified food items in stomach contents (Lawrence et al. 1984).

Offshore Marine Fishes

The majority of fisheries surveys that have been conducted in the southeastern Beaufort Sea in the vicinity of the Mackenzie River and along the Yukon coast have focussed on nearshore, brackish, water in the summer months. As a result, species that are not able to tolerate low salinities or high temperatures are under represented in survey catches. A summary of the distributions, preferred habitat characteristics, and major diet items for a number of the more common offshore marine species is presented in Table 3. Due to the low numbers of offshore marine fishes that are captured and the paucity of information regarding these species it is not known what level of importance they have in the marine food chain. Limited information is available for some offshore marine species in other areas, but their role in the Beaufort Sea still requires further study. Trawl catches suggest that sculpins and Arctic cod are among the more important species in the area (Percy et al. 1985).

3.6 MARINE MAMMALS

The southern Beaufort Sea provides seasonal or year round habitat for several species of marine mammals. Inuvialuktun names for selected marine mammals in the Siglit dialect are listed in Table B. Beluga (*Delphinapterus leucas*) and bowhead whale (*Balaena mysticetus*) make annual movements into the area each spring and summer in the near and offshore areas of the southern Beaufort Sea and Amundsen Gulf. Killer whale (*Orchinus orca*) are infrequently observed in the area, and evidence indicates that narwhal (*Monodon monoceros*) have entered into the Amundsen Gulf area on occasion (Smith 1977). Gray whales (*Eschrichtius robustus*) have been observed in the offshore areas of the western Beaufort Sea.

Ringed seal (*Phoca hispida*) are the most abundant seal in the Canadian Arctic, and are year round residents in the southern Beaufort Sea. Polar bears (*Ursus maritimus*), the primary predator of the ringed seal, are also abundant. Polar bear movements and distribution in the area are largely dependant upon ringed seal distribution and sea ice conditions. Bearded seals (*Erignathus barbatus*) are considerably less abundant than ringed seals, but are also year round residents in the southern Beaufort Sea area. Small numbers of harbour seal (*Phoca vitulina*) and walrus (*Odobenus rosmarus*) are occasionally observed in the southern Beaufort Sea (Harington 1966, Stirling 1974).

The distribution, abundance, and ecology of the principal marine mammals present in the southern Beaufort Sea (beluga, bowhead whale, ringed and bearded seal, and polar bears) are discussed in the following sections. Individuals of each of these species make seasonal migrations within and into and out of the study area. Some of these movements cover large distances, such as beluga movement into the Bering Sea to overwinter, while others may be more localized, such as ringed seal moving into offshore areas to feed. Because important aspects (wintering, pupping, etc) of each species' life history may occur outside of the defined study area for this overview, the distribution and ecology of each species is described in relation to the geographic range of that species, rather than being restricted to use and activities occurring specifically in the study area

Beluga Whale

Abundance

Genetic analysis has identified numerous stocks of beluga whale from the North American Arctic, including seven stocks from Canada and four from Alaska (Brown 1996, Brown-Gladden et al. 1997, 1999; O'Corry-Crowe et al. 1997). Beluga whales that are found in the study area are part of what is known as the eastern Beaufort Sea stock. This stock is one of the largest in Canada and the most recent survey of population size (conducted in 1992) estimated approximately 20,000 animals

(Harwood et al. 1996). However, it is felt that this number underestimates the actual population size because the entire geographic range the population occupies was not surveyed, and the estimate did not account for whales that were not enumerated because they were underwater during aerial counts (Harwood et al. 1996, Richard et al. 1997).

Movements and Seasonal Distribution

Beaufort Sea beluga share common wintering areas in the Bering Sea with whales from several other stocks (O'Corry-Crowe et al. 1997, Wong 1999), although the exact wintering areas within the Bering Sea are not known.

During April and May, the Beaufort stock moves northwards through the Chukchi sea, and then eastward through the Alaskan portion of the Beaufort Sea (Moore et al. 1993). It is thought that the whales follow far offshore, shear-zone leads through the southeastern Beaufort, and arrive along the west coast of Banks Island during late May and early June (Fraker 1979). They then move in a southwestern direction, following the land fast ice edge off of Tuktoyaktuk Peninsula (Fraker 1979, Norton and Harwood 1986). Inuvialuit say that when their route is blocked by ice they will wait for the ice to move and then follow leads along the coast and move into Kugmallit Bay when they can (Byers and Roberts 1995).

Once the land fast ice begins to break up, usually in late June to early July, large numbers of beluga move into the Mackenzie Estuary and concentrate in three areas: i) Shallow Bay; ii) around Kendall Island; and, iii) in the southwestern portion of Kugmallit Bay (Figure 2). The whales remain in these nearshore areas for most of July (Wong 1999). Other portions of the population remain in the Amundsen Gulf and throughout the offshore areas of the Beaufort Sea during July (Norton and Harwood 1985, Wong 1999). Recent results from telemetry studies indicate that some beluga, especially males, use the Mackenzie Estuary on only a short-term basis, and can undertake long movements into offshore areas (Richard et al. 1997).

Fall movements back to the Bering Sea begin in late August. Using different routes ranging from 100-400 km offshore of northern Alaska, beluga move westward to the Wrangle Island area of the eastern Siberian Sea, where they aggregate during October. Movements from the Siberian Sea south into the Bering Sea generally take place during November. A beluga with a satellite telemetry tag attached to it moved into the Bering Sea during late November.

Biology

Beluga whales concentrate in estuaries and shallow, nearshore habitats during summer. Reasons for this behaviour were thought to include feeding, thermal advantage (Fraker et al. 1979), socializing and, more recently, to be related to the annual moult (St. Aubin et al. 1990). In some areas of the Arctic, beluga have been observed actively rubbing themselves on the sea floor, ostensibly to remove old skin and accelerate moulting (Smith et al. 1992).

Inuvialuit from Tuktoyaktuk report that belugas calve in Kugmallit Bay. Elders say that their ancestors talked about the whales calving there, but that few hunters witness it today because they do not spend time on the water viewing whales as was necessary when whaleboats and schooners were used. Cows are sometimes seen with two calves, although some say they are generally a juvenile and a calf. One elder saw cows calving in a group in shallow water. Few fetuses are found in whales, but hunters thought this may be attributed to few people opening wombs of the whales they are butchering (Byers and Roberts 1995).

Few Inuvialuit report seeing whales rubbing off moulting skin. Byers and Roberts say this may be attributed to poor visibility in the silty waters of the Mackenzie River. Those that have witnessed it say that it took place on mud or rocks on the bottom of nearshore areas, and under the surface of the ice (Byers and Roberts 1995).

As discussed in the previous section, beluga whale aggregate in three main areas of the Mackenzie River Estuary during July (Figure 2). It has not been determined whether beluga whale are feeding when they are in the near shore areas of the Mackenzie Estuary. Feeding was not observed in studies conducted in other estuaries, and empty stomachs in harvested whales are common (Smith et al. 1994). However, feeding does occur in areas offshore. Richard et al. (1997) presumed that whales making extended dives to the sea floor at depths of 400 - 600 m were feeding forays, and Hazard (1988) suggested that feeding was a major activity of whales in the offshore areas. Whales tagged with satellite-linked time-depth recorders were found to occupy the Mackenzie estuary intermittently, and for only a few days at a time. Much of their time was spent offshore, near or beyond the shelf break and in the polar pack ice of the estuary, Amundsen Gulf, M'Clure Strait, and Viscount Melville Sound. These movements into passages of the Canadian Arctic Archipelago contradict the belief that beluga are sedentary, coastal animals, and suggest instead that beluga travel long distances in the summer to areas that are hundreds of kilometres from the Mackenzie Delta. The movement into the dense pack ice of summer and autumn also contradicts the belief that beluga are limited to loose ice or open water. The tracked movements also suggest that aerial surveys confined to southeastern Beaufort Sea and Amundsen Gulf may have substantially underestimated the size of the eastern Beaufort Sea stock (Richard et al. 2001)

Beluga feed mainly on fish and large invertebrates such as octopus and squid. The diet of beluga in the Bering and Chukchi seas included Arctic cod, saffron cod, sculpins, herring, smelt, capelin, Arctic char, octopus, and shrimp (Lowry et al. 1986, as cited in Wong 1999). A beluga captured offshore of Tuktoyaktuk Pennisula had been feeding on Arctic cisco (Orr and Harwood 1998), providing some evidence of feeding in the estuary. Beluga concentration in the estuary may also be associated with the presence of rainbow smelt (Lawrence et al.1984, Percy 1975). Inuvialut say that the main fish eaten by belugas are pacific herring and least cisco. Smelt, burbot and inconnu are also eaten. Belugas are thought to throw up their food when stressed, such as when they are hunted because their stomachs are generally found empty (Byers and Roberts).

Mating for most beluga stocks occurs in spring, and it is likely that most mating occurs before beluga reach the Mackenzie Estuary. Females with calves are observed in the estuary, but it is thought that most calving takes place prior to the whales' arrival in the southern Beaufort area. Inuvialuit from Inuvik reported that in the 1960s and 1970s there were years with low numbers of calves. This is not attributed to low birth rates, but to cows going to different areas to calve due to bad ice conditions or low water levels (Byers and Roberts 1995).

Besides humans, polar bears and killer whales prey upon beluga (Lowry et al. 1987, Sergent and Brodie 1969, Smith and Sjare 1990). It is likely that little predation on beluga by natural predators occurs within the study area. Inuvialuit report that killer whales in the vicinity of Kugmallit Bay will cause seals and beluga whales to stay out of the area. Scars on the backs of whales from polar bears have been observed by hunters. A fragment of a narwhal tusk was found in a beluga by two hunters (Byers and Roberts 1995).

Bowhead Whale

Abundance

There are three discrete stocks of bowhead whales that summer in Canadian waters, including populations in Davis Straight, in Foxe Basin/northern Hudson Bay, and in the western Arctic (Marine Mammal Commission 1999). Bowhead whales that summer in the southeastern Beaufort Sea are part of the western Arctic population. The most recent survey of population size was conducted in 1993, and it was estimated that there were 8,200 bowheads (7,200-9,400) in the western Arctic stock (Raftery and Zeh 1998), comprising more than 90% of the world's bowhead whales (Marine Mammal Commission 1999). Genetic analysis has revealed that the western Arctic whales are more closely related to bowhead in Foxe Basin and northern Hudson Bay than to those in Davis Straight (Maiers et al. 1999).

Movements and Seasonal Distribution

The western Arctic bowhead population winters in the Bering Sea from St. Lawrence Island to as far south as the Pribilof Islands, generally associating with the marginal ice front and polynyas of the area (Braham et al. 1980). Northern migration through the Bering Strait and then eastwards past Point Barrow takes place during April and May (Clark and Johnson 1984, George et al. 1989). The whales continue into the southeastern Beaufort Sea, moving along offshore leads (Moore and Reeves 1993), and arrive off the west coast of Banks Island during late May and early June (Fraker 1979).

Throughout the first part of the summer (mid-June to mid-August), bowhead tend to be widely distributed throughout offshore areas of the Beaufort Sea and Amundsen Gulf (Davis et al. 1982, Harwood and Borstad 1985). Bowhead distribution during late summer appears to be related to the distribution and concentration of zooplankton upon which they feed. In turn, zooplankton productivity and distribution is dictated by meteorological conditions and oceanographic features such as wind conditions, the Mackenzie River plume, marine upwellings, and turbulence off Herschel Island and Cape Bathurst (Thomson et al. 1986). Zooplankton tend to be concentrated at certain areas (by the above forces) by mid-August, and bowhead aggregate at those areas of zooplankton concentration. Three main areas have been identified in the southeastern Beaufort Sea that consistently attract large concentrations of bowhead. These include: i) the Yukon coast between Kay and Shingle Points and around Herschell Island; ii) north of the eastern Tuktoyaktuk Penninsula between McKinley Bay and Cape Dalhousie; and, iii) Amundsen Gulf (Wong 1999). Areas where bowhead were observed to concentrate from 1980-1986 are illustrated in Figure 3.

Age-specific segregation of bowheads is apparent in the southern Beaufort Sea. Amundsen Gulf appears to be used primarily by adults (>13 m) and subadults (>11 m) (Cubbage et al. 1984, Davis et al. 1982, 1986), while bowheads along the Yukon coast appear to be mostly juvenile and yearling whales (Cubbage et al. 1984, Davis et al. 1986). Adults with calves were reported from offshore areas and in deep waters near Herschel Island (Cubbage et al. 1984, Davis et al. 1983).
Bowhead begin the fall migration back to the Bering Sea in September (Sergent and Hoek 1974), and may concentrate along the Chukota coast during October (Moore et al. 1995). Some bowhead traverse from Point Barrow across the northern Chukchi Sea to Herald and Wrangel Islands before turning south, while others follow the Alaskan coast to the Bering Sea. Bowheads generally enter into the Bering Sea in November and December (Wong 1999).

General Biology

Bowhead whales are baleen whales, and feed on zooplankton filtered from the water column. Three modes of feeding have been identified by Würsig et al. (1989), including: i) pelagic (mid-water) feeding; ii) feeding along the seafloor; and, iii) surface swimming. As discussed in the preceding section, bowheads concentrate in three main areas of the southern Beaufort Sea in late summer to feed. Zooplankton most frequently consumed in those areas include copepods (*Limnocalanus macrurus, Calanus hyperboreus, Calanus glacialis*), gammariid and hyperiid amphipods, euphausids and isopods (Bradstreet and Fissel 1986, 1987, Carroll et al. 1987).

Ringed Seal

Due to their importance within the Arctic food chain and their importance to the Inuit, ringed seals are one of the most studied marine mammals in the Arctic (Reeves 1998). Long-term studies conducted in the Prince Albert Sound area of Amundsen Gulf described many important aspects of ringed seal ecology in the western Arctic. The results of these and other studies were discussed by Smith (1987), and much of the biology described in the following sections was derived from that source.

Abundance

Ringed seals have a circumpolar distribution and are one of the most abundant marine mammals in the Arctic. Spring estimates (conducted during late June, just prior to ice break up) of ringed seal abundance in the southern Beaufort Sea have shown considerable fluctuation in population size between years. Initial estimates of ringed seal populations in the southern Beaufort Sea (from the Alaska/Yukon border eastward to the Baillie Islands and extending offshore for 160 km) revealed a large decline in ringed seal numbers between 1974 (16,600) and 1975 (3,700) (Stirling et al. 1977). Estimated ringed seal numbers ranged from 2,900 animals (1977) to 12,600 animals (1978) between 1976 and 1979 (Stirling et al. 1981, 1982). The most recent spring surveys of the same area, conducted between 1981 and 1984, provided estimates ranging from 5,400 to 6,900 ringed seals (Kingsley 1986, Kingsley and Lunn 1983).

Estimates of seal abundance conducted during late summer (open water conditions) have also shown considerable variation between years. Indices of relative abundance reveal a decline from an estimated 41,200 animals in 1982 to 6,400 in 1985, followed by an increase to 14,300 in 1986 (Harwood and Stirling 1992). These surveys covered the same area as the spring surveys discussed above, but also included areas off shore of the Yukon coast.

The sharp declines in population size observed in 1975 and 1985 appear to be linked to several factors. It has been suggested that heavy ice conditions during the preceding winters and summers of both years caused decreased primary and secondary productivity, and ultimately decreased prey availability for ringed seals (Smith 1987, Stirling et al. 1977, 1981, 1982). Extensive seal mortality has been offered as a possible explanation for the sharp decline in seal numbers (Stirling et al. 1977, 1981, 1982). For example, during 1974, the most severe ice year on record, body condition of ringed seals taken in subsistence harvest was the poorest on record; observed ovulation rate was reduced to less than 50%. Conversely, during 1998, a record year for early clearing of landfast ice and length of open-water period, body condition was best and ovulation rate was nearly 100% (Smith and Harwood 2001). Alternatively, reduced prey availability may have led to large scale emigration by seals to other areas of greater food availability (Stirling et al. 1977).

Movements and Seasonal Distribution

Ringed seals remain in the southern Beaufort Sea on a year-round basis. However, localized movements within the area take place, and some large scale movements also may occur (Harwood 1989, Smith 1987, Stirling et al. 1977). Established adults maintain their territories around the prime breeding area during the winter, but travel great distances in summer to feed, whereas subadults occupy the periphery or disperse (Harwood and Stirling 1992). Seasonal redistribution by age class has been documented in eastern Amundsen Gulf, and an autumn migration westward, undertaken primarily by subadults, towards the Beaufort and Chukchi seas has been noted (Smith 1987). Some young seals branded in Amundsen Gulf have been recovered in Alaska and Siberia (Smith 1987).

Prior to ice break-up in late June, ringed seals are distributed throughout the southern Beaufort Sea, hauling out on the ice to moult. Densities of hauled out seals were highest off the Yukon coast, the Baillie Islands, Cape Bathurst, in Darnley and Franklin Bays, and Prince Albert Sound and Minto Inlet in Amundsen Bay (Stirling et al. 1982). The seals appeared to prefer areas where water was 75 to 100 m deep (Stirling et al. 1982).

During open water periods in late summer and early fall, groups of seals (up to 21 animals) concentrate into large aggregations that may cover areas ranging from 350 to 2,800 km^2 (Harwood and Stirling 1992). The location and number of aggregations within the southern Beaufort Sea varies between years, but aggregations appear to be most common north of the Tuktoyaktuk Penninsula (Harwood and Stirling 1992). Seal density within the aggregations can range from 121 to 326 seals/100 km^2, approximately 6 - 13 times higher than regional mean densities (Harwood and Stirling 1982). Similar aggregations have been reported in Amundsen Gulf (Smith 1987), and it has been suggested that the seals are concentrating in areas of greatest prey density (Harwood and Stirling 1992, Smith 1987).

As ice begins to form in late fall, adult seals move into coastal areas of stable, land fast ice where pressure ridges and hummocks are formed and establish breeding territories. Suitable ice conditions are typically found along complex shorelines around fjords and islands, and seal concentrations tend to be higher in such areas compared to simple coastlines (Smith 1987). Breathing holes through the ice are maintained on the leeward sides of pressure ridges and ice hummocks and, when enough snow has accumulated, lairs are excavated in the snow (Smith 1987). Adolescent and young of the year seals are excluded from these areas, and it appears that these younger seals move westward through the southern Beaufort Sea in mid-September (Harwood 1989, Smith 1987). This westward movement exhibits a deliberate and rapid migration from Amundsen Gulf to the Chukchi Sea. Off the North Slope of Alaska, the young seals follow the shelf break zone, diverging only when they reach Point Barrow. After passing Point Barrow, the seals migrate in a variety of directions, including through the Bering Strait toward Japan; to the Wrangel Island and Herald Canyon areas; and to the coast of Siberia in the East Siberian Sea (Harwood and Smith 2003). Smith (1987) speculated that this migration could be due to intraspecific competition for food and territorial exclusion by adult seals. Areas of the western Beaufort, Chukchi, and Bering seas remain ice free during winter, have higher productivity in some areas, and may provide young seals with a better opportunity to survive (Smith 1987).

Biology Pertinent to the Study Area

As discussed in the previous section, adult ringed seals maintain breathing holes and associated lairs beneath the snow throughout the winter months. The lairs provide thermal protection and some shelter from predators (Smith and Stirling 1975). There appears to be two types of lairs constructed. Haul-out liars are used by males and females, and are lairs where the seals haul out to rest. Birth lairs are used by females for pupping, and are larger than resting lairs. Often there are two or more birth lairs in close proximity to each other. It is thought that these form a birth lair complex that is used by a single female and pup (Smith 1987).

Breeding areas within the southern Beaufort Sea are located along the northern coast of the Tuktoyaktuk Peninsula from Kugmallit Bay eastward to the Baillie Islands, Franklin and Darnley Bays, sounds and inlets of Amundsen Gulf, and along the west coast of Banks Island. Although the majority of mating in the Amundsen Gulf area takes place between mid-May and mid-June, implantation is delayed until mid-August. The gestation period is approximately 240 days, and a single pup is born in mid-April. The pup remains with its mother for 1.5 to 2 months after its birth (Smith 1987).

Ringed seals consume a wide variety of items. Smith (1987) listed 36 different species of invertebrates and fish that were consumed by ringed seals in Amundsen Gulf. In general, the most frequently consumed prey items are crustaceans (copepods, mysids, and amphipods) and Arctic cod (*Boreogadus saida*).

Type of prey consumed appears to vary seasonally, regionally, and with the age of the seal (Smith 1987). Invertebrates form the largest portion of the diet for pups and adults feeding during open water periods, but fish are a larger part of the juvenile seal diet at that time. Fish constitute the most important dietary component of all age classes during the ice-covered months. The majority of feeding is thought to occur between early afternoon and evening (Smith 1987).

Ringed seals are the primary food source for polar bears, and an important food source for Arctic foxes (*Alopex lagopus*) (Stirling 1988a, Smith 1976). Arctic fox predation on newborn seal pups has been recorded as high as 37% in Prince Albert Sound (Smith 1987). Fluctuations in seal abundance can directly influence polar bear and Arctic fox populations. The large reduction in ringed seal numbers in the southern Beaufort Sea in 1974 resulted in reduced reproduction and a decrease in population size of polar bears and Arctic foxes (Stirling et al. 1977). Killer whale and walrus also prey upon ringed seals.

Bearded Seal

The bearded seal has a patchy circumpolar distribution, but is considerably less abundant than ringed seals. Despite its importance to indigenous peoples of the north, the bearded seal has not been as extensively studied as the ringed seal.

Abundance

Surveys of bearded seal abundance within the southern Beaufort Sea (from the Alaska/Yukon border eastward to the Baillie Islands and extending offshore for 160 km) were conducted throughout the 1970's and 1980's in conjunction with ringed seal surveys (Kingsley 1986, Kingsley and Lunn 1983, Stirling et al. 1977, 1981, 1982). As was observed for ringed seals, the estimated number of bearded seals displayed considerable annual fluctuations. A sharp decline in bearded seal abundance was observed between 1974 (1,400 animals) and 1975 (450 animals) (Stirling et al. 1977). Bearded seal numbers ranged between 250 (1979) and 2,000 animals (1978) from 1976 to 1979 (Stirling et al. 1982), and 450 to 1,700 animals during surveys conducted during the early 1980's (Kingsley 1986).

Movements and Seasonal Distribution

Bearded seals are solitary animals that are generally associated with broken, drifting ice (Burns and Frost 1979, Stirling et al. 1982). The distribution of bearded seal is largely restricted to shallower water because of their preference for feeding upon benthic organisms. Within the southern Beaufort Sea, they are concentrated along offshore leads north of the mainland coast from the Alaska/Yukon border eastward to the Baillie Islands, in the region of the Cape Bathurst polynya, and along the western and southern coastlines of Banks Island (Kingsley 1986, Stirling et al. 1982).

Movement patterns of bearded seal have not been documented during the ice free period in the southern Beaufort Sea. However, seasonal movements between the Bering and Chukchi seas appear to be related to ice formation and recession (Burns and Frost 1979).

General Biology

Bearded seal feed primarily upon benthic organisms such as crabs, shrimp, clams and snails, and fishes such as sculpins and cods (Burns and Frost 1979). Bearded seals give birth to a single pup during late April/early May.

Polar Bear

The polar bear is the largest land carnivore in the world, and is probably the most studied of all arctic mammals. Although they have a circumpolar distribution, polar bears are not evenly distributed through the Arctic. The IUCN (The World Conservation Union)/Species Survival Commission Polar Bear Specialist Group recognizes approximately 19 discrete populations of polar bears in the Arctic, 14 of which occur in or are shared by Canada (Derocher et al. 1998). Two populations have been identified in the eastern Beaufort Sea. Bears that are part of the northern Beaufort Sea population den along the coastlines of Banks Island and hunt in areas off the western shore of Banks Island and in Amundsen Gulf, while bears that are part of the southern Beaufort Sea population inhabit areas along the mainland coast from the Baillie Islands westward into Alaska (Bethke et al. 1996, Taylor and Lee 1995).

Abundance

Polar bears in the Beaufort Sea have been the subject of considerable study since the 1960's (Derocher et al. 1998). Long-term mark/recapture and telemetry studies have provided a population estimate of 1,800 animals for the southern Beaufort Sea population, and 1,200 animals for the northern Beaufort Sea population (Derocher et al. 1998).

Movements and Seasonal Distribution

Polar bear distribution is determined by the presence and distribution of various types of ice cover, and by the distribution and abundance of seals (Stirling et al. 1993), which are the main staple in a polar bear's diet (Larsen 1978, Stirling et al. 1980). This was reinforced during the heavy ice conditions of the mid-1970s and mid-1980s, which caused declines in ringed seals, and subsequent declines in polar bear natality and survival of subadults (Stirling 2002). Bears in the southern Beaufort Sea population follow a general seasonal movement pattern. During the period of ice cover, most bears are concentrated along offshore leads north of the mainland coast of Alaska eastward to the Baillie Islands, in the region of the Cape Bathurst Polynya. Easterly and westerly movements (parallelling the mainland coastline) occur during this time, and are likely related to the development of leads along the shear zone between land fast ice and pack ice (Amstrup and Durner 1997). Bears move north during summer following the retreating pack ice, and then back south to preferred hunting areas as ice forms in the fall (Stirling 1988a) Occasionally, some bears may summer on land, and have been observed on the southern tip of Banks Island, or along the mainland coast on the Baillie or Herschel islands.

Bear distribution and habitat preference during late winter and early spring was studied throughout the 1970's in the eastern Beaufort Sea and Amundsen Gulf area (Stirling et al. 1993) Results showed that land fast ice, which provides preferred pupping habitat for ringed seals, is used by adult females accompanied by cubs of the year. Adult males, lone adult females, females with two year old cubs, and subadult males were most frequently associated with floe edge and moving ice habitat, preferred habitats for non-breeding ringed seals and for bearded seals. Few bears were observed on multi-year ice (Stirling et al. 1993). It is thought that females with young cubs prefer land fast ice in order to avoid contact with adult males, which may threaten their cubs (Stirling et al. 1993).

Biology Pertinent to the Study Area

Female polar bears of the Beaufort Sea population breed for the first time at 5 years of age, compared to 4 years of age in most other populations, and cubs normally remain with their mothers for 2.5 years prior to weaning (Stirling 2002). Mating occurs during April and May on the sea ice, and pregnant females construct maternity dens during October and November (Stirling 1988a). Maternity dens in the general Beaufort Sea area can take place either on multi-year pack ice (Lentfer 1975, Stirling and Andriashek 1992) or at inland locations (Amstrup and Durner 1997). The western and southern coasts of Banks Island are the most important terrestrial denning areas in Beaufort Sea. Limited denning occurs along the northern coast of Tuktoyaktuk Peninsula, small islands on the outer periphery of the Mackenzie Estuary, and on Herschel Island (Stirling and Andriashek 1992).

3.7 COASTAL WATERFOWL AND SEABIRDS

A vast array of waterfowl, shorebirds, and seabirds seasonally inhabit the eastern Beaufort Sea and the vicinity of the Mackenzie River Estuary. The region is used for feeding, nesting, moulting, breeding and staging during spring and fall migrations. Banks Island, due to its size and location in the western Canadian Arctic, is an important nesting area for brant (Branta bernicla). Most of their colonies are found on small islands of inland lakes or large ponds, and the remainder associated with active snowy owl (Nyctea scandiaca) nests on the island's mainland (Cotter and hines 2001). Hundreds of thousands of eiders and long-tailed ducks stage in the early open water off Cape Bathurst and Banks Island during spring migration. During midsummer, tens of thousands of long-tailed ducks, scoters, scaup, and mergansers moult in the sheltered bays and behind barrier beaches and spits. Several species of geese, ducks, loons, gulls, and terns nest on islands and in wetlands along the Beaufort Sea coast, although they are few in number, relative to eastern Arctic Canada and the Bering Sea (Dickson and Gilchrist 2002). Declines in the five most common sea duck species in the region, long-tailed duck, king eider, common eider, surf scoter, and white-winged scoter, have occurred since the mid-1970s, as have western Arctic brant (Dickson and Gilchrist 2002; Haszard 2002). These declines have prompted studies, such as the Lower Mackenzie Water Bird Survey, to investigate the importance of region to the life cycle needs of waterfowl and boreal waterbirds, and determine potential stressors which may explain the declines (Ducks Unlimited Canada 2004).

Barry (1976) identified approximately 100 species of birds in the southeastern Beaufort Sea and its littoral zone. Other sources have identified over 130 bird species in the Mackenzie Delta (MDBSRLUPC 1991). However, there are approximately 10 species that comprise the majority of birds in the area and, as a group, number over 2 million individuals (Barry 1976). The common, and scientific names of the more common bird species found in the study area are listed in Table 4. Inuvialuktun names for selected birds in the Siglit dialect are listed in Table C. Known habitat and food preferences, and identified areas of use for each species are also provided.

Spring migrants arrive in the study area in April and May and begin the fall migration as early as August. Migration patterns generally follow two routes: (1) west to east from the Bering Strait, following open water leads along the coast; and, (2) north and south through the Mackenzie River

Valley. Approximately one-third of nesting seabirds follow the Bering Strait coastline, and two-thirds follow the Mackenzie Valley into the Mackenzie Delta region.

Littoral flats and marshes in river deltas are used by snow geese, brant geese, white-fronted geese, swans, dabbling ducks and shorebirds for nesting, rearing young, feeding, moulting, and pre-migration staging in the autumn. However, the diversity and abundance of waterfowl and other seabirds decline inland from the coast (Barry 1976). Specific areas that are of critical importance, and the most common bird species that use those areas are identified in Table 5. Tables 6 and 7 describe the seasonal use of specific areas and habitats within the study area by the more common bird species.

Spring Migration

During the spring migration, coastal waterfowl and seabirds depend upon the presence of open water leads that run parallel to a coastline for resting, feeding, and accumulating fat reserves (Alexander et al 1988a). The leads used by birds in the study area typically form east of the Mackenzie Delta, north of the Tuktoyaktuk Peninsula, and along Banks Island (Alexander et al 1988a). Alexander et al. (1988b) found that a small percentage of pacific and king eiders used the Beaufort Sea lead, while old squaws and glaucous gulls frequently utilized the Mackenzie Delta during spring migration as seasonal habitat until reaching nesting sites.

Table C. Inuvialuktun names for selected birds in the Siglit dialect. Some require further verification (*). Spelling of words in singular from Lowe (2001). Dual and plural spellings from Beverly Amos, Inuvialuit Cultural Resource Centre and Agnes Nasogaluak of Inuvik.

Shingle Point south to Mackenzie Delta (Table 6)

Early June to mid-July

Elevated portions of the Escape Reef provide high permanent vegetated habitat for nesting glaucous gulls, while lower gravel extensions provide only scattered nesting areas. The glaucous gulls also use the waters around the Reef for feeding and nesting. Escape Reef is used on a limited basis by brant, common eiders and Arctic terns.

The Shallow Bay/Blow River area is used extensively in the spring/early summer by Pacific loons, tundra swans, brant, Arctic terns, glaucous gulls, old squaw and other shorebirds. Ponds, channels, marshes, and grass-sedge delta provide adequate nesting grounds for these birds. Northern pintails, northern shovelers, and greater and lesser scaup also use these areas for nesting (Alexander 1988a).

Mid-July to mid-August

Major concentrations of glaucous gulls feed along the shoreline of the Shingle Point gravel spit from early to mid-August. Red-throated loons and migrating phalaropes also feed throughout this area. The Escape Reef is used extensively at this time by brood-rearing brant. Glaucous gulls and Arctic terns also utilize the area for moulting. The Blow River Delta area is used by brood-rearing or moulting Pacific and red-throated loons, brants, shorebirds, glaucous gulls, and dabbling ducks.

The Whitefish Station and the Tent Island areas are important areas for moulting, brood-rearing, and staging of glaucous gulls, tundra swans, Pacific loons, old squaw, Arctic terns, dabbling ducks and shorebirds. Shorebirds use the coastal tundra vegetation, channels, and wetlands to nest from late July to early September (Alexander 1988b).

Mid-August to late September

The entire Yukon coastline and coastal plain is utilized by shorebirds during the fall months. Escape Reef and Shingle Point are used by scoters, phalaropes, red-breasted mergansers, phalaropes, and shorebirds for staging. The Blow River Delta and Shallow Bay area are also used by geese, swans, Pacific loons, and dabbling ducks for brood-rearing, moulting, and staging. Glaucous gulls utilize the entire coastline.

The Blow River and Shallow Bay areas are used extensively by geese and swans during fall migration, however the grass-sedge flats are susceptible to storm tides and may become unusable. Pacific loons, tundra swans, Canada goose, brant, greater white-fronted goose, lesser snow geese, dabbling ducks and glaucous gulls all use this area for brood-rearing, moulting and staging (Alexander1988a).

Mackenzie Delta (Table 7)

Early June to mid-July

Tundra swans use the flood plain grass-sedge meadows, lakes and ponds in late June and open areas along the river channel in late May and early June. Nesting and moulting tundra swans, dabbling ducks, and Arctic terns also use the ponds, channel, marshes and grass-sedge delta flats extensively in this area.

Islands at the base of the Delta provide low-lying coastal tundra vegetation and wetlands for nesting Pacific and red-throated loons, tundra swans, dabbling ducks, scaup, long-billed dowitchers, stilt sandpipers, Hudsonian godwits, whimbrel, and Arctic terns. Other areas of the Delta with low lying sedge/grass marsh have been known to harbour breeding and non-breeding tundra swans, northern pintails, American widgeons, other dabbling ducks, sandhill cranes, whimbrel, Arctic terns and other shorebirds.

Garry and Pelly Islands are used by nesting glaucous gulls, Arctic terns, brant, and tundra swans. The low gravel sand spit on Garry Island is used for nesting and the surrounding waters offer feeding grounds. Pelly Island is used by tundra swans and geese for nesting and moulting. The sand spit, on Pelly Island, is used by brant, glaucous gulls, and Arctic terns for nesting. Dabbling ducks are also known to nest on Pelly Island and the shoreline and offshore waters are used by gulls and terns for feeding.

Kendall and the surrounding islands are used by glaucous gulls, tundra swans, brant, and lesser snow geese for nesting and moulting (Alexander 1988b).

Mid-July to mid-August

The Shallow Bay area is used from mid-July to mid-August by tundra swans, brant, white-fronted geese, snow geese, dabbling ducks, shorebirds, and Arctic terns. This area is used for moulting and staging for the fall migration. From Ellice Island to Mallik Bay, moderate to high use occurs on the coastal tundra vegetation, channels and wetlands. This area is used for moulting and brood-rearing tundra swans, brant, white-fronted geese, snow geese, Canada geese, dabbling ducks, scaup, shorebirds, and Arctic terns. White-fronted geese and tundra swans use the wetlands, lakes and channels southwest of Mallik Bay extensively.

Gravel and sand spits, lagoons and salt marsh areas on the numerous islands within the delta are used extensively by different types of shorebirds and seabirds. The area from Kidluit Bay to Toker Point is used intermittently. High usage occurs around Tuktoyaktuk by moulting tundra swans. Sheltered bays are used by moulting and feeding shorebirds and seabirds.

Mid-August to late September
Western and northern portions of the delta are used extensively in the fall for staging by lesser snow geese, brant, greater white-fronted geese, Canada geese, and dabbling ducks. Tundra swans also use the area for late moulting and brood-rearing. Canada geese are generally found in the inner channels, while brant and white-fronted geese are generally found in more marine areas. Lesser snow geese and glaucous gulls use the entire western part of the Delta during staging. The area south of Hansen Harbour is used by red-breasted mergansers, glaucous gulls, tundra swans, Canada geese, brant, greater white-fronted geese, and lesser snow geese for moulting, brood-rearing, and staging. The area near Toker Point is used for staging and feeding by old squaw, red-breasted mergansers, glaucous gulls, diving ducks, Pacific loons, and red-throated loons.

3.8 ENERGY FLOW, FOOD WEBS, AND ECOLOGICAL SIGNIFICANCE OF ICE

3.8.1 Food Webs

The Arctic Ocean is the least productive ocean, and the Beaufort Sea is considered to be one of the least productive seas in the Arctic (Percy et al. 1985). Primary production in the Canadian Beaufort Shelf has been estimated at approximately 20 g C/m^2/yr. A biodetrital flux, which occurs mostly over a 1-2 month period around ice breakup, has been estimated at approximately 14 g C/m^2/yr and 2 g N/m^2/yr (Macdonald and Thomas 1991). The Beaufort Sea, with a characteristically low rate of primary production and strong influence of sediment scouring and resuspension, contains relatively lower quantities of benthic invertebrates than other Arctic seas (Carey 1991). However, maximum rates of primary productivity within its polynyas are comparible to those measured in other productive Arctic waters. Rates in the Cape Bathurst polynya have been measured to be as high as 175 g C/sq m/yr (Arrigo and van Dijken 2004), which compares favorably to the 60 g C/sq m/yr measured off Lancaster Sound (Welch et al. 1992).

Arctic marine ecosystems are typically nutrient-poor and are comprised of relatively simple food webs, with low species diversity and abundance (Percy et al. 1985, Norstrom and Muir 1994). Productivity is not only low, but highly cyclic, varying with seasonal changes in photoperiod, temperature, and nutrient input/bioavailability. Changes in the timing of phytoplankton blooms impact food web structure and the relative importance of top-down versus bottom-up control of marine ecosystems. During cold water blooms, typical of polynyas, grazing by zooplankton is lower, and the food web is limited by resource supply. Conversely, warm water blooms, typical in late summer summer, experience higher rates of grazing by zooplankton, and the food web is then limited by grazing. The former favors energy transfer to the benthic, rather than the pelagic community; the latter favors energy transfer to the pelagic food web. Such shifts in energy flow can affect the recruitment of commercially important fish (Arrigo and van Dijken 2004).

The Mackenzie River Delta is a moderately productive estuary (Muir et al. 1999). Low productivity is primarily a result of nutrient limitation, low temperatures, and short growing season (Muir et al. 1997). Primary production peaks at the edge of the Mackenzie River plume, where turbidity and zooplankton abundance are low but nutrients are more plentiful (Parsons et al. 1988). In general, nearest the mouth of the Mackenzie River, a heterotroph-dominant food chain exists, relying upon energy derived from riverine dissolved organic carbon. Conversely, an autotrophic food chain (i.e., autotrophic marine diatoms) dominates in the offshore area (Parsons et al. 1988). Unlike autotrophic production, heterotrophic (bacterially-driven) production may persist year-round and may occur throughout the water column. The heterotrophic food chain was found to support gammarid amphipods and some anadromous fish, while the autrophic production supported herbivorous copepods and several predatory species such as jellyfish, chaetognaths, hyperiid amphipods, and some marine fish (Parsons et al. 1989). The relative importance of these two food chains in the Mackenzie River/Beaufort Sea Estuary varies interannually according to changing conditions such as ice cover and oceanographic conditions (Parsons et al. 1989). However, it was concluded that marine autotrophic production was the major energy source supporting secondary and tertiary consumers in the estuary (Parsons et al. 1989).

Although the Mackenzie River, the Delta lakes, and the Beaufort Sea coastal environment are highly complex systems (Hesslein et al. 1991), food webs are relatively simple and similar across the Canadian Arctic marine environment. Typically, Arctic marine food webs consist of up to five trophic levels, with polar bear occupying the fifth level (Hobson and Welch 1992). In general, marine mammals and birds tend to dominate Arctic food webs, although the Arctic cod occupy a critical position as a keystone species and an integrator (Hobson and Welch 1992). Arctic cod are particularly important for marine mammals, as they are the most abundant species in the Arctic (Norstrom and Muir 1988).

Typical Arctic food chains are comprised of the following major groups: ice biota (e.g., amphipods, ice-algae), phytoplankton, herbivorous zooplankton, carnivorous zooplankton, benthic algae, invertebrates, Greenland halibut, Arctic cod, other fish species, seabirds, ringed seal, polar bear, Arctic fox, and bowhead and beluga whales. The relative importance of each component and the precise structure of the food web vary geographically as well as seasonally. In the simplest terms, food chains consist of phytoplankton - zooplankton - fish - narwhal/beluga/seal - polar bear or phytoplankton - zooplankton - whale (Muir et al. 1997). Seabirds generally rely upon the epontic community and Arctic cod.

Arctic ecosystems have a high dependency upon fat (i.e., lipids) for the transfer of energy in food webs, due to the marked seasonality in primary production and food supply (Carey 1991, Macdonald and Thomas 1991). In general, arctic biota are characterized by low growth and maturation rates, high longevity, and low fecundity (i.e., few numbers of offspring). Thus, a large proportion of energy exists as standing biomass.

Key species for the transfer of energy from lower to higher trophic levels are the Arctic cod and *Parathemisto* sp., a pelagic carnivorous amphipod (Bradstreet et al. 1986). Both organisms are important dietary components of marine mammals and birds, although *Parathemisto* amphipods become more important in the diet of Arctic vertebrates when Arctic cod populations decline (MacDonald and Sprague 1988) or undertake seasonal movements (Hobson and Welch 1992). Both organisms appear to hold similar roles in the Arctic marine food web.

3.8.2 Ecological Significance of Ice

Although Arctic biota exploit all types of habitats, ice is one of the most important habitat features of Arctic marine food webs. Entire communities, known as the epontic biota, inhabit the underside surface of ice. Epontic biota comprise a very important feature of Arctic food webs and energy transfer pathways, particularly in winter when primary production from phytoplankton is low (Bradstreet and Cross 1982). Arctic cod are a significant component of the epontic community and serve as an important link in the transfer of energy from ice-algae and invertebrates to marine mammals and birds.

Ice seasons in the Arctic may vary by a month, in any given year. However, typically, landfast ice in the Beaufort Sea begins to form in late September or early October, growing throughout the winter and reaching its maximum thickness in May. At its greatest extent, landfast ice covers the entire Beaufort Sea mainland coast (Percy et al. 1985). Sea ice begins to melt in June, coinciding with the spring freshet in the Mackenzie River (Percy et al. 1985).

Ice leads, ice edges, and polynyas are very important physical features of the Arctic marine environment as they host a variety of floral and faunal species and are often abundant, even in the long winter period (Percy et al. 1985; Michaud et al. 1996). The occurrence of ice edges, leads, and polynyas allow bowhead and beluga whales to remain in the Arctic year-round (Norstrom and Muir 1994). Leads often support phytoplankton blooms, an abundance of invertebrates and fish, and marine mammals (Percy et al. 1985; Tremblay et al. 2002)). Ice edges in general, may harbour high levels of primary production which ultimately provide energy for marine mammals and seabirds, via the 'ice edge food chain' (Muir et al. 1999). Arctic cod, zooplankton, and other ice-associated biota (e.g., amphipods) provide the links between the bottom and the top of this food chain.

Landfast ice edges are also significant habitats for phytoplankton as there is a high level of light penetration and in some areas there may be substantive quantities of nutrients due to localized upwelling (Percy et al. 1985). The location of the landfast ice edge is highly significant in terms of determining the dominant source of primary production. When pack ice is over the Beaufort Sea shelf, benthic food webs dominate whereas if it lies over deeper water, pelagic production may be more significant (Percy et al. 1985).

3.8.3 Energy Flow Pathways and Mechanisms of Energy Transfer

Coastal Marine Environment

The most important energy flux pathway in Arctic marine ecosystems is based on phytoplankton (Norstrom and Muir 1994), which is primarily dependent upon nutrient availability (Muir et al. 1997). Nutrients and organic carbon are provided to the coastal Beaufort Sea area through a number of routes belonging to two major sources: allochthonous organic material of terrigenous origin; and, autochthonous material derived from photosynthesis in the sea (Parsons et al. 1988). The major processes important in energy supply include: shoreline erosion; primary production; discharge of the Mackenzie River; and, long-range atmospheric transport of essential (and non-essential) substances, including nutrients (Macdonald and Thomas 1991, Muir et al. 1999). In addition, ocean upwelling and mixing are important processes in the provision of nutrients to surface water in the Beaufort Sea. Upwelling of deep waters occurs due to the vertical instability of the water column (Percy et al. 1985). As wind may induce mixing and even upwelling, it plays a fundamental role in the introduction/replenishment of nutrients in the Beaufort Sea. Landfast ice formation and melting also play key roles in determining the extent, timing, and location of production in the Beaufort Sea.

One of the most significant sources of nutrients and energy to the Beaufort Sea coast is the Mackenzie River. The Mackenzie River, with an annual discharge of approximately 3.0×10^{11} m^3, is the largest North American river that flows into the Arctic (Yunker et al. 1993). Consequently, the Mackenzie River is a substantive source of nutrients, heat, sediment, and organic carbon for the Beaufort Sea and it plays a pivotal role in the supply of energy and nutrients to the coastal environment (Macdonald and Thomas 1991). The Mackenzie River is considered relatively pristine with respect to eutrophication and anthropogenic nutrient loading, and it supplies the coastal zone with ample Si, as indicated by high Si:N and Si:P ratios. Any shifts in nutrient supply (i.e., nutrient enrichment), could alter the productivity and the algal community structure in the southern Beaufort Sea (Justic et al. 1995).

Shoreline erosion is a significant source of sediments to the Beaufort Sea shelf, providing a rich supply of relict carbon as peat (Macdonald and Thomas 1991). Although terrestrial sources of carbon, primarily shoreline erosion and transport by the Mackenzie River, are well known, the relative role of various carbon sources in coastal production are not.

Seasonally dependent physical processes in the nearshore environment can dramatically affect the availability of energy and hence, the productivity of the biotic community. Re-suspension of sediments as a result of wind and/or storms in late summer (i.e., during the open water season) can introduce detritus and remineralized materials to the water column (Macdonald and Thomas 1991). Displacement of the Mackenzie River plume with saline water from wind-driven coastal upwelling is also an important mechanism of sediment flushing (Macdonald and Thomas 1991).

Seasonal Changes on Energy Flow

The Mackenzie River Estuary/Beaufort Sea Shelf is extremely dynamic and conditions are highly seasonally variable. As the principal energy supply is provided by phytoplankton, energy transfer is highly dependent upon temperature and solar radiation, which are seasonally variable. Furthermore, the chemical composition of surface water and the ice regime is cyclic. The composition of the surface water layer over the Mackenzie shelf in the Beaufort Sea varies from winter to summer as a function of ice formation and melting, variations in water circulation patterns, and discharge from the Mackenzie River (Macdonald et al. 1989).

There is a marked cycling of nutrients over the year. Inorganic nutrients are replenished in surface waters over winter, when primary production is low. Due to extreme fluctuations in temperature, light levels, and nutrient supply, energy flow in the Beaufort Sea is highly seasonally variable. Light penetration, and hence primary production, are limited by ice cover for much of the year and is seasonally variable. However, adequate light penetrates ice to support algae under the ice surface (i.e., ice algae) year-round (Percy et al. 1985). Production from the epontic community (e.g., diatoms) is, in fact, an important source of energy early in the year, before production from the phytoplankton community becomes significant.

Typically, the spring freshet provides an injection of nutrients and organic carbon, as well as bacteria, to the Beaufort Sea via the Mackenzie River. This occurrence coincides with the beginning of the open water season and increasing solar radiation and temperature. It is also noted that the Mackenzie River plume, although nutrient-rich, is highly turbid and may be light-limiting (Percy et al. 1985).

With the increase in levels of solar radiation in spring, there is a 'burst' of primary production beneath the ice (Muir et al. 1999). In summer, the top 5-10 m of the coastal shear zone is freshwater and a highly saline layer exists on the bottom. If the density of the saline water is great enough, it may entrain sediment pore water and with it, the associated nutrients and metals. In winter, the constant production of brine due to ice formation creates a current of dense, saline water originating from ice on the water surface and sinking progressively to the sediments. This density current may also extract substances from the sediment-water interface and transport them to the interior Arctic Ocean (Macdonald and Thomas 1991).

As a result of nutrient depletion in the surface water layer, production decreases or crashes. Planktonic debris that settles on sediments, provides energy for nitrogen-fixing bacteria, who in turn, regenerate the supply of nitrogen. Phosphorus is regenerated primarily by death and decay processes (i.e., detrital food web) (Percy et al. 1985), as little is provided by the phosphate-deficient Mackenzie River (Macdonald et al. 1987). Silicon (as silicate), is provided largely by discharge from the Mackenzie River (Macdonald et al. 1989) and levels are relatively constant year-round (Percy et al. 1985). Through these governing processes, the nutrient composition and salinity of the surface water layer changes on a seasonal basis (Macdonald et al. 1989).

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Table and Figures

Table 1. Depth zones and benthic invertebrate distribution in the southern Beaufort Sea (after Wacasey 1975).

Zone	Depth Range (m)	Temp. Range (^oC)	Salinity Range (ppt)	No. of Species/Site	Biomass Range (g/m^2)	Biomass Average (g/m^2)
Estuarine	0-15	-1.2 (May) 16.6 (July)	0.1 to >40	1-32 (usually <20)	0.1-20	2
Transitional	15-30	-1.8 (May) 6.3 (July)	11.6-31.3	20-40	1-20	5
Marine	30-200	-1.6 (Sep.) -0.1 (July)	30.1-32.8	3-81	1-72	14
Continental Slope	>200 (up to 900)	-0.3 (Sep.) 0.4 (July)	34.3-34.8	31-53	1-8	4

Table 2. Fishes found in coastal areas of the southeastern Beaufort Sea in the vicinity of the Mackenzie River estuary (modified from Karasiuk et al. 1993).

Family	Species Name	Scientific Name	Typical Occurrence
Petromyzontidae	arctic lamprey	*Lampetra japonica*	coastal migrant, anadromous
Clupeidae	pacific herring	*Clupea harengus pallasi*	marine
Salmonidae			
Subfamily Salmoninae	pink salmon	*Oncorhynchus gorbuscha*	coastal migrant
	chum salmon	*Oncorhynchus keta*	coastal migrant
	arctic char	*Salvelinus alpinus*	anadromous, freshwater
	dolly varden	*Salvelinus malma*	anadromous, freshwater
Subfamily Coregoninae	arctic cisco	*Coregonus autumnalis*	anadromous, coastal migrant
	least cisco	*Coregonus sardinella*	freshwater, coastal migrant
	Bering cisco	*Coregonus laurettae*	coastal migrant
	lake (humpback) whitefish	*Coregonus clupeaformis*	freshwater, coastal migrant
	broad whitefish	*Coregonus nasus*	freshwater, coastal migrant
	round whitefish	*Prosopium cylandraceum*	freshwater, coastal migrant
	inconnu	*Stenodus leucichthys*	anadromous
Subfamily Thymallinae	arctic grayling	*Thymallus arcticus*	freshwater
Osmeridae	pond smelt	*Hypomesus olidus*	freshwater
	capelin	*Mallotus villosus*	marine
	rainbow smelt	*Osmerus mordax*	anadromous
Esocidae	northern pike	*Esox lucius*	freshwater
Catostomidae	longnose sucker	*Catostomus catostomus*	freshwater
Gadidae			
Subfamily Gadinae	arctic cod	*Boreogadus saida*	marine
	saffron cod	*Eleginus gracilis*	marine
Subfamily Lotinae	burbot	*Lota lota*	freshwater
Zoarchidae	shulupaoluk	*Lycodes jugoricus*	marine
	saddled eelpout	*Lycodes muscosus*	marine
	pale eelpout	*Lycodes pallidus*	marine
	polar eelpout	*Lycodes polaris*	marine
	arctic eelpout	*Lycodes reticulatus*	marine
	threespot eelpout	*Lycodes rossi*	marine
Stichaeidae	slender eelblenny	*Lumpenus fabricii*	marine

Family	Species Name	Scientific Name	Typical Occurrence
Ammodytidae	stout sandlance	*Ammodytes hexapterus*	marine
Cottidae	rough hookear sculpin	*Artediellus scaber*	marine
	slimy sculpin	*Cottus cognatus*	freshwater
	spoonhead sculpin	*Cottus ricei*	freshwater
	arctic staghorn sculpin	*Gymnocanthus tricuspis*	marine
	twohorn sculpin	*Icelus bicornis*	marine
	spatulate sculpin	*Icelus spatula*	marine
	fourhorn sculpin	*Myoxocephalus quadricornis*	marine, freshwater
	arctic sculpin	*Myoxocephalus scorpioides*	marine
	bigeye sculpin	*Triglops nybleni*	marine
	ribbed sculpin	*Triglops pingeli*	marine
Agonidae	arctic alligatorfish	*Asphidophoroides olriki*	marine
Cyclopteridae	leatherfin lumpsucker	*Eumicrotremus derjugini*	marine
	gelatinus snailfish	*Liparis fabricii*	marine
	dusky snailfish	*Liparis gibbus*	marine
	kelpsnailfish	*Liparis tunicatus*	marine
Gasterosteidae	ninespine stickleback	*Pungitus pungitus*	freshwater, anadromous
Plueronectidae	arctic flounder	*Liopsetta glacialis*	marine
	starry flounder	*Platichthys stellatus*	marine

Table 3. Marine fishes found in the southeastern Beaufort Sea and their life history characteristics (modified from Karasiuk et al. 1993). * original table sublemented by information from Scott and Scott (1988)

Species Name	Distribution	Preferred Habitat Characteristics				Diet
		Temp (^oC)	Depth (m)	Salinity (ppt)	Substrate	
capelin	Circumpolar, boreal, and low Arctic	2.5-10.8 (spawn)	0-80 during spawing	-	pelagic, beach spawner	krill, copepods, amphipods
shulupaoluk	Arctic endemic	<0	15-90	15-23	-	-
saddled eelpout	Arctic	<-1	60-380	34-35	mud	brittle stars, clams, amphipods
pale eelpout	Circumpolar,arctic and subarctic	-2 to 1.8	11-1750	-	mud	polychaetes, molluscs, amphipods
polar eelpout	Arctic circumpolar	<0	10-190	>30	mud	amphipods, clams, polychaetes
arctic eelpout	Arctic circumpolar	<0	100-380	-	-	probably benthic invertebrates
threespot eelpout	Arctic, disjunct	-	40-250	-	-	amphipods, polychaetes
slender eelblenny	Circumpolar, boreal, and low Arctic	-1.6 to13	4-180	25-28	rocks	polychaetes, clams, crustacea
stout sandlance	Circumpolar, boreal, and Arctic	-	0-120	-	sand, sea ice	copepods, amphipods, krill
rough hookear sculpin	Circumpolar, coastal shallows	0	0-50	21-32	-	probably benethic invertebrates
arctic staghorn sculpin	Arctic circumpolar	0	10-35	32-35	sandy, pebbly	amphipods, polychaetes
twohorn sculpin	Circumpolar, boreal, and low Arctic	-1.8 to 8.8	40-180	33-35	mud, sand	amphipods, polychaetes
spatulate sculpin	Arctic circumpolar	-1.7 to 3	20-70	31-34	mud, sand	amphipods, polychaetes, molluscs
arctic sculpin	Arctic and subarctic	-	shallow, intertidal zone	-	rocky	amphipods
bigeye sculpin	-	0.1 to 1.8	200-600	34.8-34.9	silt, mud	small benthic invertebrates
ribbed sculpin	Arctic, boreal, and North Pacific	0	10-100	16-30	-	amphipods, mysids

Table 3. Continued.

Species Name	Distribution	Preferred Habitat Characteristics				Diet
		Temp (^oC)	Depth (m)	Salinity (ppt)	Substrate	
arctic alligatorfish	Arctic circumpolar	0	20-100	31-35	mud, sand	amphipods, ostracods, nemerteans
leatherfin lumpsucker	Arctic	-2 to 0	54-150	-	mud, gravel, stone	-
gelatinus snailfish	Arctic circumpolar	-1.5 to 0.56	50-300	-	mud, sand, detritus	hyperiids, mysids, other crustaceans
dusky snailfish	Low Arctic, Chukchi Sea to Labrador	-	40-200	-	rock, sand, mud	amphipods, other crustaceans
kelpsnailfish	North American low Arctic	-1.5 to 2.1	<50	-	kelp, stones, mud, sand	amphipods

Table A. Inuvialuktun names for selected fish in the Siglit dialect. Some require further verification (*).

Species or Common Name - English	**Scientific Name**	**Inuvialuktun (Siglitun) - Singlular, Dual, Plural**	**Source - Singular**	**Source - Dual and Plural**
fish of any kind		iqaluk, iqalluk, iqaluit	Lowe 2001	B. Amos/ A. Nasogaluak
broad whitefish	*Coregonus nasus*	anaakłiq, anakłiik, anaakłiit	Lowe 2001	B. Amos/ A. Nasogaluak
possibly round whitefish*	*Prosopium cylandraceum*	?	Lowe 2001, Kirby 1994	B. Amos/ A. Nasogaluak
humpback or lake whitefish, crooked back	*Coregonus clupeaformis*	pikuktuuq, pikuktuuk, pikuktuut	Lowe 2001	B. Amos/ A. Nasogaluak
herring, arctic cisco	*C. autumnalis*	qaaktaq, qaaktak, qaaktat		
big-eyed herring, least cisco*	*C. sardinella*	?	Lowe 2001	B. Amos/ A. Nasogaluak
inconnu, coney	*Stenodus leucichthys*	siiraq, siiqqak, siiqqat	Lowe 2001	B. Amos/ A. Nasogaluak
pacific herring, blue herring	*Clupea harengus pallasi*	piqquaqtitaq, piqquaqtitak, piqquaqtitat	Lowe 2001	B. Amos/ A. Nasogaluak
lake trout - brackish water	*Salvelinus namaycush*	iqaluaqpak, iqaluakpaak, iqaluaqpait	Lowe 2001	B. Amos/ A. Nasogaluak
lake trout - fresh water	*Salvelinus namaycush*	singayuriaq, singayuriak, singayuriat	Lowe 2001, Kirby 1994	B. Amos/ A. Nasogaluak
char (dolly varden or arctic char)	*Salvelinus alpinus or malma*	iqalukpik, iqalukpiik, iqalukpiit	Lowe 2001	B. Amos/ A. Nasogaluak
tom cod, arctic cod*	*Boreogadus saida*	uugaq, uukkak, uukkat	Lowe 2001	B. Amos/ A. Nasogaluak

Table A Continued.

Species or Common Name - English	**Scientific Name**	**Inuvialuktun (Siglitun) - Singlular, Dual, Plural**	**Source - Singular**	**Source - Dual and Plural**
rock cod, saffron cod*	*Arctogadus glacialis* or *Eleginus glacilis*	uugavik, uugaviik, uugaviit	Lowe 2001	B. Amos/ A. Nasogaluak
burbot, loche	*Lota lota*	tiktaaliq, tiktaallak, tiktaaliit	Lowe 2001	B. Amos/ A. Nasogaluak
arctic grayling	*Thymallus arcticus*	sulukpaugaq, sulukpaak, sulukpait	Lowe 2001 Kirby 1994	B. Amos/ A. Nasogaluak
rainbow smelt	*Osmerus mordax*	iqquaqtqaq, iqquaqtaak, iqquaqtat	Noah Felix 2002	B. Amos/ A. Nasogaluak
smelt*	unknown	iqaluaraq, iqaluakkak, iqaluakkat	Kirby 1994	B. Amos/ A. Nasogaluak
northern pike, jackfish	*Esox lucius*	siiraq, siiqqak, siiqqat	Lowe 2001	B. Amos/ A. Nasogaluak
sucker*	*Catostomus sp.*	milugiaq, milugiak, milugiat	Lowe 2001	B. Amos/ A. Nasogaluak
flounder (starry flounder)*	*Platichthys stellatus*?	nataarnaq, nataarnak, nataarnat	Lowe 2001	B. Amos/ A. Nasogaluak
sculpin, bullhead*	Cottidae *spp.*	kanayuq, kanatdjuk, kanutdjuk/ kanayuit	Lowe 2001	B. Amos/ A. Nasogaluak
small fish in seal stomachs*	unknown	iqlugaq, iqalugaak, iqalukkat	Lowe 2001	B. Amos/ A. Nasogaluak

Table B. Inuvialuktun names for selected marine mammals in the Siglit dialect. Spelling in singular from Lowe (2001). Spelling in dual and plural forms from Beverly Amos, Inuvialuit Cultural Resource Centre and Agnes Nasogaluak of Inuvik.

Species or Common Name - English	**Scientific Name**	**Inuvialuktun (Siglitun) - Singlular, Dual, Plural**
bearded seal	*Erignathus barbatus*	ugyuk, ugyuuk, ugyuit
ringed seal	*Phoca hispida*	natchiq, natchiik, natchiit
walrus	*Odobenus rosmarus*	aiviq, aivvak, aivrit
beluga whale	*Delphinapterus leucas*	qilalugaq, qilalukkak, qilalukkat
bowhead whale	*Balaena mysticetus*	arviq, arviik, arvit
killer whale	*Orchinus orca*	aarlu, aarluuk, aarluit
polar bear	*Ursus maritimus*	nanuq, nannuk, nannut

Table C. Inuvialuktun names for selected birds in the Siglit dialect. Some require further verification (*). Spelling of words in singular from Lowe (2001). Dual and plural spellings from Beverly Amos, Inuvialuit Cultural Resource Centre and Agnes Nasogaluak of Inuvik.

Species or Common Name - English	**Scientific Name**	**Inuvialuktun (Siglitun) - Singlular, Dual, Plural**
waterfowl/duck general term		tingmiluk, tingmiluuk, tingmiluit
eggs		mannik, manniik, manniit
long-tailed duck, oldsquaw	*Clangula hyemalis*	ahaanliq, ahaanlik, ahaanlit
king eider	*Somateria spectabilis*	qaugaq, qaukkak, qaukkat
male king eider	*Somateria spectabilis*	qingalik, qingallak, qingalit
teal (green-winged)*	*Anas sp.*	saviligaaluk, saviligaaluuk, saviligaaluit
snow goose, wavies	*Chen caerulescens*	kanguq, kannguk, kanngut
white-fronted goose, yellow legs	*Anser albifrons frontalis*	tingmiaq, tingmiak, tingmiat nirliq, nirliik, nirlirit
Canada goose	*Branta canadensis*	uluagullik, uluagulliik, uluagullit
brant	*Branta bernicla*	nirlirnaq, nirlirnak, nirlirnat
red-throated loon	*Gavia stellata*	qaqsaug, qaqsauk, qaqsaut
yellow-billed loon	*Gavia adamsii*	tuullik, tuulliik, tuullit
gull - general term*		nauyaq, nautdjak, nautdgat

Table 4. Scientific and common name of seabirds and shorebirds, and important habitat in the study area.

Scientific Name	Common Name	Important Habitat (as identified by Tuktoyaktuk Community Conservation Plan 2000, Searing et al 1975, Alexander et al 1988, ESSO Resources Canada, 1972)
Loons (low lying coastal tundra vegetation/ponds/channels/marshes and grass/sedge delta flats, nest at water's edge, feed on fish)		
Gavia immer	common Loon	uncommon (northern limit of breeding range); Mackenzie Delta/North Slope coast (in or near ocean habitats)
Gavia adamsii	yellow-billed loon	passes through on migration to breeding areas; Mackenzie Delta/North Slope coast (in or near ocean habitats)
Gavia arctica	arctic loon	Mackenzie Delta/North Slope coast (in or near ocean habitats)
Gavia stellata	red-throated loon	Mackenzie Delta/North Slope coast (in or near ocean habitats)
Gavia pacifica	pacific loon	Mackenzie Delta/North Slope coast (in or near ocean habitats)
Swans (entire study area important to 2/3 of Canadian population, feed on aquatic plants)		
Olor columbianus	whistling swan	marshy areas/wet-sedge tundra, Mallik Bay, Kendall Island area, Olivier Islands and Shoalwater Bay
Cygnus columbianus	tundra swan	Mackenzie Delta, mainland coast (marshy areas with low lying coastal tundra vegetation/grass/sedge meadows)
Geese (coastal salt marshes are used for feeding, feed on sedges and tundra vegetation)		
Branta canadensis	Canada goose	nest near water; feed on grasses, sedges, berries, seeds, least populous of all goose species
Branta bernicla	Brant	Tuktoyaktuk Peninsula, Tent Island/Shallow Bay (nest near water/coastal meadows or islands), river deltas/spits/gravel or mud beaches
Anser albifrons frontalis	greater,white-fronted goose	outer Mackenzie Delta, Tuktoyaktuk Peninsula (nest in coastal and upland areas); feed on seeds and grass
Chen caerulescens	lesser snow goose	Kendall Island/major colony; feed on terrestrial and aquatic vegetation/Mackenzie Delta important during spring and fall staging
Dabbling ducks (ponds, channels, marshes, grass-sedge delta flats)		
Anas platyrhynchos	mallard	nest near water (100-500 m); feed on aquatic and terrestrial plants

Table 4. Continued.

Scientific Name	**Common Name**	**Important Habitat (as identified by Tuktoyaktuk Community Conservation Plan 2000, Searing et al 1975, Alexander et al 1988, ESSO Resources Canada, 1972)**
Anas acuta	pintail	common, tundra areas (largest breeding number is in Mackenzie Delta) (prefer open areas with low vegetation) to nest, 40-1600m from water; feed on terrestrial and aquatic plants
Anas americana	American widgeon	common, Mackenzie Delta (highest breeding density, nest 36-400m from water); feed on stems and leafy parts of aquatic plants and terrestrial grasses
Anas clypeata	northern shoveler	uncommon/Mackenzie Delta
Anas creca	green-winged teal	common/Mackenzie Delta
Anas discors	blue-winged teal	rare
Anas strepera	gadwall	rare
Diving ducks (ponds, channels, marshes, grass-sedge delta flats/feed on aquatic plants, aquatic insects, molluscs, crustaceans and fish)		
Aythya spp.	scaup	Mackenzie Delta/coastal areas (bays, beaches and lakes)
Aythya valisineria	canvasback	Mackenzie Delta/coastal areas (bays, beaches and lakes)
Aythya collaris	ring-necked duck	Mackenzie Delta/coastal areas (bays, beaches and lakes)
Aythya americana	redhead	Mackenzie Delta/coastal areas (bays, beaches and lakes)
Bucephala spp.	goldeneye/bufflehead	uncommon (Mackenzie Delta, Tuktoyaktuk Peninsula)
Clangula hyemalis	Oldsquaw/long-tailed duck	small islands or upland areas near tundra ponds, 10-200m from water
Histrionicus histrionicus	harlequin duck	uncommon
Eiders (most time spent on salt water/feed on aquatic organisms eg. mussels, crabs, aquatic insect larvae and some aquatic plants)		
Somateria mollissima	common eider	migrate through area, nests close to sea/small island/near tundra ponds
Somateria spectabilis	king eider	migrate through area, Tuktoyaktuk Peninsula
Scoters		
Melanitta fusca	white-winged scoter	specific locations/shallow bays/Mackenzie Delta/open sea in fall (prefer dense cover) (forested/bushy areas)

Table 4. Continued.

Scientific Name	Common Name	Important Habitat (as identified by Tuktoyaktuk Community Conservation Plan 2000, Searing et al 1975, Alexander et al 1988, ESSO Resources Canada, 1972)
Melanitta perspicillata	surf scoter	specific locations/shallow bays/Mackenzie Delta/open sea in fall (prefer dense cover) (forested/bushy areas)
Melanitta nigra	black duck/scoter	uncommon/specific locations/shallow bays/Mackenzie Delta/open sea in fall (prefer dense cover)
Mergansers		
Mergus merganser	common merganser	specific locations/Tuktoyaktuk Peninsula
Mergus serrator	red-breasted merganser	specific locations/Tuktoyaktuk Peninsula
Cranes (feed on insects, lemmings, aquatic plants and amphibians)		
Grus canadensis	sandhill crane	coastal areas/Shallow Bay/Blow River (nests in marsh or wet meadow)
Plovers (most use low lying coastal tundra vegetation and wetlands for nesting)		
Charadrius semipalmatus	semipalmated plover	Mackenzie Delta
Pluvialis dominica	American golden plover	Mackenzie Delta
Squatarola squatarola	black-bellied plover	uncommon/Mackenzie Delta/Moose Channel
Arenarius interpres	ruddy turnstone	dry dwarf shrub tundra near coast, feeds on insects, plants, molluscs, crustaceans
Numenius phaeopus	whimbrel	upland tundra areas (Arctic slope to Mackenzie Delta)/Moose Channel/Ellice Island to Kendall Island
Totanus flavipes	lesser yellowlegs	common in Mackenzie Delta
Calidris canutus	red knot	uncommon/Moose Channel
Calidris acuminata	sharp-tailed sandpiper	rare/Moose Channel
Calidris melanotos	pectoral sandpiper	common during fall migration thorugh Mackenzie Delta
Calidris fuscicollis	white-rumped sandpiper	uncommon/Moose Channel
Calidris bairdii	Baird's sandpiper	uncommon/Moose Channel
Calidris minutilla	least sandpiper	rare/Moose Channel

Table 4. Continued.

Scientific Name	Common Name	Important Habitat (as identified by Tuktoyaktuk Community Conservation Plan 2000, Searing et al 1975, Alexander et al 1988, ESSO Resources Canada, 1972)
Limnodromus scolo paceus	long-billed dowitcher	uncommon/Moose Channel/Ellice Island to Kendall Island (more common during migration)
Calidris himantopus	stilt sandpiper	uncommon/Ellice Island to Kendall Island
Calidris pusillus	semipalmated sandpiper	common in Mackenzie Delta/Moose Channel especially during fall migration
Tryngites subruficollis	buff-breasted sandpiper	uncommon; prefers dry, grassy tundra; feeds on insects and plant seeds
Limosa haemastica	hudsonian godwit	breeds in Mackenzie delta/Moose Channel/Ellice Island to Kendall Island during migration
Crocethia alba	sanderling	common during migration
Phalaropes		
Phalaropus fulicarius	red phalarope	uncommon except during fall migration
Lobipes lobatus	northern phalarope	uncommon except during fall migration
Jaegers (mainly pelagic, except during nesting/feed on rodents and birds)		
Stercorarius pomarinus	pomarine jaeger	common during spring and fall migrations
Stercorarius parasiticus	parasitic jaeger	common during spring and fall migrations
Stercorarius longicaudus	long-tailed jaeger	common during spring and fall migrations
Gulls		
Larus hyperboreus	glaucous gull	common/prefer marine areas, especially islands and beaches (low gravel/sand spits)
Larus argentatus	herring gull	common in Mackenzie Delta especially during fall migration/nest on islands or lakeshores)
Larus thayeri	Thayer's gull	common in Mackenzie Delta especially during fall migration
Larus canus	mew gull	common in wooded portions of Mackenzie Delta
Pagophila eburnea	ivory gull	common druing fall migration
Xema sabini	Sabine's gull	common east of Mackenzie delta and during migration (nest on islands/tundra ponds near coast)
Sternus paradisaea	arctic tern	common especially during migration (low lying coastal tundra vegetation and wetlands for nesting, low gravel/sand marine areas)

Table 5. Critical habitat sites of seabirds and shorebirds in study area (as identified by Barry 1976).

Critical Areas	Species	Activity	Time of Year
Escape Reef			
	Glaucous gull	nesting	June-Sept
	Arctic tern	nesting	June-Sept
Shoalwater Bay (Blow River Delta and Moose Channel Flats)			
	Whistling swan	nesting	June-Sept
	dabbling ducks	nesting	June-Sept
	shorebirds	nesting	June-Sept
	Snow goose	staging	September
	White-fronted goose	staging	September
	Brant	staging	September
Pelly Island			
	Whistling swan	nesting	June-Sept
	Glaucous gull	nesting	June-Sept
	Brant	nesting	June-Sept
Kendall Island			
	Snow goose	nesting	June-Sept
	Brant	nesting	June-Sept
	Whistling swan	nesting	June-Sept
Mackenzie Delta			
	Whistling swan	nesting	June-Sept
	White-fronted goose	nesting	June-Sept
	Sandhill Crane	nesting	June-Sept
	shorebirds	nesting	June-Sept
Kidluit Bay			
	Glaucous gull	nesting	June-Sept

Table 6. Time of year, usage, level of usage, and area of usage by seabirds and shorebirds in the study area: Yukon Coast from Shingle Point to Shallow Bay (from Alexander et al. 1988).

	Yukon Coast from Shingle Point to Shallow Bay			
	Spring Migration		**early June to mid-July**	
Species	**Entire Region**		**Escape Reef**	**Coast**
Pacific Loon	-	-	-	moderate
Red-throated Loon	-	-	-	-
Tundra Swan	-	-	-	high
Canada Goose	-	-	-	-
Brant	-	-	moderate	high
Greater White-fronted Goose	-	-	-	-
Lesser Snow Goose	-	-	-	-
Unidentified Goose	-	-	-	-
Unidentified dabbling duck	-	-	-	-
Common Eider	moderate	moderate	moderate	-
King Eider	low	low	-	-
Scaup	-	-	-	-
Oldsquaw/long-tailed duck	moderate	low	-	moderate
Scoter	-	-	-	-
Red-breasted Merganser	-	-	-	-
Unidentified diving duck	-	-	-	-
Phalarope	-	-	-	-
Shorebird	-	-	-	moderate
Glaucous Gull	moderate	moderate	high	high
Arctic Tern	-	-	-	moderate
Common Merganser	-	-	-	-

Table 6. Continued.

	Yukon Coast from Shingle Point to Shallow Bay mid-July to mid-August			
Species	**Shingle Point**	**Escape Reef**	**Blow River Delta**	**Whitefish Station/Tent Island**
Pacific Loon	-	-	-	moderate (brood-rearing)
Red-throated Loon	low	-	moderate (broodrearing)	-
Tundra Swan	-	-	-	high (brood-rearing/molting)
Canada Goose	-	-	-	-
Brant	-	low (molting/brooding)	moderate (molting/broodrearing)	-
Greater White-fronted Goose	-	-	-	-
Lesser Snow Goose	-	-	-	-
Unidentified Goose	-	-	-	-
Unidentified dabbling duck	-	-	moderate (molting)	variable (brood-rearing/molting)
Common Eider	-	-	-	-
King Eider	-	-	-	-
Scaup	-	-	-	-
Oldsquaw/long-tailed duck	-	-	-	-
Scoter	moderate (molting)	-	-	-
Red-breasted Merganser	-	-	-	-
Unidentified diving duck	-	-	-	-
Phalarope	high (staging/feeding)	moderate (staging/feeding)	-	-
Shorebird	-	-	moderate (broodrearing/staging)	high (staging)
Glaucous Gull	high (feeding)	high (brood-rearing)**	moderate (brood-rearing)	high (brood-rearing)
Arctic Tern	-	low (brooding)	-	moderate (brood-rearing)
Common merganser	-	-	-	-

**largest colony in Beaufort Sea

Table 6. Continued.

Species	Yukon Coast from Shingle Point to Shallow Bay mid-August to late September		
	Shingle Point	Escape Reef	Blow River Delta
Pacific Loon	-	-	moderate (brood-rearing)
Red-throated Loon	-	-	-
Tundra Swan	-	-	high (molting/brood-rearing/staging)
Canada Goose	-	-	moderate (staging)
Brant	-	-	high (staging)
Greater White-fronted Goose	-	-	high (staging)
Lesser Snow Goose	-	-	high (staging)
Unidentified Goose	-	-	moderate (staging)
Unidentified dabbling duck	-	-	moderate (staging)
Common Eider	-	-	-
King Eider	-	-	-
Scaup	-	-	-
Oldsquaw/long-tailed duck	-	low (staging)	-
Scoter	high (staging)	moderate (staging)	-
Red-breasted Merganser	high(staging)	moderate (staging)	-
Unidentified diving duck	-	-	-
Phalarope	high (fall migration)	high (fall migration)	-
Shorebird	high(staging) migration)	moderate (fall migration)	-
Glaucous Gull	high (fall migration)	moderate (fall migration)	-
Arctic Tern	-	-	-
Common Merganser	-	-	-

Table 7. Time of year, usage, level of usage, and area of usage by seabirds and shorebirds in the study area: Mackenzie Delta region from Shallow Bay to Toker Point (from Alexander et al. 1988).

	Entire Mackenzie Delta Region from Shallow Bay to Toker Point				
Species	**Spring Migration**		**early June to mid-July**	**mid-July to mid-August**	**mid-August to late September**
Red-throated Loon	-	-	moderate (nesting)	high (broodrearing/feeding)	-
Tundra Swan	-	-	high (nesting/molting)	high (molting/broodrearing)	high (molting, broodrearing, staging)
Canada Goose	-	-	-	high(molting)	high (staging)
Brant	-	-	high (nesting)	high (molting/broodrearing)	high (staging)
Greater White-fronted Goose	-	-	high (nesting/molting)	high (molting/broodrearing/staging)	high (staging)
Lesser Snow Goose	-	-	high (nesting)	high (molting/broodrearing)	high (staging)
Unidentified Goose	-	-	high (molting)	high (molting/staging)	high (staging)
Unidentified dabbling duck	-	-	high (nesting/molting)	high (molting)	high (staging)
Common Eider	moderate	moderate	moderate (nesting)	-	-
King Eider	low	low	-	-	-
Scaup	-	-	moderate (nesting)	high (molting)	-
Oldsquaw/long-tailed duck	moderate	low	-	high (molting)	-
Scoter	-	-	-	high (molting)	-
Red-breasted Merganser	-	-	-	high (molting)	moderate (staging)
Unidentified diving duck	-	-	-	moderate (molting)	-
Phalarope	-	-	-	-	-
Shorebird	-	-	moderate (nesting)	high (broodrearing/staging)	high (staging)
Glaucous Gull	moderate	moderate	high (nesting)	high (broodrearing/feeding)	high (staging)
Sabine's Gull	-	-	-	-	-
Arctic Tern	-	-	high (nesting)	high (broodrearing/feeding)	-
Common Merganser	-	-	-	low (molting)	-

(To be inserted by DFO)

Figure 1. Map of the Inuvialuit Settlement Region (ISR).

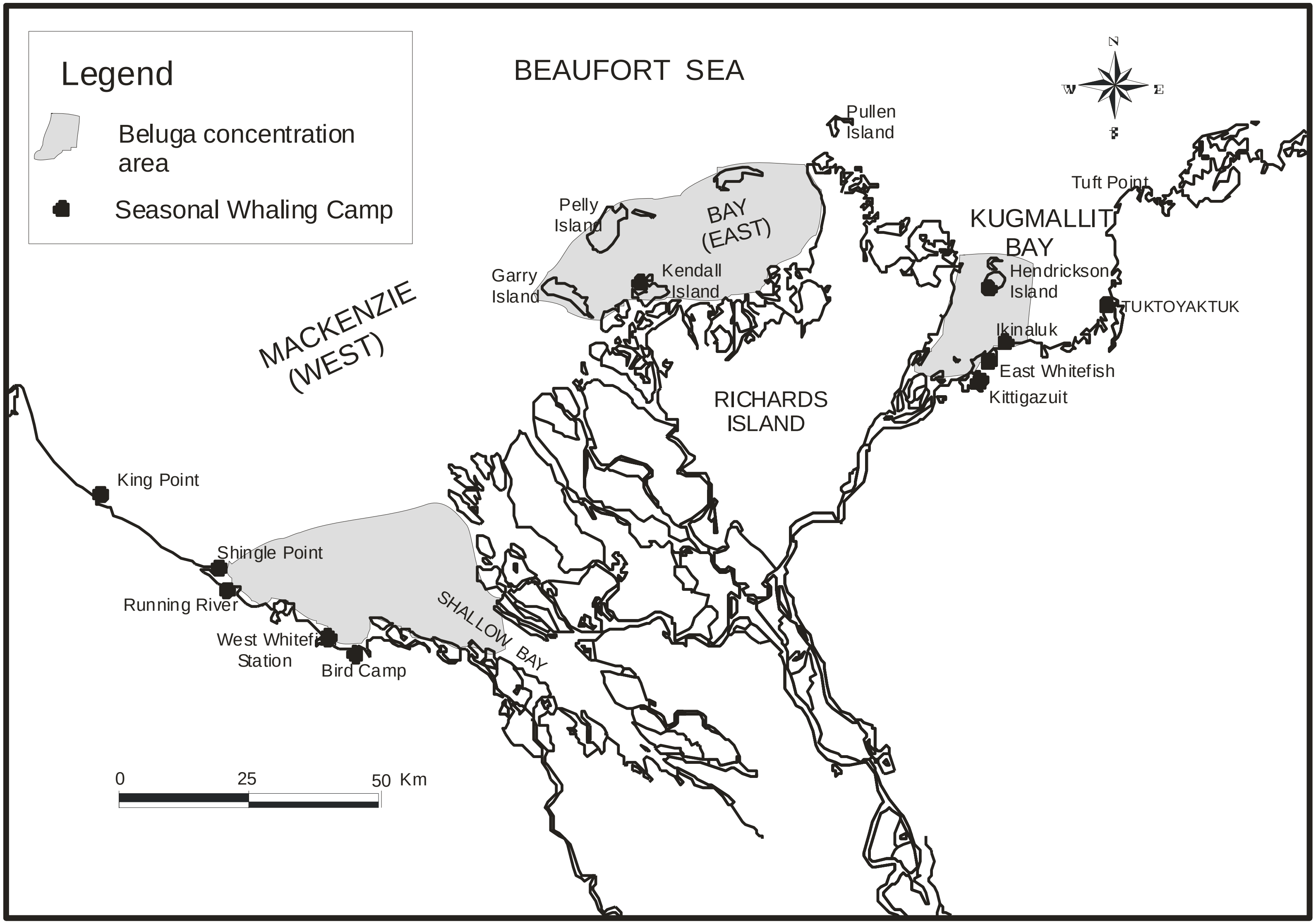
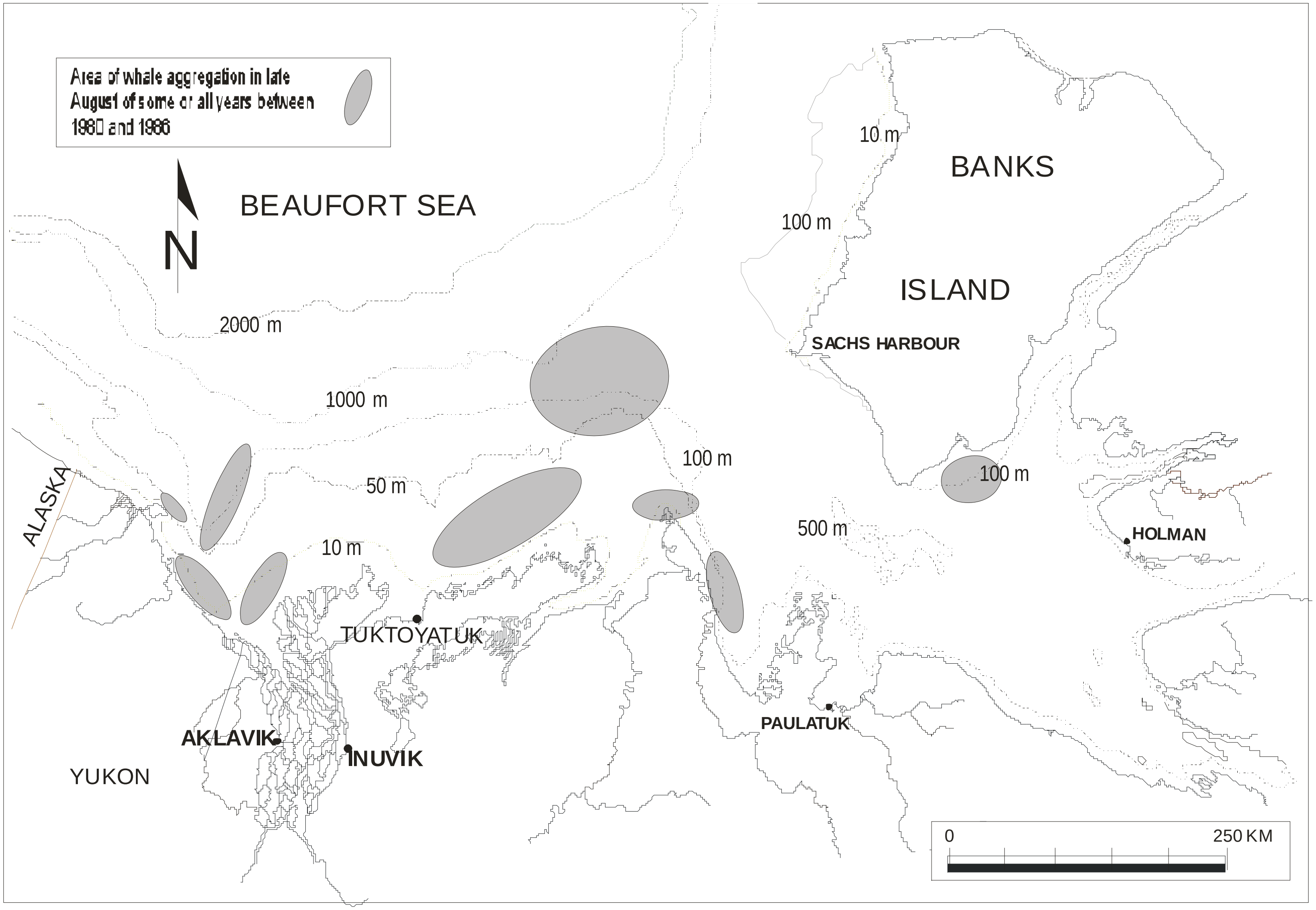


Figure 2. Beluga summer concentration areas and seasonal whaling camps in the Mackenzie River estuary



Map provided by Lois Harwood, Canada Department of Fisheries and Oceans, Inuvik

Figure 3. Areas of summer bowhead whale concentration in the southern Beaufort Sea and Amundsen Gulf region