Beaufort Sea Large Ocean Management Area: Ecosystem Overview and Assessment Report

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Acronyms

ACIA	Arctic Climate Impact Assessment
AMAP	Arctic Monitoring and Assessment Programme
ASTIS	Arctic Science and Technology Information System
BEMP	Beaufort Environmental Monitoring Project
BREAM	Beaufort Regional Environmental Assessment and Monitoring
BSIMPI	Beaufort Sea Integrated Management Planning Initiative
BSP	Beaufort Sea Partnership
BSSC	Beaufort Sea Steering Committee
CAMIS	Canadian Arctic Marine Ichthyoplankton Studies
CAPP	Canadian Association of Petroleum Producers
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSA	Canada Shipping Act
CWS	Canadian Wildlife Service
DEW	Distant Early Warning (Line)
DFO	Fisheries and Oceans Canada
DOC	Dissolved Organic Carbon
EBM	Ecosystem-Based Management
EBSA	Ecologically and Biologically Significant Area
EC	Environment Canada
EIA	Environmental Impact Assessment
EIRB	Environmental Impact Review Board
EISC	Environmental Impact Screening Committee
EL	Exploration License
EOAR	Ecosystem Overview and Assessment Report
ESRF	Environmental Studies Research Funds
ESSC	Ecologically Significant Species and Communities
FJMC	Fisheries Joint Management Committee
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GNWT	Government of the Northwest Territories
GRRB	Gwich'in Renewable Resources Board
GSC	Geological Survey of Canada
IAS	Invasive Alien Species
IFA	Inuvialuit Final Agreement

IGC	Inuvialuit Game Council
IOS	Institute of Ocean Science
IM	Integrated Management
INAC	Indian and Northern Affairs Canada
IPY	International Polar Year
IRC	Inuvialuit Regional Corporation
ISR	Inuvialuit Settlement Region
IUCN	World Conservation Union
JS	Joint Secretariat
KIBS	Kendall Island Bird Sanctuary
LOMA	Large Ocean Management Area
MBS	Migratory Bird Sanctuary
MEH	Marine Environmental Health
MPA	Marine Protected Area
NCMSP	Northern Coastal Marine Studies Program
NEB	National Energy Board
NLCA	Nunavut Land Claims Agreement
NOGAP	Northern Oil and Gas Action Plan
NRCan	Natural Resources Canada
NWT	Northwest Territories
PCB	Polychlorinated Biphenyl
POC	Particulate Organic Carbon
RCC	Regional Coordinating Committee
SARA	Species at Risk Act
SDL	Significant Discovery License
TK	Traditional Knowledge
TNMPA	Tarium Niryutait Marine Protected Areas
WMAC (NT)	Wildlife Management Advisory Council (NWT)

ABSTRACT

Cobb, D., H. Fast, M.H. Papst, D. Rosenberg, R. Rutherford and J.E. Sareault (Editors). 2008. Beaufort Sea Large Ocean Management Area Ecosystem Overview and Assessment Report. Can. Tech. Rep. Fish. Aquat. Sci. 2780: ii-ix + 188 p.

The Beaufort Sea is a complex marine ecosystem within Canada's Arctic. The productivity of the region, particularly the nearshore, has been an important resource supporting human occupation for decades. Under *Canada's Oceans Act* (1997), "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment". This Act provides the legislative framework for Integrated Management (IM) in the first Arctic Large Ocean Management Area (LOMA). In support of the IM process for the Beaufort Sea LOMA, Fisheries and Oceans (DFO), along with its co-management partners and others, have contributed their expert knowledge and advice to create the Beaufort Sea Ecosystem Overview and Assessment Report (EOAR). The EOAR represents the initial effort to provide partners and stakeholders with a comprehensive summary of ecosystem information. Over time this initial document will be updated and expanded to meet the needs of IM in the Beaufort Sea. The overview (Volume One) provides a description of the structure and function of the ecosystem and identifies knowledge gaps. The assessment (Volume Two) identifies human uses and impacts on the system and serves as an aid to government, the Inuvialuit and industry, in the development of an IM plan for the Beaufort Sea LOMA.

Key Words: Canadian Beaufort Sea, Ecosystem-based management

RÉSUMÉ

Cobb, D., H. Fast, M.H. Papst, D. Rosenberg, R. Rutherford et J.E. Sareault (éditeurs). 2008. Rapport d'examen et d'évaluation de l'écosystème des zones étendues de gestion des océans dans la mer de Beaufort. Rapp. tech. can. sci. halieut. aquat. 2780: ii-ix + 188 p.

La mer de Beaufort est un écosystème marin complexe au sein de l'Arctique canadien. La productivité de la région, notamment proche du rivage, est une importante ressource qui soutient l'occupation humaine depuis des décennies. En vertu de la *Loi sur les océans du Canada* (1997), « la conservation, selon la méthode des écosystèmes, présente une importance fondamentale pour la sauvegarde de la diversité biologique et de la productivité du milieu marin ». Cette loi fournit le cadre législatif pour la gestion intégrée (GI) de la première zone étendue de gestion des océans (ZEGO) dans l'Arctique. À l'appui du processus de GI de la ZEGO dans la mer de Beaufort, Pêches et Océans Canada (MPO), ses partenaires de cogestion et d'autres intervenants ont offert leurs connaissances approfondies et leurs conseils éclairés pour créer le Rapport d'examen et d'évaluation de l'écosystème (REEE) des zones étendues de gestion des océans dans la mer de Beaufort. Le REEE constitue la première démarche en vue de procurer aux partenaires et aux intervenants un résumé détaillé de l'information sur les écosystèmes. Au fil du temps, ce document initial sera mis à jour et étoffé pour répondre aux besoins de GI dans la mer de Beaufort. L'aperçu (volume 1) décrit la structure et la fonction de l'écosystème et cerne les lacunes des connaissances. L'évaluation (volume 2) indique les effets des activités humaines sur le système et sert de guide au gouvernement, aux Inuvialuit et à l'industrie pour l'élaboration d'un plan de GI de la ZEGO dans la mer de Beaufort.

Mots clés : mer de Beaufort, gestion écosystémique

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II. Executive Summary

The Beaufort Sea Large Ocean Management Area (LOMA) is a complex marine system that represents a number of species and trophic interactions. The productivity of the region, particularly the nearshore zone, has long been an important resource for humans. The area is still traditionally hunted and fished by both the Inuvialuit and Gwich'in, but the LOMA is on the brink of significant economic and environmental change. Thus, the Beaufort Sea is the first Arctic marine area to be assessed by Fisheries and Oceans Canada (DFO) in an attempt to successfully manage human use of the oceans in a way that does not compromise the ecosystem from the pressures of exploration, development and a changing climate.

Under Canada's Oceans Act (1997), "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment". This Act has provided the legislative framework for Integrated Management (IM) by recognizing the complextity of ecosystems; the interrelationships between organisms, their habitat and the physical environment; and that a precautionary approach is needed to ensure the sustainable use, development, and protection of areas and resources.

The Beaufort Sea LOMA is located in the extreme northwestern corner of Canada, and encompasses the marine portion of the Inuvialuit Settlement Region (ISR). The ISR was established under the terms of the Inuvialuit Final Agreement (IFA) with the Government of Canada in 1984. The IFA ensures the involvement of beneficiaries in the management of the region's resources.

This report has benefited significantly from inputs by northern experts who provided their knowledge through workshops and community tours. Many beneficiaries have shared their knowledge of the ecosystem, their culture and their desire for conservation and sustainable economic development.

An intensive review of published and unpublished reports preceded the development of the Beaufort Sea LOMA Ecosystem Overview and Assessment Report (EOAR). Wherever possible Traditional Knowledge (TK) was incorporated into the development of the major ecological components. TK was also used to assess impacts of human use on the environment.

The objectives of this report are:

- to provide a description of the structure and function of the Beaufort Sea ecosystem to provide background for development, planning, protection and monitoring;
- to identify human uses and impacts of human uses on the system;
- to aid in the development of broader integrated management projects;
- to aid government, industry and Inuvialuit in decision-making processes; and
- to identify gaps in information and knowledge of the Beaufort Sea ecosystem.

The LOMA encompasses approximately 1,107,694 km^2. It is characterized by the Beaufort Continental Shelf, a relatively short ice-free season, increased sediment and freshwater loading during spring and summer, and the Cape Bathurst polynya and associated flaw leads. The polynyas and flaw leads within the LOMA are considered areas of relatively high productivity and diversity.

The most significant geological feature within the LOMA is the Beaufort Continental Shelf. There are two large submarine canyons called the Mackenzie and Kugmallit troughs and several special bottom features, including gas vents, mud volcanoes and underwater pingos located on the Shelf. Understanding the bathymetry of the sea floor and these identified features may give scientists the ability to predict potential areas of biological and ecological significance. Changes in depth can influence many of the physical and chemical processes including temperature, salinity and water movement. Consequently these factors have significant impacts on the distribution, growth and survival of freshwater and marine organisms in the LOMA. The circulation system is dominated by the Beaufort Gyre, a clockwise rotating surface current that results in large-scale movements of sea ice and surface waters. The eastward movement of water originating from the Pacific and Atlantic Oceans results in sub-surface counter-clockwise undercurrents. These undercurrents typically follow the bottom topography along the Beaufort Shelf break and occasionally ascend during events of upwelling. These upwelling events can also occur within the two troughs and are often considered sources of increased primary productivity.

The relatively short growing season and the cold and dry climate are unique to the Arctic. Ice usually begins to form in October. Shallow waters freeze as landfast ice, and extend out to about the 20-m depth contour. The Beaufort Sea LOMA is completely ice covered in about November. A stamukhi zone forms at the 20-m depth contour as drifting and landfast ice converge, creating a division between nearshore and offshore dynamics. The Mackenzie River outflow is impounded nearshore of the stamukhi zone and pools under the landfast ice to form a freshwater lake. Beyond the zone, seaward, is an area of open water known as a flaw polynya. Beyond the polynya is the drifting pack ice. Most of the marine system, except the dynamic flaw polynya and lead systems, is covered by ice until spring break-up, thereby limiting the amount of primary and secondary production.

The largest river system to influence the Beaufort Sea is the Mackenzie River. It annually transports approximately $130x10^6$ tonnes of sediment and 18 million km^3 of freshwater into the Beaufort Sea. The fresh waters mix with marine waters and a relatively fresh mixed layer forms along the coastal areas and stratifies the ocean waters. At this point, the Mackenzie–Beaufort Shelf acts like any other coastal estuary and becomes a source of increased productivity during the summer. The nearshore surface patterns are controlled primarily by wind and, to a lesser extent, the volume of river discharge. The river discharge plume is fresh, warm and sediment-rich. Without wind influence, the plume tends to bend eastward along the coast and this easterly flow can be enhanced by strong westerly winds. The opposite is true of easterly wind events, which can initiate upwelling along the Shelf break as the plume waters are forced offshore and the nutrient rich sub-surface waters begin to rise toward the surface. The plume waters, along with the influences of wind, allow numerous species to use the area. Marine mammals, anadromous fish, larval fish, marine birds and marine fish aggregate and use the area as migratory routes, seasonal refugia and feeding areas.

The Cape Bathurst polynya is one of the most important habitats and attracts some of the highest densities of birds, benthic organisms and marine mammals in the LOMA. The polynya is an open-water or thin-ice area surrounded by thicker ice. Long, relatively narrow flaw leads extend from the polynya north along Banks Island and west along the Canadian mainland. Few scientific studies have been published on the area to date, and Inuvialuit typically do not use the polynya ecosystem due to unstable ice conditions; however, the polynya is a likely source of increased productivity and may play a critical role in overall ecosystem structure and function.

Biological components of the ecosystem are important to the understanding of ecosystem function and energy flow. The food web includes primary producers, zooplankton, benthic invertebrates, fish, marine mammals and birds. Primary producers in the Beaufort Sea include phytoplankton, ice algae, benthic algae and aquatic macrophytes (i.e. kelp beds). Primary producers use the energy of the sun to convert carbon dioxide and water into organic matter. Their growth is primarily controlled by light and nutrient availability. In the Shelf region, light controls the timing of phytoplankton production but nutrient availability controls the overall abundance. Secondary producers (zooplankton) are directly linked to primary producers, and are the major link to larger organisms of the Beaufort Sea marine ecosystem. Zooplankton are prey for a range of species from small invertebrates to large whales. This group includes small organisms like copepods, jellyfish and ichthyoplankton (larval fish). Upwelling areas are significant to both groups of organisms. Upwelling occurs at the Beaufort Shelf break, the interface between Mackenzie River plume waters and marine waters, and the Cape Bathurst polynya. These locations are ecologically and biologically significant to the productivity of the Beaufort Sea and are influenced primarily by physical oceanographic features. The availability of both phytoplankton and zooplankton is a limiting factor for the success and distribution of many other species at higher trophic level.

The diverse range of conditions present in the coastal areas of the LOMA provide suitable habitat for a variety of fish species, both marine and freshwater. Fish are found in three principal aquatic habitats: freshwater drainage, nearshore coastal waters, and offshore marine waters. Freshwater streams and rivers are used by anadromous and freshwater fishes, and brackish, mixed waters along the nearshore coastal zone provide important feeding and migratory habitat for these fish in summer. There are approximately 20–30 species of freshwater and anadromous fish in the Beaufort Sea LOMA. Some of these species may even overwinter in the freshened river outflows under ice (Mackenzie River, Darnley Bay and Minto Inlet). The Husky Lakes are also an important area for anadromous and freshwater fishes in the LOMA. There are a number of species of fish in the LOMA 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), charr (Dolly Varden), lake trout and to a lesser extent Pacific herring. Marine offshore waters, and to some extent—depending on species-specific tolerances—the brackish, mixed-zone waters are important habitat for marine fishes. Areas within the LOMA that are of ecological importance to marine fish include any marine upwelling zones at the Shelf break, recurrent polynya and flaw-lead features, the nearshore coastal-mixing zone, mixed-ice zones and ice-edges, and likely the open deep ocean (although data are deficient). The most commonly captured marine fish is the Arctic cod, which is a keystone species in the food web. It is widely distributed and highly abundant in the system, and is an important food for other fish, beluga and other marine mammals. However, very little is known about the ecology of this fish.

The southern Beaufort Sea provides seasonal and year-round habitat for several species of marine mammals. Beluga and bowhead whales move into the near- and offshore areas of the southern Beaufort Sea and Amundsen Gulf each spring and summer. Killer whales are infrequently observed in the area, and evidence indicates that narwhal occasionally enter into the Amundsen Gulf area. Gray whales have also been observed in the offshore areas of the western Beaufort Sea. Ringed seals are the most abundant seal in the Canadian Arctic, and are year-round residents in the southern areas. Polar bears, the primary predator of the ringed seal, are also abundant and their movements and distribution largely depend on ringed seal distribution and sea-ice conditions. Marine mammals are the highest level of the food web and are critical for the import and export of nutrients, given their migratory movements. A number of these species are extremely important for subsistence hunting in the LOMA, and are considered ecologically influential predators.

Marine birds (sea birds) use the offshore, inshore and both of these areas in the Beaufort Sea LOMA. Offshore sea birds use open waters in the western Arctic from spring to autumn. The recurring polynya that forms off Cape Bathurst and the associated flaw leads off Banks Island and the Mackenzie Delta are considered critical staging grounds within the LOMA. Birds stay in the area until breeding and nesting areas become available. Offshore birds use open-water areas until they are no longer available. Species that use the offshore waters include the red-throated, Pacific and yellow-billed loons, common eiders, long-tailed ducks, Sabine's gulls and glaucous gulls. The inshore birds prefer coastal lagoons, bays, barrier islands and tidal marshes along the Beaufort Sea coast from June to freeze-up. Bird species that depend on the nearshore waters during the nesting season include the red-throated loon, Pacific loon, brant, tundra swan, glaucous gull, Arctic tern, lesser snow geese, black guillemots, common eiders and thick-billed murres. Peak numbers of nearshore birds generally occur around late July to mid-August. Marine birds play an important part in the environment. They consume large quantities of marine prey each year, and areas of high bird densities indicate high densities of benthic fauna, suggesting higher productivity in the area. These birds are critical to the import and export of nutrients in the LOMA because of their migratory activities.

The information collected in the EOAR, Volume I, is the basis for the development of Ecosystem-Based Management (EBM) in the LOMA. "EBM is the management of human activities so that marine ecosystems, their structure (biological diversity), function (productivity) and overall environmental quality (water and habitat quality), are not compromised and are maintained at appropriate temporal and spatial scales" (DFO; http://www.dfo-mpo.gc.ca/canwaters-eauxcan/). The status and trends of the marine ecosystem identified in Volume I will help to identify and evaluate the ecological impacts of human activities, identify areas of concern and provide recommendations to decision-makers for priority actions and areas in Volume II, which will aid stakeholders and managers to balance economic uses and development with the maintenance of ecosystem structure and function.

All industrial activities have the potential to adversely affect the environment. Renewable resources, such as fish and whales are important for both subsistence and tourism in the LOMA. The Arctic Ocean, however, is known to be less productive than other oceans, and the level at which the ecosystem can support outside pressure is unknown. Subsistence fishing and hunting are activities supported by the IFA and other land claim agreements. These activities are monitored and supervised by the Fisheries Joint Management Committee (FJMC) and federal and territorial government departments to ensure sustainability of resources. Ecotourism, however, is also increasing in popularity. Ecotourism includes sport fishing, hunting and ecological and cultural tours, which are all sources of economic income. As communities and economic development expand, the need for resource protection (i.e. monitoring, management and enforcement) is likely also to emerge.

The Canadian western Arctic has the third-largest reserve of conventional oil and gas in Canada. Exploration and development of oil and gas in the LOMA brings with it a number of environmental and economic pressures, both short-term and long-term. Hydrocarbon development requires extensive seismic activity, drilling in coastal and offshore areas, the construction of artificial islands and pipeline systems, a demand for granular deposits (i.e. gravel and sand), a dramatic increase in all-season and winter roads, marine shipping and aviation, and risk of pollution and oil spills. These activities may have serious impacts on environmental quality. The assessment of human uses and their effects on the ecosystem will aid in the development of mitigation strategies and management decisions to protect ecosystem structure and function.

Other emerging stressors will impact the LOMA. There will be increased need for waste disposal and sewage treatment in communities and camps, relocation of coastal communities due to changing climates and coastal erosion and subsidence, and for granular deposits. There will be concern about transport of pollutants and local contaminants and shifts in physical, chemical and biological patterns (such as changes in water circulation and arrival of aquatic invasive species).

There are presently no extensive land-based impacts on the LOMA. Locations previously associated with the Canadian Distant Early Warning stations (DEW Line), dredging in Tuktoyaktuk Harbour, creation of artificial islands and exploration camps from the oil and gas industry, and the annual disposal of Sachs Harbour muskox offal may in some cases have impacts. However, the extent of degradation from these sites and activities has not yet been assessed.

Key areas identified by science and northern experts as important for research and monitoring are called Ecologically and Biologically Significant Areas (EBSAs). EBSAs are a tool used to identify areas that are particularly important to the structure and function of the marine environment or a particular ecosystem. They are not based on regulation, and are not managed in the way Marine Protected Areas (MPAs) are managed. Rather, their identification is intended to raise awareness and draw attention to activities that may threaten an area. Scientists and community members developed a list of 21 areas in the LOMA, which were then evaluated for uniqueness, aggregation, fitness, resilience and naturalness. Ten of the areas met the criteria, ten were termed "data deficient" and one was rejected as not meeting the criteria.

In conjunction with EBSA identification, scientists and northern experts collated a list of Ecologically Significant Species and Communities (ESSCs) within the LOMA. The species and communities identified are considered key ecosystem components, necessary to ensure that ecosystem structure and function are maintained in the environment. The preliminary list includes three lower-trophic-level communities and seven identified species.

Rare or depleted species in the LOMA were also included in the ESSCs. The wolffish (*Anarhichas sp.*) and the pigheaded prickleback (*Acantholumpenus mackayi*) are considered to be rare and data-deficient in the LOMA. The two western stocks (Rat River and Big Fish River) of Dolly Varden charr (*Salvelinus malma malma*) have had significant population declines. The bowhead whale, ivory and Ross's gulls are currently listed or under consideration under both the Species At Risk Act (SARA) and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

The report concludes by reviewing the goals and objectives of the *Oceans Act* (1997), Canada's Oceans Strategy (2002) and Canada's Oceans Action Plan (OAP) (2005) as they pertain to ocean planning and management priorities. Progress made toward the achievement of these goals and objectives in the Beaufort Sea are reviewed and assessed. The report concludes that significant progress has been made toward two of the four Ocean Action Plan pillars: integrated oceans management for sustainable development and understanding health of the oceans in the Beaufort Sea. Governance processes have been established and an ecosystem overview and assessment report completed.

III. General Information

1. Project Definition

Under Canada's *Oceans Act* (1997), Fisheries and Oceans Canada (DFO) is responsible for leading and implementing of Integrated Oceans Management. Integrated management (IM) recognizes the complexity of ecosystems and the interrelationships between organisms, their habitat and the physical environment. IM also recognizes that a precautionary approach is needed to ensure the sustainable use, development and protection of areas and resources (Volume I). IM incorporates social, cultural and economic values into the development and implementation of ocean use management (Volume II). Accordingly, the examination of Large Ocean Management Areas (LOMAs) within Canadian waters, extends from coastal zones, typically to the limits of Canadian jurisdiction. There are currently five defined LOMAs in Canada's Oceans, including the Beaufort Sea (Figure 1).

The Beaufort Sea LOMA is located in the extreme northwestern corner of Canada, and encompasses the marine portion of the Inuvialuit Settlement Region (ISR). The LOMA covers approximately 1,107,694 km^2. The coastal area of the LOMA extends some 750 km along the mainland from the Alaska–Yukon border at 141°W, east through the Mackenzie Delta to Clinton Point at 121°W, the entrance to Dolphin and Union Strait. The boundary then runs north to include the west coast of Victoria Island and the south and west coasts of Banks Island to M'Clure Strait at approximately 80°N. The western boundary is defined by the ISR boundary. The LOMA includes four distinct geographic regions: the Beaufort Sea, the Mackenzie Delta, the Yukon North Slope and the Arctic Islands. The Beaufort Sea region refers to marine offshore waters, whereas the Mackenzie Delta and Yukon North Slope refer to coastal waters along the southwestern portion of the Canadian mainland. The Arctic Islands include Banks Island and portions of Victoria and Melville Islands (Figure 1).

The study area is relatively pristine and is characterized by a marine environment that includes permanently and seasonally ice-covered regions and a coastal area influenced by the mixing of marine and fresh water. The major communities within the LOMA are Paulatuk, Tuktoyaktuk, Sachs Harbour, Aklavik, Inuvik and Ulukhaktok (Holman) (Figure 2, page 14).

The purpose of this Ecosystem Overview is to provide a current description of the major ecological components of the Beaufort Sea, including biological, chemical and physical characteristics and their interactions (Volume I). The ecological status and trends identified in Volume I are then used to help identify Areas of Concern (i.e. Ecologically and Biologically Significant Areas [EBSAs]) and assess human use of the Beaufort Sea in Volume II.

The work contained in the Ecosystem Overview and Assessment report (EOAR) will form the basis for IM planning within the Beaufort Sea LOMA. The information will be used by governments, industry and the Inuvialuit to make informed decisions and also to set priorities for future research to fill gaps in knowledge. It is anticipated that this document will be updated as additional knowledge becomes available.

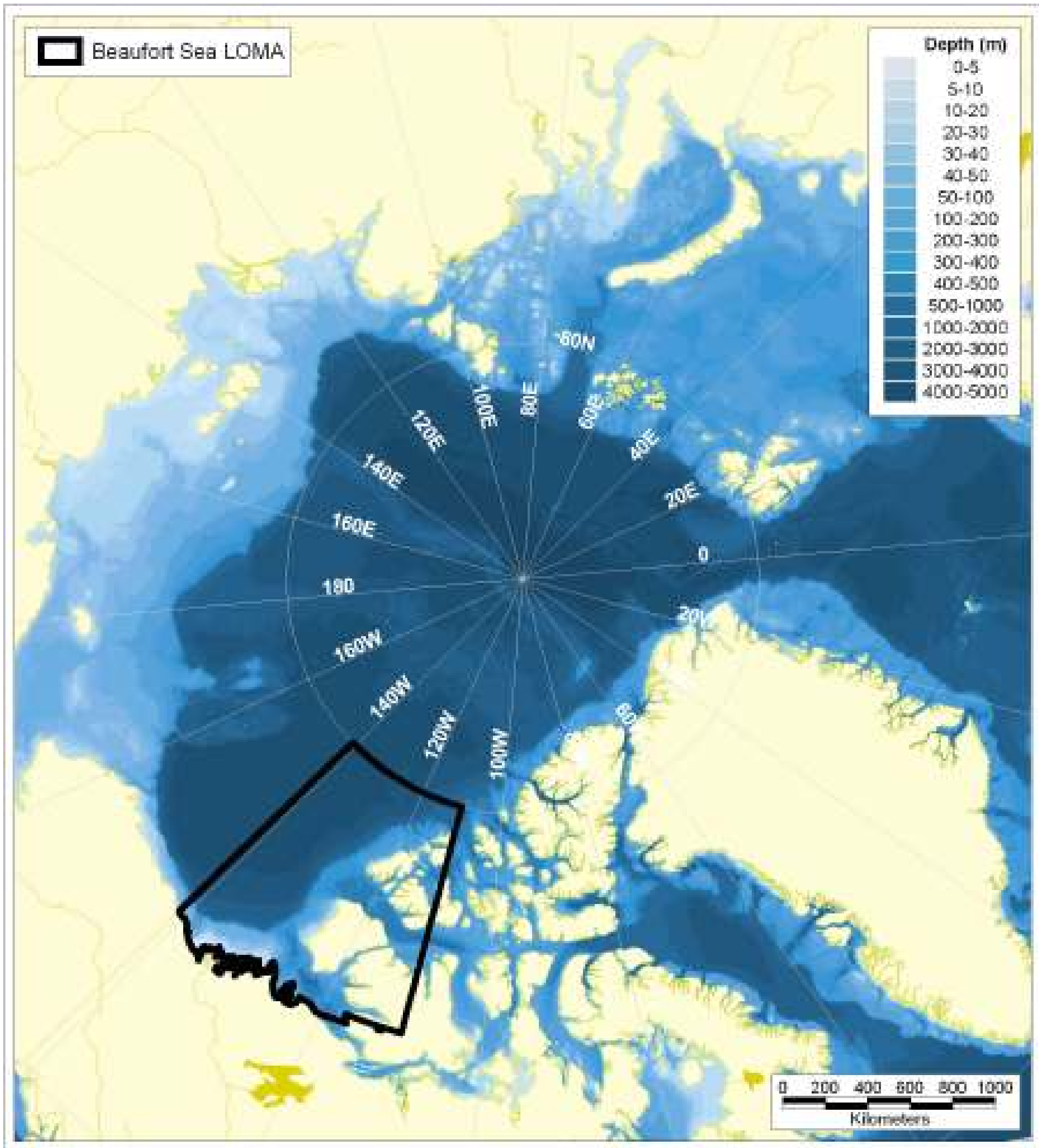

Figure 1. Location of the Beaufort Sea LOMA in the Canadian Arctic.

2. Study Methods

a. Sources of Information

The information contained in the EOAR is a compilation of published scientific literature, data from unpublished government and industry studies and Inuvialuit traditional knowledge (TK). Most of the references used in the development of this document are available from DFO, Central and Arctic Region.

The Beaufort Sea EOAR largely follows the format described in the "National Technical Guidance Document, Ecosystem Overview and Assessment (EOA) Reports" prepared by the DFO Oceans Directorate (April 2005 – draft), with some modifications. Volume I builds on the initial work by North/South Consultants of Winnipeg in the report "Inuvialuit Settlement Region Ecosystem Overview", prepared under contract for DFO, Central and Arctic Region. The present document represents an extensive redraft of this report and includes considerable additional information and scope.

b. Information Use and Reliability

Published and peer-reviewed sources of information were used and expert advice guided the incorporation of unpublished or non-peer-reviewed information wherever possible in the preparation of Volume I. TK was collected from prior studies and interviews. TK is anticipated to increase as a result of the review and assessment process, which will include regional communities and co-management partners.

The intent of Volume I is to provide a comprehensive ecological overview of the whole Beaufort Sea LOMA, but much of the available information has a strong geographical and seasonal bias. Most of the references pertain to the southeastern Beaufort Shelf region, especially for biological systems. Most of the information for the Beaufort Sea ecosystem comes from research conducted during the open-water summer months. Wherever possible, the document uses results of current or on-going research to address information gaps in the historic record. Recent and planned national and international research related to climate change, hydrocarbons, contaminants and sovereignty will aid to rectify these biases and enhance our knowledge of the broader Beaufort Sea LOMA.

Volume I – Ecosystem Overview: Status and Trends

3. Introduction

The status and trends section describes our current knowledge of the components of the Beaufort Sea marine ecosystem. The section is divided into four main sub-sections, which together define the environmental determinants with which the biological components of the Beaufort Sea LOMA interact. The first sub-section begins with a description of the regional geological systems, including coastal and marine geology. It describes the major land masses that were formed millions of years ago, but still retain many of the features that influence both climate and physical oceanography. The surficial geology and processes part describes more recent (hundreds to tens of thousands of years) landscapes, including watersheds, coastal plains, deltas, permafrost and bottom features.

The second sub-section discusses the oceanographic system. This sub-section includes a description of climate, oceanographic large- and local-scale circulation and currents, and hydrology of the Mackenzie River, a dominant factor in the ecosystem of the LOMA. Seasonal ice dynamics, perhaps the most unique aspect of the LOMA, are described, including various types of ice and polynyas. Last, this sub-section discusses the properties of seawater, including temperature, salinity and nutrients.

The third sub-section describes biological components of the marine ecosystem, beginning with the lower trophic levels (phytoplankton and bacterioplankton), that integrate organic nutrients into the food chain. Phytoplankton are then fed upon by zooplankton, which are a critical link between primary producers and larger organisms. Ichthyoplankton (larval fishes) are closely associated with phytoplankton; recruitment of ichthyoplankton into subsequent adult populations is crucial for maintenance of structure of the Arctic marine fish populations. The next part describes benthic invertebrates, demonstrating the importance of salinity and ice scour in their abundance and diversity. This part is followed by the marine and anadromous fish section. Some of these species are highly migratory, and others are considered to be keystone species with high degrees of interaction within the food web. The sub-section then discusses mammals, including marine mammals that are at the top of the food web. Some of these species have very long seasonal migrations into and out of the LOMA. The last part discusses marine birds, their seasonal use of the area, feeding and migratory patterns.

The final sub-section integrates the preceding material to provide some insight into physical-biological linkages and biological interactions. This consideration sets the stage for assessing ecologically significant areas and species, which is important for setting conservation objectives for use in IM plans.

Part A. Geological Systems

4. Coastal and Marine Geology

The earth's crust began to pull apart in the Arctic from 206–100 million years ago, resulting in the opening of the Canada Basin and subsequently the Beaufort–Mackenzie Basin (Dixon *et al*. 2001). During this time, there was no connection to other ancient oceans through the Bering Sea (McNeil 1990), and the Basin was connected only by small waterways. The modern Arctic Ocean began to be established from 66.4–36.6 million years ago by the gradual spreading of the sea floor within these small waterway connections to the North Atlantic. The waterways gradually became wider and deeper until the Arctic Ocean was united with the other ancient oceans of the world.

Much of the land mass located west of the Mackenzie Delta is associated with Canada's Western Cordillera. One of these mountain ranges, the Richardson Mountains, consists of folded and faulted sedimentary rocks, with local igneous intrusions and volcanic flows. These fold belts continue into Alaska where they are presently known 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. There is also a narrow geological strip bordering the Beaufort Sea, which is blanketed by unconsolidated moraines, glaciofluvial and fluvial deposits (Rampton 1982, Rampton 1988, Welch 1993).

East of the Mackenzie Delta region, surficial materials are derived from dolomites and quartzite bedrock (BMMDA 2001). The Mackenzie Delta region is underlain by an eroded argillite dome. This dome was gradually leveled by weathering and erosion so that the oldest rocks are at the center and the youngest run along the flanks. A little further south, in the Inuvik area, the Precambrian rocks are mostly covered by limestone and dolostone (sedimentary rocks). This large sedimentary basin is preserved under the southern Delta and is only evident from a few exposures of shale that cover the limestone throughout the area. The continuous deposition of sediments over the last 65 million years has built up to a thickness of about 15 km. Unlike much of the region west of the Delta, this area was heavily influenced by glacial activity 18–20 thousand years ago (BMMDA 2001).

The geology of the large arctic islands within the LOMA is complex. Victoria Island lies on a stable platform, which includes portions of the Canadian Shield and is attached to the North American Tectonic plate (BMMDA 2001). Most of the bedrock exposed on Victoria Island, the northeastern portion of Banks Island and the Dundas Peninsula on Melville Island is about 400–500 million years old. In particular, a large uplifted area of Precambrian rocks is present on Victoria Island and is known as the Shaler Mountains (sedimentary and igneous in origin). There are also igneous intrusions present here, which occurred 675 million years ago as a result of an upwelling in the earth's mantle. Other uplifts in the area occurred <345 million years ago along the fault lines, which are responsible for the steep, high cliffs characteristic of the region. These ancient sediments are overlain by cover materials left from 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. Outcrops of exposed bedrock are common on lowland areas, which were heavily scoured by ice (BMMDA 2001).

The bathymetry of the Beaufort Sea is dominated by an extensive shallow shelf, which gradually slopes north to a depth of 200 m before rapidly dropping off to several thousand meters (Figure 2). Two "troughs" run through the Beaufort shelf: the Mackenzie Trough, west of Richards Island, and the smaller Kugmallit Trough, east of Richards Island. In the western extremity of the LOMA, along the Yukon North Slope, the coastal bathymetry has a steep gradient. In the eastern extent of the LOMA, the Amundsen Gulf and Prince of Wales Strait are relatively shallow channels (<200 m, and generally <100 m depth). Viscount Melville Sound, to the north of Victoria Island, is connected to the Beaufort Sea via a 400-m-deep channel (M'Clure Strait). The bathymetry is responsible for much of the oceanographic phenomena of the LOMA, producing areas of "upwelling", which, as will be discussed later, help contribute to the productivity and functioning of the Beaufort Sea ecosystem (Macdonald *et al.* 1987).

a. Seismicity

There are several areas lying within the southeastern Beaufort Sea/Mackenzie Delta 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 lies in the deep waters off the Mackenzie Shelf. Of the remaining three areas, only the Husky Lakes fault zone and the Martin Point seismicity clusters appear to be significant potential sites of earthquakes. Other fault areas include a major active fault at Donna River, which runs along the west side of the Delta, the length of the Aklavik range, and an inactive fault just south of Inuvik at Dolomite Lake.

b. Resource Potential

The Beaufort–Mackenzie Basin contains large volumes of discovered oil and natural gas resources, and has high potential for future discoveries. Since the mid 1960s, 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. The largest onshore and offshore discoveries include the Taglu field, Parsons Lake field and Amauligak. Total discovered resources are estimated at 255×10^9 m^3 of recoverable gas and 161×10^6 m^3 (1 billion barrels) of recoverable oil (NEB 1998).

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 of Canada. With the exception of local gas production from the onshore Ikhil field near Inuvik, no oil or gas fields have yet been developed in the Mackenzie Delta–Beaufort Sea region. Estimates of the total petroleum resources in the Beaufort–Mackenzie Basin (discovered and undiscovered) are 1.1×10^9 m^3 (7 billion barrels) of recoverable oil and 1.9×10^{12} m^3 of recoverable gas (Dixon *et al.* 1992, 1994).

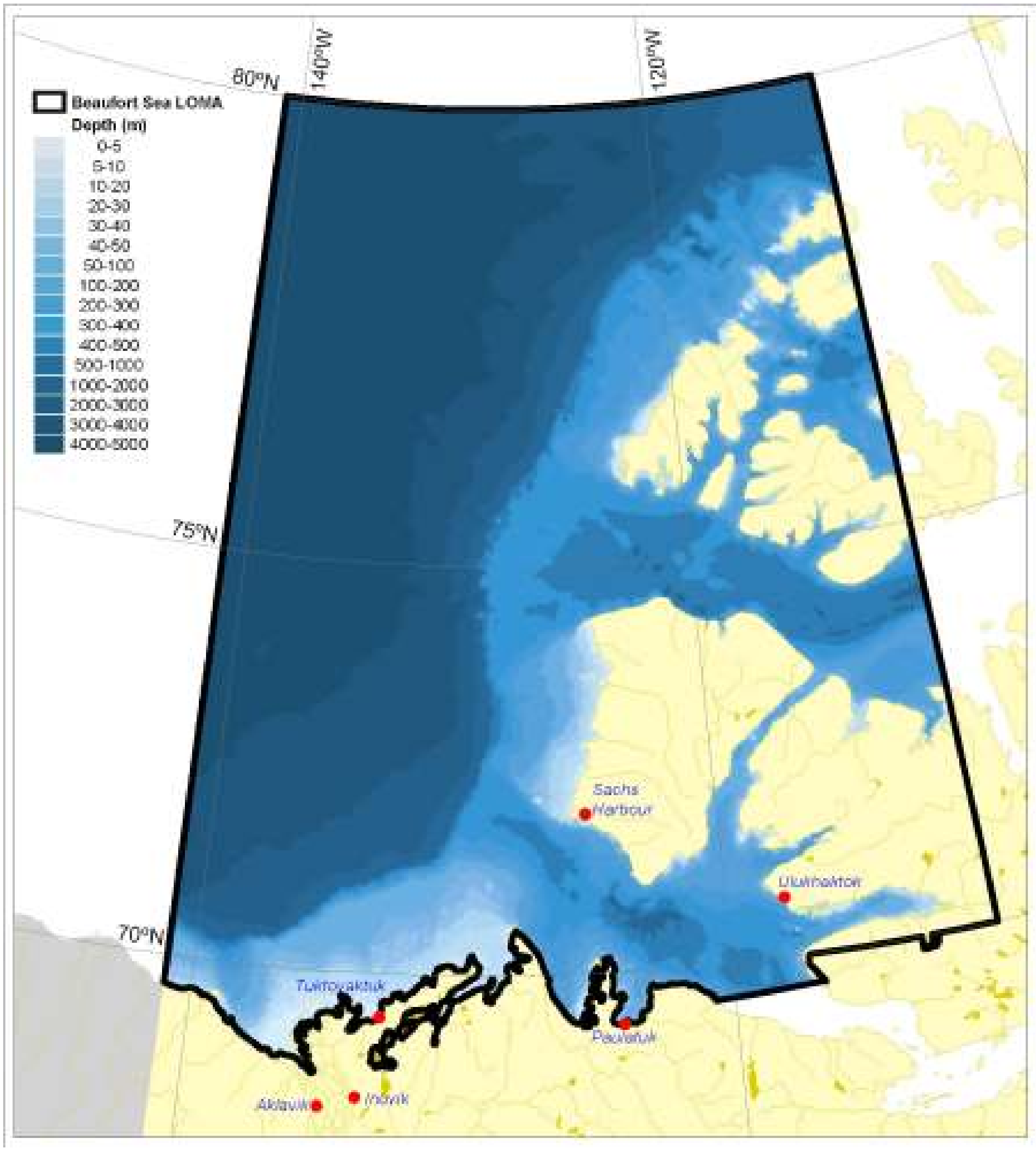

Figure 2. Bathymetry of the Beaufort Sea (DFO, Oceans).

Identified petroleum source rocks include shales in the Richards sequence and organic-rich shales in the 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 (Dixon *et al*. 1992, 1994). Other promising areas include hydrocarbons, which have been found in non-marine shorelines and Deltaic sandstones, other turbidite sandstone reservoirs in shallow-shelf areas offshore the Mackenzie Delta and where common structural traps are located, including fault blocks along the basin rift marine, deltaic growth-fault blocks in the central basin and thrust-cored anticlines in the western area.

Considerable economic potential also exists for mineral deposits such as copper, nickel and platinum group elements in the "Darnley Bay Anomaly", the coastal waters of the Bay. Exploratory surveys have also produced samples of kimberlite showing a high occurrence of diamonds (Darnley Bay Resources Ltd. 2005).

5. Surficial Geology and Processes

a. The Mackenzie Basin

Watersheds associated with the ISR occupy two extremes in scale, from the relatively small, but locally important, isolated drainage areas of numerous small rivers discharging directly into the Beaufort Sea, to the huge drainage area known as the Mackenzie River Basin.

Along the Yukon North Slope, the Firth, Babbage and Blow rivers are important drainages that locally influence the nearshore Beaufort Sea and are important to anadromous fish, especially Dolly Varden charr (Figure 3). To the east of the Mackenzie River, along the mainland of the LOMA, the Anderson, Horton, Hornaday and Brock rivers drain north to the Beaufort Sea, and are important to anadromous Arctic Charr (Figure 3). On Victoria Island, the rivers important to anadromous fishes are the Kugaluk, Kagloryuak, Kuuk and Kuujjua, while on Banks Island, the Sachs, Kellett, Masik and Thomsen rivers are locally important (Figure 3).

The dominant river that drains into the Beaufort Sea LOMA is the Mackenzie. It drains approximately 18 million km^2, and is the largest North American river bringing fresh water to the Arctic Ocean (Macdonald *et al*. 1999). This freshwater flow maintains the strong thermohaline gradient in the southern Beaufort Sea, which 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 (Figure 4). The watershed consists of four physiographical regions: (1) the mountains, valleys and plateaus of the Western Cordillera (west); (2) the rolling terrain, lakes and wetlands of the Canadian Shield (east); (3) the prairie grassland, boreal and subarctic forest, and tundra of the Interior Plains (south); and (4) the Mackenzie Delta itself, with its assemblage of tributaries, levees, wetlands and lakes (north).

The flow of the Mackenzie River reflects contributions from its major sub-basins at different times of the year. High flows occur during the snowmelt and river ice break-up period, followed by a steady decline, periodically 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 of the ISR which flow

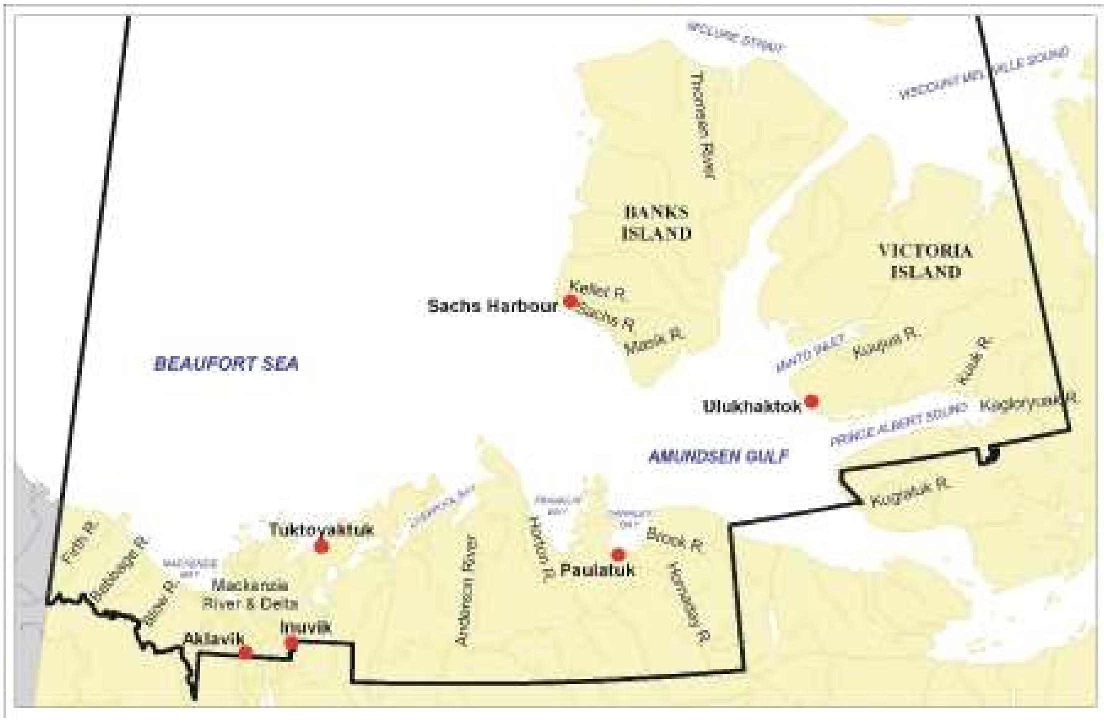

Figure 3. Location of major rivers in the Beaufort Sea LOMA (DFO).

Figure 4. Boundaries of the Mackenzie River Watershed (Geological Survey of Canada).

directly from the interior to the Sea. Most of these rivers carve steep canyons 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 freeze to the bottom 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 (Welch 1993).

b. The Mackenzie Delta and Beaufort Sea Coastal Plain

The Mackenzie River Delta (Figure 5) formed during the retreat of the continental glaciers, approximately 12,000–13,000 years ago (BMMDA 2001). The Delta includes wetlands, river channels and lakes, encompassing >13,000 km^2 (Hirst *et al*. 1987). It can be classified into three basic units: (1) channel system; (2) basin system; and (3) Delta plain (Hirst *et al*. 1987). The channel system covers approximately 15–20% of the total Delta surface area. The basin system covers approximately 40–50% of the Delta, and is composed primarily of lakes and ponds. As many as 24,000 lakes are in the Mackenzie Delta. Both the channel system and the basin system are subjected to annual flooding during spring. 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.

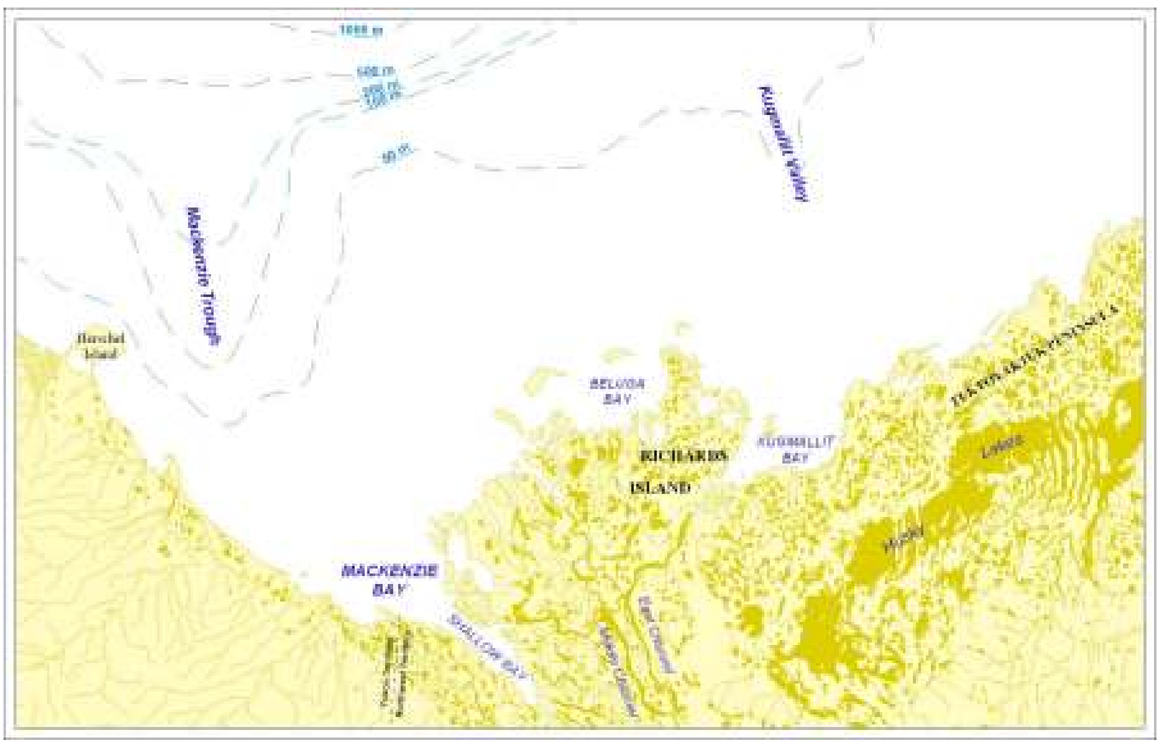

Figure 5. Mackenzie River Delta (DFO).

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 two main 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 fluvial, estuarine and morainal materials, are not typically flooded and are not affected by erosion by 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 river channels, substrates are typically fine-grained, although more coarse-grained sediments occur in areas of eroded 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).

The Mackenzie River transports about $130x10^6$ 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 autumn (Carmack and Macdonald 2002).

c. Permafrost

Permafrost conditions are reflected in the widespread distribution of patterned ground, thermokarst scars and lakes, and debris-flows. Much of the sediment in the moraine deposits undergoes redistribution when buried ground ice is exposed and melts to form thaw lakes, slump scars and sediment flows.

Inland of the Mackenzie Delta, permafrost is extensive, thick and typically has high ice content. Within the Mackenzie Delta, permafrost thickness is typically <100 m (Dyke *et al*. 1997, Solomon 2002). However, in some locations such as Inuvik, the permafrost thicknesses may exceed 100 m (Dyke *et al*. 1997). 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 Delta and Inuvik areas (LGL Ltd. 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 and Tuktoyaktuk Peninsula (Dyke *et al*. 1997). Fine-grained sediments, such as silts and clays cover much of the Tuktoyaktuk Peninsula and are prone to slope failure due to the characteristically high ice content (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). Delta channels are also prone to extensive 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 are conical to sub-conical hills with massive ice cores and are distributed in various locations in the Mackenzie Delta. They are most numerous near Tuktoyaktuk and along the peninsula (Dome *et al*. 1982), but are also located in clusters on Richardson Island and all sides of the Husky Lakes (Pelletier 2000). Pingos are formed when lakes are rapidly drained, permafrost aggrades, and pore water undergoes a process of expulsion and freezing because of increasing hydrostatic pressure.

d. The Beaufort Sea Coast and Inner Shelf

The coastline of the southern Beaufort Sea exhibits retreat rates >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 formed of unconsolidated frozen material typically erode at rates of 1–3 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). As a result, coastal erosion supplies an estimated $7x10^6$ tonnes of sediment each year near shoreline areas of the Beaufort Sea. Coastal erosion is an important local source of sediments, but the relative contribution of coastal erosion to sediment loading in the Beaufort Sea is minor compared to sediments originating from the Mackenzie River (Carmack and Macdonald 2002). However, coastal erosion will probably increase as a result of elevated temperatures resulting from climate change. Warmer temperatures can destabilize frozen sediments and ice that are found in coastal cliffs (Solomon and Forbes 1994).

e. The Beaufort Sea Shelf

The term “continental shelf” is used by geologists generally to mean the part of the continental margin that is between the shoreline and the shelf break, or where there is no noticeable slope between the shoreline and where the depth of the superadjacent water is approximately 100–200 m (United Nations 2006). Thus, the Canadian Beaufort continental shelf is bounded by Amundsen Gulf to the east, the Canada–U.S. border to the west, the Mackenzie Delta to the south, and the Beaufort Sea to the north (Figure 2, page 14). The Beaufort Shelf represents a significant geomorphological feature of the southern Beaufort Sea.

The Shelf has experienced much influence from sea-level fluctuations in recent geological history. Approximately 20,000 years ago, it was largely dry land allowing permafrost to form. As the sea level rose, the Shelf gradually became covered in fine-grained sediments supplied by the Mackenzie River (Dome *et al*. 1982). Sediments along most of the Mackenzie Shelf consist of clays and silts originating from the Mackenzie River (Dome *et al*. 1982). In general, the Beaufort Shelf is relatively narrow, i.e. <150 km offshore at any point. The component within Canadian waters is approximately 120 km wide and 530 km long. The average depth is <65 m, and can be as shallow as 10 m (off the Mackenzie Delta). Beyond the Shelf, the continental Beaufort Slope begins a sharp drop to depths of approximately 1000 m (Dome *et al*. 1982).

f. Special Sea Bottom Features

Mud volcanoes (pingo-like features) are geological formations located along the seafloor of the southern Beaufort Sea (Appendix 1). These formations occur as single features or as several hundred in long corridors. A recently discovered corridor is the “Garry Knolls” area, located west of Richards Island and extending northwest to the Shelf break. Mud volcanoes appear to be widespread in the LOMA, and their ecological implications are currently being investigated. The periodic release of methane from a subsurface hydrocarbon deposit may affect benthic and pelagic biota surrounding the feature. The feature may also be a geohazard for drilling and shipping routes. One mud volcano at Koponoar, thought to be active, is approximately 100 years old, indicating that these features are still forming on the sea bottom and could have serious implications for industry in the future.

Pockmarks or gas vents are another special feature in the Beaufort Sea (Appendix 2). These features result from the ongoing release of methane from shallow gas deposits. Significant agglomerations of gas vents and pockmarks have been identified on the Beaufort Shelf, and concerns about safety issues when drilling for hydrocarbons are being addressed. The biological significance of these features are also currently being studied.

Artificial islands, which were built as drilling platforms during the first round of exploration in the Beaufort Sea, are also considered to be special features (Appendix 3). About 36 such islands were constructed in the nearshore area, from material adjacent to the island, subsequently creating a borrow pit. These islands were originally about 4 m above the water level, but they have eroded and now sit about 4.5 m below the water level. Studies are ongoing to determine the ecological significance of these islands and borrow pits as unique habitats in the Beaufort Sea.

Ice scours are another special bottom feature (Appendix 4). Their significance to the area is discussed in Part B, Section 7d of this report.

Part B. Oceanographic System

6. Atmosphere/Ocean Exchange

a. Seasonal Climatic Patterns

i. Air Temperature

The climate of the Beaufort's southern coastal region is dry and cold, and often described as "harsh" or "severe", typical of the Marine Tundra Climatic Zone (Slaney 1976). The climate severity index is defined as 80 in the south and 80–90 farther north (Phillips 1990), which compares with indices of >90 in the eastern and northern Arctic islands, 40–50 for the northern prairies, and 20 for the south coast of British Columbia. The average annual mean daily air temperature is well below 0ºC (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 (Appendix 5). For example, the mean July high and low temperatures for Sachs Harbour are 9.6°C and 2.8°C respectively, while the January mean high and low are -26.5°C and -33.5°C respectively (BMMDA 2001).

ii. Precipitation

Mean annual rainfall, snowfall and total precipitation for 1961–1990 are 116 mm, 175.2 cm and 257.4 mm, respectively (BMMDA 2001). However, the Mackenzie and British mountains provide an exception, where precipitation is estimated to range from 380 mm in the north to more than 760 mm in the south (Burns 1974). The region's climate is strongly influenced by pressure systems, storm tracks, latitude, topography and the Beaufort Sea. Similar to the climate on the mainland, the Arctic Islands experience long cold winters, short summers and low precipitation. On average, Sachs Harbour receives about 16 cm of precipitation annually, with rainfall peaks in summer and snowfall peaks in early autumn (Appendix 5).

iii. Prevailing Winds and Storms Tracks

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

The marine influence from the Beaufort Sea suppresses storm formation along the Yukon coast, but storms do track from Alaska to the Mackenzie Valley, in turn causing some of the heavier summer precipitation events for the coast. Winds can also result from storms occurring over the Beaufort Sea during the summer's open-water season. As a result, high wind velocities of long duration have been measured in the coastal plain west of the Mackenzie Delta. For example, a velocity of 119 km/h was recorded over a 10-minute interval at Babbage River in December 1987. These strong winds (>37 km/h) can last an average of 10 hours during January and peak durations can be approximately 40 hours.

b. Heat Exchange and Budgets

The region's high latitude means 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 during summer versus winter, the high latitude has significant influence over the amount of radiation received, and therefore solar heating.

Air temperature normally decreases 1ºC for every 100 m increase in elevation at mid-latitudes. However, the normal influences of topography are altered at the high latitudes of the Mackenzie River and Beaufort Sea. Heat is continuously lost from the surface during the long polar night and extended absence of sun so the coldest air is near the surface and warmer air exists above. An inversion occurs, with 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 can promote the formation of ice fog, but during the summer, they can cause low cloud and haze along the coastline.

The Beaufort Sea itself can influence climate in several ways. It has a humidifying effect during summer and autumn, and is therefore a source of cloud and precipitation. It is both a heat sink and heat source. During spring, it is cooler than the land, and therefore delays the progress of spring near the coast. During winter, the ocean is warmer than the land, and therefore delays freeze-up near the coast. In addition, onshore winds from the Beaufort Sea usually result in low cloud over the coast, whereas offshore winds result in cloud dissipation.

7. Physical Oceanography

a. Circulation

The Beaufort Sea's main circulation is dominated by the Beaufort Gyre, resulting in large-scale movements of sea ice and surface water in a clockwise direction (Figure 6). Circulation below the surface, however, occurs in a counter-clockwise direction along the continental slope, which is known as the Beaufort Undercurrent. This flow results in the eastward movement of waters originating from the Pacific and Atlantic Oceans and the transport of nutrients from offshore waters to areas on the Canadian Shelf (Aagaard

1984). This important transport mechanism of nutrients is caused by upwelling of large circular currents (>100 km wide, 50–300 m deep), indicating that the interior of the Beaufort Sea experiences significant flow and mixing (Carmack and Macdonald 2002).

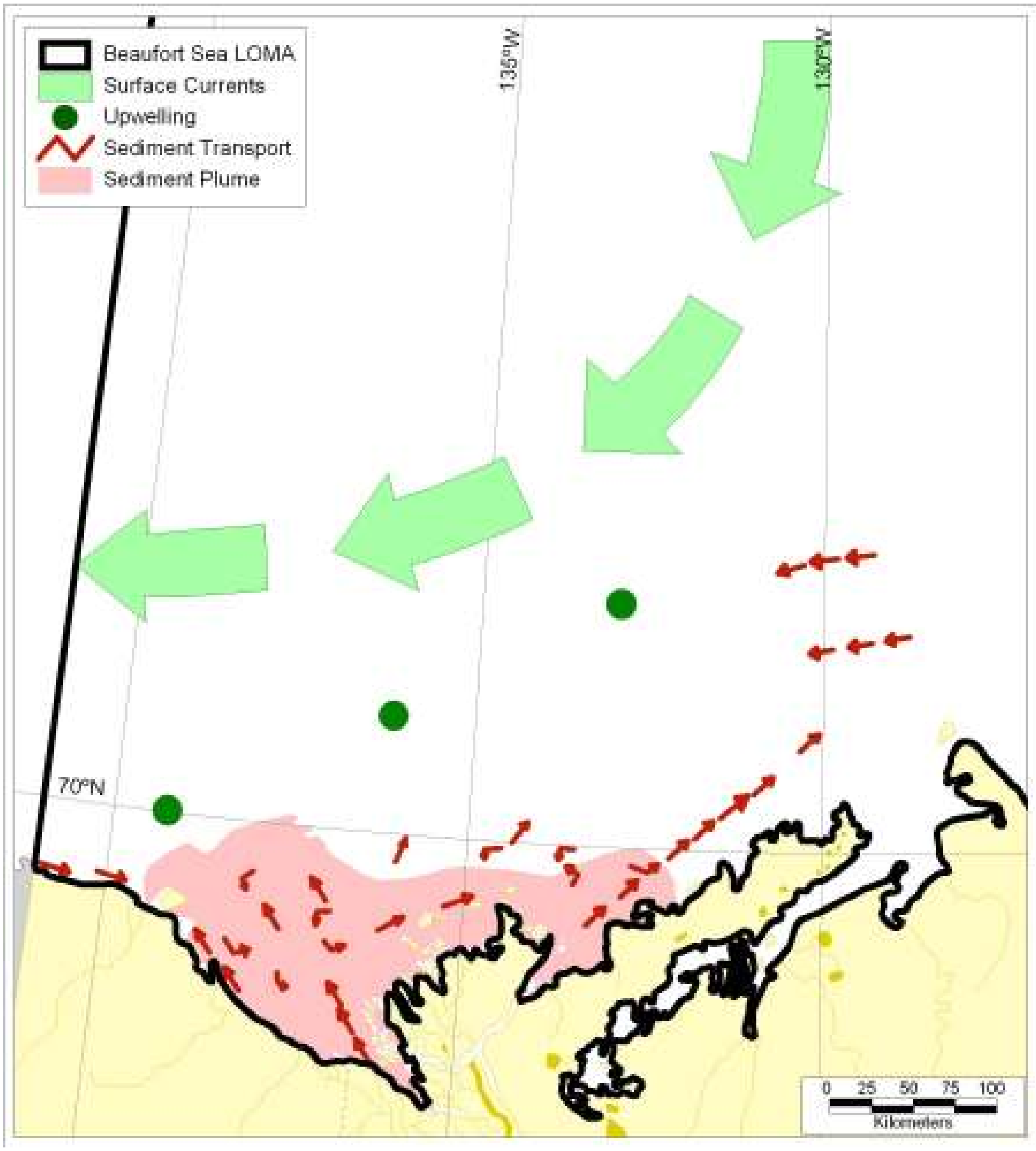

Figure 6. Circulation patterns of the Beaufort Sea. (http://gsc.nrcan.gc.ca/beaufort/oceanographic_facts_e.php)

Circulation patterns in nearshore areas display considerable variability and can be observed by sediment transport patterns (Figure 6). The general pattern of nearshore surface circulation is controlled primarily by wind direction and intensity, and modified to a lesser extent by the Mackenzie River discharge. However, interactions with the underlying water layer and local water depth 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 <5cm/s) (Dome *et al*. 1982).

Flows along coastal areas are often driven by high winds. In winter, ice cover reduces the effects of wind, and flows may be influenced by differences in water-mass densities related to salinity gradients (i.e. salt being rejected as brine 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.

b. Mackenzie River Discharge and Wind-Driven Currents

The influence of discharge of fresh water from the Mackenzie River to the Beaufort Sea is considered substantial year round. The annual volume of the discharge is about 330 km^3, which covers 60,000 km^2 of the Shelf area and exceeds 6 m in depth (Macdonald *et al.* 1989).

The freshwater input is generally lowered in late winter (about 4000 m^3/s) and accumulates behind an ice dam near the mouth of the Mackenzie River (Macdonald *et al.* 1989). This damming results in the eventual formation of a large mass of fresh or brackish water, known locally as Lake Mackenzie. Lake Mackenzie floats above underlying marine water further out into the estuary. This mass of fresh water covers an area of approximately 12,000 km^2 and has a volume of about 70 km^3.

Mackenzie River discharge peaks 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 speeds melting of the ice cover in the Delta by about two months and to a lesser degree accelerates melting in areas further away from the river mouth (Carmack and Macdonald 2002).

During the summer months, large volumes of water (about 30,000 m^3/s) continue to be discharged from the Mackenzie River along with fresh water from ice melt. Discharge from the Mackenzie River typically forms plumes, fronts and a strongly defined surface layer (Carmack and Macdonald 2002). The upper surface layers are very much determined by the spreading of the Mackenzie plume (E.C. Carmack and R.W. Williams, Institute of Ocean Science (IOS), 9860 West Saanich Road, Sidney, BC, V8L 4B2, pers. comm.). The plume of fresh water from the Mackenzie River has a tendency to flow eastwards along the Tuktoyaktuk Peninsula (Figure 6), due to the 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). The 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).

c. Seasonal Ice Dynamics

Freeze-up commences in early to mid-October after air temperatures have dropped below the freezing point, water has cooled to its freezing temperature and freezing-degree-days start to accumulate. Landfast ice forms along the coast and progresses seaward extending to the 20-m-depth contour in late September or October (Dome *et al*. 1982). Complete ice coverage is expected in November (Dumas *et al*. 2005). Typically, a stamukhi zone, a field of rubble ice formed by the convergence of landfast and drifting ice, forms along the outer boundary of landfast ice. These ridges extend downward and can gouge the sea floor (Shearer and Blasco 1975). Seaward of the stamukhi zone lies an area of open water known as the flaw polynya, and beyond this polynya lies the drifting polar ice pack (Figure 7).

Winter ice coverage in the southern Beaufort Sea is typically evident in three domains: (1) inner shelf domain below the landfast zone; (2) middle shelf domain within the flaw polynya; and (3) outer shelf domain south of the drifting ice pack (Carmack and Macdonald 2002).

The Inner shelf domain is located below the landfast ice, nearshore of the stamukhi zone, where the winter freshwater inflow of the Mackenzie River is impounded (see Section 7b) (E.C. Carmack and R.W. Williams, IOS, pers. comm.). In this zone, the differences in the freezing temperatures (fresh water and marine water) create the potential for the production of frazil ice. Frazil ice is small ice crystals formed in the water column that may adhere to each other to form larger masses, and leads to the 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 these processes occur has not been studied (Carmack and Macdonald 2002).

The middle shelf domain in winter extends from the stamukhi zone out to the shelf-break (about 80-m depth). The shear zone at the boundary of landfast and pack ice is extremely dynamic and subject to the rapid opening of a long (>100 km) and wide (up to 40 km in 1987) recurrent-flaw polynya running parallel to the coast (Figure 7). The flaw polynya is a site of increased ice production, brine release and convection. Brine release is the release of salt that convectively mixes from the surface layer down to 40–50 m water depth. Winter mixing depends on the stamukhi barrier, which prevents freshwater inflow from entering.

The outer shelf is recognized as a domain subject to shelf-break dynamics and shelf/basin exchange (E.C. Carmack and R.W. Williams, IOS, pers. comm.). The outer shelf domain extends beyond the flaw polynya during the winter and consists of a mixture of heavily ridged and drifting first-year and multi-year pack ice (Figure 7). The multi-year ice can range from 2–4 m thick year-round; first-year ice reaches a maximum of 2 m by the end

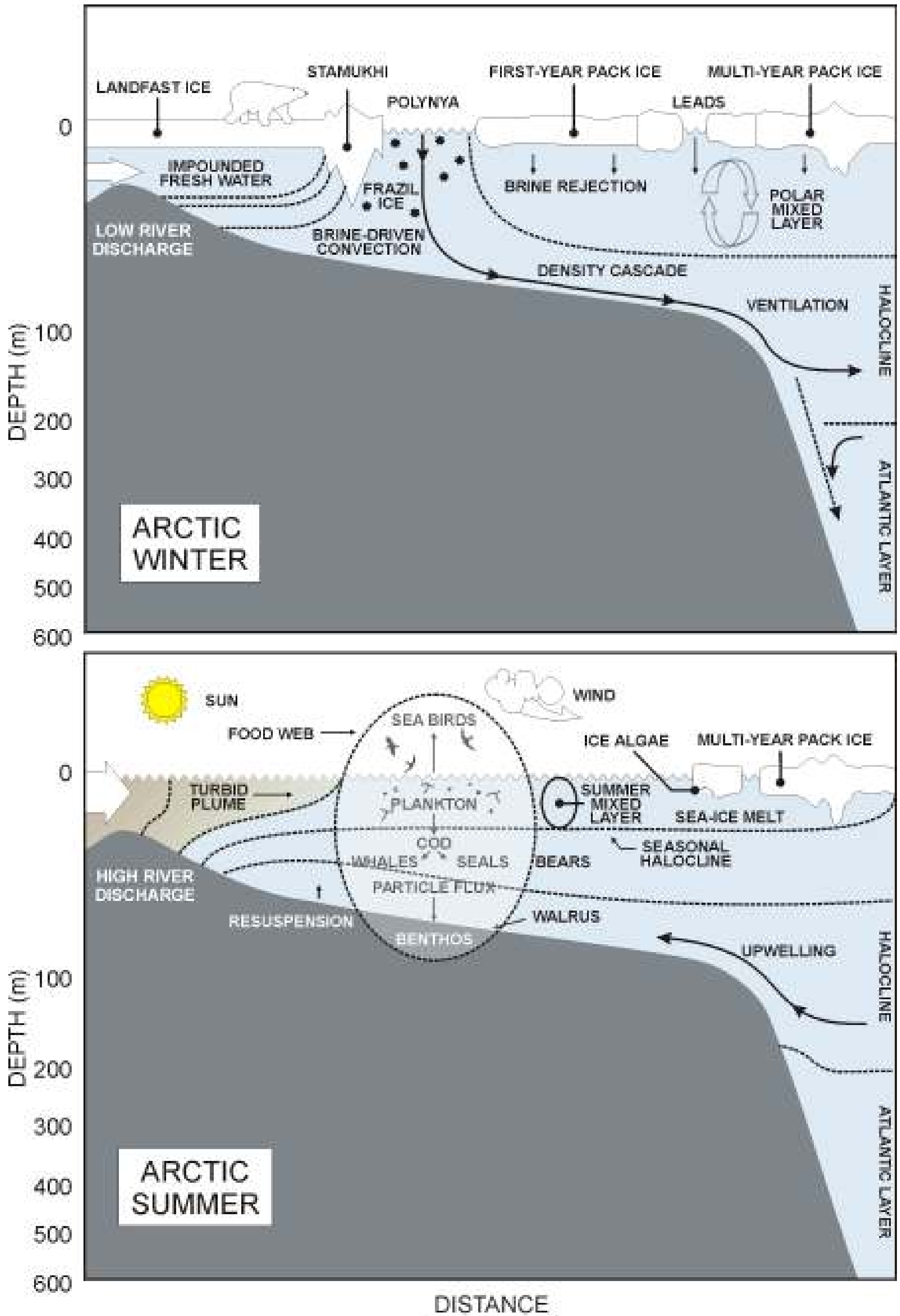

Figure 7. Beaufort Sea winter and summer sea ice dynamics and the influence of Mackenzie River discharge (Reprinted by permission of the publisher from THE GLOBAL COASTAL OCEAN: THE SEA – IDEAS AND OBSERVATIONS ON THE PROGRESS IN THE STUDY OF THE SEAS, VOLUME 14, PART A, edited by Allan R. Robinson and Kenneth H. Brink, p.72, Cambridge, Mass.:Harvard University Press, Copyright©2006 by the President and Fellows of Harvard University.)

of winter (Dome *et al*. 1982). A mixed layer of brackish water resulting from brine release extends to a depth of 30–50 m under the polar pack ice, but generally does not mix with the underlying nutrient-rich waters, which originate from the Pacific Ocean (Carmack and Macdonald 2002). Nutrient concentrations in the surface layers at the end of winter form the basis for new primary production in summer. Summer primary production is determined by the degree of vertical mixing and entrainment that occur during the preceding autumn and winter.

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

The transition to summer begins with the break-up of river ice in the headwaters of the Mackenzie River and the subsequent flooding of the Delta and coastal area, typically in late April. Heat from the Mackenzie River, which overflows and underflows the landfast ice in the nearshore, accelerates ice removal in the nearshore Delta region (Dean *et al*. 1994). Break-up of the middle and outer shelf typically spreads from existing open water in the flaw polynya, where incoming solar radiation is rapidly absorbed by the water, and accelerates further melting. During break-up, the landfast ice and much of the existing pack ice melts in place. This addition of buoyant, fresh water is mixed downwards by the wind to form a shallow, relatively fresh mixed-layer (about 10–12 m deep), which stratifies the upper ocean. At the same time, large amounts of fresh and highly turbid water are delivered during the freshet of the Mackenzie River. The Mackenzie River is free of seawater intrusions landward of the transverse bar in Kittigazuit Bay. Plume water is distinct from sea-ice melt and often forms extensive areas of highly turbid water (about 5 m thickness) extending across the shelf, and at times off the shelf (Macdonald *et al*. 1989, Macdonald et al. 1999). At this time, the Canadian Beaufort Shelf behaves much like any estuary of a large river impinging on an open shelf. The only difference is an additional, broadly distributed freshwater source from ice melt (Figure 7). The dominant influence of the Mackenzie River allows the occurrence of freshwater biota, including anadromous fish, within nearshore waters (Parsons *et al*. 1988, Parsons *et al*. 1989, Bodaly *et al.* 1989).

In the autumn, the daylight rapidly diminishes from 12 hours at the equinox (September 21) to total darkness by mid-November, and the low sun angle further limits light penetration. Intense storms in the autumn can also force on-shelf upwelling. For example, Kulikov *et al*. (1998) observed upwelling amplitudes in Mackenzie Canyon exceeding 600 m, three to four times greater than observed elsewhere along the shelf. When the wind stops, some of the dense water returns down the Canyon to the ocean basin, creating a wave-like response in the offshore ocean, whereas some remains and mixes into shelf waters to supply production.

d. Ice Scouring

Scouring is caused by the onshore and long-shore movements of 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). Scouring is common along the Beaufort Sea continental shelf, but most scouring occurs in waters that are <50 m deep. The most intensive scouring occurs at depths between about 20 and 25 m (Dome *et al*. 1982, Blasco *et al*. 1998) (Figure 8).

Scour trenches are usually <2 m deep, but can reach depths of 7 m. The width of the scour varies from a few meters to >300 m (Dome *et al.* 1982, Hequette *et al.* 1995). Scouring can create unique benthic habitats by disturbing sediments on a large scale, and producing uneven sedimentation rates, which favour organisms capable of rapidly recolonizing scoured locations (ACIA 2005). Anoxic pockets are another unique benthic habitat created by scouring, and are discussed in Section 8b.

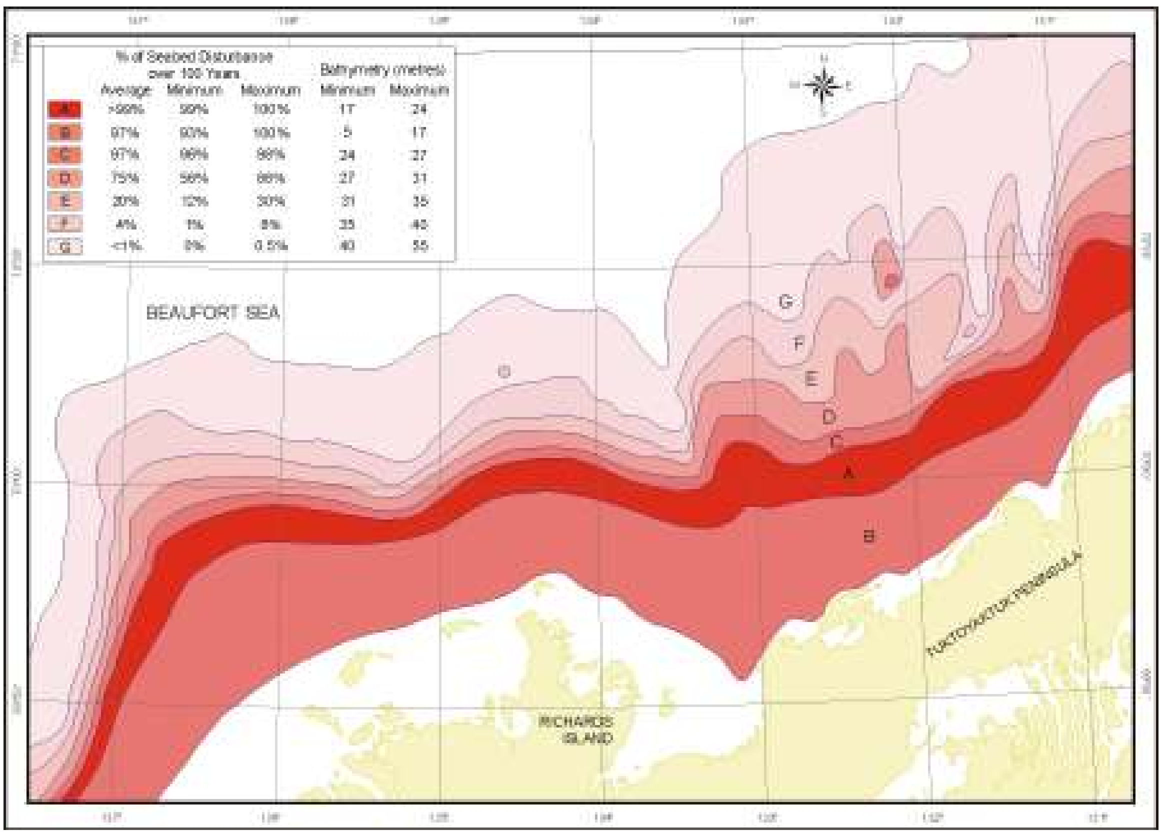

Figure 8. Zones of ice scour in the Beaufort Sea (courtesy of S. Blasco and Dr. V. Kostylev - NRCan).

e. Polynyas

A polynya is open water or a thin-ice area surrounded by thicker ice. The Cape Bathurst polynya, located in the Amundsen Gulf (150 km east of the Mackenzie River mouth), is part of the circumarctic system of flaw polynyas (Figure 9). This particular polynya is ecologically and biologically significant because it sustains habitat for some of the highest densities of birds and mammals found anywhere in the Arctic (Harwood and Stirling 1992).

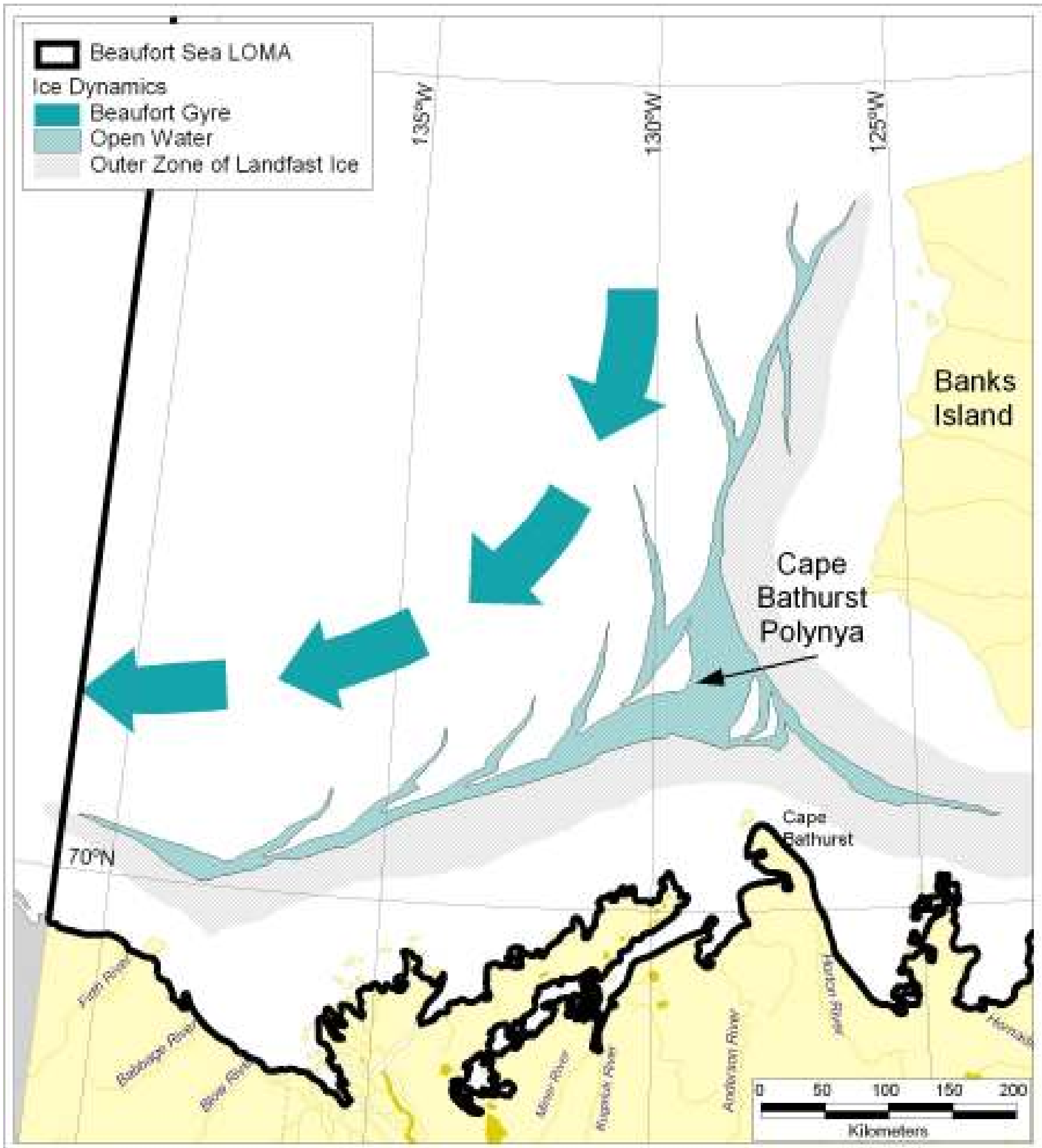

Figure 9. Ice dynamics in the Beaufort Sea, with open water at shear zones and the Cape Bathurst polynya (Percy et al. 1985).

The Cape Bathurst polynya forms as the flaw polynya begins to melt and widen in the summer. Easterly winds dominate ice-cover dynamics in this region of the Beaufort Sea, and large flaw leads form near Cape Bathurst and off the west coast of Banks Island in response to mesoscale storm or wind events (Figure 9) (Fett *et al.*1994).

The Cape Bathurst polynya exhibits marked interannual variability in the dynamics of sea ice retreat and formation. Over a five-year study cycle, the size of the polynya began a rapid and sustained increase in June, from 6000 km^2 to as large as 25,000 km^2. During the same study cycle, sea ice began to re-freeze in October, resulting in an average open-water season of four months. However, in 1998, expansion of the polynya began two months earlier and it did not re-freeze until November, resulting in a total open-water season of seven months (Arrigo and van Dijken 2004). Maslanik *et al*. (1999) attributed this unusual duration to the large positive anomaly in atmospheric temperature that occurred in 1998.

8. Physical-Chemical Properties of Seawater

a. Temperature and Salinity

Water temperature is an important environmental factor in marine systems because many species have narrow temperature tolerances, which affect their spatial distributions. Water temperature can also influence metabolism, growth rate, and reproductive output.

Salinity influences the presence of marine species both directly through salinity preferences of particular species and indirectly through its effects on stratification (water density), water movements and, hence, phytoplankton productivity. Differences in the density of seawater throughout the water column affect the aggregation of biological matter in the upper layers of the ocean. Density is a function of salinity, temperature and pressure and, therefore, varies with depth. These variables (temperature, salinity and density) are commonly measured in oceanographic surveys and stock assessments.

b. Dissolved Oxygen

Macdonald *et al.* (1987) reported that mean dissolved oxygen concentrations for a series of sampling locations in the southeastern Beaufort Sea ranged from approximately 275–425 mmol O_2/m^3 for stations sampled in August of 1974 and 1975. A clearly defined maximum dissolved oxygen concentration was observed between 10 and 50 m for the 1975 dissolved oxygen profiles. This maximum was the result of biological productivity. In 1974, the oxygen maximum was weakly developed when turbid runoff and ice cover reduced light penetration. However, in 1975, the Cape Bathurst polynya opened early resulting in warmer water temperatures and less turbid conditions. This research demonstrates the close linkage between spring ice break-up and summer biological productivity.

Kvitek *et al*. (1998, p1) reported the formation of "*black pools of death: hypoxic, brine filled ice gouge depressions [which] become lethal traps for benthic organisms in [the] shallow Arctic embayment of Resolute Bay*". It was hypothesized that these pools form annually, as the sea ice expels dense brine, which sinks and collects in previously formed ice scours. Benthic respiration early in the season drives the stratification of water, trapping organic matter, limiting oxygen renewal and leading to unique anoxic conditions (Conlan *et al*. 1998). These pools appear to persist as lethal traps for benthic and demersal organisms until dispersed by winds or currents. This phenomenon has not been reported within the Beaufort Sea LOMA ice-scour region, perhaps due to a lack of seasonal sampling of ice scours.

c. Suspended Matter – Light Availability

Primary production is usually highest nearshore and declines with water-column depth (Hsiao 1976, Parsons *et al*. 1988, Carmack *et al*. 2004). However, the Mackenzie River is the most sediment-laden river in the Arctic and production rates can be reduced at sites closest to the outflow due to light attenuation caused by increased concentrations of suspended inorganic sediments (Grainger 1975, Parsons *et al.* 1989). This increase in suspended sediments is growth-limiting to phytoplankton. Primary production increases significantly closer to the interface between plume waters and marine waters.

Light availability in offshore areas is usually not limiting during the open-water period, except in areas of persistent, multiyear ice cover. Winter sea ice, along with its associated snow cover and algal growth either absorbs or reflects incoming radiation so pelagic water-column phytoplankton production remains low for several weeks following the end of the dark polar winter. The beginning of pelagic primary production closely follows the retreat of ice at marginal ice zones when fluxes of organic matter around the flaw lead increase (O'Brien *et al*. 2006). The early retreat of sea ice may be responsible for massive spring blooms in the Beaufort Sea (Wang *et al*. 2005), whereas heavy ice cover can reduce total annual phytoplankton production by about 30%, compared to light ice-cover years (Macdonald *et al*.1989). Pelagic primary production is usually delayed by approximately one month on the inner shelf, compared to the outer shelf, due to the persistence of landfast sea ice (Carmack *et al.* 2004).

A halocline is present in the water column of the Beaufort Sea throughout summer, limiting nutrient replenishment from deeper waters at the surface. There is a rapid drawdown of nutrients during the spring phytoplankton bloom and nutrients become the limiting growth factor during the summer at offshore sites (Hsiao 1976, Dome *et al.* 1982, Carmack and Macdonald 2002).

d. Organic carbon (DOC/POC)

The Mackenzie River carries dissolved organic carbon (DOC) and particulate organic carbon (POC) into the Beaufort Sea annually. The River is unique in having comparable concentrations of POC and DOC (about 1.3×10^{12} g C/y), whereas all other Arctic rivers have much higher concentrations of DOC compared to POC (Dittmar and Kattner 2003). The DOC and POC carried by the Mackenzie River are of terrestrial origin, and from other sources such as Mackenzie Delta lakes. POC carried by the river is not easily broken down by microbial activity; thus, 60% of terrestrial POC is preserved in the benthic sediments of the Beaufort Shelf (Macdonald *et al*. 1998). However, high bacterial activity at nearshore sites indicates that terrestrial DOC is being utilized by bacteria in the Beaufort Sea (Garneau *et al.* 2006).

Autochthonous production in the Beaufort Sea yields approximately 3.3×10^{6} tonnes of POC each year. Autochthonous carbon is represented primarily by ice algae and phytoplankton, with highest phytoplankton production occurring in the Cape Bathurst polynya (Arrigo and van Dijken 2004) and within regions of upwelling (Percy *et al.*

1985, Carmack *et al.* 2004). These areas contain active biotic communities through which organic carbon is transferred to top consumers of marine food webs. Contrary to terrestrial POC from the Mackenzie River, about 97% of the autochthonous POC is efficiently recycled within pelagic and benthic food webs, with very little preserved in the benthic sediments of the Beaufort Shelf (Macdonald *et al*. 1998).

e. Nutrients – Flux and Budgets

The distribution of nutrients in the southern Beaufort Sea is dominated by the Mackenzie River discharge (Dome *et al*. 1982). Local variability in nutrient concentrations is high due to the presence of areas with large volumes of ice-melt, which contains very little nitrate, phosphate or silicate (Dome *et al.* 1982). In late summer, distribution of nitrate and phosphate can be complex. At low salinities (i.e. within the freshwater plume) phosphate values remain near zero, characteristic of nutrient-limited inland waters, whereas nitrate values generally remain high (Carmack *et al*. 2004). This situation suggests that both phosphate and light govern the rate of primary production in summer on the inner portion of the Canadian Beaufort Shelf. Farther offshore, at surface salinities between 26–30 ppt, nitrate values are bimodal, being either near zero or relatively high (>10 mmol/m^3). This situation suggests that, in the middle and outer shelf domains, primary production is light-limited (when ice is present) and nitrate-limited when ice is absent (E.C. Carmack and R.W. Williams, IOS, pers. comm.).

Silicon availability can be an important limiting factor for the production of diatoms, which generally dominant the nearshore phytoplankton community. As with nitrates, the Mackenzie River plume is a major source of silicates (Dome *et al*. 1982, Macdonald *et al.* 1987). Vertical stratification in the summer 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 occurs 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).

Part C. Biological System

9. Plankton Community

a. Phytoplankton

Primary producers in the Beaufort Sea include phytoplankton, ice algae, benthic micro- and macroalgae and aquatic macrophytes. Primary producers use the energy of the sun to covert carbon dioxide and water into organic matter. Primary production is transferred to higher trophic levels by benthic and pelagic consumers, ultimately contributing to the growth of fish, marine mammals and seabirds.

The growth of phytoplankton is controlled primarily by light and nutrient availability (Grainger 1975, Wang *et al*. 2005). Light availability on the Beaufort Shelf controls the timing of phytoplankton production, whereas nutrient availability determines the overall amount of primary production (Carmack *et al*. 2004). Light and nutrient availability can be influenced by the following characteristics of the Beaufort Sea area:

Light:

- seasonal and multiyear sea ice and snow cover
- shading by growth of sea-ice algae
- polar night
- discharge of inorganic sediments from the Mackenzie River.

Nutrients:

- vertical stratification/mixing of the water column
- sea-floor formations and water-circulation patterns creating areas of upwelling
- discharge of fresh water, inorganic nutrients and organic matter from the Mackenzie River.

i. Phytoplankton Species Composition and Abundance

Phytoplankton species of the Beaufort Sea belong to one of five distinct groups, i.e. diatoms, flagellates, dinoflagellates, chrysophytes and blue-green algae (Hsiao 1976). Diatoms were the dominant group in terms of abundance and number of species. In nearshore sites, diatom abundance represented 52–99.5% of total phytoplankton cell numbers, but only 5–20% at offshore sites (Hsiao 1976). Flagellates were most abundant at offshore sites, contributing up to 89% of total phytoplankton cell numbers (Hsiao 1976) (Figure 10).

The Beaufort Sea hosts a diverse community of phytoplankton, with species abundance similar to the number of algal species in the sea ice (von Quillfeldt *et al*. 2003). Beaufort Sea phytoplankton are adapted to cold temperatures (i.e. psychrophilic) and low light conditions (Ban *et al.* 2006). Fifty-one genera and 87 species of phytoplankton were found in the southern Beaufort Sea and Husky Lakes (Foy and Hsiao 1976). In a later multiyear survey (1984–1988), 104 species of diatoms, in addition to numerous flagellated species, were identified from the Beaufort Shelf (Hopky *et al*. 1994). The number of diatom species recorded by Hopky et al. (1994) is similar to the number of diatoms species in the water column in the eastern part of the Arctic Archipelago during spring (Riedel *et al*. 2003).

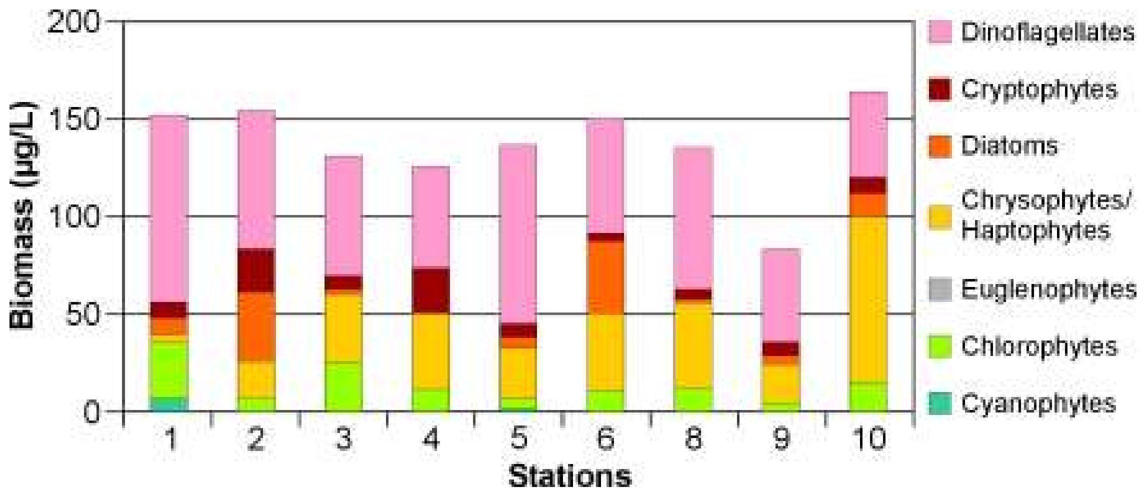

Figure 10. Phytoplankton species composition and abundance across a transect of the Beaufort Sea shelf from Toker Point during the 2005 CCGS Nahidik ecosystem program. Station numbering is from nearshore (stn 1=5 m) to offshore (stn 10=50 m) (P. Ramlal, DFO, 501 University Crescent, Winnipeg, MB, R3T 2N6, pers. comm.).

Variations in species composition are related to the ability of each species to survive given the ambient light and nutrient conditions. For example, flagellate species appear to flourish in offshore sites where nutrient concentrations are low and light availability is high, whereas diatoms have high nutrient requirements (Dome *et al*. 1982).

Phytoplankton abundance from the southern Beaufort Sea was investigated during the summers of 1973–1975 (Hsiao 1976, Foy and Hsiao 1976) and cell abundances ranged from 2–654x10^3 cells/L. There were clear trends in cell abundance, corresponding with water depth and distance from shore. Phytoplankton abundance was highest in the low-salinity, surface waters (1–5 m deep) compared to the deeper, more saline water. When ice was present, phytoplankton biomass was concentrated in the upper 1 m of the water column. Average nearshore cell abundances were 10 times higher compared to nearby offshore sites of comparable water depths (Hsiao 1976). One inshore site had a maximum abundance of 4800x10^3 cells/L, indicating the presence of a phytoplankton bloom at that site.

Phytoplankton blooms can occur at near- and offshore sites in the Beaufort Sea. Blooms were observed in nearshore surface water as early as May, and occurred more than once during the growing season. Offshore blooms were not observed until August and were dominated by flagellated species (Hsiao 1976). The earliest blooms occur shortly after the retreat of the sea ice (O'Brien *et al*. 2006) and are important for the transfer of organic matter to the benthic environment because low zooplankton grazing favours the transfer of algal biomass to the bottom (Arrigo and van Dijken 2004).

Phytoplankton biomass at any given time is determined by the combination of production and loss factors. Loss factors include: (1) consumption of phytoplankton by zooplankton grazers, with potential transport of algal biomass to the benthos as part of zooplankton fecal pellets (Michel *et al.* 2002); (2) direct sinking of intact algal cells to the benthos

(O'Brien et al. 2006); and (3) microbial breakdown of phytoplankton biomass within the surface waters or during sedimentation. Factors controlling the production of phytoplankton will be discussed in the following paragraphs.

ii. Phytoplankton Production

The Beaufort Sea is generally considered to be an oligotrophic environment with total primary production estimated to be between 12–20 g C m^{-2} y^{-1} (Macdonald *et al*. 1989, Carmack *et al*. 2004). However, production can reach high levels in nearshore regions and at localized sites. For example, high production rates have been observed on the Shelf in the western Beaufort Sea (2.9 g C m^{-2} d^{-1}; Bates *et al*. 2005) and in the Bathurst polynya (i.e. maximum production 175 g C m^{-2} y^{-1}; Arrigo and van Dijken 2004).

The onset of phytoplankton production is controlled primarily by light availability and water-column stability (Carmack and Macdonald 2002). Sea ice, along with its associated snow cover and algal growth, absorbs or reflects incoming radiation, so that pelagic water-column phytoplankton production remains low for several weeks following the end of the dark polar winter. When pelagic primary production begins, it follows closely the retreat of the ice at marginal ice zones, with increased fluxes of organic matter around the flaw lead (O'Brien *et al*. 2006). The early retreat of sea ice may be responsible for massive spring blooms in the Beaufort Sea (Wang *et al*. 2005), whereas heavy ice cover can reduce total annual phytoplankton production by about 30%, compared to light ice-cover years (Macdonald *et al*. 1989). Pelagic primary production is usually delayed by approximately one month on the inner Shelf, compared to the outer Shelf, due to the persistence of landfast sea ice (Carmack *et al.* 2004).

Primary production during the open-water period in the Beaufort Sea has been assessed in several studies. Consistent patterns of production have been observed for the Beaufort Shelf, despite the use of different methods to determine production rates. Production is generally highest nearshore and declines with water-column depth (Hsiao 1976, Parsons *et al*. 1988, Carmack *et al*. 2004). However, production rates can be lower at sites closest to the outflow of the Mackenzie River due to light attenuation by the high concentration of suspended sediments (Grainger 1975, Parsons *et al*. 1989).

Average phytoplankton production in surface waters was estimated to be 6.7 and 1.4 mg C m^{-3} h^{-1} at near- and offshore sites, respectively, during the summers of 1973–1975 (Hsiao 1976, Hsiao *et al.* 1977). Maximum phytoplankton production in the surface waters during the summers of 1986 and 1987 was >10 mg C m^{-3} h^{-1} (Parsons *et al*. 1988, Parsons *et al.* 1989), matching the production rates reported by Hsiao *et al.* (1977) and Subba Rao and Platt (1984).

Average primary production values integrated over several depths were estimated to be five times higher at near- than offshore sites. Mean integrated production from sites in the southern Beaufort Sea was 1139 and 212 mg C m^{-2} d^{-1} at near- and offshore sites, respectively (Hsiao 1976). Production values from a transect extending north from

Tuktoyaktuk were estimated to be 10–600 mg C m^{-2} d^{-1} (Carmack *et al.* 2004), falling within a slightly lower range compared to the earlier study of Hsiao (1976).

Light availability in nearshore areas is usually the limiting growth factor for phytoplankton due to the attenuation of light by inorganic sediments delivered by the Mackenzie River. The Mackenzie River delivers about $130x10^6$ tonnes of sediments per year to the Shelf (Carson *et al.* 1998). However, the river also delivers inorganic nutrients, particularly nitrate and silicic acid, which support high nearshore production (Dome 1982, Macdonald *et al*. 1987). Any potential nutrient limitation in nearshore areas (i.e. <20 m deep) is likely related to low phosphate concentrations (Carmack *et al*. 2004).

Light availability in offshore areas, is usually not limiting during the open-water period, except in areas of persistent, multiyear ice cover. A halocline is present throughout the summer, limiting nutrient replenishment at the surface from deeper waters. Rapid drawdown of nutrients occurs during the spring phytoplankton bloom, and nutrients become the limiting growth factor during the summer at offshore sites (Hsiao 1976, Dome *et al.* 1982, Carmack and Macdonald 2002). Nitrogen is the limiting nutrient offshore, although silicic acid, required for diatom cell growth, can also be limiting for this phytoplankton group (Carmack *et al*. 2004).

High production rates have been observed within localized regions during the open-water period. These regions of increased production are believed to be the result of interactions between water circulation and the topography of the ocean floor, causing upwelling of nutrient-rich waters. Upwelling has been detected over many years on the eastern (Macdonald *et al*. 1987) and western (O'Brien *et al*. 2006) sides of the Mackenzie Canyon, and probably caused high production rates observed in the Kugmallit Canyon area (Parsons *et al*. 1988, Carmack *et al*. 2004).

b. Bacterioplankton

Bacterioplankton (non-photosynthetic bacteria) are important components of the marine ecosystem because they influence energy flow and transfer, biodegradation and carbon cycling in the microbial and classical phytoplankton-to-fish foodweb pathways (Azam *et al.* 1983). Bacterial carbon enters the food web via heterotrophic protists, which consume bacteria and are subsequently consumed by marine zooplankton.

Referred to as a *benthic desert*, the Arctic Ocean actually provides a wealth of bacterial biodiversity (8–31% microbial biomass) (Bunch 1974, Morita and Griffiths 1976, Kaneko *et al*. 1978, Woods and Smiley 1987). Bacterial activity results in fundamental biochemical and mineral conversions in the Arctic Ocean (Griffiths *et al.* 1978, Parsons *et al*. 1988, Parsons 1989).

i. Bacteria Species Composition and Abundance

Diverse taxa of bacteria exist in the Arctic Ocean (Bano and Hollibaugh 2002). Beaufort Sea psychrophilic (able to function in cold temperatures) bacteria occur at concentrations comparable to temperate ocean bacteria (Kaneko *et al*. 1978). A number of studies have estimated bacterial abundance within the Beaufort Sea. Bacterial abundance in the Beaufort Sea was estimated from viable counts (plating) during the summers of 1973 and 1974 (1–30x10^3 cells/mL), the higher estimate corresponding to a spring phytoplankton bloom (Bunch and Harland 1976). Franklin Bay surface-water analyses confirmed high bacterial concentrations even during ice-covered periods (Riedel *et al*. 2006). Nearshore bacterial abundances are consistently higher than offshore estimates (Parsons *et al.* 1988, Parsons *et al*. 1989) reflecting a correlation between abundance and water-column salinity (Garneau *et al*. 2006), possibly supported by DOC from the Mackenzie River.

ii. Bacterial Production

Bacterial production is significant in nearshore areas of the Beaufort Sea (Parsons *et al*. 1988). In 1987, nearshore bacterial production was estimated to be twice as high as autotrophic primary production (Parsons *et al*. 1989). Similar results for marine heterotrophic activity were obtained by Garneau *et al.* (2006).

Heterotrophic bacterial activity in the coastal Beaufort Sea is dominated by cells associated with inorganic sediment (Garneau *et al*. 2006). Bacterial mineralization of river DOC suggests bacterial production and food webs can exist independently of phytoplankton production. The importance of heterotrophic-based production is apparent: biogenic material captured in sediment traps remained high in September and October during decreasing light availability (O'Brien *et al.* 2006).

In addition to their important role in energy flow and transfer, the role of bacteria may become very important in a changing Arctic. With renewed interest in oil and gas in the Beaufort Sea, the role of oleoclastic bacteria in bioremediation is being studied. This potential role was studied in the 1970s (Bunch 1974, Bunch and Harland 1976), and more recently in the Alaskan Beaufort Sea (Braddock and Gannon 2001, Braddock 2001).

Bacterioplankton are likely to be affected by climate change and associated raised water temperatures, degraded permafrost and sea ice. Canadian sea-ice is currently about 18% below the level of the 1980s (NSIDC 2005). Assessing changes to sea ice and polynyas will be difficult due to a lack of historical studies of foodweb dynamics in the Beaufort Sea and the Cape Bathurst polynya (Arrigo and van Dijken 2004), and relative to other polynyas (Bunch and Harland 1990, Gradinger and Zang 1997). New bacterial dynamics may result from emerging microbial species not historically accessible to the Arctic, thus shifting the arctic microbial balance, and potentially exposing marine mammals to new diseases (Mattlin *et al.* 2000).

c. Zooplankton

Zooplankton are the link between the primary producers and larger organisms of the Beaufort Sea marine ecosystem. They are prey for a range of species from small invertebrates to large whales. All species of fish feed on zooplankton during some stage of their life cycle. The availability of zooplankton is a limiting factor for the success of many species in the ocean, and the spatial distribution of zooplankton may provide information on the distribution of higher trophic levels, and vice versa.

i. Zooplankton – Aspects of Ecology and Role in the Ecosystem

Zooplankton contribute significantly to secondary production in aquatic environments because several of the most commonly occurring species are herbivorous and feed directly on phytoplankton. Other species of zooplankton feed on herbivorous zooplankton, thereby providing a critical link between primary producers, lower trophic levels and higher trophic levels, particularly vertebrates (e.g. fish, whales) (Raymont 1983, Beardsley *et al*. 1996, Kaartvedt 2000).

The abundance and community structure of zooplankton vary with water depth in virtually all aquatic environments; however, information regarding the vertical distribution of zooplankton in the Beaufort Sea region is lacking.

Similar to other groups of organisms, zooplankton species can also be characterized by their affinity to specific living conditions (as marine or brackish species) or by their capability to withstand broad or narrow ranges of environmental factors (erytopic vs stenotopic species), but this type of information regarding Beaufort Sea zooplankton is not well understood. However, some patterns have emerged. For example, Grainger (1965) observed a preference by the copepod *Acartia longiremis* for waters of relatively low salinities and high temperatures.

Another pattern typical of zooplankton is the variability in numbers and species composition at any one time throughout the year. Seasonal succession of species results because of 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 the Beaufort Sea region. However, the high variability in spatial distributions of Beaufort Sea zooplankton species, caused by complex dynamics of the main abiotic factors shaping the ecosystem and the seasonally constrained periods of investigation, has diminished the resolution of seasonal-distribution patterns (Dome 1982).

ii. Species Composition, Distribution and Abundance

The zooplankton of the southern Beaufort Sea were investigated intensively for the first time during the summers of 1973, 1974 and 1975 by Grainger (1975), who identified >95 species. Zooplankton investigations during the Northern Oil and Gas Action Plan (NOGAP 1986) resulted in the identification of 89 zooplankton taxa. The two most diverse groups were the Copepoda, represented by 41 taxa (species and genera), and the Hydrozoa, represented by 15 taxa (Hopky *et al*. 1994).

These investigations revealed the great importance of Mackenzie River hydrological conditions and oceanic water currents for zooplankton composition and distribution in the Beaufort Sea. 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. The pelagic (water column) environment in the Beaufort Sea can be roughly divided into a marine zone free from influence of the Mackenzie River, a frontal zone of variable extent where water of riverine origin overlays marine water of higher salinity, and a coastal zone with a prevalence of brackish (low-salinity) water. The smallest standing stock and lowest taxonomic diversity of zooplankton is near the Mackenzie plume. Species diversity is the highest at the offshore stations, although abundances may not be high. Total zooplankton abundance was the highest in Mason Bay and Tuktoyaktuk Harbour, inshore sampling locations; however, diversity there was low, with only five species represented, including four copepod species (Grainger 1975).

Zooplankton in the southern Beaufort Sea consists of taxa representative of both freshwater and marine habitats. The dominant species in the nearshore area are *Acartia clausi*, *Eurytemora herdmani*, *Pseudocalanus minutus* and *Limnocalanus macrurus*, all copepods known to inhabit estuarine or brackish-water habitats. Freshwater genera, including the copepods *Diaptomus* and *Cyclops*, and the cladocerans *Daphnia* and *Bosmina*, become much more abundant near and in the mouth of the Mackenzie River. A collection of zooplankton from Tuktoyaktuk Harbour in the summer of 1970 contained a small number of relatively widespread species characteristic of fresh to brackish waters, such as the copepod genera *Cyclops*, *Diaptomus* and *Eurytemora* (Sutherland 1982). In the marine zone, the predominating species of copepods are *Calanus glacialis, C. hyperboreus* and *Metridia longa*. Abundant non-copepod taxa in the open-sea zone include the hydromedusae *Aglantha digitale*, the pteropod snail *Limacina helicina,* the amphipod *Themisto libellula* and the euphausiid *Thysanoessa raschii* (Grainger and Mc Sween 1976, Forbes *et al.* 1992).

iii. Feeding by Higher Trophic Levels

Most studies devoted to issues of foodweb structure and trophic links in the Beaufort Sea ecosystem have focused on the top predator, the bowhead whale (*Balaena mysticetus*).

The largest population of the bowhead whale, the Bering-Chukchi-Beaufort seas stock, migrates annually between the eastern Beaufort Sea–Amundsen Gulf in summer and the Bering Sea in the winter (Schell *et al*. 1989, Lowry 1993, Moore and Reeves 1993). This stock numbered about 10,470 individuals in 2001, and is increasing at about 3.4% per year (George *et al*. 2004).

Among marine mammals, the bowhead whale occupies a unique position because this species feeds almost exclusively on lower-trophic-level prey such as copepods and euphausiids (Hoekstra *et al*. 2002). Copepods are the principal prey for bowhead whales in the Canadian and eastern Alaskan Beaufort Sea, whereas euphausiids are their dominant prey in the western Beaufort Sea near Barrow, Alaska (Lowry and Frost 1984, Lowry 1993).

Factors that may affect bowhead whale distribution in the southern Beaufort Sea were investigated by LGL Ltd. (1988). The study focussed 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 freshwater plume; biomass was highest in water not influenced by the Mackenzie River plume. In both years, bowhead whales fed 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).

Additional evidence from monitoring programs conducted in recent years supports the opinion that distribution of bowhead whales in the southeastern 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 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).

d. Ichthyoplankton

Ichthyoplankton are the eggs and larvae of fish, which are closely associated with zooplankton in the water column. Larval fish and fish eggs are passively transported long distances by wind and other physical oceanographic factors. Passive transport is a survival mechanism ensuring transport to areas of high productivity (Craig 1984, Doyle *et al.* 1993, Jarvela and Thorsteinson 1999). Many other factors contribute to the occurrence, distribution and abundance of ichthyoplankton in any given location (Figure 11).

Many studies of ichthyoplankton in the Beaufort Sea have shown significant temporal and spatial variance in Hunter 1979, Craig *et al*. 1982, Craig 1984, Bradstreet *et al*. 1986, Chiperzak *et al*. 2003a, Chiperzak *et al*. 2003b, Chiperzak *et al*. 2003c. The distributional range of an adult population is dictated by environmental factors (Figure 11) which, over evolutionary time, dictate the spawning strategies of that species of fish. However, small changes in environmental factors at annual and seasonal scales can force fish to deviate from their typical distribution and spawning location causing subsequent changes to where the drift transports the ichthyoplankton. In such cases, they may not be transported to areas with ideal environmental factors, thus their survival, condition and subsequently recruitment may change (Figure 11).

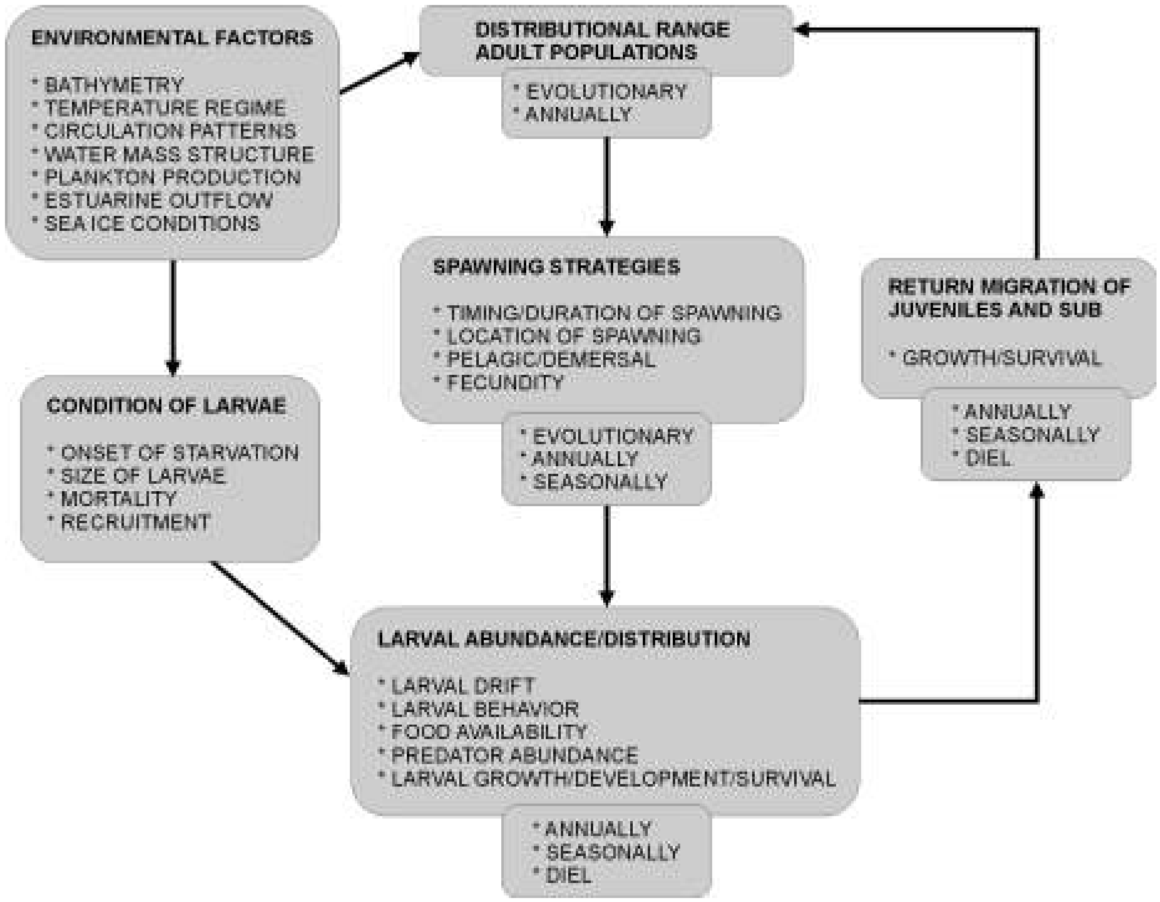

Figure 11. Hierarchy of factors that contribute to the occurrence, distribution and abundance of arctic marine larval fish (modified from Doyle, M.J., W.W. Morse, and A.W. kendall Jr. 1993. A comparison of larval fish assemblages in the temperate zone of the Northeast Pacific and Northwest Atlantic Oceans. Bull. Mar. Sci. 53(2): 588-644).

The model presented by Doyle *et al*. (1993) details how one can predict the fate and the structure of assemblages of ichthyoplankton in the Beaufort Sea. The recruitment of ichthyoplankton into subsequent adult populations is crucial for the maintenance of the structure of the Arctic food web.

<u>i. Habitat Use and Functional Areas</u>

Few surveys have been conducted on ichthyoplankton in the Beaufort Sea LOMA over the past 30 years. Intensive sampling and research in the southern Beaufort Sea was originally initiated by the prospect of oil and gas exploration and extraction, and the concern by Inuvialuit and the federal government over the state of current ecosystem functioning. The most intensely sampled areas are the southeastern nearshore Beaufort Sea (Hunter 1979, Griffiths and Buchanan 1982, Chiperzak *et al*. 2003a, Chiperzak *et al*. 2003b, Chiperzak *et al.* 2003c) and the Amundsen Gulf (Hunter 1979) due to favourable environmental conditions in these areas.

The outflow of the Mackenzie River into the nearshore region is a source of increased production during the summer months because the brackish, turbid waters of the plume are penetrated by cold arctic marine masses (Craig *et al*. 1982, Craig 1984, Fissel *et al*. 1987). The freshwater plume interacts with marine waters to create oceanographic fronts and upwellings of high productivity that are exploited by anadromous coastal fishes, euryhaline marine fishes, marine mammals (Griffiths and Buchanan 1982) and marine ichthyoplankton/zooplankton.

ii. Species Composition, Distribution and Abundance

Species collected from 1984–1987 under NOGAP subproject B.2 Critical Arctic Estuarine and Marine Habitat, and 2003–2005 under the Canadian Arctic Marine Ichthyoplankton Studies (CAMIS) (J. Sareault, 501 University Crescent, Winnipeg, MB R3T 2N6, pers.comm.) are summarized in Appendix 6 (modified from Coad and Reist 2004, www.fishbase.org). A total of 13 families and 27 species were collected in the Beaufort Sea LOMA during these times. The most commonly captured families are the sculpins (Cottidae), the cods (Gadidae), the snailfish (Liparidae) and the pricklebacks (Stichaeidae) (Figure 12).

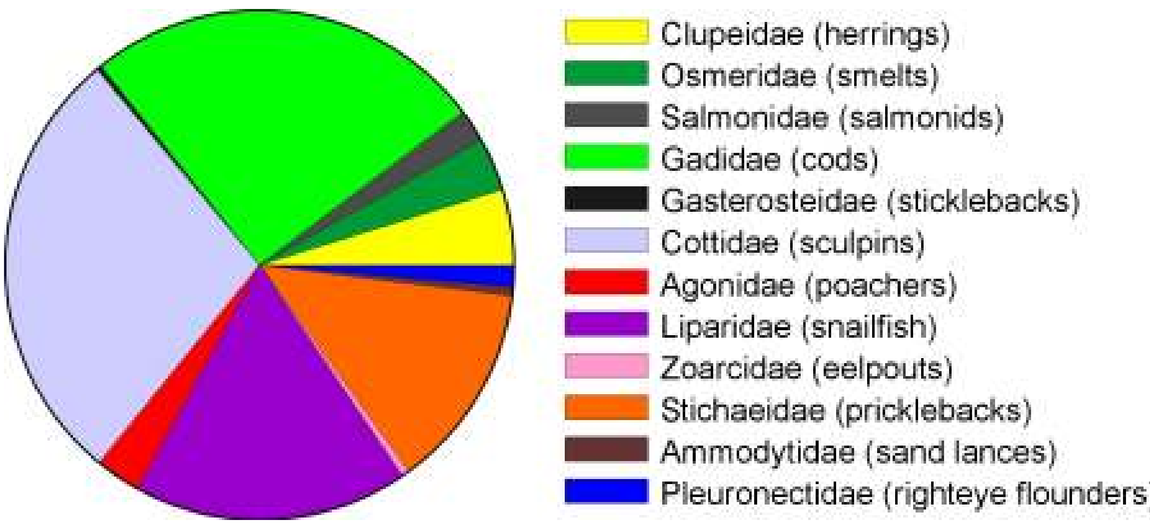

Figure 12. Percent occurrence of families of arctic marine larval fish in the southeastern Beaufort Sea (J. Sareault, DFO, 501 University Crescent, Winnipeg, MB R3T 2N6, pers. comm.).

Six species of sculpins were collected in the nearshore waters in 5–50 m. All species are tolerant of fresh water from the Mackenzie River and are common in brackish waters. During the summer (August), big-eyed and ribbed sculpins (*Triglops pingelii and T. nybelini)*, four-horned sculpin (*Myoxocephalus quadricornis)* and the arctic staghorn sculpin (*Gymnocanthus tricuspis)* were at the end of their larval stages and approaching the onset of the juvenile stage (post-flexion developmental stage), whereas *Icelus sp.* was relatively under-developed in comparison (flexion/post-flexion).

The species of Liparidae captured included the gelatinous snailfish (*Liparis fabricii)* and the kelp snailfish (*Liparis tunicatus)*. Species captured at depths of ≥30 m were in post-flexion developmental stages and those captured at 10–30 m were under-developed and in the flexion stage making them difficult to identify (*Liparis sp*.). The gelatinous snailfish was the dominant species caught from this family in waters >40–50 m.

Three species of Stichaeidae were captured during these two studies. Pricklebacks prefer marine environments but have been captured in depths of 10 m. In CAMIS program sampling, the slender eelblenny (*Lumpenus fabricii)* was in post-flexion developmental stages, whereas the Arctic shanny (*Stichaeus punctatus punctatus)* was in the flexion stages of development. The stout eelblenny (*Anisarchus medius)* was the only species of Stichaeidae collected during the NOGAP study.

Clupeids and osmerids were captured almost exclusively in 5–10 m of water in all years. The single species of Clupeidae collected was the Pacific herring (*Clupea pallasii pallasii*). This species is thought to migrate to coastal, nearshore shallow bays to spawn. The larvae were still in the pre-flexion to flexion stage during capture, indicating that spawning had taken place sometime in the spring. The rainbow smelt (*Osmerus mordax mordax*) is an anadromous species and the few captured were in their late-larval to early-juvenile stage.

The little-known Arctic alligatorfish (Agonidae: *Ulcina olrikii)* was captured at depths of 20–150 m. The family Agonidae also includes the Atlantic poacher (*Leptagonus decagonus)*; however, few of these species were captured in either the NOGAP or CAMIS surveys.

The gadids ranked second in % occurrence (Figure 12) but only three species were collected, two of which were uncommon: polar cod (*Arctogadus borisovi)* and saffron cod (*Eleginus gracilis*). The larvae of saffron cod were often only captured along the coast and in Tuktoyaktuk Harbour (Ratynski 1983), and polar cod were only captured in upwelling areas in the Mackenzie and Kugmallit troughs. The most commonly captured species overall was *Boreogadus saida* (Arctic cod). Arctic cod constitutes almost 70% of species sampled in the southeastern Beaufort Sea during summer. The widespread distribution and high catches of Arctic cod demonstrate its importance in the food web because few other food sources of similar size or energy seem to exist in the Canadian Beaufort Sea ecosystem (Craig *et al*. 1982, Sekerak 1982, Craig 1984, Bradstreet *et al*. 1986). Adult Arctic cod constitute 52% of the diet of marine mammals and birds (Bradstreet *et al*. 1986) and may even influence movements of these species (Craig *et al.* 1982), demonstrating the importance of Arctic cod and the value of understanding the larval stages and recruitment. Tuktoyaktuk Harbour and coastal Kugmallit Bay did not have the same high numbers in summer as the Beaufort Sea (Ratynski 1983), likely because of the increased flow of fresher water from the Mackenzie River.

10. Benthic Communities

Organisms and communities that live on or within the seabed are known as “benthos”. The Beaufort Sea benthos is relatively poorly studied compared to other Canadian waters. Most of the Beaufort Sea benthic studies reported here used grabs or dredges to sample macrofauna (i.e. animals longer than 1 mm), providing good taxonomic resolution but limited spatial coverage. A total of 919 macrobenthic taxa was recorded in the southern Beaufort Sea between 1955 and 2000, as summarized in Chapman and Kostylev (2005).

Most specimens were identified to the species level, but sometimes only to genus, order, class or even phylum. Phyla with the most species recorded were Arthropoda (307), Annelida (230) and Mollusca (155).

The spatial distribution of benthic invertebrates in the Beaufort Sea is influenced by the presence and dynamics of sea ice and by the outflow of the Mackenzie River. These two processes influence benthic ecosystems by modifying suitability and stability of bottom substrates, influencing oceanographic regime (e.g. water temperature and salinity gradients) and limiting availability of food. Ice mechanically disturbs the sea bed, destroying benthic habitats. When ice melts, it alters salinity and structure of the water column. The outflow of the Mackenzie River increases water turbidity, limiting light penetration through the water column, and deposits fine sediments on the sea bed. A general lack of suitable substrate and high turbidity of shallow areas in most of the southern Beaufort Sea do not favour growth of sessile epifauna and macrophytes. Soft muddy sediments covering most of the Beaufort Sea are most suitable for benthic infauna i.e. organisms such as bivalves and polychaetes living within soft bottom substrata.

The two major gradients in the distribution of benthic communities on the Beaufort Shelf are onshore–offshore and west–east. The onshore–offshore gradient is driven largely by ice scouring, salinity and water depth. The west–east gradient is driven largely by productivity and substrate. The benthos in the eastern Beaufort Sea depends upon autochthonous production that is not very closely coupled with primary production in the overlying water column. Percy (1983) described zonation of Isopoda species across the onshore–offshore gradient. *Mesidotea entomon* was restricted to nearshore (most common in <10 m, but never in >40 m), estuarine areas*, M. sibirica* occurred primarily in the transitional zone (5–25 m), whereas *M. sabini* occurred in the marine zone up to depths of 440 m, but also overlapped with *M. sibirica*.

a. Depth Zonation

Wacasey (1975) did the largest-scale benthic survey in the southern Beaufort Sea region. He investigated in the Beaufort Sea between Herschel Island and Cape Dalhousie, from May to September over a four-year period (1971, 1973–1975). The Mackenzie River releases a large volume of fresh water into this portion of the Beaufort Sea, and mixing with saline (marine) waters produces a large estuarine region (Wacasey 1975). Wacasey (1975) described four depth zones for the southern Beaufort Sea, based upon water depth, temperature, salinity and benthic invertebrate diversity and biomass (S. Blasco and V. Kostylev (S. Blasco and V. Kostylev, NRCan, 1 Challenger Drive, Dartmouth, NS B2Y 4A2, pers. comm.) assembled data on marine zoobenthos sampled in the Canadian Arctic, and organized the data into a quick-reference guide to aid in future research on Arctic benthos. Benthic biomass (g/m^2) and diversity (i.e. species richness: $taxa/m^2$), based on 21 biological reports from the Canadian Beaufort Sea between 1975 and 2002, are shown in Figure 13. The general trends in diversity and biomass with depth are similar to those described by Wacasey (1975). Species richness (Figure 13A) shows one peak at the beginning of the transition zone (10–15 m) and another one at 60–100 m water depth. Total biomass gradually increases with water depth (Figure 13B), especially beyond the zone of high ice scouring (>30 m) (Table 1).

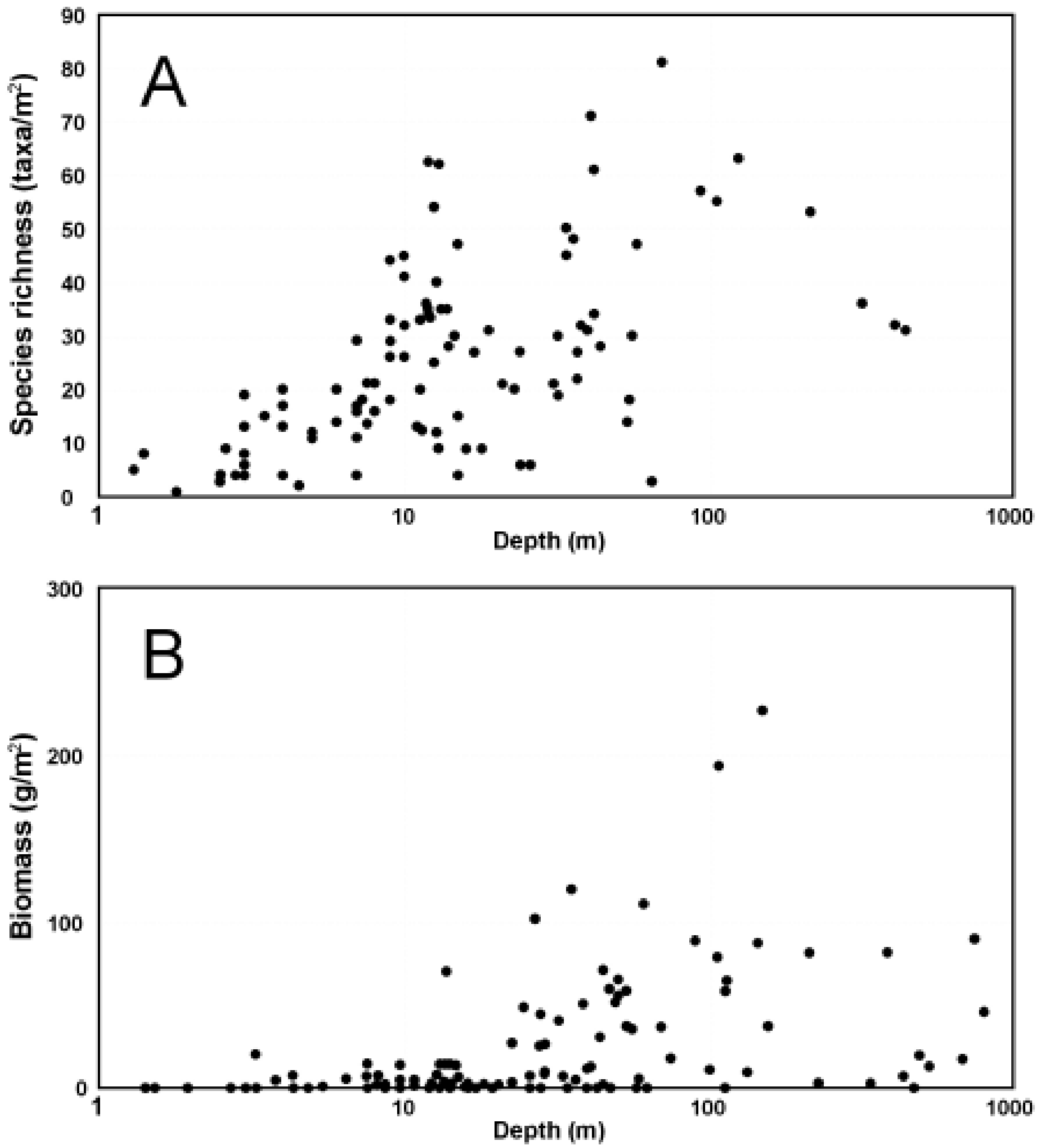

Figure 13. Changes in species richness (A) and biomass (B) with water depth based on 21 biological reports on the Canadian Beaufort Sea published between 1975–2002 (S. Blasco and V. Kostylev, NRCan).

Table 1. Summary of depth zones and benthic invertebrate distributions in the southern Beaufort Sea (after Wacasey 1975).

Zone	Range			Biomass		
	Depth (m)	Temp. (˚C)	Salinity (ppt)	Range (g/m^2)	Average (g/m^2)	Species/site
Estuarine	0–15	-1.2 (May) 16.6 (July)	0.1–>40	0.1–20	2	1–32
Transitional	15–30	-1.8 (May) 6.3 (July)	11.6–31.3	1–20	5	20–40
Marine	30–200	-1.6 (Sept) -0.1 (July)	30.1–32.8	1–72	14	3–81
Continental Slope	>200–900	-0.3 (Sept) 0.4 (July)	34.3–34.8	1–8	4	31–53

b. Estuarine Zone

The nearshore estuarine zone, extending from the shore to water depths of 15 m, is strongly influenced by freshwater input from the Mackenzie River (Wacasey 1975). As a result, salinities are typically <20 ppt. Salinities are low (0.1 ppt) nearshore in Mackenzie and Kugmallit bays and gradually increase with distance from the river outlets. Diversity is low in this zone, with stations bordering the transitional zone having a higher number of species. Wacasey (1975) attributed the low species diversity (<20 species per station) in the estuarine zone primarily to the reduced tolerance of many species (e.g. echinoderms) to low salinities over extended periods of time. Characteristic invertebrates of this zone include the polychaete *Ampharete vega*, the amphipods *Boeckosimus affinis*, *Onisimus glacialis* and *Pontoporeia affinis*, the cumacean *Diastylis sulcata*, the bivalves *Macoma balthica*, *Cyrtodaria kurriana* and *Yoldiella intermedia*, the mysids *Mysis femorata* and *M. relicta*, and the isopod *Mesidotea entomom*. Echinoderms were absent from this zone. Average benthic biomass was approximately 2 g/m^2 (a high of 5g/m^2), with the lowest biomass in Mackenzie and Kugmallit bays (Wacasey 1975). Biomass values were higher in a protected embayment, Mason Bay, than in the remainder of the zone, perhaps reflecting the more stable conditions and nutrient enrichment in this relatively protected area. The shallow, inshore areas of the Mackenzie Delta (e.g. Mackenzie Bay) sampled by Snow and Chang (1975) had very low densities of benthos, similar to the observations of Wacasey (1975). Anoxia occurs in some estuarine areas, e.g. at depths >15 m in Sachs river estuary (Siferd 2001).

c. Transitional Zone

Wacasey (1975) found this particular zone more difficult to delineate due to fluctuations in temperature and salinity (20–30 ppm) of the bottom waters. Water between 15–30 m demarcate the transitional zone. A high proportion of this zone is located within an area that experiences the highest rates of ice scouring, where ice keels mechanically disturb the bottom sediments. Scouring rates in shallower areas are limited by the presence of landfast ice, whereas they are limited by water depth in the deeper areas. Diversity of benthic invertebrates is higher than in the estuarine zone (>20 species/station) due to the presence of species from both the estuarine and further-offshore marine zone. Review of archived data (S. Blasco and V. Kostylev, NRCan, pers. comm.) suggests that diversity is highest just offshore of the peak scouring depth (Figure 13). Species representative of this zone include the polychaetes *Artacama proboscidea* and *Trochochaeta carica*, the bivalve *Portlandia arctica* and the isopod *Mesidotea sibirica*. Echinoderms are also present. 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.

d. Marine Zone

The marine zone extends from water depths of approximately 30 m up to 200 m, with salinities ranging from approximately 30–33 ppt (Wacasey 1975). The eastern portion of this zone produced the greatest number of species and the highest biomass of all areas investigated. Average biomass for the entire zone was 14 g/m^2 (range 3-34 g/m^2) with the greatest value north of Liverpool Bay (Wacasey 1975). This suggests that nutrient enrichment of deeper waters is likely the cause for increased diversity and biomass (Wacasey 1975). However, the lack of disturbance by ice scour may be another contributing factor (S. Blasco and V. Kostylev, NRCan, pers. comm.). Few species sampled from this zone were found in the estuarine zone, probably because salinity limited 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..

e. Continental Slope Zone

The continental slope zone is encountered beyond water depths of 200 m (Wacasey 1975). Average biomass here 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 decreased with increasing water depth. As in the marine zone, Wacasey (1975) regarded nutrient availability as the primary variable governing benthic invertebrate biomass and diversity. The benthic invertebrate community observed in this zone is distinguished by the occurrence of species that are 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*.

f. Harbours and Inshore Areas

Primary sources of information on the benthos in the LOMA include reports from Thomas *et al.* (1981), Thomas *et al*. (1983), and Hopky *et al.* (1994) at Tuktoyaktuk Harbour and Sifred (2001) at Sachs Harbour. Distributions of benthic invertebrates appeared to be most strongly influenced by variables related to water depth, such as temperature and salinity gradients (Thomas *et al.* 1981). The community in water <6 m deep was subjected to relatively large and episodic variations in water temperature and salinity, and was characterized by the bivalves *Cyrtodaria kurriana* and *Macoma inconspicua*, 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*.

Comparative studies of nearshore areas conducted by Sackmann (1987) were based on benthic samples from Tuktoyaktuk Harbour, McKinley Bay and Hutchison Bay. McKinley Bay had the highest overall densities of benthic organisms. The dominant species were the polychaete *Aglaophamus neotenus* and worms of the family Cirratulidae. The dominant species in Hutchison Bay were the bivalves *Portlandia arctica* and *Macoma inconspicua*. Tuktoyaktuk Harbour had the lowest density of benthic infauna, dominated by sipunculid worms and the bivalve *Cyrtodaria kurriana* (Sackmann 1987). Species composition and abundance of benthic invertebrates in harbours and nearshore areas are representative of the estuarine and transitional zones demarcated by Wacasey (1975), which are strongly influenced by the freshwater discharge of the Mackenzie River (Thomas 1988).

g. Macrophytes

Our knowledge of marine macrophytes in the Western Arctic is poor, but they do not appear to play a major role in the ecosystem of the Beaufort Sea. Their distribution in the Beaufort Sea region is limited, unlike other regions of the Canadian Arctic, where macrophytes communities are well developed. A number of possible reasons include the light-limiting effects of suspended sediment in areas influenced by the Mackenzie River plume, severe ice scouring and lack of suitable substrate for attachment.

Kelp (*Laminaria solidungula*) and the seaweed *Fucus sp.* occurred rarely at Sachs Harbour (Siferd 2001), and *Laminaria* sp. and *Phyllophora* sp. were collected for experimental work by Hsiao (1976) from Liverpool Bay and the Husky Lakes. TK suggests that kelp beds also occur along protected embayments or behind islands along the Yukon North Slope (Aklavik OAP Community Tour 2006). Dunton *et al*. (1982) suggested that, in Prudhoe Bay, Alaska, boulder patches in Stefansson Sound support abundant kelp communities because of unusual sediment transport and absence of ice scour. Thus, conditions in most of the Beaufort Sea may not be conducive to the establishment of marine macrophytes.

Macrophytes are known to provide important fish habitat, so those areas in the Beaufort Sea that support macrophytes should be mapped and further studied to provide information on their role as fish habitat.

In conclusion, more studies are needed in specialized habitats of the LOMA, such as boulder patches and deeper zones below the shelf break. Large benthos (>1 cm long) have recently been studied using video and photo observations of the seabed (V.

Kostylev, NRCan, pers. comm.), and benthic meiofauna (<1 mm long) have been studied as part of the Beaufort Sea Ecosystem programme (P. Ramlal, DFO). These studies will no doubt result in a better overall understanding of the benthos of the Beaufort Sea.

11. Fish Communities

Diverse conditions in coastal areas of the southeastern Beaufort Sea, in the vicinity of the Mackenzie River estuary, provide suitable habitat for a distinct assemblage of fish species (Craig 1984). 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, whereas 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 (e.g. Tuktoyaktuk Harbour). The shape and depth profile of the bay results in formation of a surface layer of up to 6 m of fresh water over a bottom layer of salt water during periods of winter ice cover. The resulting conditions provide suitable habitat for a large number of species (Chang-Kue and Jessop 1991).

A number of species of fish in this area are of cultural and/or economic importance to local residents, e.g. salmonids (whitefishes, ciscoes and inconnu), charr (Dolly Varden) and to a lesser extent Pacific herring. Arctic cod and possibly rainbow smelt provide links in the food web, and may be important sources of food for other fish, beluga whales and other marine mammals.

Anadromous fishes (e.g. Arctic cisco, Dolly Varden, rainbow smelt and least cisco) numerically dominate captures in coastal areas. 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 a relatively stable buoyancy boundary current (Carmack and Macdonald 2002), and thus 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 as 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).

Fish species collected in the Beaufort Sea LOMA are summarized from Coad and Reist (2004) (Appendix 6). There have been approximately 71 species representing sixteen families of fish captured in the Beaufort Sea LOMA.

Fish sampling in the Beaufort Sea LOMA has been concentrated around the Mackenzie Delta, mainly between Herschel Island and Cape Parry (Stewart *et al*. 1993). Fewer studies have been conducted east and west of this area, and very few have examined offshore areas or coastal waters of Banks or Victoria islands. Most samples have been taken in water depths ≤10 m; most of the remaining samples have been taken between 10–100 m (Ratynski *et al*. 1988). Most marine fish have been sampled using mid-water trawls, with an emphasis on juvenile life stages. Limited deep-water bottom trawling has been done in the Beaufort Sea LOMA (Shields 1988).

a. Marine Fish

Species of cod (Gadidae), snailfish (Liparidae) and sculpin (Cottidae) have been the most frequently reported marine fish collected from the western Beaufort sea and Canadian High Arctic (Galbraith and Hunter 1975, Griffiths *et al*. 1975, Kendel *et al*. 1975, Sekerak and Graves 1975, Sekerak *et al*. 1976, Buchanan *et al*. 1977, Griffiths *et al*. 1977, Jones and DenBeste 1977, Bain and Sekerak 1978, Craig and Griffiths 1978, Thomson *et al*. 1978, Craig and Holdorson 1979). Lawrence *et al.* (1984) reported that marine species represented 52% of coastal gillnet catches along Richards Island in a 1980 survey, and 55% and 61% of catches along the Tuktoyaktuk Peninsula in 1978 and 1979, respectively. Fourhorn sculpin (*Myoxocephalus quadricornis)* and Arctic flounder (L*iopsetta glacialis)* were the most abundant species, whereas saffron cod (*Eleginus gracilis*) and Pacific herring (*Clupea harengus pallasi*) were less frequently caught (Lawrence *et al*. 1984).

There are many reports of Pacific herring in the Canadian Beaufort Sea (Ratynski *et al*. 1988). This species is most abundant east of the Mackenzie Delta, particularly in Tuktoyaktuk Harbour and Tuktoyaktuk Peninsula, Liverpool Bay/Husky Lakes and Cape Bathurst areas (Stewart *et al.* 1993). Pacific herring spawn in protected waters and mature herring have been captured in Kugmallit Bay in mid-May (Chiperzak *et al*. 1991). The species is reported to spawn in Tuktoyaktuk Harbour and the Fingers area of Liverpool Bay, about the time of ice break-up from early June to mid-July (Bond 1982, Gillman and Kristofferson 1984, Shields 1985). Shields (1985) estimated that 8.2 tonnes of herring deposited about 568×10^6 eggs in the Fingers area of Liverpool Bay from 12 June–16 July, 1985.

Large but variable numbers of capelin, (*Mallotus villosus*) have been reported in the Amundsen Gulf region (Shields 1988). These large concentrations have been reported in Sachs Harbour (Usher 1965) and near the Holman Island area.

Movements and distributions of marine fish can vary dramatically from year to year in the Arctic (Shields 1988). Maturation patterns of some pelagic species like Pacific herring suggest that species do not spawn annually (Hunter 1981), which may partly explain yearly variations in movements and catches of Pacific herring and capelin in the Canadian Beaufort Sea.

Arctic cod (*Boreogadus saida*) in the Beaufort Sea have been rarely used by humans, but are an important link in the transfer of energy from lower trophic levels to seabirds and marine mammals (Figure 14) (Bradstreet *et al*. 1986). It is a small, short-lived fish rarely attaining a length of >300 mm or an age of seven years (Bradstreet *et al*. 1986). Arctic cod frequently occur where water temperatures are relatively low and where salinities are >24% (Hunter 1981). Arctic cod in the Beaufort Sea frequently occur in survey catches, especially in trawl samples; however, the numbers caught vary greatly with the locality sampled, sampling method and the vagaries of Arctic cod movements (Stewart *et al.* 1993). The location and extent of the Mackenzie River freshwater plume may also determine the location and seasonal variation in abundance of Arctic cod (Hunter 1981).

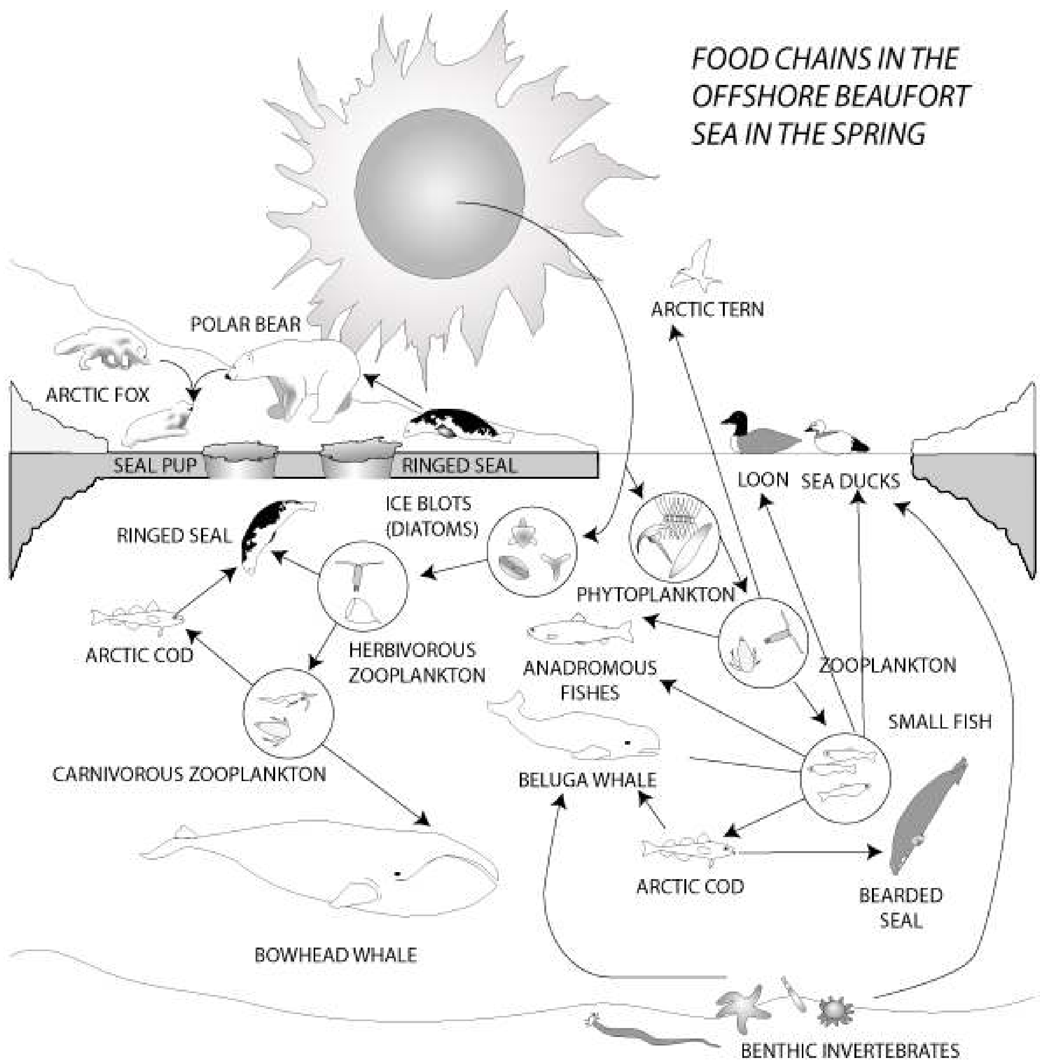

Figure 14. Food web showing the importance of Arctic cod (*Boreogadus saida*) in the Arctic ecosystem (modified from Bradstreet *et al.* 1986).

Estimates of abundance of Arctic cod in the Arctic region range greatly depending on the sampling gear used, the location and the time of the year (Bradstreet *et al*. 1986). For example, estimates of young-of-the-year Arctic cod densities for the Beaufort Sea were 0.18/1000 m^3, for the eastern Chuckchi Sea were 2.8/1000 m^3 and for Lancaster Sound ranged from 2.65–6.77/1000 m^3 (Sekerak 1982).

b. Freshwater and Anadromous Fish

Freshwater and anadromous fishes occupy the coastal waters in the Beaufort Sea during the summer (Appendix 7). They use nearshore waters mainly to feed on the abundant small invertebrates and fishes that are living on or near the bottom substrates (Craig and Haldorson 1981).

The northern portion of the Mackenzie Delta is mainly used by important freshwater species for feeding, rearing and spawning (LGL 1982). Large volumes of fresh water discharging into coastal areas of the southern Beaufort Sea produce a safe haven for freshwater species (Arctic grayling, northern pike and round whitefish) because salinities are at a low level (LGL 1982).

Nearshore waters are important feeding and migration areas for juvenile and adult anadromous fish (LGL 1982). Migration routes usually extend east and west of the Mackenzie Delta during ice break-up and early spring. Fishes will return to rivers in the autumn (LGL 1982).

Abundance patterns and locations of important freshwater and anadromous fish species follow. The species are presented in phylogentic order (Appendix 7).

Petromyzontidae (Arctic lamprey): Arctic lamprey (*Lethenteron camtschaticum*) is near the eastern limit of its range in this area and is rarely seen in high numbers (Karasiuk *et al.* 1993). Adults are parasitic on 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 fresh water, 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 fresh water in as little as a year to spawn (Karasiuk *et al.* 1993).

Catostomidae (longnose sucker): Longnose sucker (*Catostomus catostomus*) is a freshwater species that is rarely found in the brackish waters of the Mackenzie Delta (Karasiuk *et al*. 1993). Salinities in coastal areas where this species has been captured are low (0.02–1.66 ppt), which indicates that longnose sucker probably do not migrate very far into brackish waters (Lawrence *et al.* 1984).

Esocidae (northern pike): Northern pike (*Esox lucius*) is primarily found in fresh water and can only tolerate low levels of salinity. Some northern pike have been captured in coastal areas, but these fish were usually in channel mouths in areas of low salinity. Further inland, northern pike become much more numerous, and are frequently captured in 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).

Salmonidae (Arctic cisco): Arctic cisco (*Coregonus autumnalis*) occurs 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. Arctic cisco have higher salinity tolerances than least cisco but tend to remain in nearshore areas, probably due to a preference for warm water temperatures (Karasiuk *et al.* 1993). However, 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 the 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 the channel of the Mackenzie River in which they travelled downstream. Juvenile Arctic cisco from the Mackenzie River migrate along the coastline to the Colville River, Alaska, where they spend the next 5–7 years maturing. They then migrate back to the Mackenzie River, where they spawn. 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, and 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).

Salmonidae (lake [or humpback] whitefish): Lake whitefish (*Coregonus clupeaformis*) and broad whitefish (see below) distributions in the southeastern Beaufort Sea are similar. These two species 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). Adult fish migrate up the Mackenzie River in autumn to spawning locations, larger fish migrating upstream before smaller individuals. Fish spawn over gravel shoals in lakes in the upper Mackenzie Delta or in the Mackenzie River, and overwinter in the Delta or areas of the inner estuary, such as south Kugmallit Bay and Tuktoyaktuk Harbour (Lawrence *et al*. 1984). Young-of-the-year lake whitefish do not appear to use 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 stomachs of lake whitefish from lakes include gastropods, amphipods, bivalves and chironomids. The diets of coastal fish vary with timing and area, but some common diet items include isopods, amphipods, plant matter, mysids, bivalves and aquatic insect larvae (Lawrence *et al*. 1984).

Salmonidae (broad whitefish): Broad whitefish (*Coregonus nasus*) is found in nearshore waters of the Mackenzie River estuary, and in streams and rivers of this coastal area as far west as Herschel Island. Inuvialuit recognize three kinds of broad whitefish: (1) a large "jumbo" type (Tallman and Reist 1997); (2) a dark-coloured type, which lives in lakes and is said to have firmer flesh and is better tasting; and (3) a silvery colour type, which lives in rivers and has watery flesh. Some Inuvialuit report a large fish that appears to be a cross between an inconnu (coney) and a broad whitefish (Freeman 1997). Hybrids have been reported from the area (Reist *et al.* 1992).

Typical migration patterns involve summer-feeding movements along the coast, and upstream migrations from mid-October – early November to spawn over gravel shoals in the mainstem of the Mackenzie River. Some Inuvialuit say that broad whitefish spawn in lakes primarily from September – October, whereas other Inuvialuit say spawning is from November – December. Spawning is thought to take place in the cool, vegetated shallow waters of lakes, or on the sandy substrate. Some Inuvialuit recognize that whitefish can go far upstream and spawn in areas unknown to them (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. 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. In fact, most jumbo whitefish are caught in August after the dryfish-making season.*
> *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* (Freeman and Stevenson 1995, p 30).

Non-spawning adult fish 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 3–5 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 autumn"* (Freeman and Stevenson 1995, p 31). Inuvialuit have suggested that smaller whitefish might stay in these lakes for a couple of years before coming back down because big whitefish are often seen coming out of the lakes in the spring (Freeman and Stevenson 1995). This species feeds heavily on chironomid larvae, other aquatic insects, small crustaceans, molluscs and annelids (Lawrence *et al*. 1984, Karasiuk *et al.* 1993).

Salmonidae (least cisco): There are several different life-history types of least cisco (*Coregonus sardinella*) 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. Lacustrine least cisco appear to become sexually mature earlier than anadromous fish, are larger and more deep-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 (perhaps because of 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 along the nearshore zone 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 freshwater 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 within the Mackenzie estuary, although some fish also enter lakes within the Tuktoyaktuk Peninsula (Bond and Erickson 1989).

Overwintering habitat consists of lakes in the Mackenzie Delta and Tuktoyaktuk Peninsula and sheltered, freshened coastal bays, such as Mallik Bay and Tuktoyaktuk Harbour (Chang-Kue and Jessop 1992). Diet studies indicate that least cisco in coastal waters feed on copepods, amphipods, mysids, polychaetes and fish, whereas lacustrine least cisco eat amphipods, snails, clams, ostracods, aquatic insect larvae and small fish such as ninespine stickleback (Lawrence *et al*. 1984). Spawners do not appear to feed as they migrate into the Mackenzie Delta (Karasiuk *et al.* 1993).

Salmonidae (salmon and Dolly Varden): Very small numbers of pink salmon (*Onchorhynchus gorbuscha*) and chum salmon (*O. keta*) spawn in the Mackenzie River system and migrate westward along the Beaufort Sea coast to Alaskan waters. Sexually mature sockeye (*O. nerka*) and pink salmon caught in the Sachs River estuary on Banks Island represent their furthest-known distributions (Bablauk *et al*. 2000). All anadromous charr that spawn in streams and rivers located west of the Mackenzie River are Dolly Varden (Reist *et al.* 1997). Dolly Varden Charr 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 use a "sneak spawning" strategy to spawn with anadromous pairs (Reist 1989).

The availability of accessible spawning and over-wintering habitat appears to be a limiting factor for Dolly Varden in the western Arctic. The high-gradient rivers running off the Yukon North Slope freeze to the bottom over much of their length, except for areas of groundwater discharge, which maintain under-ice flows or open-water areas suitable for fish habitat (Sandstrom *et al*. 2001). All species of fish, including Dolly Varden, spawn and overwinter in sections of rivers or creeks that are fed by these springs. The limited size of these areas results in the entire population of a river system, from egg to adult, occupying the same limited habitat for 9–10 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 to a study on the Big Fish River charr fishery said that the charr enter the river during a run that lasts for 2–3 weeks, primarily between August – 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 charr would go to the Rat River instead. Charr lay eggs from late October – November. Juveniles leave the grounds when they are between 4–12 inches long, and the charr leave the Fish Hole after break-up. Two interviewees noted that some charr stay in the river all year, downstream from Cache Creek Falls (Byers 1993).

Spawning and overwintering grounds for the Rat River stock, which may contain several sub-populations, appear to be located in at least two areas 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 populations (J. Reist, DFO, 501 University Crescent, Winnipeg, MB R3T 2N6, pers. comm.). Additional populations of anadromous Dolly Varden also occur along the Yukon North Slope, Babbage River, Firth River and Joe Creek.

During the summer months, anadromous adult and large juvenile Dolly Varden migrate to the sea to feed, whereas small juveniles and residual adults remain in fresh water. Sea-run fish undergo feeding migrations along the coast of Northwest Territories, Yukon and Alaska. Juvenile fish (three or four years old) 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). Aklavik residents have noted changes to the water and ocean currents along the Yukon North Slope to Alaska, and have reported that Dolly Varden are further offshore today than before. Residual males and juvenile charr in fresh water feed mainly on aquatic insect larvae, whereas anadromous fish rarely feed while in rivers (Armstrong and Morrow 1980). Small charr (<300 mm long) in coastal waters feed on aquatic insects such as chironomid larvae; charr between 300–500 mm long eat amphipods, small isopods and some fish; and large charr (>500 mm long) feed mostly on fish such as fourhorn sculpin and Arctic cod, and smaller numbers of insects and crustaceans (Karasiuk *et al*. 1993).

Salmonidae (Arctic grayling): Arctic grayling (*Thymallus arcticus arcticus*) are found in streams and lakes containing suitable 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 warm, 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 large tributaries or in the Mackenzie River. Fish in North Slope coastal rivers, such as the Big Fish River, overwinter near thermal springs, as the remainder of the river freezes to the bottom. The Arctic grayling's low tolerance for salinities >3.0 ppt renders estuaries unsuitable as overwintering habitat (Karasiuk *et al.* 1993). Spawning migrations begin about mid-May – mid-July, and 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, aquatic insect larvae, small fish and fish eggs (Karasiuk *et al*. 1993).

Salmonidae (Arctic charr): Arctic charr (*Salvelinus alpinus*) occur in the lakes and rivers of the eastern portion of the Beaufort Sea LOMA, as both sea-run and landlocked forms (DFO 1999, Paulatuk *et al*. 2000, Sachs Harbour *et al*. 2000, Ulukhaktok *et al.* 2000). Arctic charr are often confused with Dolly Varden charr; however, the two species are morphologically and genetically distinct (Reist *et al.* 1992). Arctic charr generally have a shorter head and snout and their tail has a slightly deeper fork with a narrow base (Sachs Harbour *et al.* 2000). They utilize rivers and lakes along the eastern mainland and the Arctic islands to spawn and over-winter. Spawning typically occurs in late September and early October when the winter ice begins to form (DFO 1999). During this time adults take on their characteristic spawning features: they turn from silver in color to orange, red and often deep vermilion and the males develop a protruding hook on their lower jaw called a kype (DFO 1999, Paulatuk *et al.* 2000, Sachs Harbour *et al*. 2000, Ulukhaktok *et al*. 2000). Adult charr spawn every two to three years; however, the frequency of spawning and age of maturity are highly variable and depend on individual fitness and environmental conditions (DFO 1999). Eggs are laid in coarse gravel and hatch in the spring. When the ice beings to retreat, adults that did not spawn and charr making their first trip to sea (3–5 years old) leave the over-wintering areas and make their annual migration to the sea (DFO 1999). They are carnivorous and feed mainly on marine organisms, including amphipods, and fish species such as Arctic cod and capelin (DFO 1999). Arctic charr captured near Pearce Point had full stomachs of capelin, indicating that capelin play an important role as prey items for charr during summer (DFO 1999). Growth at sea is rapid and they make the annual migrations to sea until they are mature enough to spawn (approximately 7–8 years old) (DFO 1999). Arctic charr are an important source of food for Paulatuk, Sachs Harbour and Ulukhaktok communities in the Beaufort Sea LOMA. Important charr habitat near Paulatuk includes Pearce Point, Hornaday River, Argo Bay and the Fish Lakes area (Paulatuk *et al.* 2000). Important habitat in Ulukhaktok includes the Kuujjua, Kuuk and Kagluk river systems and Tahiryuak Lake (Ulukhaktok *et al.* 2000), while the Sachs Harbour Community Conservation Plan (Sachs Harbour *et al*. 2000) indicates the Sachs, Masik, Kellet, Thomsen, De Salis, Bernard, Rufus and Atitok river systems and Fish, Raddi and Swan lakes are also important habitat areas.

Salmonidae (inconnu): Inconnu (*Stenodus leucichthys*) is found in the Mackenzie River drainage and along the coast. Most inconnu that are located along the Yukon coast are immature or are adult fish resting 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 can migrate up to several hundred kilometers 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 feeding migrations in the Mackenzie River, followed by spawning, occur from June – 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, Tuktoyaktuk Harbour and Kugmallit Bay provide overwintering habitat (Lawrence *et al*. 1984). Additional overwintering areas include Shallow Bay, Shoalwater Bay, major channels and lakes of the inner Mackenzie Delta (Husky, Peel, Enoch, West, Aklavik, Reindeer and East channels) and 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, small numbers of isopods, mysids, amphipods or other invertebrates (Stein *et al*. 1973, Lawrence *et al*. 1984, Karasiuk *et al.* 1993).

Gadidae (burbot): Burbot (*Lota lota*) is primarily a freshwater species that is occasionally found in estuarine waters of large rivers that flow into the Arctic Ocean. Burbot in Yukon coastal waters have been captured at Shingle Point, Kay Point and 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 salinities in the upper 4 m of the water column were reduced (Lawrence *et al*. 1984). Burbot in the outer Mackenzie Delta feed on fishes such as sculpins, smelts, other burbot and ninespine stickleback; invertebrates such as notostracans, amphipods, molluscs, isopods and mysids, and fish eggs (Lawrence *et al*. 1984, Karasiuk *et al*. 1993).

Gasterosteidae (ninespine stickleback): Ninespine stickleback (*Pungitius pungitius*), occurs in both freshwater and brackish coastal waters and is an important forage fish for a large number of species (Karasiuk *et al*. 1993). This species is distributed along the Beaufort Sea 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 and tundra ponds and lakes, and are capable of inhabiting waters with salinities up to 16–20 ppt. Downstream migrations often occur in the autumn as fish move downstream to estuaries or lakes to overwinter. In the summer, ninespine sticklebacks migrate into fresh water to spawn (Lawrence *et al*. 1984, Karasiuk *et al*. 1993).

Cottidae (slimy sculpin and spoonhead sculpin): Slimy sculpin (*Cottus cognatus)* and spoonhead sculpin (*C. ricei*) are freshwater species that are commonly located in lakes and streams in the inner Mackenzie Delta. Slimy sculpin have also been recorded in Yukon coastal waters (Karasiuk *et al.* 1993). Stomachs from spoonhead sculpin captured in streams and lakes of the Mackenzie Delta contained chironomids, ostracods, mysids and plecopterans (Lawrence *et al.* 1984).

12. Marine Mammal Communities

The southern Beaufort Sea provides seasonal or year-round habitat for several species of marine mammals (Appendix 8). Beluga (*Delphinapterus leucas*) and bowhead whale (*Balaena mysticetus*) move into the near- and offshore areas of the southern Beaufort Sea and Amundsen Gulf each spring and summer. Killer whales (*Orchinus orca*) are infrequently observed in the area (e.g. Aklavik residents reported two killer whales in Shallow Bay during 2006) and narwhal (*Monodon monoceros*) have entered 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 seals (*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 dependent 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 seals (*Phoca vitulina*) and walrus (*Odobenus rosmarus*) are occasionally observed in the southern Beaufort Sea (Harington 1966, Stirling 1974).

Distribution, abundance and ecology of the principle marine mammals in the southern Beaufort Sea (beluga and bowhead whales, ringed and bearded seals, 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 Beaufort Sea LOMA. Some of these movements cover large distances (e.g. beluga movement into the Bering Sea to overwinter), whereas other movements may be more localized (e.g. ringed seal movement into offshore areas to feed). Important aspects of each species' life history (e.g. wintering, pupping) may occur outside of the study area so the distribution and ecology of each species is described for its full geographic range.

a. Cetaceans

i. Beluga Whale

Beluga whales aggregate in estuaries and shallow nearshore habitats during summer for feeding, thermal advantage (Fraker *et al.* 1979), socializing and annual moulting (St. Aubin *et al.* 1990). In some areas of the Arctic, belugas actively rub 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 observation 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, which may be attributed to poor visibility in the silty waters of the Mackenzie River (Byers and Roberts 1995). Those that have witnessed this activity 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).

Beluga whales aggregate in three main areas of the Mackenzie River estuary during July (inset, Figure 15). It is uncertain whether beluga whales are feeding when they are in the nearshore areas of the Mackenzie estuary. Feeding is not frequently observed in studies conducted in other estuaries and empty stomachs in whales harvested in estuaries are common (Sergeant 1973, Smith *et al*. 1994). Most feeding may occur away from the Mackenzie estuary. For example, Richard *et al*. (1997) presumed that whales making extended dives to the sea floor at depths of 400–600 m in Viscount Melville Sound, were on feeding forays, and Hazard (1988) also suggested that feeding was a major activity of whales in the offshore areas. Belugas feed mainly on fish and large invertebrates such as octopus and squid. The diet of belugas in the Bering and Chukchi seas included Arctic cod, saffron cod, sculpins, herring, smelt, capelin, Arctic charr, octopus and shrimp (Lowry *et al.* 1986).

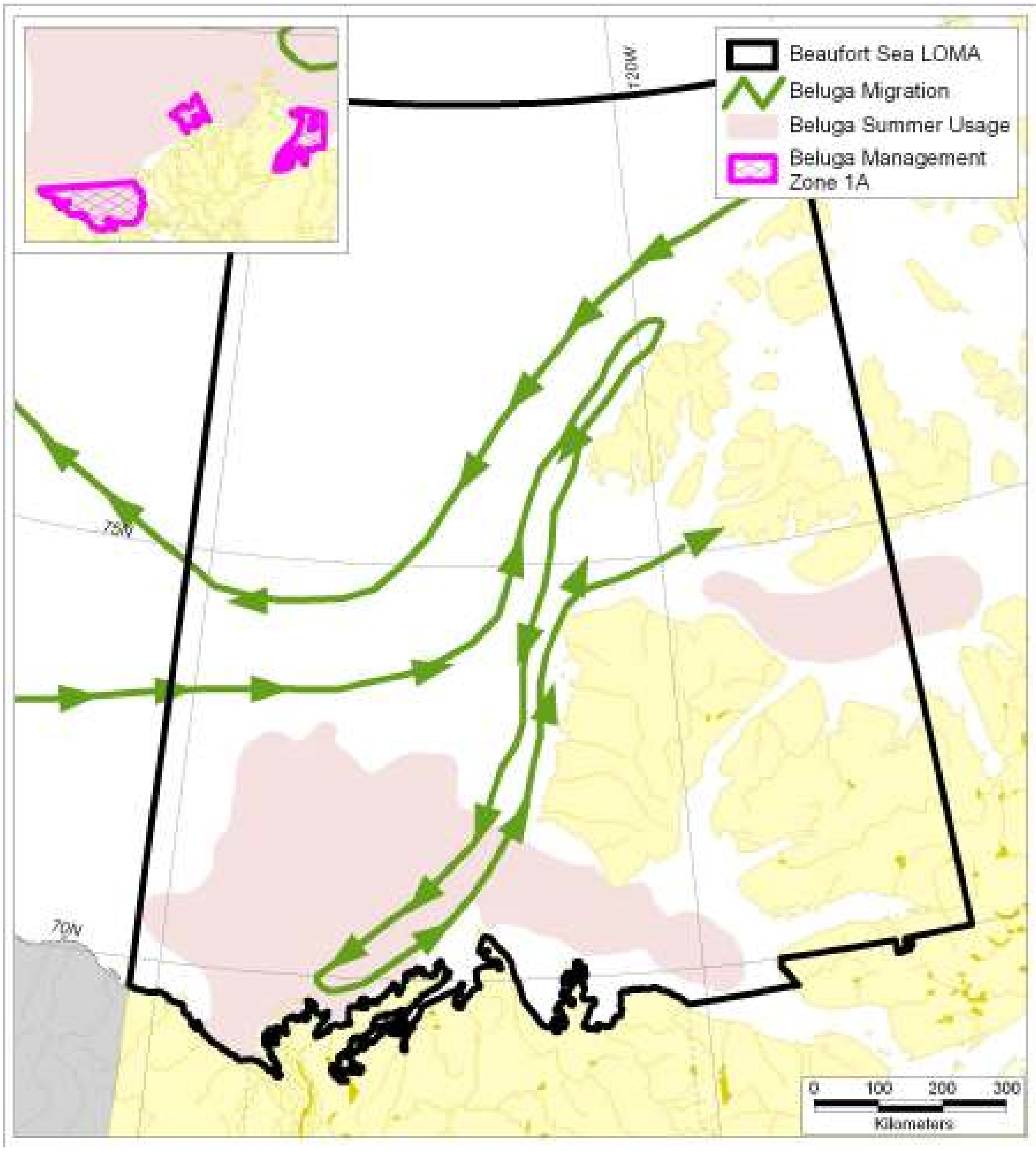

Figure 15. Satellite tag tracking of a male beluga whale migration from the Bering Sea to the Beaufort Sea and areas of summer beluga concentration zones in the LOMA; inset shows Beluga Management Zone 1A areas (courtesy of Lois Harwood, DFO, PO Box 1871, Inuvik, NT X0E 0T0, and P.R. Richard, DFO, 501 University Crescent, Winnipeg, MB R3T 2N6).

In spite of a lack of published evidence of extensive feeding within the Mackenzie estuary, some Inuvialuit have observed feeding. They have reported finding fish such as, Pacific herring and least cisco in stomachs (Byers and Roberts 1995). Smelt, burbot and inconnu are also eaten. A beluga captured near Tuktoyaktuk Peninsula had been feeding on Arctic cisco (Orr and Harwood 1998), providing evidence of some feeding in the estuary. Beluga aggregation in the estuary may also be associated with the presence of rainbow smelt (Lawrence *et al*.1984, Percy 1975). Inuvialuit suggest that belugas may throw up their food when stressed, such as when they are hunted, because their stomachs are generally found empty in the estuary (Byers and Roberts 1995).

Mating for most beluga stocks probably occurs in late winter or early spring (Brodie 1971, Sergeant 1973, Doidge 1990). Therefore, it is likely that most mating occurs before belugas reach the Mackenzie estuary. Females with calves are frequently 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 (Byers and Roberts 1995). They attributed that observation to cows going to different areas to calve due to bad ice conditions or low water levels, rather than to low birth rates.

Humans, polar bears and killer whales prey upon belugas (Sergeant and Brodie 1969, Lowry *et al*. 1987, Smith and Sjare 1990). It is likely that little predation on belugas by natural predators, beside humans, occurs in the estuary. Killer whale predation is probably rare given the paucity of such observations by Inuvialuit. Inuvialuit report that killer whales in the vicinity of Kugmallit Bay caused seals and beluga whales to stay out of the area. Scars from polar bears on the backs of whales have been observed by hunters. A fragment of a narwhal tusk was found in a beluga by two hunters but this finding was probably the result of an interspecific aggressive encounter, rather than an attempt at predation (Orr and Harwood 1998). Narwhals are fish and invertebrate eaters.

Abundance: Genetic analysis has identified numerous stocks of beluga whales from the North American Arctic, including seven stocks from Canada and four from Alaska (Brown 1996, Brown-Gladden *et al.* 1997, Brown-Gladden *et al*. 1999, O'Corry-Crowe *et al.* 1997). Beluga whales that are found in the study area are 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 at or near the surface during surveys (Harwood *et al*. 1996). However, this number probably underestimates the actual population size because the entire geographic range of the population was not surveyed, and the estimate did not account for whales that were underwater during aerial counts (Harwood *et al.* 1996, Richard *et al*. 2001).

Movements and Seasonal Distribution: Beaufort Sea belugas 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 eastern Beaufort Sea beluga 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 first arrive along or in the vicinity of the west coast of Banks Island during late May and early June (Fraker 1979). A recent track from a satellite-tagged beluga, which returned to the Beaufort Sea after spending the winter in the Bering Sea, is shown in Figure 15 (P.R. Richard, DFO, 501 University Crescent, Winnipeg, MB R3T 2N6, pers. comm.) They then move in a southwestern direction, following the landfast ice edge off 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 (Byers and Roberts 1995).

Once the landfast ice begins to break up, usually in late June to early July, large numbers of belugas move into the Mackenzie estuary and concentrate in three areas: (1) Shallow Bay; (2) around Kendall Island; and (3) in the southwestern portion of Kugmallit Bay (Figure 15). Other areas used by the population in July and August are the Amundsen Gulf, offshore areas of the Beaufort Sea, island passages of M'Clure Strait, Prince of Whales Strait and Viscount Melville Sound (Richard *et al.* 2001). Whales tagged with satellite-linked time-depth recorders occupy the Mackenzie estuary intermittently, and for only a few days at a time (Richard *et al.* 2001, P.R. Richard, DFO, pers. comm.). Much of their time is 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 belugas are sedentary, coastal animals, and suggest instead that belugas travel long distances in the summer to areas that are hundreds of kilometers from the Mackenzie Delta. Their movement into the dense pack ice of summer and autumn also contradicts the belief that belugas are limited to loose ice or open water. These 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).

Most autumn movements back to the Chukchi Sea begin in September (Richard *et al.* 2001). Belugas use different routes, ranging up to 700 km offshore of northern Alaska, and move westward to the Wrangel Island area of the western Chukchi Sea, where they aggregate during October. Movements from the Chukchi Sea south into the Bering Sea generally occur during November. A beluga carrying a satellite telemetry tag moved into the Bering Sea during late November (Richard *et al*. 2001).

ii. Bowhead Whale

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: (1) pelagic (mid-water) feeding; (2) feeding along the seafloor; and (3) surface swimming. As discussed above, 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* and *C. glacialis*), while other invertebrates (gammariid and hyperiid amphipods, euphausids and isopods) have been reported in the diet of bowhead (Bradstreet and Fissel 1986, Bradstreet and Fissel 1987, Carroll *et al.* 1987).

Abundance: There are three discrete stocks of bowhead whales that summer in Canadian waters, including populations in Davis Strait, Foxe Basin/northern Hudson Bay and the western Arctic (Marine Mammal Commission 1999). Bowhead whales that summer in the southeastern Beaufort Sea are part of the western Arctic population. Population size was most recently surveyed in 1993, and 8200 bowheads (7200–9400) were estimated in the western Arctic stock (Raftery and Zeh 1998), comprising >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 Strait (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 occurs 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 – mid-August), bowhead tend to be widely distributed in 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 are 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 in certain areas by these forces by mid-August and bowhead aggregate in those areas. Three main areas that consistently attract large concentrations of bowhead have been identified in the southeastern Beaufort Sea including: (1) the Yukon coast between Kay and Shingle points and around Herschel Island; (2) north of the eastern Tuktoyaktuk Penninsula between McKinley Bay and Cape Dalhousie; and (3) Amundsen Gulf (Wong 1999) (Figure 16).

Age-specific segregation of bowheads occurs in the southern Beaufort Sea. Amundsen Gulf appears to be used primarily by adults (>13 m long) and subadults (>11 m long) (Davis *et al.* 1982, Davis *et al*. 1986, Cubbage *et al.* 1984), whereas bowheads along the Yukon coast appear to be mostly juvenile and yearling whales (Cubbage *et al*. 1984, Davis *et al.* 1986). Adults with calves have been reported from offshore areas and in deep waters near Herschel Island (Davis *et al.* 1983, Cubbage *et al*. 1984).

Bowhead begin the autumn migration back to the Bering Sea in September (Sergent and Hoek 1974), and may aggragrate along the Chukchi 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, whereas others follow the Alaskan coast to the Bering Sea. Bowheads generally enter the Bering Sea in November and December (Wong 1999).

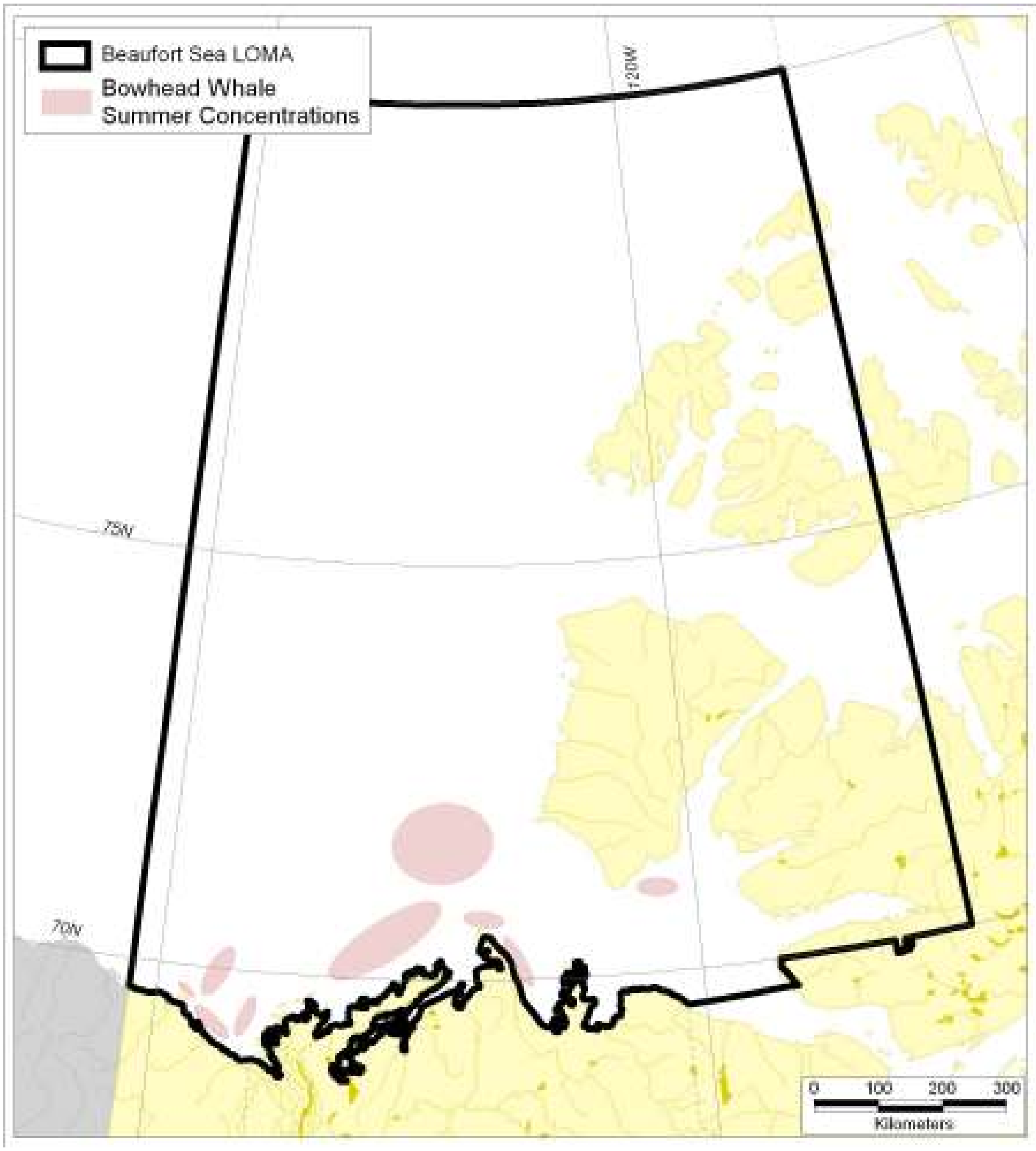

Figure 16. Summer bowhead whale concentration (1980–1986) in the southern Beaufort Sea and Amundsen Gulf region (courtesy of L. Harwood, DFO).

b. Pinnipeds

i. Bearded Seal

Bearded seals are widely distributed throughout the circumpolar Arctic but are considerably less abundant than ringed seals. Despite its relative importance to Inuit, the bearded seal has not been as extensively studied as the ringed seal.

Abundance: Bearded seal abundance was surveyed within the southern Beaufort (from the Alaska/Yukon border eastward to the Baillie Islands and extending offshore for 160 km) throughout the 1970s and 1980s in conjunction with ringed seal surveys (Stirling *et al.* 1977, Stirling *et al*. 1981, Stirling *et al*. 1982, Kingsley and Lunn 1983, Kingsley 1986). The estimated number of bearded seals fluctuated considerably interannually, as was observed for ringed seals. A sharp decline in bearded seal abundance was observed between 1974 (1400 animals) and 1975 (450 animals) (Stirling *et al.* 1977). Bearded seal numbers ranged between 250 (1979) – 2000 animals (1978) from 1976–1979 (Stirling *et al.* 1982), and 450–1700 animals in surveys conducted during the early 1980s (Kingsley 1986).

*Movements and Seasonal Distribution***:** Bearded seals are solitary animals found mainly over shallow waters of the continental shelf. They are thought to generally remain on the sea ice usually in association with moving ice or shoreleads and polynyas (Burns 1970, Burns and Frost 1979, Stirling *et al.* 1982). Bearded seals occasionally occur in fast-ice areas, indicating that they have some ability to maintain breathing holes (Stirling and Smith 1977). Within the southern Beaufort Sea, bearded seals 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 (Stirling *et al*. 1982, Kingsley 1986).

Movement patterns of bearded seals have not been documented during the ice-free period in the southern Beaufort Sea. However, their seasonal movements between the Bering and Chukchi seas appear to be related to ice formation and recession (Burns 1967, Burns and Frost 1979). They are mainly pelagic during the open-water season, although some may remain with pack ice. Few studies have directly addressed bearded seal movements and diving (e.g. Krafft *et al*. 2000). Pups tagged in Svalbard dispersed offshore from their coastal birthing area after weaning, moving to Greenland and Jan Mayen (Gjertz *et al*. 2000). Populations appear to be mainly sedentary, as evidenced by the development of strong regional dialects (Cleator *et al*. 1989).

General Biology: Bearded seals in Svalbard give birth on small, first-year, ice floes in the free-floating pack ice or on similarly sized white, glacial-ice areas frozen into gray landfast ice (Kovacs *et al*. 1996, Andersen *et al*. 1999) and pups are nursed for approximately 24 days (Lydersen and Kovacs 1999).

Bearded seals have particularly sensitive whiskers and are predominantly benthic feeders. They eat shrimp, clams, crabs, other benthic invertebrates and fishes (Burns and Frost 1979, Lowry *et al*. 1980, Anotonelis *et al*. 1994, Hjelset *et al.* 1999). Bearded seals represent an intermediate trophic level similar to ringed seals, belugas and narwhals (Hobson and Welch 1992, Hobson et al. 2002). Most of their diet is usually made up of fish, crustaceans and molluscs. Less is known about their diet in deep, offshore areas but their foraging specialization appears to be associated with expanding and retreating ice edges (Antonelis *et al*. 1994). Bearded seals are sometimes preyed upon by polar bears (Stirling and Archibald 1977, Smith 1980, Derocher *et al*. 2002) and walruses (Lowry and Fay 1984).

ii. Ringed Seal

Ringed seals are one of the most-studied marine mammals in the Arctic due to their importance within the Arctic food web and their importance to the Inuit (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 surveys (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 (3700) (Stirling *et al.* 1977). Estimated ringed seal numbers ranged from 2900 animals (1977) to 12,600 animals (1978) between 1976 – 1979 (Stirling *et al*. 1981, Stirling *et al*. 1982). The most recent spring surveys in the same area, conducted between 1981–1984, provided estimates ranging from 5400–6900 ringed seals (Kingsley and Lunn 1983, Kingsley 1986).

Late-summer surveys (open-water conditions) of seal abundance have also shown considerable variation between years. Indices of relative abundance reveal a decline from an estimated 41,200 animals in 1982 to 6400 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 and also included areas offshore of the Yukon coast.

The sharp declines in population size observed in 1975 and 1985 appear to be linked to several factors. Heavy ice conditions during the preceding winters and summers of both years may have reduced primary and secondary productivity and, ultimately, reduced prey availability for ringed seals (Stirling *et al.* 1977, Stirling *et al*. 1981, Stirling *et al.* 1982, Smith 1987). For example, 1974 was the most severe ice year on record and body condition of ringed seals taken in the subsistence harvest was the poorest on record; observed ovulation rate was reduced to <50%. Conversely, 1998 was a record year for early clearing of landfast ice and length of the open-water period and body condition was the best that has been recorded and ovulation rate was nearly 100% (Smith and Harwood 2001). Thus, the sharp decline in seal numbers may have been due to either extensive seal mortality (Stirling *et al.* 1977, Stirling 1981, Stirling *et al*. 1982), or 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 and some large-scale movements may occur within the area (Stirling *et al*. 1977, Smith 1987, Harwood 1989). 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 there is an autumn migration westward, undertaken primarily by subadults, towards the Beaufort and Chukchi seas (Smith 1987). Some young seals branded in Amundsen Gulf have been recovered in Alaska and Siberia (Smith 1987) (Figure 17).

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 along the Yukon coast, around Cape Bathurst and Cape Parry, and along the southwest coast of Banks Island (Stirling *et al.* 1982). The seals appeared to prefer areas where water was 75–100 m deep (Stirling *et al.* 1982).

Groups of seals (up to 21 animals) form large aggregations that may cover areas ranging from 350–2800 km^2 during open-water periods in late summer and early autumn (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 121–326 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 (Smith 1987, Harwood and Stirling 1992).

As ice begins to form in late autumn, adult seals move into coastal areas of stable, landfast 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) (Figure 17). This westward movement exhibits a deliberate and rapid migration from Amundsen Gulf to the Chukchi Sea. The young seals follow the shelf-break zone off the North Slope of Alaska, dispursing 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 than in areas to the east (Smith 1987).

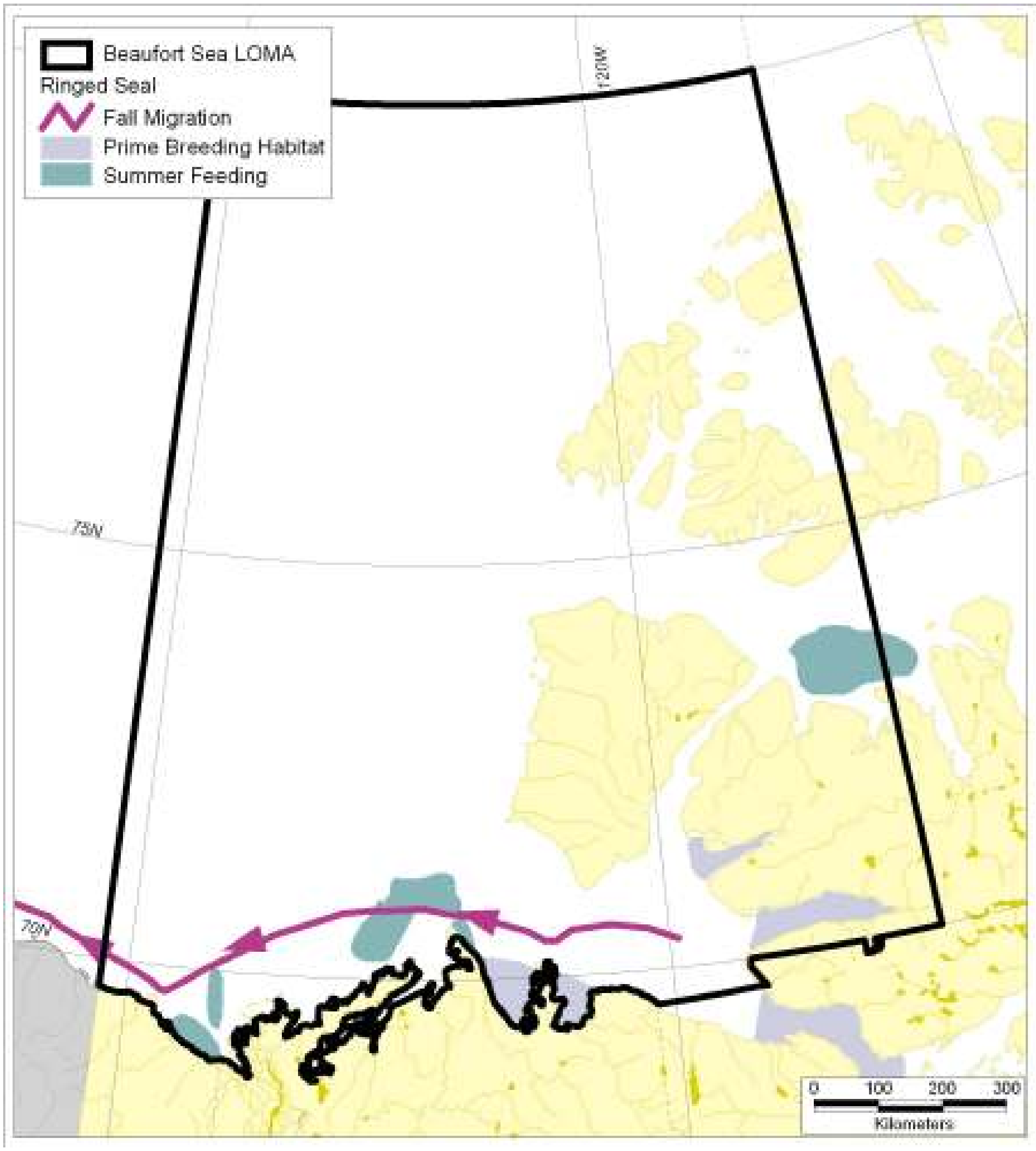

Figure 17. Localized movements (grey areas), and large-scale migrations (red line) of young ringed seals (http://www.beaufortseals.com/telemetry.htm).

Biology Pertinent to the Study Area: Adult ringed seals maintain lairs and associated breathing holes beneath the snow throughout the winter months. The lairs provide thermal protection and some shelter from predators (Smith and Stirling 1975). Two types of lairs are constructed: (1) haul-out lairs used by males and females to rest; and (2) birth lairs used by females for pupping (larger than resting lairs). Two or more birth lairs often lie in close proximity to each other, forming a birth-lair complex 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. Most mating in the Amundsen Gulf area occurs between mid-May – mid-June, but 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 1.5–2 months after its birth (Smith 1987).

Smith (1987) listed 36 different species of invertebrates and fish that were consumed by ringed seals in Amundsen Gulf. The most frequently consumed prey items are usually crustaceans (copepods, mysids and amphipods) and Arctic cod (*Boreogadus saida*).

The type of prey consumed appears to vary seasonally, regionally and with 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. Most 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*) (Smith 1976, Stirling 1988). Killer whale and walrus also prey upon ringed seals. Arctic fox predation on newborn seal pups can be 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 decline 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).

c. Polar Bear

The polar bear is the largest land carnivore in the world and is probably the most studied of all arctic mammals. Polar bears have a circumpolar distribution but they are not evenly distributed through the Arctic. The World Conservation Union (IUCN)/Species Survival Commission Polar Bear Specialist Group recognizes 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. Bears that are part of the southern Beaufort Sea population inhabit areas along the mainland coast from the Baillie Islands westward into Alaska (Taylor and Lee 1995, Bethke *et al*. 1996).

Abundance: Polar bears in the Beaufort Sea have been the subject of considerable study since the 1960s (Stirling 2002). Long-term mark/recapture and telemetry studies have provided a population estimate of 1800 animals for the southern Beaufort Sea population and 1200 animals for the northern Beaufort Sea population (Stirling 1988).

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 (Stirling and Archibald 1977, Smith 1980). The heavy ice conditions of the mid-1970s and mid-1980s 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 (paralleling the mainland coastline) occur during this time, and are likely related to the development of leads along the shear zone between landfast 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 autumn (Stirling 1988, Amstrup *et al*. 2000). 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 (Figure 18).

Bear distribution and habitat preference during late winter and early spring, studied throughout the 1970s in the eastern Beaufort Sea and Amundsen Gulf area by Stirling et al. (1993), showed that landfast 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 habitats, which are preferred habitats for non-breeding ringed seals and for bearded seals. Few bears were observed on multi-year ice (Stirling *et al*. 1993). Females with young cubs probably prefer landfast ice to avoid threats to their cubs caused by contact with adult males (Stirling *et al.* 1993).

Biology Pertinent to the Study Area: Female polar bears of the Beaufort Sea population breed for the first time at five years old, compared to four years old 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, Stirling 1988b). Maternity dens in the general Beaufort Sea area are found on either multi-year pack ice (Lentfer 1975, Stirling and Andriashek 1992, Amstrup and Gardner 1994) or at inland locations (Amstrup and Durner 1997). The western and southern coasts of Banks Island are the most important terrestrial denning areas in the Beaufort Sea. Limited, but important, denning occurs annually 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).

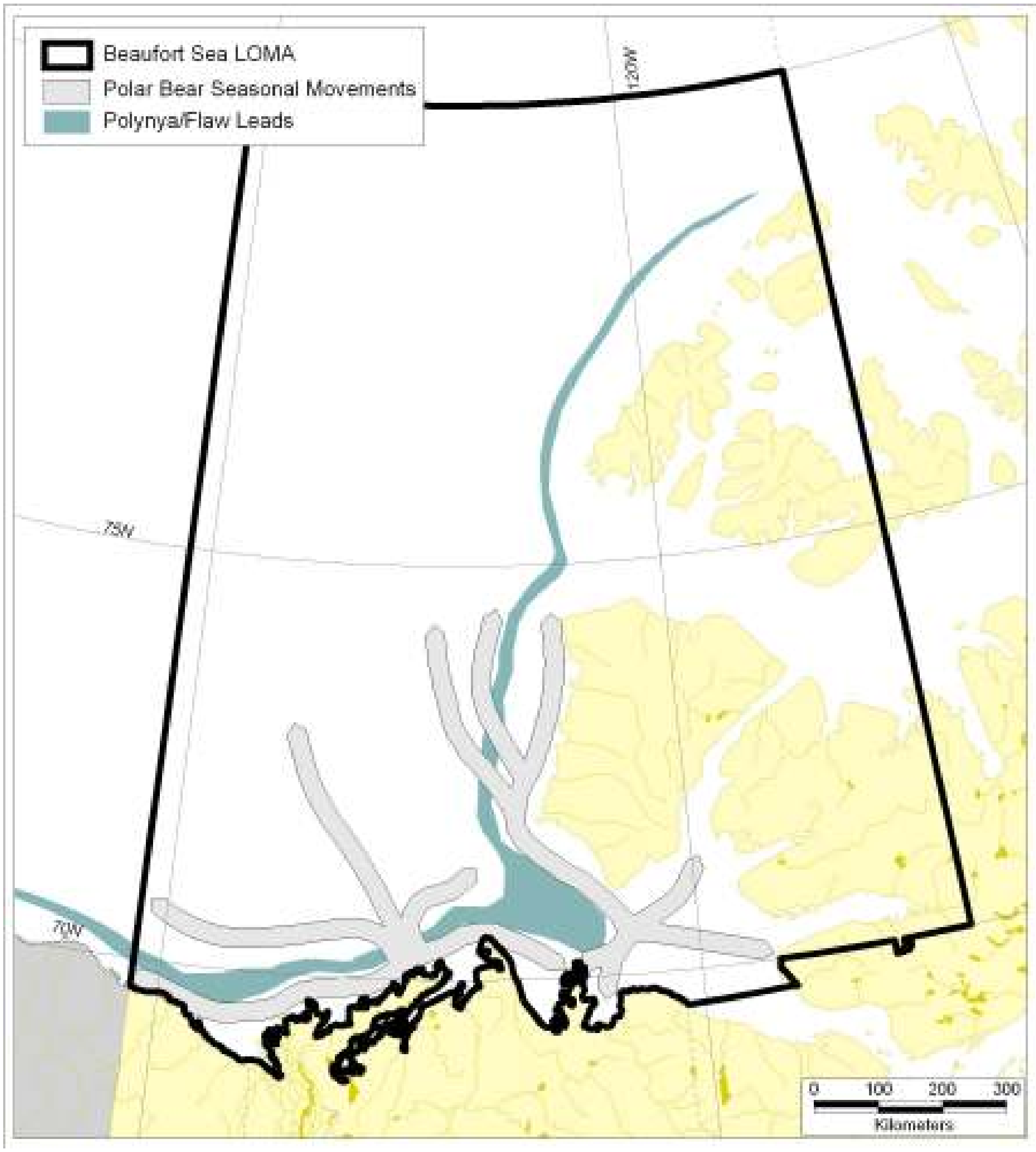

Figure 18. General pattern of seasonal polar bear movements in the Beaufort Sea (modified from Stirling 2002).

13. Marine Bird Communities

A diverse bird community uses coastal and offshore waters in the Beaufort Sea (Appendix 9). Many species migrate long distances from wintering areas as far south as the Antarctic to breed and fledge young in high-latitude regions. Six major species groups are represented: (1) ducks; (2) geese and swans; (3) murres and guillemots; (4) gulls, terns and jaegers; (5) loons; and (6) shorebirds. Seabird abundance is lower than in the eastern Canadian Arctic; however, the region provides critical habitat for Arctic ducks and geese (Mallory and Fontaine 2004). Critically important habitat for birds exists in both offshore and coastal areas. The recurring polynya off Cape Bathurst and the associated leads off Banks Island and the Mackenzie Delta provide critically important habitat for marine birds during spring migration (Alexander *et al.* 1997).

a. Ducks

Five duck species (Pacific common eider, king eider, long-tailed duck, and white-winged and surf scoters) are of international concern due to recent population declines (Goudie *et al.* 1994, Suydam *et al*. 1997, Caithamer *et al*. 2000, Suydam *et al*. 2000, Sea Duck Joint Venture Management Board 2001). All five species are susceptible to oil spills in moulting or wintering areas or along migration routes because they congregate in large flocks at sea (Brown and Fredrickson 1997, Goudie *et al*. 2000, Suydam 2000, Dickson and Gilchrist 2002). Other species found in the region include northern pintail, scaup and mergansers.

Polynya and lead habitats off Cape Bathurst, Banks Island and the Mackenzie Delta are critically important to sea ducks (king and common eiders and long-tailed ducks) during spring migration (Barry 1976, Johnson and Herter 1989, Alexander *et al.* 1997, Larned and Balogh 1997, Suydam *et al*. 2000, Dickson *et al*. 2005, Dickson *et al*. 2006). Most, if not all, of the Canadian western populations of king and common eiders stop to rest and feed for 2–4 weeks in the early open water of the southeastern Beaufort Sea, with peak numbers occuring from mid-May to mid-June (Figure 19) ((Dickson *et al*. 2005, Dickson *et al.* 2006). This early open water is critical to eider survival; thousands of birds starve to death in years when unfavourable wind and ice conditions cause the leads to close (Barry 1968, Fournier and Hines 1994). This area is also likely essential for accumulating energy reserves needed for successful reproduction (Parker and Holm 1990).

The area of highest spring sea duck concentration is the open water adjacent to the landfast ice between Tuktoyaktuk and Cape Bathurst (Figure 19) (Alexander *et al*. 1988, Alexander *et al.* 1997, Dickson *et al*. 2005, Dickson *et al*. 2006). This area is heavily used by common eiders regardless of the relative abundance of open water elsewhere (Alexander *et al*. 1997). King eiders stage primarily in this area and off the west coast of Banks Island (Alexander *et al*. 1997). Long-tailed ducks are more widely distributed, but most abundant between Cape Dalhousie and Baillie Islands, with a substantial number also staging off the Mackenzie Delta and Yukon coast (Alexander *et al*. 1997). Eider distribution during spring migration is likely affected by the location of the landfast ice edge, water depth, water turbidity and benthic biomass. Eiders feed mostly on bottom-dwelling invertebrates (chiefly molluscs and crustaceans) and tend to concentrate along the ice edge in water <25 m deep (Alexander *et al.* 1997, Goudie *et al*. 2000, Suydam 2000). Few eiders are found off the Mackenzie Delta where the water is turbid;

invertebrate production is reduced by turbidity and reduced visibility hampers foraging (Parsons *et al.* 1988 in Alexander *et al.* 1997).

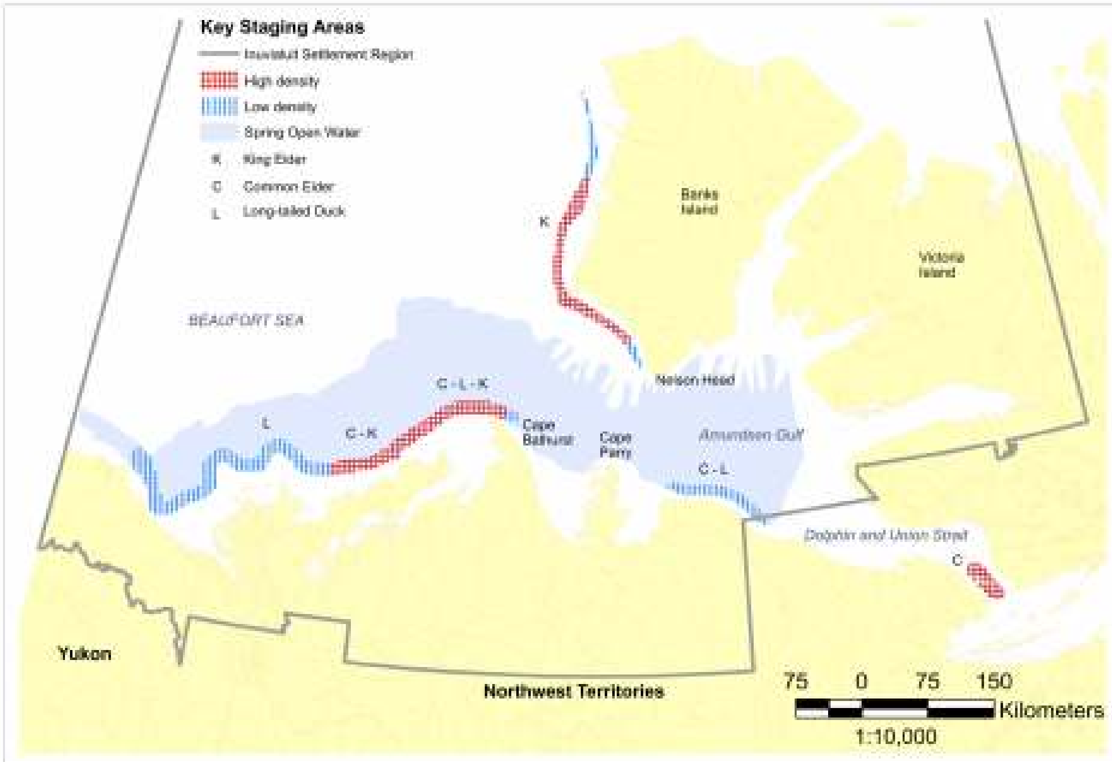

Figure 19. Location of major spring migration staging areas for several species of sea ducks (modified from Dickson and Gilchrist 2002).

The proportion of the western long-tailed duck population that uses leads in spring is unknown because some of these ducks migrate overland (Robertson and Savard 2002). However, they are abundant from Herschel Island to Cape Parry, with numbers peaking in late May and early June (Alexander *et al.* 1997). This species prefers to feed on bottom-dwelling invertebrates (mostly epibenthic crustaceans) in water <15 m deep; however, it is known to feed in water up to 66 m deep and also on ice-associated invertebrates (Alexander *et al.* 1997, Robertson and Savard 2002). It is therefore not as restricted in distribution along the landfast ice edge as eiders, and more widely distributed in the offshore leads in spring (Figure 19**)**. Long-tailed ducks remain in leads until breeding areas are available for nesting (Robertson and Savard 2002), and the highest concentrations occur in years with a late spring thaw (Alexander *et al.* 1997).

Most eiders migrate to breeding areas east of the Beaufort Sea (Dickson *et al.* 1997, Cornish and Dickson 1997). Moderate densities of king eiders nest on Tuktoyaktuk Peninsula and the west side of Banks Island (Dickson *et al.* 1997). They nest on inland lakes, but females and broods gradually move among water bodies in the direction of the sea (Suydam 2000). Common eiders nest solitarily or in colonies primarily on small (<2 ha) islands in marine waters, and rear their young in sheltered coastal waters (Dickson and Gilchrist 2002). A small number remain in the western Arctic, mostly nesting off the west side of Victoria Island (Cornish and Dickson 1997, Dickson and Gilchrist 2002). Colonies in this region have not been mapped in >25 years. Coastal islands also need to be resurveyed to confirm location of colonies and brood-rearing areas (L. Dickson, Canadian Wildlife Service (CWS), 4999-98 Ave., Edmonton, AB T6B 2X3, pers. comm.). Other duck species nesting in the region (e.g. long-tailed duck, northern pintail and scoters) rear their young on fresh water.

Starting in late June, ducks (primarily males and failed breeding females from inland nesting areas) flock to coastal bays and sheltered waters behind barrier islands to moult their flight feathers (Alexander *et al*. 1997). Peak numbers generally occur from late July to mid-August (Barry *et al*. 1981, Johnson and Richardson 1982, Cornish and Allen 1983). Probably >100,000 ducks moult along the Canadian Beaufort Sea coast (see data in Cornish and Dickson 1984, Cornish and Dickson 1986, Cornish and Dickson 1994, Cornish *et al.* 1991, Cornish *et al*. 1992, Dickson *et al*. 1993). Areas heavily used by moulting and pre-moulting ducks include McKinley Bay–Phillips Island, the Kukjuktuk and Hutchison Bay area, and Workboat Passage at Herschel Island (Latour *et al*. 2006) (Figure 20). Species include long-tailed duck, white-winged scoter, surf scoter, scaup and red-breasted merganser (Barry and Barry 1982, Cornish and Dickson 1994). The presence of large concentrations of flightless sea ducks during moult suggests that near-shore areas are very productive and support high densities of benthic fauna (Dickson and Gilchrist 2002), except for the turbid water off the Mackenzie Delta where few ducks are found during the moult (Alexander *et al.* 1988).

Westward movement of eiders across the southeastern Beaufort Sea towards wintering areas starts in late June, with staggered movement throughout summer and autumn into mid-November (Dickson *et al*. 2005, Dickson *et al.* 2006). Unlike in spring, the migratory pathway is generally a broad front up to 150 km offshore from the Mackenzie Delta, coming closer to land again off Alaska (Dickson *et al.* 2003). Some king eiders stop for 2–3 weeks off Banks Island or Cape Bathurst in July and August, presumably to accumulate reserves to continue migration. By contrast, eiders moving through in October tend to cross the southeastern Beaufort Sea within a week. Flocks of eiders (both species) seen along the coast of Tuktoyaktuk Peninsula in mid-summer are likely local breeders staging prior to moult migration (Cornish and Dickson 1983). Large spread-out flocks of long-tailed ducks and scoters predominate along the coast in September (Alexander *et al*. 1988).

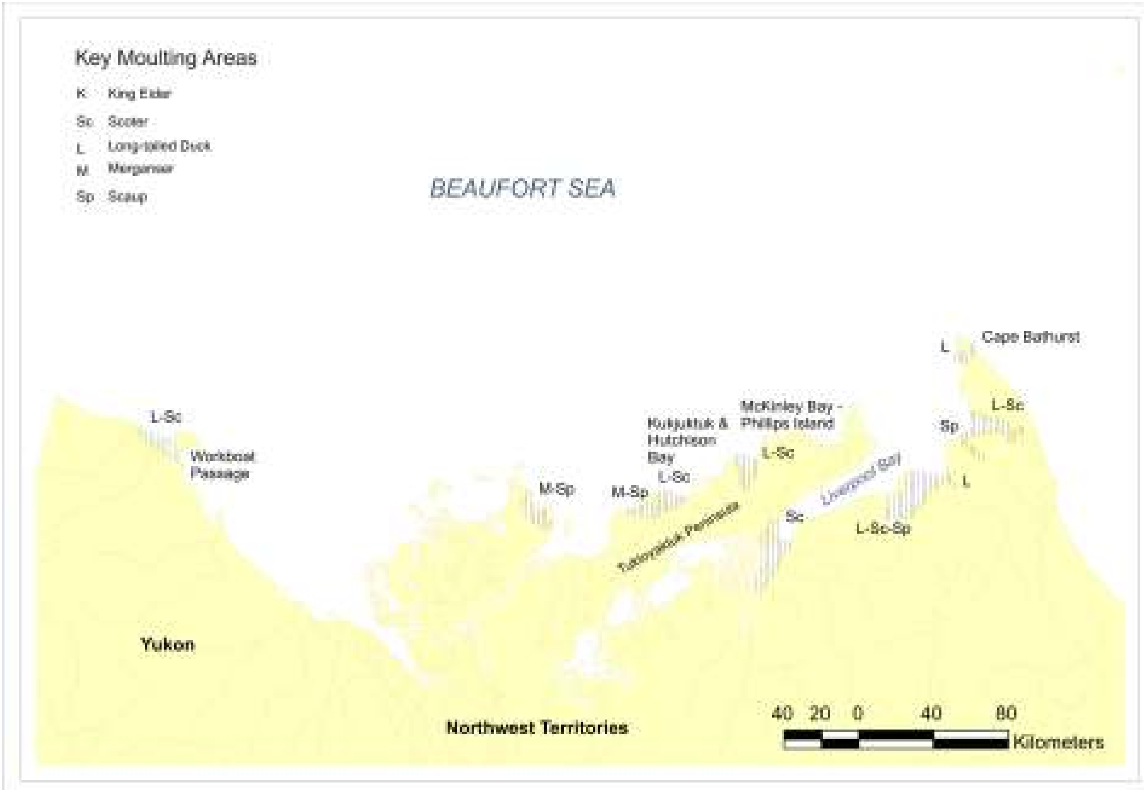

Figure 20. Location of key moulting areas for several species of sea ducks (modified from Dickson and Gilchrist 2002).

b. Geese and Swans

Five species of geese (Pacific black brant and lesser snow, greater white-fronted, Canada and cackling geese) and tundra swans occur in the Beaufort Sea. Use of marine habitats by geese and swans varies with species, time of year and area, with brant being the most marine-oriented species. Pacific black brant have been declining on a continental scale over the past 30 years (Reed *et al.* 1998).

Some brant use the offshore leads in spring, but most are found along the coastline (Alexander *et al*. 1997). Brant feed mainly on grasses and sedges on tidal flats during the summer nesting season (Barry 1967). Birds arrive on their nesting grounds in the Beaufort Sea in late May to early June (Reed *et al.* 1998) (Figure 21). Brant nest mainly along the coast, barely above the normal tide line (Dickson and Gilchrist 2002). Those nesting near the coast often raise their young in brackish waters (Alexander *et al*. 1988). Brant migrate west along the Beaufort Sea coastline in mid- to late August and September. Birds stop to rest and feed at numerous tidal marshes, deltas and lagoons along the coastline (Barry *et al.* 1981). The number of birds at any particular site and time can represent a significant portion of the autumn population (Latour *et al.* 2006). The Mackenzie Delta provides critical habitat during autumn migration, with up to 20% of the population stopping in small flocks to feed on tidal grasses (Latour *et al.* 2006).

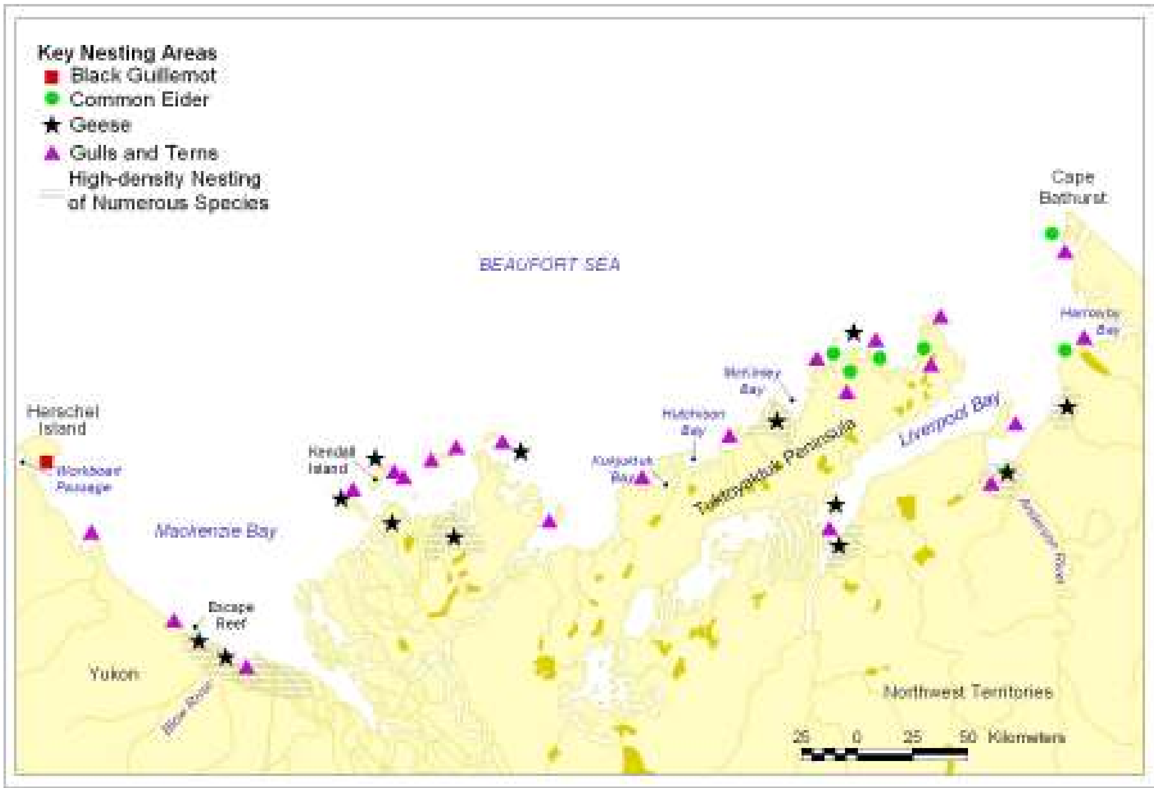

Figure 21. Location of key nesting areas for several species of marine birds (modified from Dickson and Gilchrist 2002).

Lesser snow geese generally do not use marine habitats to rear their young, although a small percentage of the total population nests in deltas and uses brackish waters (Alexander *et al.* 1988). The small islands south of Kendall Island support a breeding colony numbering >2000 birds (Latour *et al.* 2006) (Figure 21), and these birds use the surrounding marine waters. Greater white-fronted geese first appear in late May and begin autumn migration by late August. The McKinley Bay–Phillips Island area contains one of the highest breeding densities on the Beaufort Sea coast, and the Mackenzie Delta is also heavily used (Latour *et al*. 2006). Harrowby Bay and the Kukjuktuk and Hutchison Bay area are used for moulting (Alexander *et al*. 1988, Cornish and Dickson 1994). Harrowby Bay and the Kugaluk River provide important moulting habitat for Canada geese, and the Mackenzie Delta is heavily used by both cackling and Canada geese (Alexander *et al.* 1988). Tundra swans are widely distributed along the coast but do not use marine habitats for nesting, preferring to nest by lakes and raise their young in fresh water. The outer reaches of the Mackenzie Delta provide critical moulting habitat and also support a smaller number of nesting birds (Latour *et al.* 2006). The Kukjuktuk and Hutchison Bay area is also used for moulting (Alexander *et al.* 1988, Cornish and Dickson 1994). Some tundra swans and white-fronted geese nest in river deltas or near the coast and moult in sheltered brackish-water areas. Latour *et al*. (2006) describe the important stretches of the Northwest Territories coastline where these uses occur (Figure 21). Important areas along the Yukon coast include a small river delta at Phillips Bay and the Mackenzie Delta westward to Blow River (Alexander *et al*. 1988).

c. Murres and Guillemots

Seabirds are less abundant in the western Arctic than in the east, which may be related to food availability or a lack of suitable cliff nesting sites (Dickson and Gilchrist 2002). Two species nest in the western Canadian Arctic, the thick-billed murre and black guillemot. Auks are highly susceptible to oil spills (Dickins *et al.* 1990), making protection of the foraging areas around these colonies a priority.

The thick-billed murre colony at Cape Parry is the only one in the western Canadian Arctic and the only colony of the *arra* subspecies in Canada (Johnson and Ward 1985). The maximum number of murres counted per year has ranged from 125–784 and stood at 570 birds in 2002 (Latour *et al.* 2006). These birds are heavily dependent on the marine environment for food during nesting and brood-rearing. Thick-billed murres eat primarily midwater schooling fishes and crustaceans (Gaston and Hipfner 2000) and can forage up to 200 km from their colony (Gaston and Nettleship 1981, Hatch *et al*. 2000). However, most foraging occurs within a 30-km radius (Mallory and Fontaine 2004). Murres have low reproductive rates, laying only one egg per year (Gaston and Hipfner 2000), which makes the species susceptible to disturbance.

A few black guillemots nest at Cape Parry (Latour *et al*. 2006), and another colony is located at Herschel Island (Figure 21) (Kuyt *et al.* 1976, Barry *et al.* 1981, Johnson and Ward 1985). This colony numbered about 100 adult birds during the mid-1980s (Alexander et al. 1988) and 60 adults in 2005 (Eckert *et al.* 2006). The black guillemot is rarely found far offshore (Nettleship and Evans 1985), preferring inshore shallow waters where it can forage on fish and invertebrates on or near the bottom (Butler and Buckley 2002). Guillemots typically feed closer to shore than murres, and Mallory and Fontaine (2004) defined a 15-km radius around colonies as key marine areas. Adults move to moulting areas soon after the young fledge, and they may begin moving toward wintering areas (leads, polynyas and ice edges) during or soon after moult (Butler and Buckley 2002).

d. Gulls, Terns and Jaegers

This is a diverse group of marine birds, consisting of gulls, jaegers and the Arctic tern. Most are opportunistic omnivores that eat a wide variety of food items; some species, particularly jaegers and the larger gulls, are significant predators on the eggs and young of other birds. Many species are found in a variety of habitats and use both coastal and offshore environments. Arctic tern population declines have been noted in some areas (Hatch 2002), but trends for the western Canadian Arctic are unknown. Population trends for glaucous gulls are poorly known, with few changes in population size or distribution reported (Gilchrist 2001). Breeding populations have increased in coastal Alaska (Schmutz and Hobson 1998). Gilchrist (2001) identified a number of sources of baseline data, across a wide geographic range, which could help determine population trends with repeated surveys. There is no information on Thayer's gull population trends (Snell 2002).

Polynya and lead habitats are critically important to glaucous gulls during spring migration. They are common in the open-water leads throughout the Beaufort Sea, peaking in number in the last week of May (Alexander *et al.* 1997). They are known to concentrate along the margins of sea ice in the Arctic before returning to breeding sites (Gilchrist 2001), which suggests that the entire local breeding population of glaucous gulls is present offshore in the Beaufort Sea for a period in spring. The recurrent leads immediately north of Cape Parry are an important migration corridor for nationally significant populations (Barry and Barry 1982, Alexander *et al*. 1988). Ivory gulls and Ross's gulls may overwinter in offshore leads in some years (Barry 1976).

Coastal lagoons, bays, barriers islands and tidal marshes are heavily used during the nesting season by glaucous gulls and Arctic terns (Barry *et al.* 1981, Dickson and Gilchrist 2002). The glaucous gull is a common nester throughout the Beaufort Sea region (Dickson and Gilchrist 2002), nesting in colonies or in single pairs in a variety of habitats including islands, river deltas and barrier beaches (Gilchrist 2001). Gulls that forage away from the nest, along coasts or at sea, often nest colonially (Gaston and Nettleship 1981, Gilchrist and Gaston 1997). Some colonies in the Beaufort region, such as those at Escape Reef, are highly dependent on marine resources. Thayer's gull colonies are located on cliff habitats on north and southwest Banks Island (Manning *et al*. 1956) and the west side of Victoria Island (Cornish and Dickson 1996).

e. Loons

Three species of loons occur in the western Canadian Arctic. Red-throated loons in Alaska have declined >50% since the 1970s (Barr *et al.* 2000), but the census history in the Canadian Beaufort Sea is too brief to show trends (Dickson 1991, Dickson 1992). There is no continental information on yellow-billed loon population trends, but numbers appear stable in Alaska (North 1994). Population trends for Pacific loons are positive on a continental scale; however, there have been declines in parts of Alaska (Russell 2002). All three species are heavily dependent on the polynya and lead habitats off Banks Island and the Mackenzie Delta during spring migration. The recurrent leads immediately north of Cape Parry are an important migration corridor for nationally significant populations of yellow-billed loons (Barry and Barry 1982, Alexander *et al.* 1988). The entire local breeding population of red-throated loons likely stages in the leads in the Beaufort Sea each spring until nesting ponds become available (Alexander *et al.* 1997). Red-throated loons that nest farther to the east may also stage in the Beaufort Sea.

Numbers of red-throated loons in the spring migration generally peak in late May to mid-June (Alexander *et al*. 1997). They remain in the offshore leads until nesting ponds have open water, typically by mid-June (Dickson 1993). Important areas in the lead system include the region between Herschel Island and Tuktoyaktuk in particular and the coastline east to Cape Dalhousie (Alexander *et al.* 1997). They are common breeders on the Yukon coastal plain and Tuktoyaktuk Peninsula (Dickson 1993), but are less abundant in the Mackenzie Delta and on Victoria Island (Cornish and Dickson 1996, Barr *et al*. 2000). Red-throated loons nest on freshwater ponds close to the coast. Breeding ponds are shallow and support no fish, so adults must forage at sea and transport fish back to the nest (Dickson and Gilchrist 2002). Coastal habitats (lagoons, bays, barriers islands and tidal marshes) are therefore critically important feeding areas during nesting and brood rearing (Barry *et al*. 1981, Dickson and Gilchrist 2002). Birds generally depart upon autumn migration in early September (Johnson and Herter 1989). Small numbers migrate past the Alaskan and Yukon Beaufort Sea coasts but most migrate offshore (Barr *et al*. 2000).

Yellow-billed loons migrate along the coasts of the Beaufort Sea on their way to nest on freshwater lakes on Banks and Victoria islands (North 1994), typically arriving on the Yukon coast between late May and mid-June (Richardson *et al*. 1975, Salter *et al*. 1980). The Lambert Channel polynya is an important staging area during spring migration (Alexander *et al*. 1997). Yellow-billed loons generally do not use marine environments while nesting and brood rearing. Rather, they gather most of their food from the breeding territory, which is usually located on a lake (North 1994). However, some adults forage out to sea during the breeding season (Barr *et al*. 2000). Post-breeding birds move to the coast in August to mid-September, with peak westward migration occurring in mid-September (North 1994). They are often observed staging for migration on nearshore marine waters but some large movements may occur far offshore (North 1994).

Migration of Pacific loons peaks along the Canadian Beaufort Sea coast in mid-June, with substantial variability among years (Richardson and Johnson 1981). Upon arriving at the breeding grounds, individuals may spend time along the coast and in estuaries, where open water permits foraging, until frozen lakes thaw for nesting (Russell 2002). Pacific loons breed throughout the region (Russell 2002, Latour *et al*. 2006), usually on large waterbodies with enough fish and invertebrates to support their young (Dickson and Gilchrist 2002). Some adults feed along the coast during nesting but to a much lesser extent than red-throated loons (L. Dickson, CWS, pers. comm.). Autumn migration usually begins by late August and peaks during mid-September (Russell 2002). Some birds remain until late September in sheltered bays and on the open ocean along the Yukon coast (Salter *et al.* 1980).

f. Shorebirds

The Canadian Arctic supports a large number of nesting shorebird species (Morrison *et al.* 2001). This diverse group includes plovers, sandpipers, snipe and phalaropes. Shorebirds nest on inland waters so they tend not to use the marine area (excluding brackish coastal ponds), with phalaropes being a notable exception. Two species (red and red-necked phalaropes) occur in the Canadian Beaufort Sea and these birds often forage far offshore in marine environments (Rubega *et al*. 2000, Tracy *et al*. 2002). Red-necked phalarope populations have declined in some areas (Rubega *et al*. 2000), and red phalarope populations have declined in the eastern Arctic (Tracy *et al*. 2002).

Marine waters adjacent to the barrier beaches and spits near Herschel Island and Workboat Passage (Figure 21) are a major staging area for phalaropes prior to autumn migration (Alexander *et al*. 1988, Ealey *et al*. 1988). They are present from late July to early September, but are most abundant from early to mid-August, when >50,000 can be counted on a given day. They forage for small invertebrates in the water column within a few metres from shore, primarily on the windward side of the beach (Ealey *et al*. 1988). Red phalaropes may be found quite far offshore during autumn migration but this occurrence has received no study (V. Johnston, CWS, 5204 50^{th} Avenue, Suite 301, Yellowknife, NT, X1A 1E2, pers. comm.). Effects of the marine environment on adjacent nesting habitat and feeding ponds may pose the largest potential impact on other shorebird species. Pollution in coastal marine zones could potentially impact adjacent terrestrial shorebird populations (V. Johnston, CWS, pers. comm.).

Part D. Ecosystem Relationships

Marine ecosystems are complex, with biotic and abiotic interactions occurring at different levels of intensity over both space and time. A number of previous sections in this report have described the dominant physical processes that influence the Beaufort Sea LOMA. These dominant forces include: sea ice extent and duration; the Mackenzie River inflow, which supplies nutrients, sediment, and warm freshwater to the Beaufort Shelf; and oceanographic currents and upwelling driven by local and large-scale factors. It is within this physical environment that the Beaufort Sea food web functions, individual components of which have been described in previous sections. This section describes physical and biological linkages and biological interactions.

14. Physical–Biological Linkages

Sea Ice in the Beaufort Sea LOMA plays a dominant role in the ecosystem. It makes this LOMA unique compared to the other four LOMAs currently being studied under Canada's *Oceans Act* (1997). The seasonality and annual variability in extent of sea ice controls the timing and magnitude of production and provides an important habitat for lower trophic levels, such as ice algae and ice-associated invertebrates. Higher trophic levels, such as Arctic cod, are common along sea ice margins, feeding upon the ice-associated invertebrates. Sea ice also provides a critical habitat for the top predators, including seals, polar bears and humans. Sea ice also controls the timing and migratory routes for some fish and marine mammals.

The timing of sea ice formation and melt can vary annually by as much as one month. Landfast ice generally begins to form in early October, reaching maximum thickness in May. At its greatest extent, landfast ice covers the entire Beaufort Sea mainland coast (Percy *et al.* 1985). Ice begins to melt in June, coinciding with the Mackenzie River freshet. Year round (multi-year) sea ice remains at far-offshore sites within the LOMA.

Ice cover influences timing and magnitude of production in the Beaufort Sea area by limiting light availability for pelagic and benthic production, and restricting pelagic primary production to relatively small areas of polynyas. Sea ice is also an important habitat for a diverse and active community including bacteria, algae and a variety of micro- and meiofauna (Horner and Schrader 1982). Algae are the major component of sea-ice biomass, with the highest algal concentration occurring at the bottom of first-year landfast ice. Primary production within ice is significant and is estimated to contribute >25% of total Arctic primary productivity (Gosselin *et al.* 1977, Legendre *et al*. 1992). Sea ice production in the Beaufort Sea is especially important early in the growing season (Hill and Cota 2005). Ice algae provide an early and abundant food source for planktonic grazers at a time when other food sources are not available (Michel *et al.* 1996). However, ice algae can effectively shade the environment below, thereby impeding any pelagic or benthic primary production. Pelagic copepods and amphipods form the primary diet of Arctic cod, which are a key link to higher trophic levels, thus demonstrating the seasonal importance of ice algae at the foundation of Arctic marine food webs (Bradstreet and Cross 1982). Nutrients are released in bulk to the water column during the melt period, supporting increased production and flux of carbon to depth (O'Brien *et al.* 2006). Biomass in sea ice can quickly reach the benthos, resulting in a rapid increase in benthic activity during the melt period (Renaud *et al.* 2006).

Sea ice directly influences production and survival of higher-trophic-level organisms in the Beaufort Sea LOMA. Sea ice creates a barrier to food resources within the water column for organisms such as birds and polar bears, and heavy ice cover can be lethal to whales if they are not able to surface to breathe. Sea ice is an important platform used by birds, foxes, seals and polar bears for migration, hunting and/or reproduction.

Active food webs are associated with ice edges and polynyas. Primary production is enhanced at these sites due to the increased availability of light and nutrients. Ice edges can support intense phytoplankton blooms (Wang *et al*. 2005) relative to surrounding ice-covered areas. This increased primary production is efficiently transferred through invertebrates and Arctic cod to higher trophic levels, including birds and mammals, which congregate within these productive areas (Harwood and Stirling 1992).

The second most important physical determinant linked to ecosystem structure and function in the Beaufort Sea LOMA is the Mackenzie River. The seasonality of discharge from the Mackenzie River delivers large volumes of sediment and nutrient-laden fresh water to the Beaufort Shelf. This fresh water has the potential to influence vast areas of the Shelf depending upon wind and storm events, which modify the extent and direction of the Mackenzie plume.

The Arctic Ocean is generally considered to be the most oligotrophic ocean in the world, having lower productivity and species diversity than any of its counterparts (Dayton *et al*. 1994). Estimates of primary productivity in the Beaufort Sea range from 12–20 g C^{-1} m^{-1}. (Macdonald *et al.* 1989, Carmack *et al.* 2004). At the most basic level of the ecosystem, there are three major sources for carbon: (1) inorganic sediments; (2) terrestrial organic (allochthonous carbon); and (3) carbon derived *in situ* (autochthonous carbon). Sediments are supplied by rivers, coastal erosion, groundwater flow, sea ice and atmospheric deposition (Macdonald et al. 1998). However, the Mackenzie River remains the dominant (>95%) source of inorganic sediments and terrestrial carbon for the Beaufort Shelf.

The delivery of sediment and terrestrial carbon to the Beaufort Shelf is influenced by the timing of ice break-up, with riverine input being constrained to the area of landfast ice in spring and early summer (O'Brien et al. 2006). Inorganic sediments and allochthonous carbon transported by the Mackenzie River plume during the open-water period can reach as far as the Shelf edge. Annual deposition of sediments at the Shelf edge can vary annually by a factor of seven, with highest values being observed in the Mackenzie Canyon and lowest values occurring around the mid-Shelf edge (O'Brien et al. 2006).

Sediments deposited on the shelf can be re-suspended by ice scour, which occurs with the greatest intensity around the 20-m isobath (Carmack and Macdonald 2002), and by winds that drive currents and water-column mixing. For example, northwesterly gales in the area between Mackenzie Bay and the Bathurst Peninsula re-suspended sediments that were deposited beneath the landfast ice, whereas southeasterly gales enhanced the erosion of steep coastlines (O'Brien 2006). About half the inorganic sediments carried by the Mackenzie River are deposited within the Delta area, 40% on the Shelf and about 10% beyond the outer Shelf (Macdonald et al. 1998).

Particulate organic carbon delivered by the Mackenzie River is not easily broken down by microbial activity, and >50% is preserved in the benthic sediments of the Shelf (Macdonald et al. 1998). High bacterial activity at nearshore sites indicates that terrestrial dissolved organic carbon is being utilized by bacteria in the Beaufort Sea (Garneau et al. 2006).

Autochthonous production is represented mainly by ice algae and phytoplankton, with highest phytoplankton biomass occurring in the Cape Bathurst polynya (Arrigo and van Dijken 2004) and within regions of upwelling (Percy et al.1985, Carmack et al. 2004).

The combination of Mackenzie River and other smaller rivers flowing into the Beaufort Sea, along with ice melt, creates an environment where fresh and marine waters meet, forming a brackish-water (10–25 % salinity) band that is critical for anadromous fish migrating along the coastline from overwintering to spawning habitats, and for juvenile marine fish species (Craig 1984, Carmack and Macdonald 2002).

15. Biological Interactions – Ecosystem Structure and Dynamics

A number of previous sections in this report have noted that species are linked through trophic interactions. The exact nature of these interactions has been an important question in Arctic ecology for many years (Hunter and Price 1992). Trophic interactions are an important consideration when contemplating ecosystem-based management (EBM), because one of the objectives of EBM is to maintain each of the biotic components of the ecosystem so that they can continue to fulfill their historic role in the food web, i.e. to maintain their role in the trophic structure of the ecosystem. The previous section described the link between the physical and biological components of the ecosystem (i.e.

the physical drivers); this section will describe our current understanding of biological interactions of the Beaufort Sea LOMA food web.

A comprehensive, quantitative model of the Beaufort Sea food web has not been developed; however, the principle components and linkages of the food web are known (Figure 14, page 51). Arctic primary production is consumed by invertebrates (e.g. zooplankton, benthic invertebrates), which use a variety of feeding modes, such as predation (e.g. amphipods and echinoderms) and suspension feeding (e.g. copepods and bivalves) (Hobson and Welch 1992). Pelagic invertebrates are consumed primarily by fish, although they are also part of the diet of seals, birds and even whales (e.g. squid and octopus) (Lowry et al. 1986). Bearded seals and other benthic feeders, such as some fish species, also feed on invertebrates in the sediments (e.g. clams). Figure 14 is a schematic diagram of the Beaufort Sea food web showing the importance of ice algae, and associated biota, and open-water phytoplankton components of the marine food web. What is missing from this food web is the critical role bacteria plays as an integrator of carbon into the food web. We know bacteria are important; however, we do not fully understand the dynamics involved.

Small marine forage fish, principally Arctic cod, are a central link in both the ice algae and open-water phytoplankton parts of the food web. Arctic cod are thought to play this pivotal role in much of the Arctic Ocean (Craig 1984, Welch et al. 1992). There are presently no quantitative estimates of the size of the Arctic cod population in the Canadian Beaufort Sea, and the ecology of this important species is poorly understood. Lowry and Frost (1984) estimated a biomass of 85,890 tonnes for Arctic cod in the Alaskan Beaufort Sea, based on back calculations from all other consumers. The major food items of Arctic cod in the Beaufort Sea are zooplankton and fish larvae (Lacho 1986), but they also prey on benthic and planktonic organisms and other biota associated with the under-ice surface (Lowry and Frost 1984). These relatively small fish are then consumed by a variety of larger fish (e.g. charr) and are a major dietary component of birds and marine mammals (Bradstreet and Cross 1982), although they do not appear to be the sole food source of any one species (Smith 1987, Hobson and Welch 1992). Lowry and Frost (1984) estimated that in the Alaskan Beaufort Sea, ringed seals consumed 21,203 tonnes , beluga consumed 5875 tonnes and marine birds consumed 1552 tonnes of Arctic cod per year.

When examining Arctic food webs (e.g. Bradstreet et al. 1986, Welch et al. 1992), it is worth noting the many foodweb linkages to Arctic cod. Arctic cod is an important consumer of zooplankton and small fish, and is also prey for vertebrate consumers. This relationship emphasizes the critical role Arctic cod play in the Arctic ecosystem, thus suggesting they are an ecologically significant species in the LOMA (DFO 2006). Their significance could be an important factor to consider when forecasting impacts of climate change and increased development on the ecosystem of the Beaufort Sea LOMA.

The Beaufort Sea marine food web contains several vertebrate consumers that seasonally migrate into the Beaufort region (Figure 14). Bowhead whales, beluga whales and sea birds enter the system each summer, consuming significant numbers and biomass of forage species. Arctic charr and other anadromous fish migrate from fresh water to coastal brackish waters in the summer where they actively feed on invertebrates and small fish. Summer feeding in the brackish coastal waters accounts for as much as 80% of the yearly food intake of anadromous Arctic charr. The seasonal migrations of fish (e.g. Arctic charr), marine mammals (e.g. bowhead, beluga and ringed seals) and sea birds, after feeding extensively within the LOMA, could represent a significant net export of energy out of the Beaufort Sea (DFO 2006). Further research is needed to better understand the energy flow between seasonal environments used by highly migratory species within and outside of the Beaufort Sea LOMA.

Whales and polar bears represent the highest trophic levels of the Arctic marine food web, exclusive of humans. Whales consume a variety of fish and crustaceans, whereas polar bears are closely tied to a diet of ringed seals (Stirling 2002), occasionally preying on larger species such as beluga and narwhal (Smith and Sjare 1990). The annual fluctuation in several populations of ringed seals (L. Harwood, DFO, PO Box 1871, Inuvik, NT, X0E 0T0, pers. comm.) and polar bears (I. Stirling, CWS, Edmonton, AB T6H 3S5, pers. comm.) is being monitored within the Beaufort Sea LOMA to understand the impacts of industrial development and climate variability on these species.

Our quantitative understanding of the Beaufort Sea marine ecosystem has improved only marginally since Craig's (1984) report, but our general understanding of the complexity of marine ecosystems has increased significantly. The ability of large- and small-scale stressors to induce trophic shifts and trophic cascades in marine ecosystems has been documented (Zwanenburg et al. 2006). Both trophic shifts and cascades result in changes to the linkages between consumer and prey communities, which can have profound effects on the stability and productivity of an ecosystem. Recent theories of ecosystem function suggest that predatory-prey interactions may be more complex than depicted in Figure 14. For example, Walters and Kitchell (2001) have proposed that top predators cultivate their young by cropping down forage species that are potential predators. Such an interaction might well occur in a system where the key prey species (e.g. Arctic cod) is also a key consumer of small fish and invertebrates.

Clearly, if we are to better assess the impacts of human- and naturally induced changes (see Volume II) to the ecosystem of the Beaufort Sea LOMA, a more comprehensive and quantitative understanding of the marine food web and trophic interactions is a priority. A renewed emphasis on the north means that ongoing or planned research (e.g. Canadian Arctic Shelf Exchange Study, Northern Oil and Gas Science, and International Polar Year [IPY]), will produce a wealth of new knowledge on the Beaufort Sea Ecosystem. The next version of this report will incorporate that knowledge.

Volume II – Ecosystem Overview and Assessment

Part E. Ecological Assessment

16. Introduction

Volume I of this report provides information on marine and coastal ecosystems. It is based on the best science and knowledge available, and is intended to support IM planning and further decision-making.

Volume II of this report, Ecosystem Overview and Assessment, focuses on environmental issues of concern for the Beaufort Sea LOMA. It is intended to help decision-makers identify and set management priorities for the region. Maps are used liberally to document and illustrate areas that have special characteristics because of their ecological significance, or their use for specific activities, and to identify areas that warrant further attention within the IM planning process.

Volume II provides findings of research completed from 2006–2007 concerning the identification of EBSAs and key species in the Beaufort Sea LOMA. Scientists, northern experts and the six Inuvialuit communities provided input into this identification process through a series of workshops, community tours and meetings. The discussion begins with a review of the challenges that were addressed during the selection and evaluation process. The results of this process are provided next. These results will be used by scientists, managers and stakeholders to set environmental objectives for future monitoring of the LOMA, and to inform the IM Plan (Figure 22, page 88). To complement the identification of significant areas, researchers identified species with potentially controlling influences on ecosystem structure and/or function. These species and conditions are referred to as Ecologically Significant Species and Communities (ESSCs). This work was undertaken in parallel with the EBSA work. The process followed is described, a list of candidate ESSCs is provided, as is a list of rare/depleted and/or sensitive species and their corresponding conservation status in the Beaufort Sea LOMA.

The next section documents the region's extensive history of conservation, which includes regional and community landuse planning, and territorial, federal and other parks and conservation areas. Included are the proposed Marine Protected Area (MPA), bird sanctuaries, landmarks and kelp beds (Figure 23, page 94). Impacted areas are considered next, with the main areas of concern having their origin during oil and gas activities of the 1970s and 1980s (Figure 24, Page 97).

The discussion of activities and stressors reviews land-based activities, oil- and gas-related activities, marine transport, subsistence harvesting and marine tourism, as well as climate change, which is likely to affect where communities are situated, whether travel is safe or predictable, and where roads and pipelines can be constructed. Climate change is also likely to affect the concentrations and distributions of pollutants, and to increase vulnerability to introduced and non-native aquatic species.

Climate change will be one of the most important environmental and socioeconomic issues facing the Beaufort Sea LOMA, but this report does not attempt to treat this subject. Rather, the goal of EBM, which this report does address, is to preserve the ability of ecosystems to adapt to climate change, (i.e. preserve their natural resilience). Coastal residents will have to rely on their capacity for resilience and adaptation to cope with a changing and uncertain environment. It is hoped that, by working together, additional resources and intelligence will be brought to bear on these questions.

17. Areas of Concern

a. EBSAs

Canada's *Oceans Act* (1997) authorizes DFO to provide enhanced protection to areas of the oceans and coasts that are ecologically or biologically significant (DFO 2004). The identification of EBSAs is not a general strategy for protecting all habitats and marine communities that have ecological significance. Rather, it is a tool for calling attention to areas that have particularly high ecological or biological significance, to facilitate provision of a greater-than-usual degree of risk aversion in the management of activities in such areas (DFO 2004). Concluding that an area is ecologically or biologically significant does not give it any special legal status. Such identification provides guidance on the standard of management that is considered to be appropriate at any given time.

The identification of EBSAs within the Beaufort Sea LOMA presented a number of significant challenges, including: (1) the need to incorporate traditional and local knowledge; (2) a significant lack of scientific data; (3) significant seasonal and geographic bias in existing data; and (4) a bias towards knowledge of species that are important to communities for subsistence fishing and hunting. Workshops were held with the scientific and local communities to help identify potential EBSA candidates, which were evaluated in a final workshop (M.H. Papst et al., DFO, 501 University Crescent, Winnipeg, MB, R3T 2N6, pers. comm.). Each candidate area was evaluated using the National Evaluation Framework developed by DFO, which provided the necessary criteria (DFO 2004). Each area was ranked against the main dimensions (uniqueness, aggregation, fitness consequences) and the additional dimensions (resilience and naturalness) outlined in the Framework.

Each candidate EBSA was assigned to one of three categories:

- EBSA – the area was considered to be significant using the evaluation criteria (DFO 2004) and available information;
- EBSA data deficient – there is sufficient information to conclude the area is likely an EBSA, but insufficient information exists to complete an evaluation; or,
- Rejected EBSA – the area was identified by either the scientific or community workshops or both but was judged in the final workshop (M.H. Papst et al., DFO,

pers. comm.) not to meet the definition of an EBSA, based on the criteria of the Framework.

Identification of an area or species as significant indicates that, if the area or species were perturbed severely, the ecological consequences would be greater than an equal perturbation of most other areas or species (DFO 2004). Concluding an area is not an EBSA does not imply the area is not important; all species, habitats and areas have some ecological function.

i. EBSA Evaluation Results

Results of the community workshop and scientific workshop were combined to form the final list of 21 candidate EBSAs (Figure 22). In some cases the EBSA names used in each of the workshops (community and scientific) were changed to better describe the candidate area (EBSA evaluation results). For example, Herschel Island/Yukon North Slope (community workshop) and Herschel Island (scientific workshop) became Herschel Island/Yukon North Slope for the evaluation process (Table 2).

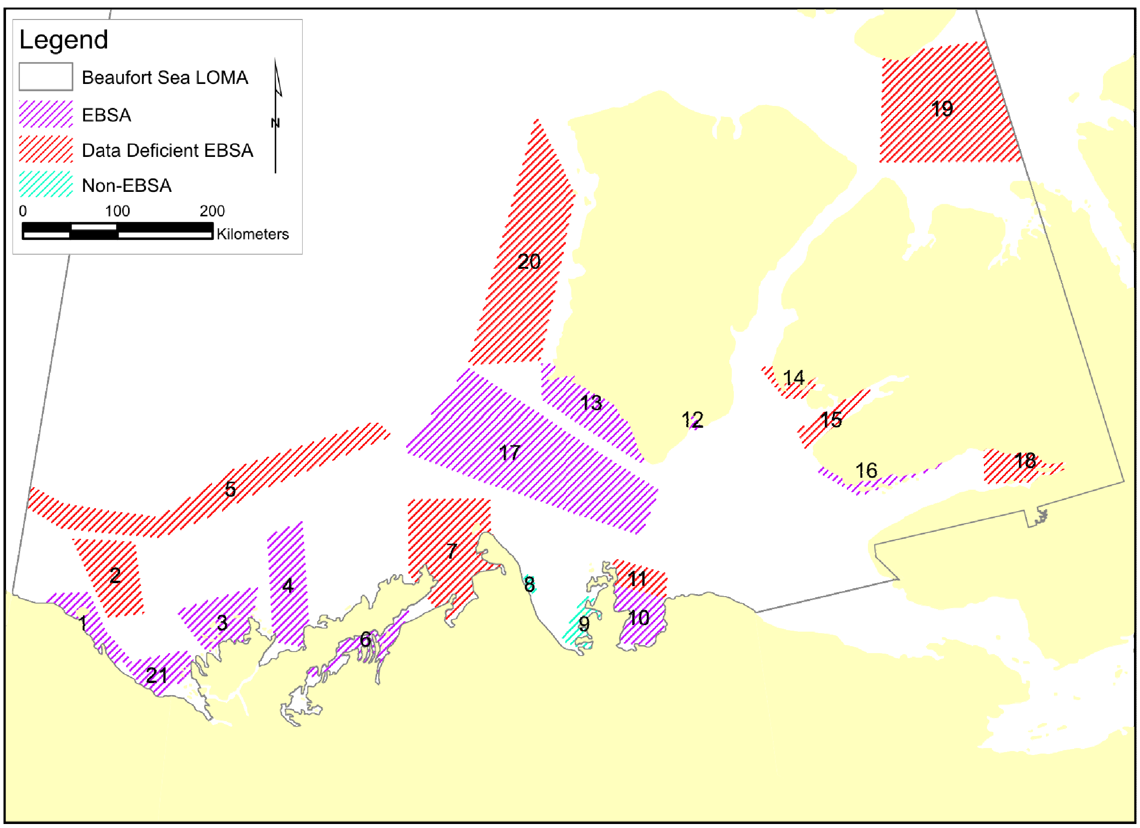

Figure 22. Ecologically and Biologically Significant Area (EBSAs) in the Beaufort Sea LOMA.

The evaluation summary consists of: (1) the EBSA name; (2) a summary of the evaluation with a copy of the matrix used to evaluate the candidate EBSA against the DFO criteria (DFO 2004); and (3) a map showing the geo-referenced boundaries of the EBSA (Figure 22).

Table 2. Results from the community, scientific and EBSA evaluation workshops. Evaluation results in red were classified as EBSAs, blue were EBSA data deficient and black were rejected EBSAs.

	Community Workshop		Scientific Workshop		EBSA Evaluation Results
1	Herschel Island	1	Herschel Island	1	Herschel Island/Yukon North Slope
2	Yukon North Slope	2	Mackenzie Trough	2	Mackenzie Trough
3	Kendall Island	3	Mackenzie Shelf Break	3	Beluga Bay
4	Kugmallit Bay	4	Mackenzie Plume	4	Kugmallit Corridor
5	Husky Lakes	5	Husky Lakes	5	Beaufort Shelf Break
6	Liverpool Bay	6	Liverpool Bay	6	Husky Lakes
7	Cape Kellett	7	Amundsen Gulf	7	Liverpool Bay
8	Sachs Harbour	8	Cape Bathurst Polynya	8	Horton River
9	Southern Darnley Bay	9	Prince Albert Sound	9	Langton Bay
10	Pearce Point	10	Minto Inlet	10	Hornaday River
11	Horton River	11	Viscount Melville Sound	11	Pearce Point
12	Eastern Franklin Bay			12	De Salis Bay
13	Walker Bay			13	Thesiger Bay
14	Albert Islands			14	Walker Bay
15	Kagloryuak River			15	Minto Inlet
				16	Albert Islands/Safety Channel
				17	Cape Bathurst Polynya
				18	Kagloryuak River
				19	Viscount Melville Sound
				20	Banks Island Flaw Lead
				21	Shallow Bay

The matrix results are shown in Appendix 10. All EBSA boundaries should be considered preliminary because they will be refined based on future monitoring and research efforts. Some of the EBSAs, such as the flaw lead and the Cape Bathurst polynya, vary in their exact location annually, so only an approximate location for these boundaries was used in this report.

The evaluation process produced 10 EBSAs, 10 EBSA data deficients and one rejected EBSA (Table 2). The results of these workshops and the final evaluations will be used by managers and stakeholders to set conservation objectives for the development and implementation of management plans in the Beaufort Sea LOMA (DFO 2004). These EBSA evaluations are another step towards integrated EBM in the region.

b. ESSCs

Canada's *Oceans Act* (1997) directs DFO to lead an ecosystem-based approach to integrated management of human activities in the sea (DFO 2004). This approach is intended to provide enhanced protection to species and community properties that are particularly significant to maintaining ecosystem structure and function. Species and community properties can be ecologically "significant" because of the functions they serve in the ecosystem and/or because of useful features they provide for parts of the ecosystem. All species have some function in the ecosystem that they inhabit. Identifying ESSCs is not a general strategy for protecting all populations and marine communities. Rather, it is a tool for calling attention to species or community properties that have particularly high ecological significance, to facilitate provision of a greater-than-usual degree of risk aversion in the management of human activities that may affect such species or community properties. Similar to EBSAs, a general process for identifying ESSCs based on their trophic roles has been developed as a National Evaluation Framework (DFO 2006).

The DFO general process for identifying ESSCs recommends assessing four types of species and community properties:

- Type 1 - species-based assessments of ecological significance, i.e. identifying species with potentially controlling influences (e.g. a crucial trophodynamic role) on ecosystem structure and function;
- Type 2 - the species provides three-dimensional structure important to biodiversity and productivity of the ecosystem;
- Type 3 - there are aggregate ecosystem properties at the community level that are essential to maintaining ecosystem structure and function; and
- Type 4 - species or species groups that, if abundant, could pose a particular threat to ecosystem structure and function; they may be candidates for enhanced management because of their ecological significance (e.g. to control their abundance and/or distribution rather than protect and promote it).

The general process for identifying ESSCs recognizes that there is often insufficient information to quantify how interactive strengths are distributed among species in an ecosystem. Therefore, the general process for identifying ESSCs focuses on four key trophic roles in the ecosystem: (1) forage species; (2) highly influential predators; (3) nutrient importing and exporting species; and (4) primary production and decomposition communities and/or species.

The identification process for ESSCs in the Beaufort Sea LOMA followed DFO (2006), and candidate species were identified through consultation with local community members and the scientific community. The general structure of the ecosystem, as outlined in Volume I, Part D, Section 15 was used to identify trophic roles for species and/or communities in the Beaufort Sea. Species and communities in the ecosystem were assessed initially by the regional EOAR team, followed by compilation of a list of ESSCs in the Beaufort Sea LOMA with rationales for the designated species and/or communities.

<u>i. ESSC Evaluation Results</u>

Four communities and 43 taxa were identified as possible ESSCs. The EOAR team then assessed each one using the National ESSC Evaluation Framework (DFO 2006). Three communities and nine species were identified as candidate ESSCs for the Beaufort Sea LOMA, and rationales for each choice were provided (Table 3).

Table 3. Candidate ESSCs in the Beaufort Sea LOMA.

Species/Community	Scientific Name	Rational
Ice algae community		Primary producers
Herbivorous zooplankton community		Key grazer species and key forage species
Herbivorous zooplankton	*Limnocalanus macrurus*	Key forage species
Ice-associated amphipods		Key forage species
Mysids	Mysidae	Key forage species
Arctic cod	*Boreogadus saida*	Key forage species
Arctic charr	*Salvelinus alpinus*	Influential predator/ nutrient importing and exporting species
Arctic cisco	*Coregonus autumnalis*	Key forage species/nutrient importing and exporting species
Beluga whale	*Delphinapterus leucas*	Influential predator/ nutrient importing and exporting species
Bowhead whale	*Balaena mysticetus*	Influential predator/ nutrient importing and exporting species
Ringed seal	*Phoca hispida*	Influential predator/ nutrient importing and exporting species
Polar bear	*Ursus maritimus*	Influential predator

ii. Rare, Depleted and Sensitive Species

In addition to the ESSCs identified for the Beaufort Sea LOMA, 16 species were added to the list due to their rarity and or sensitivity (Table 4). These 16 species have been given an even higher level of risk-averse management then otherwise would be suggested based on their status under the Species at Risk Act (SARA), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or the Government of the Northwest Territories General Status Ranking Program.

SARA was proclaimed in 2003, and is part of a strategy for the protection of wildlife species at risk. The Minister of the Environment is generally responsible for SARA 's overall administration, except when the Act gives responsibility to the Minister of Fisheries and Oceans for the protection and recovery of aquatic species at risk in his/her jurisdiction. COSEWIC advises the federal government on the status of wildlife species, by conducting assessments of species. The Government of the Northwest Territories created the NWT General Status Ranking Program, which has been collecting information on species of the NWT since 1999. Reports on the general status ranks for the NWT are published every five years. The NWT Species 2006–2010 report presents lists and general status ranks for 1700 wild species. Ranks are valid for five years, and provide priority lists of species that require more detailed assessment and may need special protection efforts now or in the future. The NWT rank of "sensitive" does not mean that species are at risk of extinction or extirpation, but may require special attention or protection to prevent them from becoming "at risk". However, the sensitive ranking used by the NWT does not follow the National Evaluation Framework (DFO 2006) used in the ESSC evaluation.

Table 4. Rare/Depleted and/or Sensitive species and their corresponding conservation status in the Beaufort Sea LOMA.

Group	Common Name	Scientific Name	SARA	COSEWIC	NWT*
Bird	Northern pintail	*Anus acuta*			Sensitive
Bird	Brant	*Branta bernicla*			Sensitive
Bird	Long-tailed duck (Oldsquaw)	*Clangula hyemalis*			Sensitive
Bird	White-winged scoter	*Melanitta fusca*			Sensitive
Bird	Common eider	*Somateria mollissima*			Sensitive
Bird	King eider	*Somateria spectabillis*			Sensitive
Bird	Thick-billed murre	*Uria lomvia*			Sensitive
Bird	Ivory gull	*Pagophila eburnean*	Special Concern	Endangered – April 2006	At Risk
Bird	Ross's gull	*Rhodostethia rosea*	Threatened	Threatened–2007	Sensitive
Bird	Red phalarope	*Phalaropus fulicaria*			Sensitive
Fish	Northern Dolly Varden[1]	*Salvelinus malma*			Sensitive
Fish	Pigheaded prickleback (Blackline)	*Acantholumpenus mackayi*	No Status	Data Deficient - 2003	
Fish	Northern wolffish	*Anarchichas denticulatus*	Threatened	Threatened - 2001	
Marine mammal	Bowhead whale[2]	*Balaena mysticetus*	Special Concern	Special Concern–2005	Sensitive
Marine mammal	Polar bear	*Ursus maritimus*	No Status	Special Concern – 2002	
Marine mammal	Grey whale[3]	*Eschrichtius robustus*	Special Concern	Special Concern – 2004	

* NWT Species 2006–2010 General Status Ranks of Wild Species in the Northwest Territories
[1] Rat River and Big Fish River populations
[2] Bering-Chukchi-Beaufort population
[3] Eastern North Pacific population

The 2006 COSEWIC assessment of the ivory gull determined that it is endangered, and the species is currently being considered for addition to Schedule 1 of SARA. Schedule 1 is the legislatively protected list of threatened or endangered species. This bird feeds along ice-edge habitats in the high Arctic and breeds in very remote locations. The Ross's gull is considered threatened by SARA. To date there are only two known breeding sites of this species in Canada.

The Bering-Chukchi-Beaufort population of bowhead whale was listed as of "special concern" in 2005 by COSEWIC and is currently under consideration by SARA for addition to Schedule 1. This population was hunted to low levels during commercial whaling, but today's hunts are regulated, and the population is recovering.

The northern Dolly Varden charr is a unique taxonomic form of salmonid to Canada with only seven or eight known populations. In the Beaufort Sea, both the Rat and Big Fish river populations in the Beaufort Sea LOMA are considered depleted (J. Reist, DFO, pers. comm.). Also, the pigheaded prickleback has been categorized as "data deficient/ unknown" by COSEWIC. This species, along with the wolffish are considered rare, and there are few records of their distributions extending into the Beaufort LOMA (Coad and Reist 2004). They are considered data deficient until research can be conducted to determine their status in the LOMA.

c. Conservation Areas

The Beaufort Sea region has a long history of marine conservation efforts (Figure 23). These efforts include extensive regional and community landuse planning. Each community in the ISR has developed a Conservation Plan and preliminary guidelines for wildlife management and conservation, including subsistence and commercial harvesting, tourism and local enjoyment. Local knowledge and outside expertise were used in developing these Conservation Plans, which include a one-page summary for each species of concern.

The Beaufort Sea region also has three national parks, one territorial park, five CWS migratory bird sanctuaries (MBSs), important coastlines designated as conservation areas under the Inuvialuit Final Agreement (IFA) and international recognition of two islands for their importance to waterfowl. A MPA has been proposed and is likely to be announced in 2007–2008.

The three National Parks in the Beaufort Sea LOMA include Tuktut Nogait, Aulavik and Ivvavik. Tuktut Nogait (*young caribou*) is located 170 km north of the Arctic Circle and is home to the bluenose west caribou herd, wolves, grizzly bears, muskoxen, Arctic charr, and a high density of raptors. Aulavik (*place where people travel*) protects >12,000 km^2 of Arctic lowlands on the north end of Banks Island, and is home to both the endangered Peary caribou and to the highest density of muskoxen in the world. Ivvavik (*a place for giving birth, a nursery*), is the first national park in Canada to be created as a result of an aboriginal land claim agreement. The park protects a portion of the calving grounds of the Porcupine caribou herd and represents the Northern Yukon and Mackenzie Delta natural regions.

MBSs are established by Environment Canada (EC) under the *Migratory Birds Convention Act*. CWS is responsible for the conservation and management of migratory birds in Canada. MBSs seek to conserve the diversity of migratory birds by controlling human activities within the sanctuary boundaries. The Kendall Island MBS (KIBS) was established in 1961 and has an area of approximately 606 km^2. The KIBS contains habitat for 7500 lesser snow geese and some of the 60,000 pairs of shorebirds that nest in the

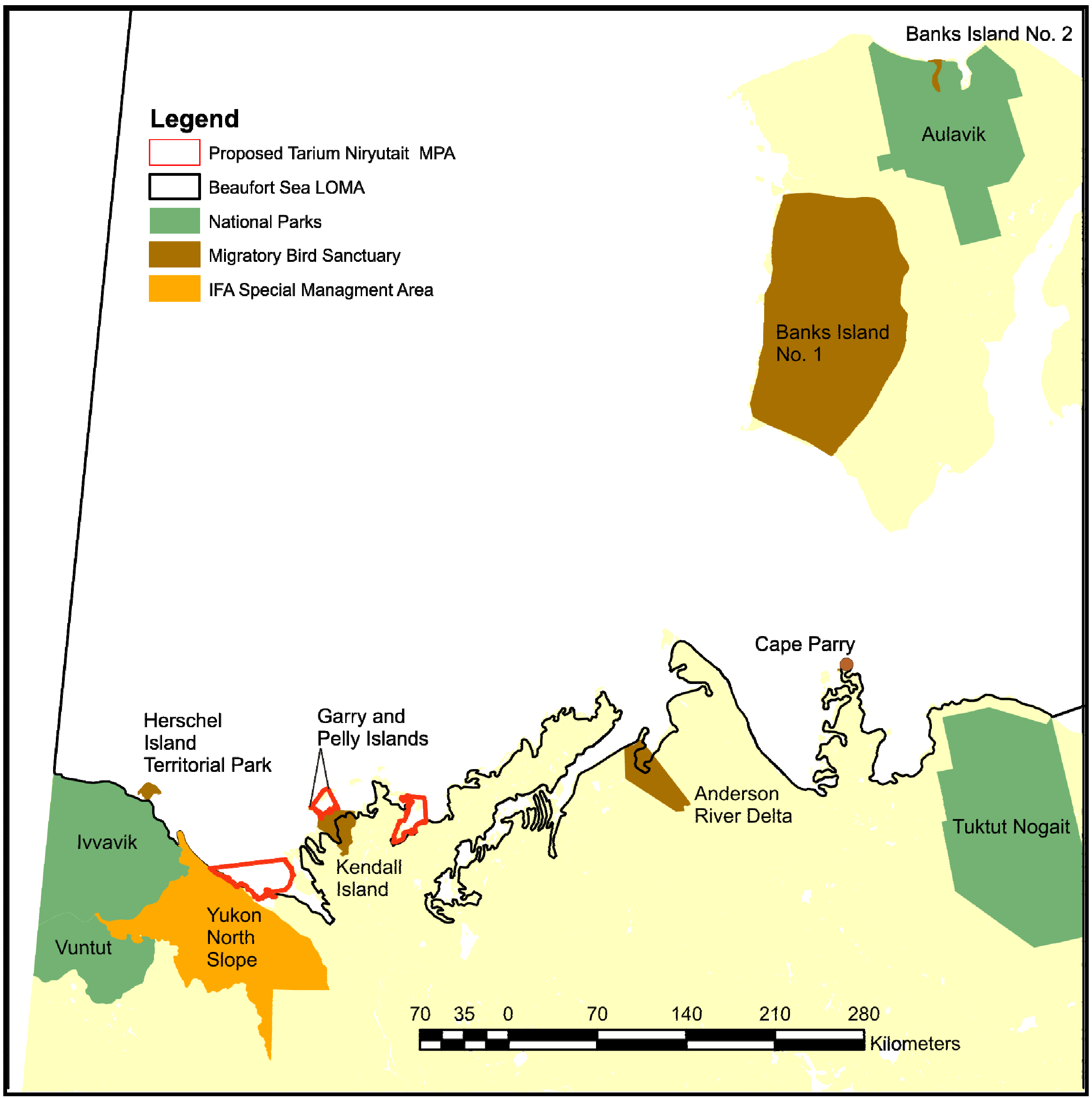

Figure 23. Conservation and protected areas in the Beaufort Sea LOMA (CWS, DFO, Parks Canada).

outer Mackenzie Delta. The Anderson River Delta MBS was established in 1961 and has an area of 1025 km^2. The area is used for breeding, moulting and staging by black brant, tundra swan, lesser snow geese, and the greater white-fronted geese. Oldsquaw, scaup, scoters, dabbling ducks, shorebirds, raptors and songbirds are all found in the MBS. The Cape Parry MBS was established in 1961, has an area of 2 km^2 and is located at the northern end of the Parry Peninsula. The only thick-billed murre colonies in the western Canadian Arctic are found in this sanctuary, nesting on the limestone cliffs. Banks Island MBS #1 and #2 are located on the southern and northern sides of Banks Island, bordering the Beaufort Sea. These sanctuaries were established in 1961 and have areas of approximately 20,000 km^2 and 170 km^2, respectively. The largest lesser snow goose breeding colony in the western Arctic can be found at the confluence of the Egg and Big rivers in Banks Island MBS #1.

The area known as the Yukon North Slope was designated under the IFA as a Special Management Area. It is more ecologically diverse than many Arctic environments, and falls under a special conservation regime whose dominant purpose is the conservation of wildlife, habitat and traditional native use. All development proposals relating to the Yukon North Slope are screened to determine whether they could have a significant negative impact on the wildlife, habitat or ability of the natives to harvest wildlife. Uses that may have a significant negative impact on wildlife, habitat or native harvesting are permitted if it is decided that public convenience and necessity outweigh conservation or native harvesting interests in the area. Development proposals relating to the Yukon North Slope that may have a significant negative impact are subject to a public environmental impact assessment (EIA) and review process.

Herschel Island Territorial Park is a small historic park located off the north coast of Yukon in the Beaufort Sea. It was a whaling station in the closing years of the 19th century. Both beluga and bowhead whales may be seen offshore in July and August. The Inuvialuit community of Kittigaryuit was declared to be of national historic significance in 1978, but has not yet been commemorated as a National Historic Site. Kittigaryuit is an important Inuvialuit archaeological site. As a semi-permanent settlement, the village was occupied by the Inuvialuit for centuries and continues to be used on a seasonal basis today.

Garry and Pelly islands have been established as International Biological Program sites because of their value to waterfowl. These sites are not presently protected by any federal or territorial legislation, but they are recognized by federal and territorial agencies as important natural areas and are considered candidates for future designation under environmentally protective legislation.

A reindeer reserve started operation in 1935 and covers roughly 46,500 km^2. The reserve was meant to protect rangeland for summer grazing by reindeer and to regulate hunting to preserve this food source for the Inuvialuit. The reserve was established through regulation (*Northwest Territories Act*), but there are no restrictions on development or other types of activities within the reserve. The reserve has not been successful in terms of establishing reindeer as a food source for the Inuvialuit.

The *Oceans Act* (1997) granted DFO the authority to designate MPAs for one or more of the following reasons: (1) the conservation and protection of commercial and non-commercial fishery resources, including marine mammals and their habitats; (2) the conservation and protection of endangered or threatened marine species and their habitats; (3) the conservation and protection of unique habitats; (4) the conservation and protection of marine areas of high biodiversity or biological productivity; and (5) the conservation and protection of any other marine resource or habitat necessary to fulfill the mandate of the Minister (Canada 1997).

An MPA called the Tarium Niryutait (TNMPA) has been proposed for designation, following an extensive and thorough consultation process. The TNMPA consists of three separate but related MPAs: Imaryuk (Shallow Bay), Kittigaryuit (Kugmallit Bay) and Okeevik located in the Mackenzie River estuary of the Beaufort Sea. Conservation objectives for the proposed TNMPA are meant to protect beluga whales and their habitat. The MPAs will be managed as two zones: (1) the Primary Protection Zone, which comprises 99% of the MPAs and conveys the highest level of protection; and (2) the Special Management Zone, which allows some industrial use in two areas where Significant Oil and Gas Discovery Licences already had been granted by Indian and Northern Affairs Canada (INAC).

d. Impacted Areas

The Beaufort Sea LOMA is a relatively pristine area compared to other Canadian LOMAs. However, people impact the marine environment not only through activities such as oil and gas exploration, but also as a result of accident, neglect and unintentionally through the general activities of our society (Figure 24).

The Canadian Distant Early Warning (DEW Line) stations were constructed in the 1950s in response to the Cold War. Dozens of camps and airstrips also had to be built and maintained along with these stations. Polychlorinated biphenyl (PCB) contamination is a major problem at all of the sites, because these chemicals were used in everything from transformers to paint in the 1950s. To date, many of these sites have been decommissioned and closed by the federal government, with the exception of Atkinson Point, which is slated for cleanup and restoration activities in the summer of 2007.

The Hamlet of Tuktoyaktuk and its harbour functioned as a key logistical support centre for oil and gas exploration in the Beaufort Sea during the 1970s and 1980s. The harbour was also dredged during that time to deepen and widen access for logistical support equipment. Community members have reported that the Arctic cisco populations that were resident in the area prior to dredging have never recovered.

Numerous artificial islands were constructed in the southern portion of the Canadian Beaufort Sea during oil and gas developments of the 1970s and 1980s. These structures were required to support year-round oil and gas exploration and they were temporary in nature, typically being occupied for <1 year. Construction water depths ranged from 1.3–45 m. Drilling equipment and slope protection were removed following completion of exploration activities, permitting the granular fill to be dispersed by waves. These islands have been seen by the local people as detriments to the environment (e.g. affecting polar bear distributions); however, no alternative management has ever been implemented.

The remnants of exploration camps are another by-product of oil and gas exploration. In addition to their physical infrastructure, these camps housed human-waste-disposal units,

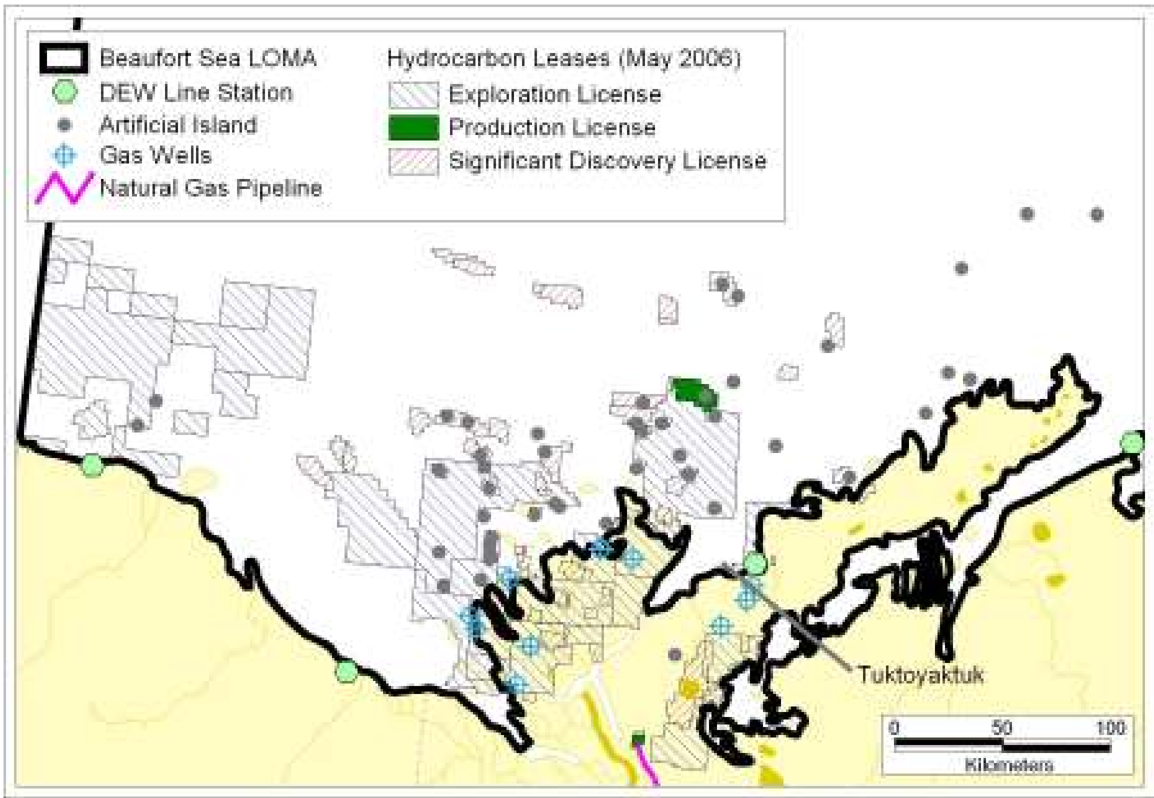

Figure 24. Development-related activities in the Beaufort Sea LOMA (INAC, DFO).

large tank farms of diesel and jet fuels, and drilling mud chemicals. Most sites were decommissioned at the end of use but a number of sites still remain. The federal government has become the caretaker of these sites, many of which need to be confirmed and assessed. Johnson Point on Banks Island is slated for cleanup during the summer of 2009.

Sea dumping is another source of marine pollution. In Canada, such dumping is regulated by EC under the *Canadian Environmental Protection Act*. The municipality of Sachs Harbour runs a commercial hunt of muskox every few years in which tonnes of muskox offal and bones are produced. The municipality is permitted to dispose of this waste at an offshore site located at least 2 km from shore. No more than 200 tonnes can be disposed of at this site each year. The offal mixes with the marine environment during spring breakup.

The implications of these locally disturbed areas at the ecosystem scale are not well understood; therefore, they are presently data deficient in the context of the national guidance on degraded areas.

18. Impacting Activities and Stressors

Stressors evident in the Beaufort Sea LOMA include activities occurring both in and outside the LOMA (Table 5) (see 0 for details on marine transport and oil and gas activities). Coastal infrastructure, watershed activities and long-range transport of pollutants fall under land-based activities. Impacts of seismic, exploratory and ultimately exploitation activities are stressors related to oil and gas and mineral and granular resource extraction. Marine transport impacts include those that occur with the passage of ships and barges, discharge of ballast water, and unplanned spills and discharges. Hunting and fishing is conducted at subsistence levels, and impacts are minor, as they are with the fairly limited recreational and tourism activities occurring in the region. Climate change is a major stressor with multiple impacts, many of which are poorly understood. These impacts are not manageable, certainly at the regional level, so adaptation will be the primary response. These stressors all have impacts on the ecosystem. These impacts include water and sediment pollution, biological changes and physical alterations.

a) Major Human Activities

i) Land-Based

Sewage treatment in the six small LOMA communities is rudimentary (Table 5). Some communities discharge untreated or primary treated sewage into rivers and coastal waters, including waters frequented by fish. Other communities rely on storage in sewage lagoons or holding ponds with very slow bacterial processes. These lagoons are at risk of breaching during flood times, and wastes from these systems may leach into surface drainage systems. Solid waste may be disposed of by incineration, which results in release of contaminants into the air, or in open sites where decomposition can take many decades due to slow biological processes. Contaminants from open solid-waste sites may leach into the adjacent environment, including waters frequented by fish (EMAN-North 2005). As these communities expand, they will have increased development and recreational uses, require ice and all season roads, and generally leave a larger ecological footprint on adjacent estuarine, coastal and marine environments.

The Mackenzie Delta and adjacent offshore waters may also experience impacts related to oil and gas activities (Table 5). Construction camps, temporary roads, wellsites and other infrastructure produce short-term impacts. Permanent installations on land, coasts and offshore areas produce long-term impacts. Exploration and production facilities, mainline pipelines and gathering systems, compressor stations, and all the associated roads and infrastructures will all produce impacts.

In summer, marine and air transport is the primary mode of travel. In winter, ice roads along coasts and rivers are used extensively, with the potential for additional ice and temporary roads to service hydrocarbon activities. There are presently no restrictions on the construction and operation of ice roads. All-terrain vehicles, commonly used in the LOMA, do not require ice roads and are not subject to any restrictions or limitations for travel along rivers, lakes and coasts. Increased use of winter transport will increase the risk of spills, contamination and accidents in the Mackenzie Delta and along coasts.

Table 5. Beaufort Sea activities and stressors (see Appendix 11 for details on marine transport and oil and gas activities).

Beaufort Sea activities vs. stressors		Climate change	Marine transport			Oil and gas			Land-based			Hunting and fishing		Recreation/ tourism
		Adaptation	Shipping	Ballast water	Spills and discharge	Seismic	Exploratory	Exploitation	Coastal infrastructure	Watershed	Long-range transport	Subsistence	Commercial (small charr fisheries)	
Water and sediment pollution	Organic waste	x	x		x		x	x	x	x				x
	Bacteria	x	x		x				x	x				x
	Nutrients		x				x	x	x	x				x
	Oil waste/spills		x		x		x	x	x	x				
	Chemical contaminants		x				x		x	x	x	x	x	
	Sediment movement	x	x				x		x	x		x		
	Salinity changes	x												
Biological	Invasive species and range extensions	x	x	x										
	Accidental kill		x			x						x	x	
	Disease and parasites	x	x	x										
	Behaviour		x			x						x	x	x
	Harassment		x			x	x	x						x
	Over-harvesting											x	x	
Physical alteration	Change in currents	x							x					
	Change in temperature	x												
	Freshwater inputs	x								x				
	Debris		x		x		x		x			x		
	Obstructions						x						x	
	Gear on bottom		x				x					x		
	Collisions		x											
	Noise		x			x	x							x
	Light		x			x	x							x
	Sea level	x												
	Ice cover	x												
	Permafrost	x							x					

ii) Oil and Gas

The National Energy Board (NEB) estimates that nine trillion cubic feet of discovered gas reserves exist in the Mackenzie Delta and an additional 55 trillion cubic feet may exist in undiscovered reserves (NEB 2004). Thus, the Mackenzie Delta region has become a major focus for energy producers in North America. The management of oil and gas resources in the northern offshore zone is a federal responsibility, which is carried out by the Northern Oil and Gas Directorate of INAC. Significant Discovery Licences (SDL) are defined as areas where there is a confirmed hydrocarbon discovery that satisfies specific technical criteria, and describes the area over which the discovered resources extend. The SDL is issued by INAC and allows the licensee company to hold, in perpetuity, the area and the rights to its potential production.

An Exploration License (EL) gives a company the right to explore an area for oil and gas deposits and is valid for up to nine years. Issuance of ELs is a two-stage process. First, INAC issues a Call for Nominations and interested companies nominate parcels of NWT land that they believe contain oil and gas potential. Once the Call for Nominations closes, INAC offers the nominated parcels in a Call for Bids. Any company is then free to bid for the exploration rights to the parcels. There are approximately 63 SDLs and 21 ELs in the Beaufort Sea LOMA, with >250 wells drilled in the offshore zone and Delta. Hundreds of seismic programs have been conducted.

There has been a longstanding focus on hydrocarbon exploration in the Beaufort Sea LOMA. Hydrocarbon exploration activities include extensive seismic activity and drilling in coastal and offshore areas, construction of gathering and mainline pipeline systems in offshore and coastal areas, and supporting infrastructure on land and at sea (Table 5). Hydrocarbon exploration, construction, production and transportation will require a dramatic increase in all-season and winter roads, marine shipping and aviation, with associated impacts within the LOMA. Some induced development activities and impacts may include:

- exploration and production facilities in the estuarine, coastal and offshore waters of the LOMA;
- ongoing seismic activities with possible impacts on fish and marine mammals, depending on the time and type of seismic activity;
- establishment of seasonal and permanent base camps, including airstrips;
- extensive gravel and sand extraction;
- development of pipelines and gathering systems; and
- oils spills and contamination.

Table 6, compiled by representatives of the Canadian Association of Petroleum Producers (CAPP), provides a more detailed list of potential oil and gas exploration and development activities in the Canadian Beaufort Sea.

Table 6. Potential oil and gas exploration and development activities (CAPP 2006). BOP = blow out preventer, CRI = caisson retained island, CIDS = concrete island drilling system, SDC = steel drilling system, ROV = remotely operated vehicle, LNG = liquefied natural gas, GBS = gravity based structures.

Activity	Details
2D and 3D nearshore seismic	• Vibroseis vehicles on ice (must be frozen to the bottom) • Airguns and geophones drilled through the ice (<20 m water depth, one airgun or receiver per hole) • Shotholes drilled through the ice (<20 m water depth, charge size limited by pressure measurements) • Ocean bottom cables with mini airguns (<70 m water depth in the open-water season)
2D and 3D offshore seismic deep water	• Seismic vessels using airgun arrays and streamers (>20 m water depth in open-water season)
Wellsite surveys	• High-resolution seismic and geotechnical surveys
Exploration drilling–landfast ice zone	• Drilling from spray ice pads grounded (<15 m water depth) • Drilling from spray ice pads floating (>15 m water depth within the landfast ice zone) • Construction of ice roads to shore
Offshore exploration drilling–shallow-water zone (including landfast ice zone)	• Drilling from gravel or sand islands (<20 m water depth) (surface BOP, up to 12-month season) • Drilling from GBS (like CRI, CIDS, <20 m water depth) (surface BOP 12-month season)
Offshore exploration drilling–deep-water zone	• Drilling from GBS (like SDC, Molikpaq, >10m–<40 m water depth) (surface BOP, up to 12-month season) • Drilling from floating drillships, (like Kulluk, >15 m water depth) (subsea BOP 3–6-month season)
Offshore drilling support	• Small and heavy lift helicopters • Supply vessels and barges • Ice breakers for towing, anchor handling and ice management • Spill response vessels and equipment • Marine maintenance facilities (i.e. floating drydocks)
Offshore development–shallow-water zone	• Gravel islands (<20 m water depth) • Causeways or subsea pipelines to shore
Offshore development–shallow-water zone	• GBS (<60 m water depth) • GBS may need ocean bottom excavation and sand or gravel foundation • Directionally drilled production wells from GBS • Subsea pipelines to shore
Offshore development–deep-water zone	• Floating development drilling • Subsea wells and satellite well clusters (>60 m water depth), with subsea gathering lines • Subsea pipelines to onshore processing facilities • LNG facility onshore, and ice-breaking LNG tanker offtake

Activity	Details
Offshore development–deep-water zone	• Subsea wells and satellite well clusters (>60 m water depth), with subsea gathering pipelines to GBS (located at <60 m depth) • Subsea pipelines to shore or floating development drilling • Crude oil storage on GBS, with ice-breaking crude oil offtake
Subsea oil, gas and NGL gathering and transportation pipelines	• Dredging, pipelaying, hydrotesting, backfilling of trenches • Pipeline landfalls (trenched or directionally drilled)
Offshore production support	• Small and heavy lift helicopters • Icebreakers for ice management • Supply vessels, with oil-spill-response capability and barges • Marine maintenance facilities (i.e. floating dry docks) and other repair shops • Floating well workover, wireline and other well-servicing equipment • Marine and logistics bases, including diesel storage and storage for oil-spill equipment • Helicopter support bases • Camps with offices, control room and medical facilities • Multiple storage and warehousing facilites for companies providing drilling and production support services
Inspections	• Subsea ROV, multi-beam and side scanning sonar inspections of pipelines, GBS and subsea satellites • Diver inspections of pipelines, GBS and subsea satellites

Notes:

All water depths given are approximate; technology innovation may increase acceptable water depths for individual technologies.

Floating production and storage offshore (FPSO) development technology is unlikely to be proposed for use in the Canadian Beaufort due to multi-year ice risk.

Compressed natural gas (CNG) tankers are currently also considered unlikely to be proposed for use in the Canadian Beaufort (CAPP 2006).

iii) Mineral and Granular Resources

There are mineral deposits in or adjacent to the LOMA, with a large iron ore deposit in the Yukon North Slope, and kimberlite pipes containing diamonds near Paulatuk in Darnley Bay off the Arctic coast. There do not seem to be any immediate plans to exploit the diamond deposit in Darnley Bay.

There are granular materials on land and in the estuarine and coastal areas of the Mackenzie Delta. Granular materials are in demand to meet the needs of local communities to build roads and other infrastructure. Granular resources will be in great demand in the future to meet the needs of hydrocarbon development, ongoing community and infrastructure development, and to remedy coastal erosion and permafrost degradation.

Up to 7 million m^3 of gravel could be required from new and existing borrow sites for the proposed Mackenzie Gas Project, with some gravel sites located in the ISR (GNWT 2005). These materials were used in the past for offshore platform development (i.e. artificial islands) and were extracted adjacent to the required facilities.

iv) Marine Transport

Travel in winter takes place on coastal and ice roads and through aviation corridors. On-ice harvesting and travel are also winter activities. Boating and shipping take place during the ice-free season. A public right of navigation for vessels and cruise ships through the Beaufort Sea LOMA exists. Marine shipping and transportation in the Mackenzie Delta and along Arctic coasts provide community re-supply, hydrocarbon activity support, transportation and safety, military and security functions (Table 5)

Increases in oil- and gas-related activity in the Beaufort Sea will also lead to increases in shipping activities. Seafloor bathymetry in shallow water dictates location of the corridors, and shipping routes and dates are guided by ice regimes. Shipping activity in the Beaufort Sea and Mackenzie Delta is regulated through the *Arctic Waters Pollution Prevention Act* (1984) and the *Canada Shipping Act* (1985). These Acts are administered by Transport Canada, and outline ship-classification standards, Canadian Coast Guard icebreaker use, reporting requirements, spill response and emergency planning. The health and prosperity of communities in the Delta region depend on the arrival of goods shipped by barge and transported by truck on winter ice roads. Maintaining regular shipping activity and winter ice roads is therefore of utmost importance to these communities.

The reduced ice cover and longer shipping season resulting from global warming may encourage increased transport in Canadian waters, and an argument has been made that they are international waters for the purposes of navigation. There may also be increasing pressure from the United States and other parties to consider coastal waters as international straits, subject to a right of navigation and shipping. This argument will have economic, environmental, military and security implications for the LOMA. Increased vehicular transportation in the winter (i.e. ice roads, all terrain vehicles and air transport) and the summer (i.e. marine or air transport) will also accompany a longer shipping season.

The Yukon Government and the State of Alaska concluded a port access strategy study in December 2006, in response to changes in the global economy. The study will provide objective and quantified information that will enable public and private investors to study the possibility developing port facilities and related transportation links (Yukon Legislative Assembly, 2 May 2006, 199 Hansard)

v. Other Sea-Based Activities

Marine tourism is an important economic activity in the NWT. Many locals operate as small tour operators to subsidize their traditional hunting and fishing activities. Guided fishing and hunting trips, whale watching and visiting the national parks are some of the main attractions. Commercial tourism including cruise ships, and more sport fishing and tourism by boat, float or amphibious planes could increase, with increased access due to less ice cover.

Fishing activities are subsistence-based rather than commercial. Subsistence fishing, sport and commercial fishing, and harvesting of freshwater, coastal and marine resources are recognized and, in many cases, are constitutionally protected oceans uses under the IFA and other land claim agreements. The proximity of these activities to areas where hydrocarbon development and related infrastructure and transportation activities take place may be a future issue. In this regard, a formal beluga harvest monitoring program for the Mackenzie estuary was first initiated in 1973, and continues annually with a hunter-based monitoring program now conducted by the FJMC. There has been limited discussion of the possibility of commercial fishing activities, although it does not appear there is sufficient biological productivity for this activity to occur.

Harvesting marine mammals consists primarily of beluga whales and seals in the Mackenzie Delta and adjacent coastal waters. Terrestrial and on-ice harvesting of polar bears is also done for traditional and commercial purposes. Most harvesting is done by the Inuvialuit, with some activity by the Gwich'in.

b) Climate Change

Climate change is one of the biggest challenges facing the Beaufort Sea LOMA and its people, institutions and processes. All ecosystems are likely to be affected either negatively or positively by climate change. Studies using global climate change scenarios have indicated the potential for substantial changes in many components of the Arctic environment, including temperature, precipitation, winds, ocean currents, lake and river hydrology, and snow and ice cover.

Decreasing ice concentration and increasing wind speeds together suggest a more severe wave climate in the Beaufort Sea. Coasts in much of the Mackenzie Delta are merely consolidated ice, gravel and sand, which were historically protected by landfast ice and ice-covered seas. These coasts are increasingly subject to greater ice-free periods and high rates of coastal erosion and subsidence due to extreme storm events, and now global warming. Sea ice previously protected infrastructure and inhibited wave formation. Mobile sea ice could cause ice scour, more coastal erosion and damage to infrastructure. Tuktoyaktuk, the only community in the Arctic with coastal defences, is vulnerable to storm events due to its low lying topography and exposure to the Arctic Ocean.

The physical changes that are predicted to occur in the Arctic create stressors on the ecosystem which induce trophic shifts or cascades in the biological components of the marine ecosystem (Figure 14, page 51). These shifts result in changes to the linkages between consumer and prey communities in the ecosystem and have profound effects on the stability and productivity of the ecosystem. Given that ice algae, open water and the near shore components of the food chain have linkages through common forage fish dominated by Arctic cod (Craig 1984, Welch 1992), a perturbation that significantly impacts cod could have a cascade effect through the entire food web.

IPY 2007–2008 is an international program of coordinated interdisciplinary science, research and observation focussed on the Arctic and Antarctic. 0 lists projects with particular relevance to understanding climate change impacts on the Beaufort Sea. One Canadian-funded project will study the effects of changes in the Circumpolar Flaw Lead system (described in Volume I) on the larger marine ecosystem. A second study will establish a scientific basis for sustained monitoring of Arctic seas in the wake of global warming. Other studies will assess impacts of severe arctic storms and climate change on coastal areas; the relationship between permafrost conditions and climate change; variability and change in the Canadian cryosphere to project future climatic conditions; and changing ice conditions of the Arctic Ocean. These projects will lead to a better understanding of the effects of climate change on the North, and in particular the Beaufort Sea Region.

In addition to the science-based research to be conducted under IPY, a number of research projects addressing adaptation responses to social, cultural and economic conditions have been funded by Canada (0). One study will focus on the capacity of northern communities to adapt to a changing world. Another will focus on the impacts of oil and gas activity on the health, traditional livelihoods, economic development and ecosystem change in the Arctic.

c) Long-Range Transport of Pollutants

Certain classes of pollutants have long been known to enter the Arctic via long-range transport and bio-magnify through the food web. However, the effects of climate change may clearly alter the complex atmospheric, hydrologic and oceanographic pathways by which halogenated organic contaminants and trace metals, including mercury, are delivered to, distributed and concentrated in the Arctic (ACIA 2005). Climate change will make concentrations and trends of pollutants in the environment and wildlife species more complicated to interpret, because these pollutants will not directly reflect trends in atmospheric transport or the effectiveness of international action in controlling pollution. For example, there has been a four-fold increase of mercury (Hg) over the last two decades in beluga (Figure 25) and other marine mammal tissues (Lockhart *et al*. 2005). Global emissions of Hg have been decreasing lately (Pacyna 2002) and the Arctic atmosphere shows no recent increasing trend in Hg levels (Steffen 2005), so the increasing trends of Hg in marine mammals suggest that something has been changing in the biogeochemical cycling of Hg in the Arctic and/or in the food web structure that conveys Hg and carbon to upper-trophic-level species (Stern and Macdonald 2005). This observed phenomenon could be due to a combination of recently enhanced mercury depletion events (Schroeder *et al*. 1998, Lu *et al*. 2001, Lindberg *et al*. 2002), and climate-related changes in hydrology, organic carbon cycling and marine ecosystem structure in the Arctic (Macdonald and Yu 2005, Outridge 2005, Stern and Macdonald 2005). A similar trend towards increased levels of halogenated organic compounds has been observed over a 15-year period in western Arctic beluga populations.

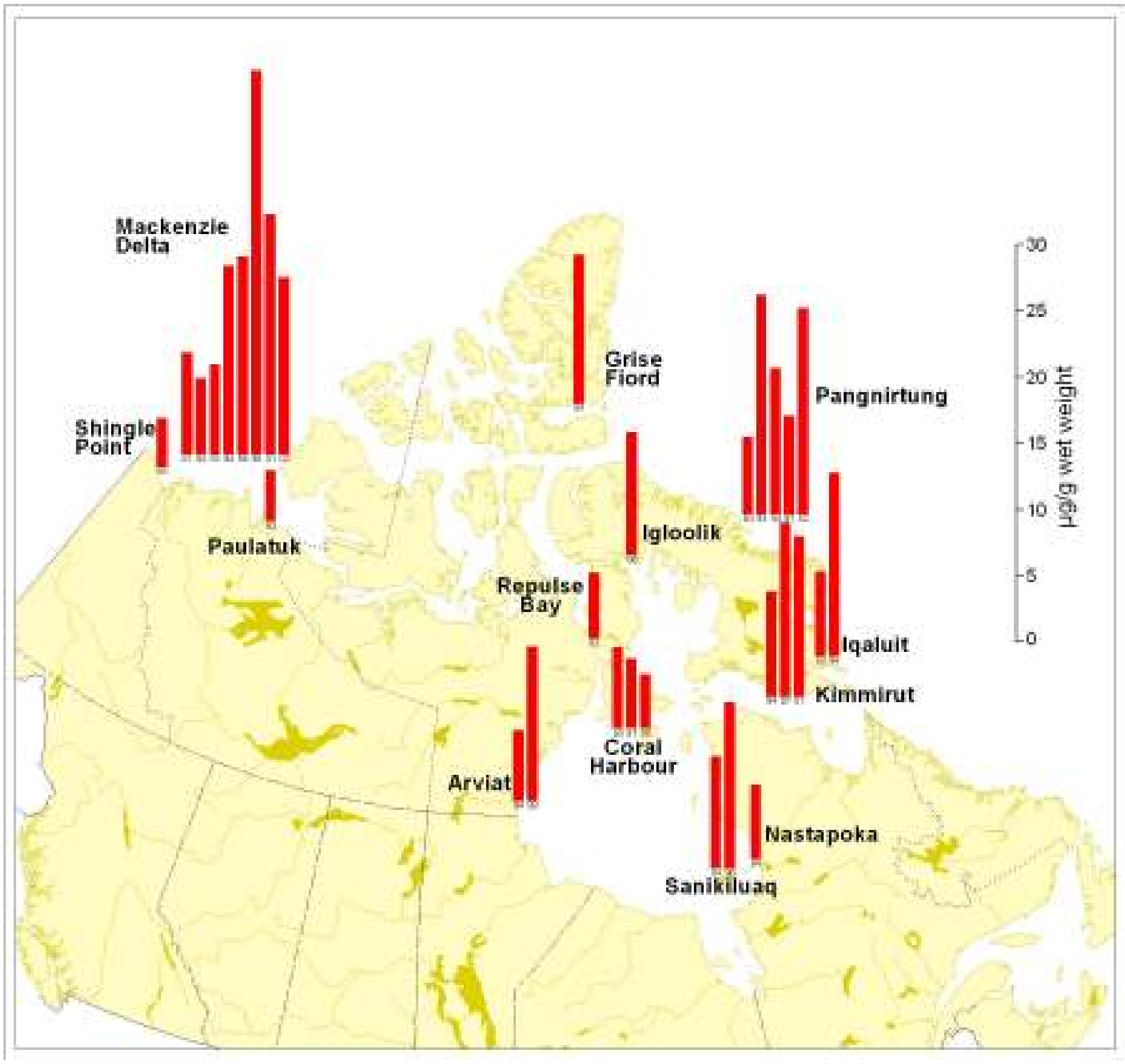

Figure 25. Mercury concentrations in liver (µg/g wet wt) of beluga whales (age corrected to 13.1 years) (adapted from Lockhart *et al.* 2005).

A suite of "new" contaminants has only recently been detected in Arctic animals. These new contaminants include brominated flame retardants, commonly used in the manufacture of many household items. There has been an exponential increase in the most common brominated flame retardants, the PBDE congeners in the blubber of ringed seals sampled from Holman Island, NWT, Canada (Ikonomou *et al.* 2002). Monitoring of trends over time for bioaccumulating substances such as metals, halogenated organic compounds and new contaminants is ongoing under the environmental trends component of INAC's Northern Contaminants Program.

d) Aquatic Invasive Species

The Beaufort Sea LOMA may be more vulnerable in the future to introduced and non-native aquatic species. Invasive alien species (IAS) are animals, plants or micro-organisms either accidentally or deliberately introduced into Canada that damage the environment, economy or even our health. In light of the increased movement pf people and goods among different countries and global bio-security, a solution to IAS is now considered by the federal government to be a top priority.

Sources of aquatic IAS include ballast-water discharge associated with increased maritime transport, and climate shifts, including warmer waters that could allow human-introduced species to survive. In addition, temperate and sub-Arctic species may naturally migrate to the Beaufort Sea area as climate change occurs. Determining whether a species is introduced is difficult. For example, have salmon been introduced to the area? Chum salmon are the most abundant salmon species, past and present. By contrast, pink salmon are recorded infrequently and coho salmon have been reported only twice. Chinook and sockeye salmon have been harvested irregularly in small numbers since the 1990s. Climate change may eventually enhance the ability of Pacific salmon to colonize the Beaufort Sea, but there is no evidence of newly established populations, and insufficient data to say that salmon are increasing in frequency (Stephenson 2006).

Anticipated oil and gas development in the Beaufort Sea, and a pipeline along the Mackenzie River will increase shipping and barge activity. Barge traffic along the Mackenzie River is anticipated to increase by six-fold (e.g. barging large production facilities from outside the Beaufort Sea LOMA to the Mackenzie Delta). Thus, concerns have been raised regarding the introduction of IAS. DFO scientists are currently examining the issue of exotic invasive species from a national perspective, and the Arctic will be part of this research priority in the future.

Part F. Conclusions and Recommendations

The *Oceans Act* (1997) describes oceans management as a collective responsibility that requires collaboration among all levels of government and stakeholders. The three policy objectives of Canada's Oceans Strategy (2002) are:

- understanding and protecting the marine environment;
- supporting sustainable economic opportunities; and
- international leadership.

Canada's OAP (2005) subsequently identified five priority large oceans management areas. One of those was the Beaufort Sea. The OAP is based on four pillars: (1) international leadership, sovereignty and security; (2) integrated oceans management for sustainable development; (3) health of the oceans; and (4) oceans science and technology. Pillars 2 and 3 have underpinned the development of the Beaufort Sea LOMA, and considerable progress has been achieved over the past two years.

The integrated management pillar has evolved into a collaborative planning process led by a regional implementation committee called the Beaufort Sea Regional Coordinating Committee (RCC). Membership includes the Inuvialuit Regional Corporation; the Inuvialuit Game Council, the Fisheries Joint Management Committee; Yukon Government; Government of the Northwest Territories; Fisheries and Oceans Canada, Natural Resources Canada, Transport Canada, Environment Canada, Parks Canada Agency; and Indian and Northern Affairs Canada. The RCC oversees implementation of the IM planning for the Beaufort Sea LOMA.

A broader group of stakeholders, the Beaufort Sea Partnership (BSP), is the primary forum for stakeholder engagement. This group is being asked to provide advice and recommendations to the RCC concerning the development of an IM plan for the Beaufort Sea LOMA. An inter-agency Planning Office drafted the Plan, and Working Groups have been tasked with ensuring full community engagement in these processes, and conducting a social-cultural-economic assessment in support of the plan.

This evolving governance process is being guided by the following principles: recognition of Inuvialuit rights under the IFA; recognition of existing agreements and commitments; recognition and affirmation of the mandated authority or jurisdiction of participants; respect for all parties; commitment towards building a common vision; accountability, fairness, inclusiveness and transparency; equality of all participants; and the use of local, traditional and scientific knowledge.

This EOAR is the major contribution to date, in support of the third OAP pillar, health of the ocean for the Beaufort Sea LOMA. Volume I provided a description of the structure and function of the Beaufort Sea ecosystem, and identified gaps in information and knowledge concerning that ecosystem. Volume II identified areas and species known to be of particular importance to the ecosystem, which included areas and species with no protection, as well as areas and species already protected, or proposed for protection. The range of activities and stressors already impacting the Beaufort Sea LOMA marine ecosystem, or likely to do so in future, were then discussed. By providing a comprehensive review of the marine environment, and of the economic activities being undertaken and/or considered in the region, the groundwork was laid for development of an IM plan for the Beaufort Sea LOMA.

Challenges facing this evolving governance process are numerous. These challenges include addressing uncertainties resulting from an inherently unpredictable future; learning and problem-solving through networks and partnerships; and designing and living inclusive and collaborative processes in which stakeholders truly share management power and responsibility (Berkes and Fast 2005). IM will take time to effect change. With time and effort, however, it is expected that multiple users can produce sound decision-making at the ecosystem level (Berkes and Fast 2005).

F. Berkes (Natural Resources Institute, University of Manitoba, 303-70 Dysart Road, Winnipeg, MB R3T 2N2, pers comm.) observes that the sharing of resource management responsibilities between governments and stakeholders has become a common phenomenon, and is part of a worldwide trend toward public-private-civil society partnerships in sustainable environmental management. This new governance approach is necessary to address sustainability problems in a rapidly changing world in which an ever-increasing number of demands are being placed on resources.

Over the past 18 months, governance processes have been established to lead IM processes in the Beaufort Sea LOMA. A substantial body of work summarizing what is known about the vast and mysterious Beaufort Sea has been completed. There is broad support for a management process that is highly compatible with northern indigenous perspectives in which land, water and sea are an indivisible, coherent whole, i.e. “the Land” (Hubert *et al*. 2005). It is time to act.

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Part H. Glossary

Allochthonous carbon—Sources of carbon that come from outside the aquatic system (i.e. plant and soil materials). Typically, these sources of carbon are high in streams and small lakes, whereas large lakes and oceans are dominated by autochthonous carbon sources (see below).

Amphipod—Small crustacean (order Amphipoda) such as the beach flea, having a laterally compressed body with no carapace. Amphipods are important for breaking down decaying matter and an important part of the food web.

Anadromous fish—Fish that migrate from salt water to spawn in fresh water as part of their life history.

Anoxic—The absence or deficiency of oxygen in a region of the environment.

Anticlines—A fold of rock layers that slopes downward on both sides of a common crest. Anticlines form when rocks are compressed by plate-tectonic forces. They can be as small as a hill or as large as a mountain range.

Areas of interest—Important ocean areas identified by stakeholders and Fisheries and Oceans Canada to be assessed as a candidate for protection as part of the Marine Protected Areas program.

Autochthonous carbon—Sources of carbon that originate or form in the aquatic ecosystem (e.g. algae and the microbial breakdown of organic carbon).

Autotrophic—Any organism capable of self-nourishment by using inorganic material as a source of nutrients and using photosynthesis or chemosynthesis as a source of energy (e.g. most plants and certain bacteria).

Beaufort Sea Gyre—A wind-driven clockwise circulation (looking from above the North Pole) of surface waters in the Beaufort Sea. The Beaufort Gyre slowly swirls the surface waters of the Arctic basin, moving the Polar Ice Cap along with it. It makes one complete rotation about every four years.

Beaufort Sea Integrated Management Planning Initiative (BSIMPI)—A collaboration between Inuvialuit, government and industry in Integrated Management Planning for marine and coastal areas in the Inuvialuit Settlement Region. Includes representation from the Inuvialuit Regional Corporation, Fisheries Joint Management Committee, Inuvialuit Game Council, Fisheries and Oceans Canada and industry, represented by the Canadian Association of Petroleum Producers.

BSIMPI Secretariat—Comprised of staff from the Oceans sector of Fisheries and Oceans Canada to provide administrative, technical, research and communication support for the BSIMPI Working Group.

BSIMPI Senior Management Committee—A high-level multi-stakeholder committee guiding the activities of the Beaufort Sea Integrated Management Planning Initiative.

Includes representation from Inuvialuit Regional Corporation, Inuvialuit Game Council, Fisheries Joint Management Committee, Canadian Association of Petroleum Producers and Fisheries and Oceans Canada.

BSIMPI Working Group—Carries out integrated management activities such as identifying issues, planning and community engagement. Includes representation from Inuvialuit Regional Corporation, Inuvialuit Game Council, Fisheries Joint Management Committee, Canadian Association of Petroleum Producers, Indian and Northern Affairs and Fisheries and Oceans Canada.

Beaufort Sea Beaufort Sea Large Ocean Management Area (LOMA)—The marine and offshore islands of the Northwest and Yukon Territories, including the estuarine portions of the Mackenzie River Delta, extending north to the 80th parallel, and following the Canada–US border to that parallel. The scope of influence on the LOMA includes fresh, coastal and marine waters.

Beaufort Sea Partnership—The means by which the federal government, as facilitated by Fisheries and Oceans Canada, can implement the broad cabinet-endorsed requirements of the Oceans Action Plan for the LOMA.

Benthic area—The bottom of fresh and marine waters, an area inhabited by organisms that live in close relationship (if not physically attached) to the substrate.

Benthic infauna—Organisms that inhabit the benthic area (also referred to as “benthos” or “benthic organisms”).

Biota—The organisms (flora and fauna) of a specific region considered as a group.

Bivalve—Any mollusc having two shells hinged together and a soft body (e.g. oyster, clam, scallop, mussel).

Bottomfast ice—Ice that is attached or fully grounded to the sea floor (typically in shallow waters such as the Mackenzie Delta).

Brackish water—A mixture of salt and fresh water.

Brine release—A release of salt, from the melting of ice, that convectively mixes from the surface layer down to 40–50m deep.

Climate change—Any change in global temperature and precipitation over time due to natural variability or to human activity.

Coastal drowning—Erosion of sediment due to the gradual flooding of coastal areas in the Beaufort Sea, which results from subsidence of the Earth’s crust. This process can be accelerated by storms and storm surges.

Copepod—Tiny marine or freshwater crustaceans of the order (or subclass) Copepoda, lacking compound eyes or a carapace and usually having six pairs of limbs on the thorax. Some are abundant in plankton samples and others can be parasitic on fish.

Coregonids—A subfamily of fish in the family Salmonidae. Many of the important subsistence species of the Beaufort Sea LOMA are found in this subfamily and include anadromous species such as whitefish and cisco.

Cumacean—An order of small marine crustaceans. Most inhabit the benthic marine environment, whereas some species can be found living temporarily in brackish and even fresh water.

Cumulative effect—The effect on the environment that results from a project when combined with those of other past, existing and reasonable foreseeable projects and activities. Cumulative effects may occur over a certain period of space and time.

Delta(ic)—A landform where the mouth of a river flows into an ocean or estuary, building outwards as sediments are carried by the river and deposited when water currents dissipate (deltaic deposit).

Demersal—Organisms living at the bottom of the sea.

Diatoms—Any of various microscopic one-celled or colonial algae. Diatoms are composed mostly of silica and can perform photosynthesis. They make up a large portion of the marine/freshwater plankton and are an important food source for many aquatic animals.

Ecological Monitoring and Assessment Network (EMAN)—Network administered by Environment Canada for the coordination of ecological monitoring in Canada, including the three northern Territories and northern Manitoba. EMAN-North is the Arctic network.

Ecologically and Biologically Significant Area (EBSA)—Ocean areas that have been flagged as ecologically or biologically significant because of the functions they serve in the ecosystem and/or because of their structural properties.

Ecosystem-based management—Application of an ecosystem or holistic approach to management that also incorporates the influence and impacts of human activities on the ecosystem.

Environmental Impact Review Board (EIRB)—Established under the Inuvialuit Final Agreement, the EIRB carries out detailed environmental impact assessments and public reviews of development projects referred to it by the Environmental Impact Screening Committee. The EIRB decides whether a project should proceed and, if so, under what specific terms and conditions. In making its decision, the EIRB considers the need for wildlife compensation, mitigation and remedial measures.

Environmental Impact Screening Committee (EISC)—Established under the Inuvialuit Final Agreement, the EISC conducts environmental screening of development activities proposed for the Inuvialuit Settlement Region. It decides whether a development could have a negative impact on Inuvialuit or wildlife. Developments considered include permit or licence applications for mineral exploration and extraction, industrial site clean-up and restoration, granting of water rights, commercial tourism ventures and land use associated with government-sponsored or -funded research.

Ericaceous— Heather-like shrub species belonging to the family Ericaceae, most of which prefer acidic soils and occur in the upland areas of the Mackenzie River Delta.

Esker—A long narrow ridge of coarse gravel deposited by a stream flowing in or under decaying glacial ice.

Estuary—A partly enclosed coastal body of water where river water is mixed with sea water; therefore, an estuary is defined by salinity rather than geography.

Eurytopic—The ability of an organism to adapt to a wide range of environmental conditions (e.g. temperature and salinity).

Exploration Licence—Confers certain rights relating to oil and gas exploration on the lands to which the licence applies over its term. A company that has been issued an Exploration Licence has the right to explore a specified area for oil and gas deposits. The licence is valid for up to nine years. Indian and Northern Affairs Canada, Northern Oil and Gas Directorate, in Ottawa is responsible for the issuance of petroleum rights on Crown land in the Northwest Territories, Nunavut and adjacent offshore waters.

Fault block—A rock mass that is bounded by faults; the faults may be elevated or depressed and not necessarily the same on all sides.

Fault lines—The intersection of the fault surface with the surface of the earth, or any other horizontal surface of reference.

Fisheries Joint Management Committee (FJMC)—The FJMC is a co-management body (Inuvialuit and Canada representation) established by the Minister of Fisheries and Oceans in accordance with the Inuvialuit Final Agreement. FJMC is responsible for advising the Minister on Fisheries management in the Inuvialuit Settlement Region.

Flagellated protozoan—A non-photosynthetic, free-living protozoan with whip-like appendages used for locomotion.

Flaw lead—An open area of water that separates the central Arctic ice pack from landfast ice. It is known to be a highly productive area in the Beaufort Sea.

Flaw polynya—An area of unfrozen sea water surrounded by ice.

Frazil ice—A collection of loose, randomly oriented, needle-shaped ice crystals in water. It forms on the surface of water and resembles slush. It is the first stage in the formation of sea ice.

Glacial ice (glacier)—An extended mass of ice that forms from the accumulation of snow. It flows (moves) very slowly, either descending from high mountains, or moves outward from centers of accumulation.

Glaciofluvial—Geomorphic feature whose origin is related to the processes associated with glacial meltwater, or to the deposits and landforms produced by the meltwaters.

Gwich'in Renewable Resource Board (GRRB)—The GRRB was established under the guidance of the *Gwich'in Comprehensive Land Claim Agreement* to be the main instrument of wildlife, fish and forest management in the Gwich'in Settlement Area.

Halocline—A well-defined, vertical salinity gradient in oceans or other saline waters.

Heavily impacted areas—Areas are areas that have been disturbed or changed by local or global human actions or due to natural circumstances.

Heterotrophic organism—An organism that cannot synthesize its own food and depends on complex organic substances for nutrition.

Hypoxia—Oxygen depletion that occurs in aquatic environments as dissolved oxygen becomes reduced in concentration to a point that is detrimental to aquatic organisms living in the system.

Ice rafting—The transportation of rock and other minerals, of all sizes, on or within ice floes, river drift, or other forms of floating ice.

Ice scour—A geological term for long, narrow "ditches" in a seabed, created by the collision of fast ice and pack ice, or when wind-driven large ice rubble grounds against the seafloor along the coast. Synonyms include gouging, ice ploughing and ice scour. It may also refer to ice sheets in the intertidal zone, which create physical abrasion and possible dislodgment of marine organisms upon movement of the ice.

Ichthyoplankton—The eggs and larvae of fish that are passively transported long distances by wind and other physical oceanographic features.

Integrated Management (IM)—A proactive approach toward sound oceans management. It is an ongoing and collaborative planning process that brings together interested parties, stakeholders and regulators to reach general agreement on the best mix of conservation, sustainable use and economic development of coastal and marine areas for the benefit of all Canadians.

International Polar Year—An international programme of coordinated, interdisciplinary scientific research and observations on the Earth's polar regions, celebrated every 50 years.

Inuvialuit Final Agreement (IFA)—The first comprehensive land claim agreement signed north of the 60th parallel and only the second in Canada at that time. Signed on 5 June 1984 and approved by the Canadian Parliament as the Western Arctic Claims Settlement Act, it took precedence over other Acts inconsistent with it. The Act was also protected under the Canadian Constitution in that it cannot be changed by Parliament without the approval of the Inuvialuit. In the IFA, the Inuvialuit agreed to give up exclusive use of their ancestral lands in exchange for certain other guaranteed rights from the Government of Canada. The rights came in three forms: land, wildlife management and money.

Inuvialuit Game Council (IGC)—IGC was incorporated as a Society under the Northwest Territories Societies Ordinance on 20 April 1983. Under the Inuvialuit Final Agreement, the IGC represents the collective Inuvialuit interest in all matters pertaining to the management of wildlife and wildlife habitat in the Inuvialuit Settlement Region. This responsibility gives the IGC authority for matters related to harvesting rights, renewable resource management and conservation.

Inuvialuit Regional Corporation(IRC)—The IRC was established with the overall responsibility of managing the affairs of the Settlement as outlined in the Inuvialuit Final Agreement (IFA). Its mandate is to continually improve the economic, social and cultural well-being of the Inuvialuit through implementation of the IFA and by all other available means.

Inuvialuit Settlement Region—A settled land claim of the Inuvialuit in the western Arctic, Northwest Territories, Canada, signed in 1984. The land encompasses an area of 91,000 km^2. Most of the beneficiaries live in the six communities of Inuvik, Aklavik, Tuktoyaktuk, Paulatuk, Ulukhaktok and Sachs Harbour.

Invertebrates—Organisms lacking a backbone or spinal column; not vertebrate.

Isopod—Any freshwater, marine or terrestrial crustacean of the order or suborder Isopoda, having seven pairs of legs typically adapted for crawling. Includes several aquatic parasites on crab and shrimps, and numerous swimming or bottom-dwelling species.

Joint Secretariat (JS)—The JS was established in 1986 to provide technical and administrative support to the Inuvialuit Game Council, the Environmental Impact Screening Committee, the Environmental Impact Review Board, the Wildlife Management Advisory Council (Northwest Territories) and the Fisheries Joint Management Committee. It also records and makes available all materials associated with the business of those groups. The Joint Secretariat office is located in Inuvik, Northwest Territories. A Secretariat office for the Wildlife Management Advisory Council (North Slope) is located in Whitehorse, Yukon.

Kame—A short ridge or mound of sand and gravel deposited during the melting of ice and glacial ice.

Keel of pressure ridge—Downward-oriented ice associated with ice ridges (see stamukhi), which can be driven landward and can cause ice scours in the seabed.

Land-based activities—Activities that take place on land and affect the marine environment. Most of the impacts are transported by water, down rivers into bays and estuaries. Some of the impacts are airborne from long-range transport and from local sources such as smelters, power plants, home heating and cars. It is the coastal area where the impacts are most pronounced.

Landfast ice—Any type of sea, river or lake ice attached to the shore, beached, stranded in shallow water or frozen to the bottom of shallow waters (see also bottomfast ice).

Liparidae—A family of mainly benthic marine fishes occurring in the Beaufort Sea LOMA, commonly referred to as snailfish.

Mackenzie Gas Project—A proposal to build a 1220-km pipeline system along the Mackenzie Valley. It would link northern natural-gas-producing wells to southern markets. The main Mackenzie Valley Pipeline would connect to an existing natural gas pipeline system in northwestern Alberta.

Macrophytes—Large aquatic plants, growing in or near water and either emergent, submergent or floating.

Marine Protected Area (MPA)—Established under Canada's *Oceans Act* (1997), MPAs are marine environments that enjoy certain protection and conservation management programs by virtue of their unique ecosystems and/or cultural resources. The *Oceans Act* (1997) gives Fisheries and Oceans Canada the ability to establish MPAs to conserve and protect unique habitats, endangered or threatened marine species and their habitats, commercial and non-commercial fishery resources (including marine mammals) and their habitats, marine areas of high biodiversity or biological productivity, and any other marine resources or habitats requiring special protection.

Marine transport—The transport of goods in the marine environment by all sizes of ships from tankers, container ships and self-unloading bulk carriers, to tour boats and recreational craft.

Metamorphosis—The process by which rocks are altered in composition, texture or internal structure by extreme heat, pressure and the introduction of new chemical substances.

Moraine—The rock debris (boulders and stones) that has been transported and deposited by glaciers or ice sheets.

Northern Ecosystem Initiative—An Environment Canada-led programme that supports projects addressing science needs in the North.

Oceans Act—An act passed on 31 January 1997 that made Canada the first country in the world to have comprehensive oceans management legislation. The Act authorizes the Minister of Fisheries and Oceans Canada to lead the development of a national oceans management strategy, guided by the principles of sustainable development, the precautionary approach and integrated management.

Oceans Action Plan (OAP)—The OAP responds to the *Oceans Act* (1997) commitment and advances the legislation and policy in place, as well as the Government of Canada's commitment to smart regulation. The OAP articulates a government-wide approach to seize opportunities for sustainable development. The OAP serves as the overarching umbrella for coordinating and implementing oceans activities, and as the framework to sustainably develop and manage our oceans.

Oleoclastic—Petroleum-degrading micro-organisms (i.e. bacteria).

Oligotrophic—An aquatic system that lacks plant nutrients, supports a sparse growth of algae and other organisms, and contains large amounts of dissolved oxygen due to low organic content of the water.

Pack ice—A large area of floating ice formed over a period of many years when pieces of ice are driven together by wind and currents.

Pelagic—Living in the open oceans or seas rather than waters adjacent to land or inland waters.

Permafrost—A permanently frozen subsoil layer that occurs at variable depths in perennially frigid regions.

Photosynthesis—The process making complex organic materials using sunlight as the source of energy, and aided by chlorophyll and associated pigments. Most photosynthesis releases oxygen as a by-product.

Phytoplankton—Photosynthetic or plant constituents of plankton, mainly unicellular algae.

Pingos—An Arctic mound or conical hill of soil-covered ice pushed up by hydrostatic pressure in an area of permafrost.

Polychaete—An annelid of the class Polychaeta, including mostly marine worms that are characterized by paired appendages tipped with bristles on each body segment.

Polynya—An area of perennially open water or thin ice surrounded by sea ice. Usually formed due to upwelling of relatively warm, nutrient-rich sea water.

Primary production—The total amount of new organic matter produced by photosynthesis (i.e. algae).

Psychrophilic—Thriving at relatively low temperatures (i.e. bacteria and fungi).

Retreat rates—The distance over time at which the Beaufort Sea coastline is eroding as a result of unstable and dynamic shorelines; caused by storm surges and permafrost melting (see coastal drowning).

Secondary production—The measurement of biomass of herbivores in a system. These organisms mainly consume primary producers.

Seismicity cluster—The relative frequency or magnitude and distribution of earthquake activity in a given area.

Sessile epifauna—Organisms that are found attached to, or on top of, soft bottoms, sand, mud flats or rocky shores, in and around the shallow nearshore subtidal zone. Includes organisms such as clams, mussels and kelp.

Shelf-break—An obvious steepening or point of increased slope (increased depth) between the continental shelf and the continental slope.

Significant Discovery Licence (SDL)—An SDL is an area containing a confirmed hydrocarbon discovery that satisfies specific technical criteria. The SDL describes the area over which the discovered resources extend. When a discovery is made, the company must apply for an SDL so the area can be recognized and declared a Significant Discovery Area by the National Energy Board. The company can then apply to Indian and Northern Affairs Canada for an SDL. The SDL allows the licencee company to hold the area and the rights to its potential. Rights granted as part of an SDL include: the right to explore for, and the exclusive right to drill and test for petroleum; the exclusive right to develop lands for petroleum production; and the exclusive right to obtain a production licence.

Sipunculid—An unsegmented marine worm-like invertebrate known commonly as peanut worms.

Stamukhi (zone)—A field of rubble ice formed by the convergence of landfast and drifting ice. These ridges extend downward and are known to gouge the seabed.

Stenotopic—The ability of an organism to adapt within only a small range of environmental conditions.

Stichaeidae—A family of fish inhabiting benthic marine/brackish water, commonly called pricklebacks.

Surges—A coastal rise in water level caused by wind.

Tarium Niryutait Marine Protected Areas (TNMPA)—A proposal to establish three areas in the Canadian Mackenzie River estuary of the Beaufort Sea in the Northwest Territories as a Marine Protected Area. The three separate but related areas total approximately 1800 km^2. They are known as Imaryuk MPA (Shallow Bay), Kittigaryuit MPA (Kugmallit Bay) and Okeevik MPA (east Mackenzie Bay near Kendall and Pelly Islands). The TNMPA consists of the surface of the water, the water column and the seabed. The landward boundary of the MPA is the low-water mark.

Thermokarst—A land surface with small domes that form on the surface due to frost heaving with the onset of winter. They evidently collapse with the arrival of the next summer.

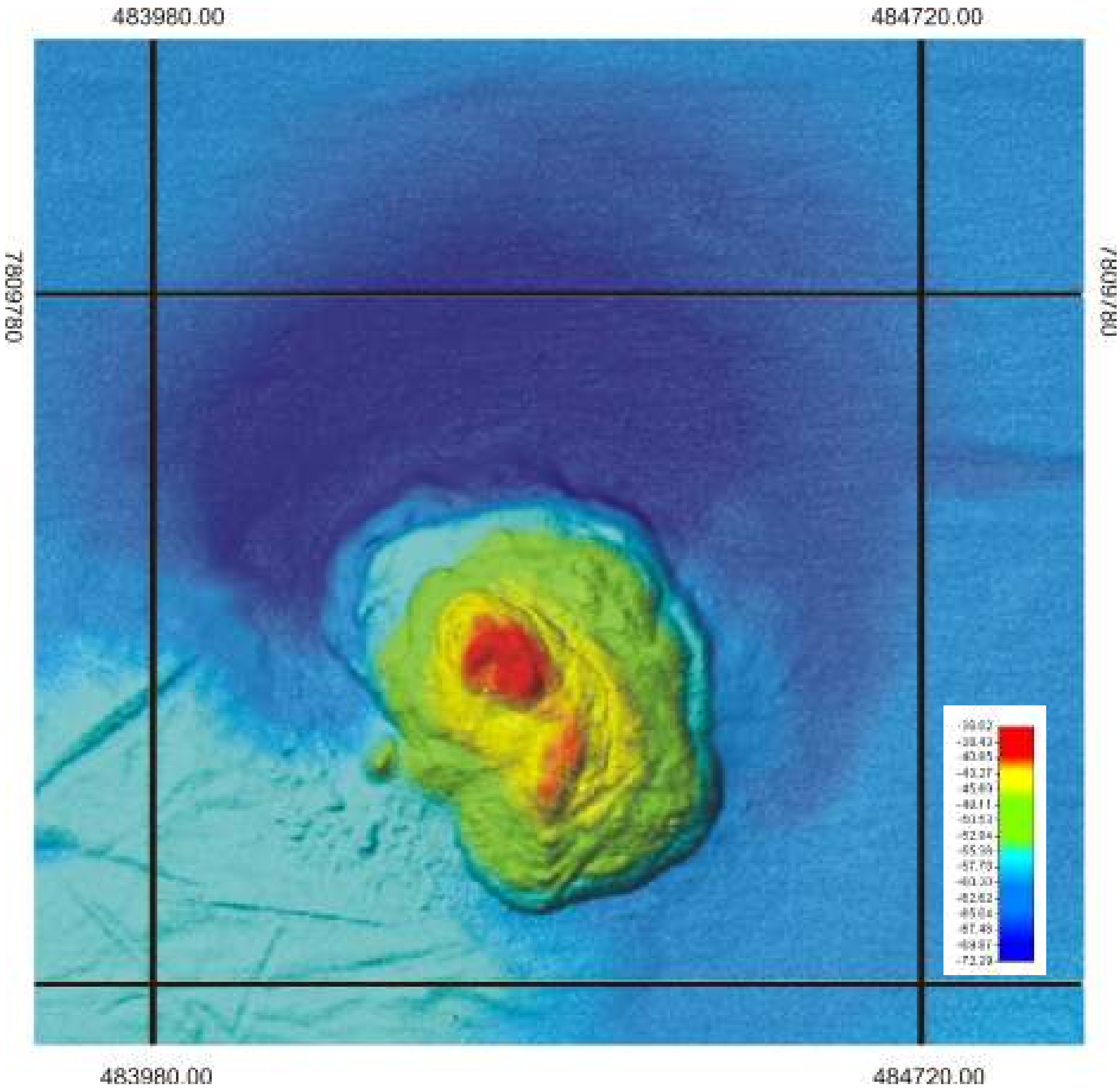
Turbidity—Having sediment or foreign particles stirred up or suspended; muddy, turbid water.

Wildlife Management Advisory Council (NS)- A Council established by the Yukon Government to conserve wildlife. The Council's geographic area of jurisdiction is the Yukon North Slope, the part of the Inuvialuit Settlement Region within the Yukon. As established in the Inuvialuit Final Agreement, the Yukon North Slope falls under a special conservation regime, the dominant purpose of which is the conservation of wildlife, habitat and traditional native use.

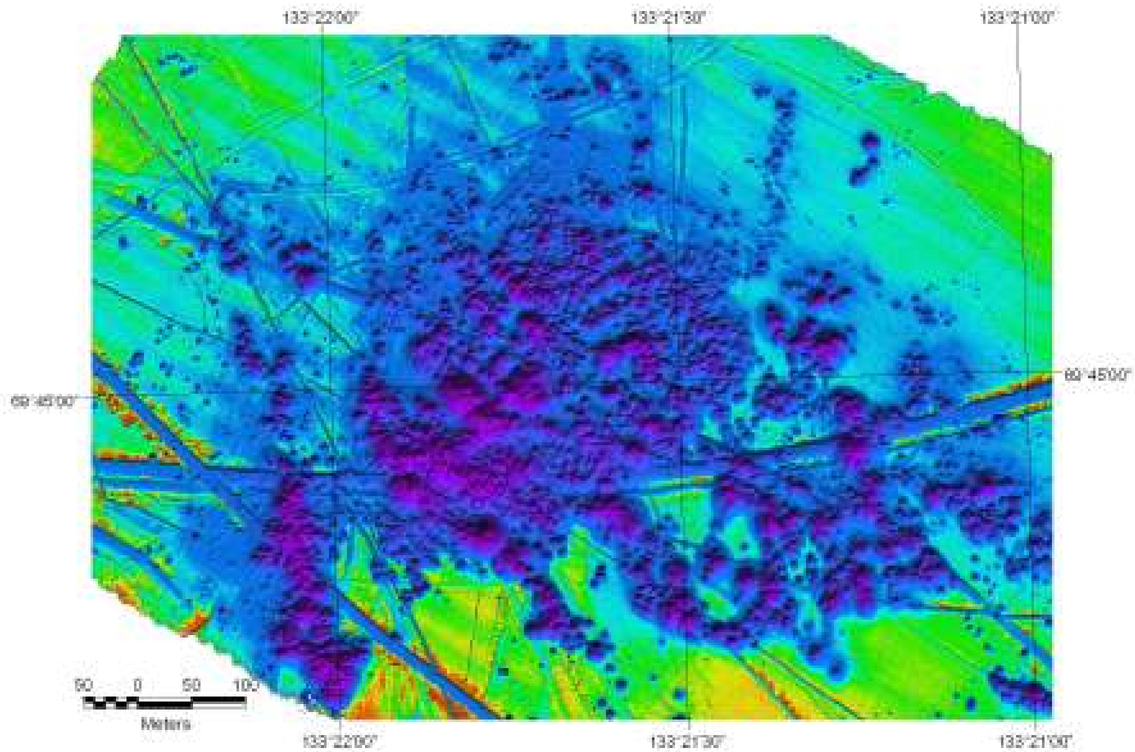
Wildlife Management Advisory Council (NWT)– A Council established by the Government of the NWT focussing on the conservation of terrestrial wildlife species (including polar bears) and birds. Its geographic area of jurisdiction is the part of the Inuvialuit Settlement Region within the Northwest Territories. The Council's mandate is to advise appropriate ministers on all matters relating to wildlife policy, and the management, regulation, research, enforcement and administration of wildlife, habitat and harvesting for the western Arctic Region of the NWT.

Zooplankton—Organisms that inhabit the water column and lack the ability to maintain their position against large water movements (currents). This group of organisms is the major link between primary producers (algae) and higher trophic levels of the food web (fish and mammals).

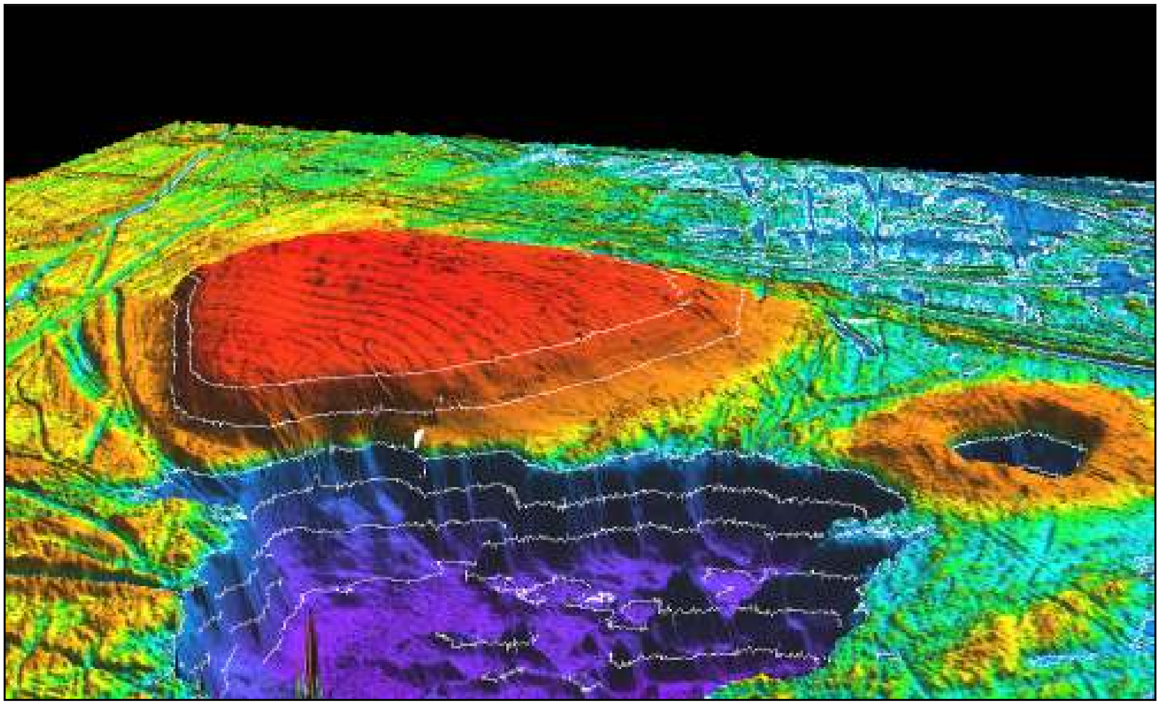
Appendix 1 – Multibeam image of a mud volcano in the Beaufort Sea (courtesy of S. Blasco, NRCan).



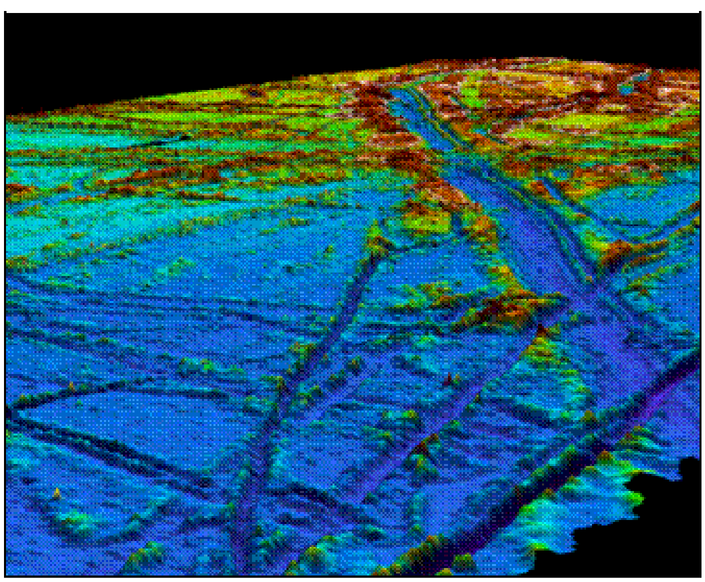
Appendix 2 – Multibeam image of Kugmallit gas vents in the Beaufort Sea (courtesy of S. Blasco, NRCan).



Appendix 3 – Multibeam image of Issungnak artificial island and borrow pit (courtesy of S. Blasco, NRCan).



Appendix 4 – Multibeam image of ice scours along the bottom of the Beaufort Sea floor (courtesy of S. Blasco, NRCan).



Appendix 5 – Comparisons of temperature and precipitation in selected locations within the Canadian western Arctic (Ayles and Snow 2002).

Location	Komakuk Beach	Shingle Point	Inuvik	Tuktoyaktuk	Cape Parry	Clinton Point	Sachs Harbour
January temp.							
Daily maximum	-19.7	-20.1	-24.1	-23.9	-25.1	-24.0	-26.5
Daily minimum	-29.5	-29.6	-33.5	-31.2	-31.6	-31.1	-33.5
Daily mean	-24.0	-24.1	-28.8	-27.2	-28.2	-27.6	-29.9
July temp							
Daily maximum	12.0	15.8	19.5	15.4	9.3	11.3	9.6
Daily minimum	3.2	6.2	8.0	6.4	2.9	3.5	2.8
Daily mean	7.6	11.0	13.8	10.9	6.1	7.4	6.2
Annual mean temp.	-11.0	-	-9.5	-10.5	-12.0	-11.4	-13.7
Precipitation							
Rainfall	85.0	125.2	116.0	75.4	69.8	96.6	49.7
Snowfall	68.9	105.8	175.2	66.8	129.6	85.0	83.8
Total precipitation	154.0	231.0	257.4	142.1	160.3	181.5	126.5

Temperature in ºC; snowfall in cm; rainfall and total precipitation in mm

Appendix 6 – Scientific, common and Inuvialuktun names of marine fish (Iqaluk, Iqalluk, Iqaluit) and larval fish (*) found in the Beaufort Sea LOMA (modified from Coad and Reist 2004, www.fishbase.org).

Common Name	Scientific Name	Inuvialuktun (Singular – Lowe 2001) (Dual/Plural – Hart and Amos 2004)
Skate	Rajidae	
Arctic skate	*Amblyraja hyperborea*	
Skates (unspecified)	*Bathyraja sp.*	
Herring	Clupeidae	
Pacific herring*	*Clupea pallasii pallasii**	piqquaqtitaq, piqquaqtitak, piqquaqtitat
Smelt	Osmeridae	
Capelin	*Mallotus villosus*	
Cod	Gadidae	
Polar cod*	*Arctogadus borisovi**	
Arctic cod*	*Boreogadus saida**	uugaq, uukkak, uukkat
Saffron cod*	*Eleginus gracilis**	uugavik, uugaviik, uugaviit
Greenland cod	*Gadus ogac*	
Sculpin	Cottidae	kanayuq, kanatdjuk, kanutdjuk, kanayuit
Hamecon*	*Artediellus scaber**	
Arctic hookear sculpin	*Artediellus unicinatus*	
Arctic staghorn sculpin*	*Gymnocanthus tricuspis**	
Sculpin*	*Icelus sp.**	
Two-horn sculpin	*Icelus bicornis*	
Spatulate sculpin	*Icelus spatula*	
Fourhorn sculpin*	*Myoxocephalus quadricornis**	
Arctic sculpin	*Myoxocephalus scorpioides*	
Shorthorn sculpin	*Myoxocephalus scorpius*	
Big-eye sculpin*	*Triglops nybelini**	
Ribbed sculpin*	*Triglops pingelii**	
Poacher	Agonidae	
Atlantic poacher*	*Leptagonus decagonus**	
Arctic alligatorfish*	*Ulcina olrikii**	
Lumpsucker	Cyclopteridae	
Leatherfin lumpsucker	*Eumicrotremus derjugini*	
Atlantic spiny lumpsucker	*Eumicrotremus spinosus*	
Snailfish	Liparidae	
Sea tadpole	*Careproctus reinhardti*	
Gelatinous snailfish*	*Liparis fabricii**	
Variegated snailfish	*Liparis gibbus*	
Greenland seasnail*	*Liparis tunicatus**	
Eelpout	Zoarcidae	
Two-lip pout	*Gymnelus bilabrus*	
Knipowitsch's pout	*Gymnelus knipowitschi*	
Aurora pout	*Gymnelus viridis*	
Eelpout*	*Lycodes sp.**	
Glacial eelpout	*Lycodes frigidus*	
Shulupaoluk	*Lycodes jugoricus*	
White sea eelpout	*Lycodes marisalbi*	
Saddled eelpout	*Lycodes mucosus*	
Canadian eelpout	*Lycodes polaris*	

Common Name	Scientific Name	Inuvialuktun (Singular – Lowe 2001) (Dual/Plural – Hart and Amos 2004)
Threespot eelpout	*Lycodes rossi*	
Archer eelpout	*Lycodes sagittarius*	
Longear eelpout	*Lycodes seminudus*	
Prickleback/blenny	Stichaeidae	
Pighead prickleback	*Acantholumpenus mackayi*	
Fourline snakeblenny	*Eumesogrammus praecisus*	
Slender eelblenny*	*Lumpenus fabricii**	
Daubed shanny*	*Leptoclinus maculates**	
Stout eelblenny*	*Anisarchus medius**	
Arctic shanny*	*Sticaeus punctatus punctatus**	
Wolffish	Anarhichadidae	
Northern wolffish	*Anarhichas denticulatus*	
Spotted wolffish	*Anarhichas orientalis*	
Sand lance	Ammodytidae	
Sand lance*	*Ammodytes sp.* *	
Northern sand lance	*Ammodytes dubius*	
Pacific sand lance	*Ammodytes hexapterus*	
Right-eyed flounder	Pleuronectidae	
Bering flounder	*Hippoglossoides robustus*	
Starry flounder*	*Platichthys stellatus**	nataarnaq, nataarnak, nataarnat
Arctic flounder	*Pleuronectes glacialis*	
Greenland halibut	*Reinhardtius hippoglossoides*	

Appendix 7 – Scientific, common and Inuvialuktun names of anadromous and some freshwater fish (Iqaluk, Iqalluk, Iqaluit) and larval fish (*) found in the Beaufort Sea LOMA.

Common Name	Scientific Name	Inuvialuktun (Singular – Lowe 2001) (Dual/Plural – Hart and Amos 2004)
Lamprey	Petromyzontidae	
Arctic lamprey	*Lethenteron camtschaticum**	
Sucker	Catostomidae	
Longnose sucker	*Catostomus catostomus*	milugiaq, milugiak, milugiat
Pike	Esocidae	
Northern pike	*Esox lucius*	siiraq, siiqqak, siiqqat
Smelt	Osmeridae	
Pond smelt	*Hypomesus olidus*	
Rainbow smelt	*Osmerus mordax mordax*	iqquaqtqaq, iqquaqtaak, iqquaqtat
Salmon and whitefishe	Salmonidae	
Cisco	*Coregonus artedi*	
Arctic cisco	*Coregonus autumnalis*	qaaktaq, qaaktak, qaaktat
Lake whitefish	*Coregonus clupeaformis*	pikuktuuq, pikuktuuk,pikuktuut
Bering cisco	*Coregonus laurettae*	
Broad whitefish	*Coregonus nasus*	anaakłiq, anakłiik, anaałkiit
Least cisco	*Coregonus sardinella*	
Pink salmon	*Oncorhynchus gorbuscha*	
Chum salmon	*Oncorhynchus keta*	
Coho salmon	*Oncorhynchus kisutch*	
Sockeye salmon	*Oncorhynchus nerka*	
Chinook salmon	*Oncorhynchus tshawytscha*	
Round whitefish	*Prosopium cylindraceum*	
Arctic grayling	*Thymallus arcticus arcticus*	sulukpaugaq, sulukpaak, sulukpait
Arctic charr	*Salvelinus alpinus*	iqalukpik, iqalukpiik, iqalukpiit
Dolly varden	*Salvelinus malma malma*	iqalukpik, iqalukpiik, iqalukpiit
Lake trout	*Salvelinus namaycush* (brackish/freshwater)	iqaluaqpak, iqaluakpaak, iqaluaqpait/singayuriaq, singayuriak, singayuriat
Inconnu	*Stenodus leucichthys*	siiraq, siiqqak, siiqqat
Cod/burbot	Gadidae	
Burbot	*Lota lota*	tiktaaliq, tiktaallak, tiktaaliit
Stickleback	Gasterosteidae	
Three-spine stickleback	*Gasterosteus aculeatus*	
Nine-spine stickleback	*Pungitius pungitius**	
Sculpin	Cottidae	kanayuq, kanatdjuk, kanutdjuk/kanayuit
Slimy sculpin	*Cottus cognatus*	
Spoonhead sculpin	*Cottus ricei*	

Appendix 8 – Scientific, common and Inuvialuktun (Siglit dialect) names for selected marine mammals in the Beaufort Sea LOMA.

Common Name	Scientific Name	Inuvialuktun (Singular – Lowe 2001) (Dual/Plural – Hart and Amos 2004)
Bearded seal	*Erignathus barbatus*	ugyuk, ugyuuk, ugyuit
Ringed seal	*Phoca hispida*	natchiq, natchiik, natchiit
Walrus	*Odobenus rosmarus*	aiviq, aivvak, aivrit
Beluga whale	*Delphinapterus leucas*	qulalugaq, qilalukkak, qilalukkat
Bowhead whale	*Balaena mysticetus*	arviq, arviik, arvit
Killer whale	*Orchinus orca*	aarlu, aarluuk, aarluit
Polar bear	*Ursus maritimus*	nanuq, nannuk, nannut

Appendix 9 – Scientific, common and Inuvialuktun (Siglit dialect) names for selected sea birds in the Beaufort Sea LOMA.

Common Name	Scientific Name	Inuvialuktun (Singular – Lowe 2001) (Dual/Plural – Hart and Amos 2004)
Yellow-billed loon	*Gavia adamsii*	tuullik, tuulliik, tuullit
Red-throated loon	*Gavia stellata*	qaqsaug, qaqsauk, qaqsaut
Pacific loon	*Gavia pacifica*	
Tundra swan	*Cygnus columbianus*	
Brant	*Branta bernicla*	nirlirnaq, nirlirnak, nirlirnat
Lesser snow goose	*Chen caerulescens*	kanguq, kannguk, kanngut
Scaup	*Aythya spp.*	
Oldsquaw/long-tailed duck	*Clangula hyemalis*	ahaanliq, ahaanlik, ahaanlit
Common eider	*Somateria mollissima*	
King eider	*Somateria spectabilis*	qaugaq, qaukkak, qaukkat
White-winged scoter	*Melanitta fusca*	
Surf scoter	*Melanitta perspicillata*	
Red-breasted merganser	*Mergus serrator*	
Black guillemots	*Cepphus grille*	
Thick-billed murres	*Uria lomvia*	
Red phalarope	*Phalaropus fulicarius*	
Red-necked phalarope	*Phalargous lobatus*	
Glaucous gull	*Larus hyperboreus*	
Sabine's gull	*Xema sabini*	
Arctic tern	*Sternus paradisaea*	

Appendix 10 – Abbreviations

Abbreviations used in the EBSA evaluation matrices.

AC = Arctic charr

AF = anadromous fish

AR = Arctic cod

AT = arctic tern

BF = broad whitefish

BG = black guillemot

BL = beluga whale

BN = benthos

BR = brant

BS = bearded seal

BW = bowhead whale

CG = cackling goose

CP = capelin

DV = Dolly Varden charr

FF = freshwater fish

FI = fish (unspecified type)

GU = gull

HR = herring

IP = ichthyoplankton

KW = killer whale

LT = lake trout

MB = migratory birds

ME = merganser sp

MF = marine fish

MM = marine mammal

MY = mysid

NP = northern pintail

PB = polar bear

PF = peregrine falcon

PH = phalarope

PP = phytoplankton

PR = pigheaded prickleback

RS = ringed seal

SB = sea bird

SD = sea duck

SF = shellfish

SG = snow goose

SH = shorebird

SL = seal (unspecified type)

TS = tundra swan

WF = wolfish

WG = white-fronted goose

WI = whitefish (unspecified type)

WR = walrus

ZP = zooplankton

Appendix 10 – Herschel Island/Yukon North Slope

Candidate Location: Includes the Firth River mouth, Herschel Island south along the coastline to the opening of Shallow Bay
Identified by: Science and Aklavik community

Oceanographic Feature: Freshwater corridor, steep bathymetry into the trough along the coast of Herschel Island – potential upwelling
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	PB, AR		BG	BL, BW, SH	AR	BG, PB	AR		PB				L[1]	Y	BG breeding site
Nursery/ rearing	BL, BW	PB	BG	BL, BW	BG	PB		BG	PB				H	Y	
Feeding	BL, BW, PB	BN[2]	AF		PB, BN	AF, BL, BN, BW,		PB	PH				H	Y	
Migration	PB, BL, BW,BR MF	SD	AF, PH	PB, BL, BW, MF	SD, GU	AF, PH, BR	PB, BL, BW, MF	SD, GU, BR	AF				H	Y	Data deficient: RS
Seasonal refugia	BL, BW, FI	PB, SD		BL, BW, AF	PB, SD		BL, AF, BW	SD, GU	PB				H	Y	SD moulting area
Biodiversity															
Endangered, threatened or rare species	Depleted populations of DV in the Rat and Big Fish rivers														
Highly diverse or productive communities		ZP				ZP								Y	Kelp beds also data deficient
Structural habitat															
Structural habitats	Kelp beds reported, gravel shoals														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient
[1] Artificial nests for BG [2] Data deficient

Appendix 10 – Mackenzie Trough

Candidate Location: Includes the Trough from 50–300 m
Identified by: Science

Oceanographic Feature: Upwelling
EBSA Ranking: Data deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Naturalness	Data deficient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	SL, PB			SL	PB		PB						H	Y	
Nursery/ rearing	SL	PB		SL, PB				PB					H	Y	
Feeding	SL, PB	BW		SL	BW, PB			BW					H	Y	
Migration		BW			BW			BW					H	Y	
Seasonal refugia													H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	BN					BN		BN		Data deficient: AF, FF,MF, ZP/IP					
Structural habitat															
Structural habitats	Data deficient														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Beluga Bay

Candidate Location: East of the Mackenzie trough within 10-m depth contour
Identified by: Science and Tuktoyaktuk, Aklavik and Inuvik communities

Oceanographic Feature: Freshwater and saltwater mixing zone
EBSA Ranking: EBSA

Feature	Uniqueness Low	Uniqueness Med	Uniqueness High	Aggregation Low	Aggregation Med	Aggregation High	Fitness consequences Low	Fitness consequences Med	Fitness consequences High	Resilience Low	Resilience Med	Resilience High	Naturalness	Data deficient	Notes
Ecological															
Spawning/ breeding					HR			HR					H	Y	
Nursery/ rearing	GU, TS, BR, SH	WG, SG	BL, PB	GU, TS, WG, SG, BR, SH	RS	BL, HR, PB	GU, SG, TS, WG, BR, SH	RS	BL, HR, PB				H	Y	
Feeding	BL, GU	PB			HR		BL, GU	PB					H	Y	
Migration		BR, WG	BL, TS		WG	TS, BL, BR		WG	BR, TS				H	Y	
Seasonal refugia		TS, WG	BL		TS, WG	BL			TS, WG				H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	None identified														
Structural habitat															
Structural habitats	Gravel shoals, landfast ice, Mackenzie Lake (under ice freshwater in winter)														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Kugmallit Corridor

Candidate Location: Kittigazuit Bay North to the Kugmallit Valley at 50m; within Toker Point and Summer Island as a corridor
Identified by: Science and Tuktoyaktuk community

Oceanographic Feature: Mackenzie Plume
EBSA Ranking: EBSA

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Naturalness	Data deficient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	HR, PB				PB	HR	PB		HR				H	Y	
Nursery/ rearing	RS, GU, PB		BL		RS, GU, PB	BL	GU		BL				H	Y	
Feeding	BL, PB			BL	PB		PB		RS				H	Y	
Migration	BL, PB	WG	AF, BW	BW	PB, WS	AF, BL	PB	WG	AF				H	Y	
Seasonal refugia			AF, BW		AF	BL							H	Y	Overwinter of AF under-ice
Biodiversity															
Endangered, threatened or rare species	PR population in Tuktoyaktuk harbour is considered a Special Concern (data deficient) under COSEWIC.														
Highly diverse or productive communities		IP				IP			IP	Data deficient	Data deficient		H	Y	IP studies show increased diversity within the corridor
Structural habitat															
Structural habitats	Artificial islands, underwater pingos, gas vents, ice scouring, James Shoal and Kugmallit Trough.														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Beaufort Sea Shelf Break

Candidate Location: Runs the length of the continental shelf in the Beaufort Sea
Identified by: Science

Oceanographic Feature: Upwelling of nutrient rich Pacific waters
EBSA Ranking: Data deficient

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding		PB			PB			PB					H	Y	PB are known to move offshore to pack ice
Nursery/ rearing													H	Y	PB are known to move offshore to pack ice
Feeding	MF		PB	MF	BN, BW	PB		MF	BW, PB				H	Y	
Migration	SD	PB			PB, SD		SD	PB					H	Y	
Seasonal refugia		BN				BN							H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	PP				PP				PP	Data deficient: MF, ZP/IP, BN, SL, MM usage					
Structural habitat															
Steep shelf break	The edge of the continental shelf. A steep drop from approximately 100m to 1000m. Limited ice scouring and/or disturbance														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Husky Lakes

Candidate Location: Encompasses the entire Husky Lakes area
Identified by: Science and Tuktoyaktuk community

Oceanographic Feature: Unique estuary, Strong tidal flows
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	RS	HR	LT, BR		LT, RS	HR, BR	RS	LT	HR, BR				H	Y	BR-10% of Cdn Population
Nursery/ rearing	RS, GU	LT	BR	GU	LT, RS	BR	RS, GU	LT	BR				H	Y	
Feeding	BL	LT, GU	ME		BL, LT, RS, GU	ME	BL, RS	GU, ME	LT				H	Y	
Migration		MB		MB				MB					H	Y	
Seasonal refugia	CG, WG, SD	TS	BR	WG, SD, CG	TS	BR	WG, TS, SD, CG		BR				H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: The unique oceanographic features of this area implies that is likely a unique environment.														
Structural habitat															
Structural habitats	Gravel shoals														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Liverpool Bay

Candidate Location: Includes Liverpool Bay, Ballie Island to the depth of 50-m contour
Identified by: Science and Tuktoyaktuk community

Oceanographic Feature: Upwelling, tides
EBSA Ranking: Data deficient

Feature	Uniqueness Low	Uniqueness Med	Uniqueness High	Aggregation Low	Aggregation Med	Aggregation High	Fitness consequences Low	Fitness consequences Med	Fitness consequences High	Resilience Low	Resilience Med	Resilience High	Naturalness	Data deficient	Notes
Ecological															
Spawning/ breeding	SL, PB	BR		SL, PB	BR		BR	BR					H	Y	MB use area *en route* to nesting areas and to moult *en route* south
Nursery/ rearing	SL, PB, GU, TS	BR, AT		SL, PB, BR, AT, GU, TS			BR, TS, AT, GU						H	Y	BW aggregations identified by aerial surveys
Feeding	SL, PB, SH, GU	BW	SD	SL, PB, SH, GU	BW	SD	SH, GU		SD				H	Y	MY ecology unknown
Migration		BW	SD		BW	SD			SD				H	Y	
Seasonal refugia	WG	MY, TS, SD, BR		BR	MY TS WG	SD	WG, BR	TS, SD					H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: AF, FF, MF, ZP/IP, BN, MM usage														
Structural habitat															
Structural habitats	Kelp beds identified by traditional knowledge on the north-eastern coastal area														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Horton River

Candidate Location: Western Coast of Franklin Bay
Identified by: Paulatuk community

Oceanographic Feature: Upwelling; freshwater influence from the river
EBSA Ranking: Data deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Naturalness	Data deficient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding													H	Y	
Nursery/ rearing	PB			PB			PB						H	Y	Communities indicate that BL and BW use the area; BL do not stay long; just pass through
Feeding	BL, BW, PB, AC	PP		BL, PB, BW	AC	PP	BL, BW, PB	AC					H	Y	
Migration	BL, BW, AC			BL, BW	AC		BL, BW	AC					H	Y	
Seasonal refugia													H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities		Meiofauna				Meiofauna				Data deficient: lack of information for ZP, BN and MF and MM; CASES publications will likely fill some of the gaps					
Structural habitat															
Structural habitats	Bathymetry – steep slope														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Langton Bay

Candidate Location: Southern portion of Franklin Bay
Identified by: Paulatuk community

Oceanographic Feature: Shallow Islands
EBSA Ranking: Rejected EBSA

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding													H		
Nursery/ rearing													H		
Feeding	BL, MF			BL, MF			BL						H		
Migration	BL			BL			BL						H		
Seasonal refugia													H		
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient														
Structural habitat															
Structural habitats	Bathymetry – shallow (gravel)														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Hornaday River

Candidate Location: Southern region on Darnley Bay near Paulatuk, including the Hornaday and the Brock River systems
Identified by: Paulatuk community

Oceanographic Feature: Freshwater and saltwater mixing zone; coastal estuary
EBSA Ranking: EBSA

Feature	Uniqueness Low	Uniqueness Med	Uniqueness High	Aggregation Low	Aggregation Med	Aggregation High	Fitness consequences Low	Fitness consequences Med	Fitness consequences High	Resilience Low	Resilience Med	Resilience High	Naturalness	Data deficient	Notes
Ecological															
Spawning/ breeding		HR			HR								H	MF	
Nursery/ rearing		RS			RS			RS					H	Y	
Feeding				BF	BW, RS	AC		RS	AC				H	BW	Community reports increased BW and BL activity
Migration	AC, BL	AC, SL, BL, BF, BW		BL		AC		BF					H	BL	Community reports increased BW and BL activity
Seasonal refugia													H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities		ZP					Data deficient: all aspects of the ecosystem								
Structural habitat															
Structural habitats	Kelp beds identified														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Pearce Point

Candidate Location: Pearce Point
Identified by: Paulatuk Community

Oceanographic Feature: Unknown
EBSA Ranking: Data Deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	RS, PB		SB	RS, PB		SB			SB				H	Y[1]	SB-only colony of this subspecies in Canada
Nursery/ rearing	RS, PB		SB	RS, PB		SB			SB				H	Y[2]	
Feeding	BL, PB, MF, AC	BW		BL, MF	BW, PB, AC								H	Y[1]	
Migration	BL, BW, AC			BL	BW, AC		BL, BW					BW, BL	H		
Seasonal refugia													H	Y[3]	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: All aspects of the ecosystem.														
Structural habitat															
Structural habitats	Data Deficient - Bathymetry														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient
[1] MF [2] BW [3] BL, BW

Appendix 10 – De Salis Bay

Candidate Location: South-eastern bay on Banks Island
Identified by: Sachs Harbour Community Conservation Plan

Oceanographic Feature: Upwelling
EBSA Ranking: EBSA

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Naturalness	Data deficient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	SD	BR		SB	BR		BR, SD						H	Y	
Nursery/ rearing	PB	BR, SD		PB	BR, SD		BR, SD						H	Y	
Feeding	AC	BW, SL, BL			BW, SL, BL, AC			BW, SL, BL, AC					H	Y	
Migration	AC	BW, SL, BL			BW, SL, BL, AC			BW, SL, BL, AC					H	Y	
Seasonal refugia		SD			SD			SD					H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: all aspects of ecosystem														
Structural habitat															
Structural habitats	None identified – Data deficient														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Thesiger Bay

Candidate Location: Extends offshore from Cape Kellett to Cape Lambton including Sachs Harbour
Identified by: Science and Sachs Harbour community

Oceanographic Feature: Flaw polynya and freshwater and saltwater mixing in the harbour
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-	Data	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	ralness	defi-cient	
Ecological															
Spawning/ breeding		CP			CP								H	Y	MF, CP runs known - data deficient
Nursery/ rearing	SL, PB	CP			SL, PB, CP								H	Y	SL includes RS and BS
Feeding	SL, PB, BL	CP			SL, CP, BL, PB,			SL, PB, BL					H	Y	
Migration	AC, BL, PB		AC, SD	PB	BL	SD		AC, BL	SD				H	Y	CP runs known - data deficient
Seasonal refugia													H	Y	
Biodiversity															
Endangered, threatened or rare species	WR, PF														
Highly diverse or productive communities		BN			BN		Data deficient: AF, FF, MF, ZP/IP, BN, MM. Few studies have been completed in the area, based on this information the area is deemed significant								
Structural habitat															
Flaw leads	The flaw lead is variable and forms in spring during breakup, thought to be a productive area														
Structural habitats	Kelp beds, gravel shoals and saline lakes/salt depressions in the harbour.														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Walker Bay

Candidate Location: Includes Ramsay Island and extends from Berkeley Point to Cape Peter
Identified by: Science and Ulukhaktok community

Oceanographic Feature: Freshwater and saltwater mixing zone; coastal estuary
EBSA Ranking: Data deficient

	Uniqueness			Aggregation			Fitness consequences			Resilience					
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Naturalness	Data deficient	Notes
Ecological															
Spawning/ breeding	MB			MB			MB						H	Y	
Nursery/ rearing	SL, PB, MB			MB	SL, PB		MB	SL, PB					H	Y	RS, BS
Feeding	AC, SL, PB	SF			AC, SL, PB	SF		SL, PB	AC				H	Y	SF are identified as data deficient by CCP
Migration	AC, SL, PB			MB	AC		MB		AC				H	Y	
Seasonal refugia	SD			SD		SD							H	Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: AF, FF,MF, ZP, BN														
Structural habitat															
Structural habitats	Data deficient: bathymetry														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Minto Inlet/Kuujjua River

Candidate Location: Coastline south of the Kuujjua River to Cape Ptarmigan
Identified by: Science

Oceanographic Feature: Freshwater and saltwater mixing zone; coastal estuary
EBSA Ranking: Data deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Naturalness	Data deficient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	MB			MB			MB						H[1]	Y	
Nursery/ rearing	SL, GU, PB				SL, GU, PB		GU	SL, PB					H[2]	Y	RS, BS
Feeding	AC				AC				AC				H[3]	Y	
Migration	MB	AC		MB		AC	MB		AC				H[4]	Y	
Seasonal refugia														Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: MF, ZP, BN														
Structural habitat															
Structural habitats	Nearshore corridor used by migratory fish; confined by bathymetry														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient
[1] MB [2] SL, PB [3] AC [4] MB, AC

Appendix 10 – Albert Islands/Safety Channel

Candidate Location: Includes Queen, Jack Bay and the Albert Islands
Identified by: Science and Ulukhaktok community

Oceanographic Feature: Freshwater and saltwater mixing zone; flaw lead
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding		CP							CP				H	Y	
Nursery/ rearing	SL, PB, MB	CP, SD, GU			PB, CP, SD	SL, MB, GU		SD, GU	SL, MB, CP				H	Y	
Feeding	SL, PB, AC	CP			MF, PB	SL, MB, CP, AC		SL, PB, MF	AC, CP				H	Y	
Migration	MB, AC		SD		MB	AC, SD	SD						H	Y	
Seasonal refugia	MF	SD			SD			SD					H	Y	
Biodiversity															
Endangered, threatened or rare species							WF and KW Sighting								
Highly diverse or productive communities			X			X			X		Data deficient: AF, FF, MF, ZP/IP, BN, CP runs, BL and BW uses.				
Structural habitat															
Albert Islands	Several islands along the southern part of Banks Island creating a small channel close to the coast														
Structural habitats	Data deficient: bathymetry														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Cape Bathurst Polynya

Candidate Location: Amundsen Gulf Entrance – diffuse boundary
Identified by: Science

Oceanographic Feature: Polynya, upwelling
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-	Data	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	ralness	defi-cient	
Ecological															
Spawning/ breeding	PB				PB			PB					H	Y[1]	
Nursery/ rearing													H	Y[1]	
Feeding	BL	BN, PB	PP, SB		RS, PB	BL,PP BN, SB		PB	PP, SB				H	Y[2]	
Migration	PB				PB		PB						H		
Seasonal refugia													H		
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: dramatic increase in productivity therefore likely presence of highly diverse communities														
Structural habitat															
Structural habitats	Ice melting and increase in sunlight penetrating the water column and ice-edge habitat; deep water basin														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient
[1] MF [2] MF, BL

Appendix 10 – Kagloryuak River

Candidate Location: Eastern Portion of Prince Albert Sound, includes the Kuuk and Kagloryuak Rivers
Identified by: Science and Ulukhaktok community

Oceanographic Feature: Freshwater and saltwater mixing zone; coastal stuary
EBSA Ranking: Data deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	MB, SD			MB, SD			MB, SD						H	Y	
Nursery/ rearing	SL, PB, MB	SD		MB, SD	SL, PB		MB, SD	SL, PB					H	Y	RS, BS
Feeding	AC, SL, WI, PB				AC, SL, WI, PB			SL, PB	AC, SL, WI				H	Y	WI info from TK
Migration	AC, MB	SD		MB	AC, SD		MB, SD		AC				H	Y	
Seasonal refugia														Y	
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: anadromous/freshwater and marine fish, zooplankton, benthos, bathymetry														
Structural habitat															
Structural habitats	Data deficient: bathymetry														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Viscount Melville Sound

Candidate Location: Eastern extent of M'Clure Strait to the most easterly LOMA boundary
Identified by: Science

Oceanographic Feature: Unknown
EBSA Ranking: Data deficient

Feature	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding															Tagged BL and RS known to migrate here for unknown reasons. BL perform deep dives.
Nursery/ rearing															
Feeding															
Migration															
Seasonal refugia															
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	Data deficient: MF, ZP/IP, BN Majority of the region is data deficient														
Structural habitat															
Structural habitats	Data deficient: bathymetry and oceanographic features														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Banks Island Flaw Lead

Candidate Location: Banks Island Flaw Lead
Identified by: Science

Oceanographic Feature: Open water polynya
EBSA Ranking: Data Deficient

Feature	Uniqueness Low	Uniqueness Med	Uniqueness High	Aggregation Low	Aggregation Med	Aggregation High	Fitness consequences Low	Fitness consequences Med	Fitness consequences High	Resilience Low	Resilience Med	Resilience High	Naturalness	Data deficient	Notes
Ecological															
Spawning/ breeding													H	Y	AC, MF - unknown
Nursery/ rearing													H	Y	AC, MF - unknown
Feeding		PP	BL, SD, SB		RS, PB	BL, PP, SD, SB			BL, PP, SD, SB				H	Y	AC, BW, BN, MF - unknown
Migration			BL, SD, SB			BL, SD, SB			SD				H	Y	
Seasonal refugia			BL			BL							H	Y	AC - unknown
Biodiversity															
Endangered, threatened or rare species	None identified.														
Highly diverse or productive communities	Data deficient: Productivity more variable than the Cape Bathurst Polynya.														
Structural habitat															
Structural habitats	Open water; ice melt and increase in sunlight penetrating the water column and ice-edge habitat														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient

Appendix 10 – Shallow Bay

Candidate Location: Mouth of Shallow Bay and southern Mackenzie Bay
Identified by: Science and Tuktoyaktuk, Aklavik and Inuvik communities

Oceanographic Feature: Freshwater and saltwater mixing zone, shallow waters
EBSA Ranking: EBSA

	Uniqueness			Aggregation			Fitness consequences			Resilience			Natu-ralness	Data defi-cient	Notes
Feature	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High			
Ecological															
Spawning/ breeding	RS, PB	HR, GU	BL	RS, PB	HR, GU	BL	RS, PB	HR, GU					H	Y[1]	GU colony
Nursery/ rearing		GU	BL		RS, GU PB	BL, HR		RS, GU PB	BL, HR				H	Y[2]	
Feeding	BL	AF		BL			BL						H		
Migration	SH	BR, PH	BL, WG, AF	PH, SH	BR, SG	BL, WG, AF	SG, SH	BL, WG, BR	AF				H		AF likely have low resilience
Seasonal refugia			BL, AF		BF	BL			BL, AF				H	Y[3]	AF unknown overwintering
Biodiversity															
Endangered, threatened or rare species	None identified														
Highly diverse or productive communities	None identified														
Structural habitat															
Structural habitats	Gravel shoals, landfast ice, Mackenzie Lake (under ice freshwater in winter)														

Naturalness is evaluated as H (high), M (medium) or L (low). Data deficient
[1] HR [2] BL [3] AF

Appendix 11 – Beaufort Sea activities and stressors associated with marine transport and oil and gas activities (after R. Rutherford, Thaumas Environmental Consultants Ltd., Dartmouth, unpubl. data)

STRESSOR	ACTIVITY	
	Marine transport: Shipping, ballast water, spills and discharge	**Oil and gas exploration: Seismic, exploratory**
Pollution	Ship's masters or owners must report any discharge of a pollutant that occurs or the probability that such a discharge will occur. Shipping and boat traffic have a wide range of impacts on the marine environment. They incorporate many common land-based impacts because they take people onto the water, as well as direct impacts such as collisions, harassment and noise, with the potential risk of large spills of the oil or chemicals being shipped.	Operators of oil and gas handling facilities must report any discharge of a pollutant that occurs or the probability that such a discharge will occur. These facilities incorporate many of the common land-based impacts because they take people onto the water and construct large platforms, as well as having direct impacts such as harassment and noise, with the potential risk of large spills of the oil and chemicals being used for exploration.
Organic waste (sewage)	It is generally considered that, on the high seas, the oceans are capable of assimilating and dealing with raw sewage through natural bacterial action. Therefore, ships are prohibited from discharging sewage within four miles of the nearest land, unless they are using an approved treatment plant. Between four and 12 miles from land, sewage must be broken down into small particles and disinfected before discharge.	Sewage disposal at sea normally includes enhanced primary treatment. Food wastes are disposed of at sea and all other wastes are disposed of on land via supply ships. Cleaning solvents are disposed of via supply ship, and all spills are reported to regulatory agencies on a regular basis.
Bacteria	The source of bacteria from shipping is sewage and ballast water. The impact is generally low compared to the land-based sources, which is why controls have not been placed on discharges into Canadian waters.	
Nutrients	The loading of nutrients is from sewage and the disposal of organic food wastes and other operational wastes. There are no Canadian controls on this disposal but most ships have to meet international standards. The impact on the ecosystem is considered to be minor in comparison to land-based sources, and controls are being delayed until they are matched on land.	

STRESSOR	ACTIVITY	
	Marine transport: Shipping, ballast water, spills and discharge	**Oil and gas exploration: Seismic, exploratory**
Oil Waste	Oil discharges from ships are a major concern for the marine environment. Discharges come from the normal operations of ships and boats, the potential risk of both intentional and accidental small discharges and, of course, major accidents discharging fuel oils or cargo. Internationally, marine transport accounts for about one-third of the transportation input. Of the shipping inputs, 44% comes from bilge oils, 28% from tanker operations and 20% from tanker accidents. The impact of oil spills includes: physical and chemical alteration of natural habitats (e.g. resulting from oil incorporation into sediments); physical smothering effects on flora and fauna; lethal or sub-lethal toxic effects on flora and fauna; and changes in biological communities resulting from oil effects on key organisms. Factors that have proved to be important in determining oil spill impacts and subsequent recovery rates include: oil type; oil loading (the thickness of deposits on the shore); local geography, climate and season; biological and physical characteristics of the area; relative sensitivity of species and biological communities; and type of clean-up response.	Most drilling muds are now synthetic or water-based. The rules may vary depending on which agency is regulating the site but the current standard is for oil or hydrocarbon synthetic muds to be collected and disposed of on land. Muds used to drill the hole for the initial casing and some muds left with the cuttings are disposed of at the site. All muds are separated from the drill cuttings and reused.
Chemical contamination	The risk of spills is low. The *Canada Shipping Act* (CSA) regulates pollutant substances from ships.	Produced waters are released from rock formations as the drilling proceeds. These waters are dumped from the rigs at or near the surface. The heavy metal content of these waters may be very high, depending on the type of rock. There is generally very little produced water during exploration phases because well casing and drilling muds prevent its entry into the hole.

STRESSOR	ACTIVITY	
	Marine transport: Shipping, ballast water, spills and discharge	**Oil and gas exploration: Seismic, exploratory**
Sediment Movement	Propeller wash and bow waves cause the re-suspension of fine sediment in shallow-water areas and can damage macrophytes in coastal embayments. Impacts in the Beaufort Sea LOMA have not been documented. Dredging is used to deepen waterways. The impacts on habitats are considered through formal regulatory review and environmental assessment processes, including ocean-dumping permits if the material is to be disposed of at sea. Dredge spoils have the obvious effect of burying habitat, but they also move with currents, so the ultimate deposition site has to be considered.	Erosion around rig legs and anchors affects only a small area and is controlled by the use of steel mats or similar techniques to prevent shifting or instability. Dredging is used to create platforms (artificial islands) and platform stability.
Invasive Species	Ballast water has been associated with the unintentional introduction of a number of organisms in Canadian waters. Transport Canada has established guidelines intended to minimize the probability of future introductions of harmful aquatic organisms and pathogens from ships' ballast water while protecting the safety of ships. See http://www.tc.gc.ca/MarineSafety/Tp/Tp13617/menu.htm The guidelines provide instructions to ships transiting between Canadian and American, or other foreign locations, to exchange their ballast at sea prior to entering Canadian waters. All vessels are required to report on their ballast exchange status when they request clearance to enter Canadian ports. Many of the species, that can be brought in ballast water can also travel on the hulls of ships.	
Accidental Kill	Most whales and fish are aware of approaching vessels and are able to avoid collisions. Marine animals in high traffic areas often become confused or are unable to avoid being hit. Confused, tired or sick animals can be fatally injured if they do not take avoidance action. Where this becomes a problem, buffer areas could be established around critical areas, shipping lanes could be changed, and slower transit of the area are possible mitigation techniques.	Seismic "shock waves" within 3 m of the airguns affects the animal tissue of different densities at different velocities and can cause tearing of tissues and rupture of the air bladder. The lethal radius for eggs and larvae is <3m or 226–234 dB, (Turnpenney and Nedwell 1994). For an 80-m-wide array at 6 m deep, the impact zone could be from 3 m down to 9 m and 80 m wide along the length of the track line.
Diseases and Parasites	Ballast water has been implicated in the transport of diseases and parasites.	

STRESSOR	ACTIVITY Marine transport: Shipping, ballast water, spills and discharge	 Oil and gas exploration: Seismic, exploratory
Behaviour/ harassment	Schwarz and Greer (1984) studied the responses of penned herring to various sounds and noted three kinds of responses, including a startle response and avoidance. Twenty-five percent of the fish groups habituated to the sound of a large vessel and 75% of the responsive fish groups habituated to the sound of a small boat. Chapman and Hawkins (1969) also noted that fish adjust rapidly to high sound levels in the open sea; fish that are at the side of a boat will avoid the sound of a moving boat by swimming away from it or trying to outrun it. Most schools of fish will not show avoidance if they are not in the path of the vessel. When the vessel passes over fish, some species show sudden escape responses that include lateral avoidance and/or downward compression of the school. Avoidance reactions are quite variable and depend on species, life-history stage, behaviour, time of day, whether the fish have fed recently, and sound propagation characteristics of the water (Misund 1997). Harassment is an issue for marine mammals because they will adjust to the presence of boats and the related noise, but when the boats come too close or when boats interfere with their feeding and daily migratory behaviours the whales become stressed. Fisheries Act marine mammal regulations and guidelines have been designed to address this issue.	*Invertebrates* Copepods use well-developed "hearing" receptors to detect predators (Hartline et al. 1996). They may be able to detect far-field sounds emitted by a seismic array. Schooling zooplankters, such as euphausiids, use these receptors to maintain school structure but the effects of noise are not known. *Fish and marine mammals* The pulsed sounds of the seismic airgun can cause fish and whales to take defensive postures or respond with fear reactions. Whales may surface too quickly and develop nitrogen bubbles in blood and bleeding. The dB level for this response is not clear and will vary with maturity, experience, reproductive state and species of whale. Underwater noise can alter the behaviour of some fish. Sudden changes in noise level can cause fish and marine mammals to dive or to avoid the sound by changing direction. Time of year, whether or not they have eaten recently and the nature of the sound all may determine whether fish react to underwater noise. Migrating bowhead whales, gray whales and humpback whales have been observed moving away from feeding locations or making statistically significant deviations in the direction of the swimming and/or migration corridor as they approach or pass the sound sources.
Debris	Canada's *Garbage Pollution Prevention Regulations* (http://www.tc.gc.ca/acts-regulations/GENERAL/C/CSA/regulations/020/csa022/csa22.html), prohibit the discharge of garbage in waters under Canadian jurisdiction.	Domestic garbage is taken ashore for disposal. "No dumping" regulations now require the removal of all materials for shore disposal. The only thing that remains is the wellhead, which develops a hard-bottom community.

STRESSOR	ACTIVITY	
	Marine transport: **Shipping, ballast water, spills and discharge**	**Oil and gas exploration:** **Seismic, exploratory**
	The CSA prohibits the dumping of garbage into any area of the marine environment under Canadian jurisdiction (200 nautical mile limit) including solid galley waste, food waste, paper, rags, plastics, glass, metal, bottles, crockery, junk or similar refuse from any vessel not propelled by oars. Oar-propelled boats do not have any debris regulation.	
Collisions	Oil and chemical spills could occur in the event of a collision between ships. There is really very little capacity to respond to a large event and technically very little that can be done once the spill has occurred in open waters. Prevention and response plans, which deal effectively with the damaged ships, should be in place and kept updated.	
Noise	Ship noise at 190 dB will affect the behaviour of marine animals but will dissipate in approximately 70 m to a level below which there are significant impacts. Increased levels and sources may confuse some animals. The noise and operations of the ship may interfere with the migration of fish species.	The repetitive pulsing noise of the airguns at 240 dB and the use of powerful supply ships (170–180 dB) add to the marine noise. Seismic and related ships are just one aspect of noise within the range of other activities in the Beaufort Sea. Jack-up rigs operate at 199–127 dB, which is just above background at the lower end and dissipates below the level of any behavioural changes within 70 m. Supply ships and tenders operate at 170–180 dB and, with spherical dispersion of the sound, it disperses below the 160 level of concern within a few tens of m. The other rigs have the same noise levels. Noise and operations of the rig may interfere with the migration of fish species.

STRESSOR	ACTIVITY	
	Marine transport: Shipping, ballast water, spills and discharge	**Oil and gas exploration: Seismic, exploratory**
Light	Ships are well lit but the only expected impact is on sea birds. EC has guidelines that direct ships' crews on correct ways to handle impacted birds.	Light from ships operating at night attracts fish during times when the seismic guns are not firing, which brings fish in closer contact with the noise from airguns when they are fired. Ships and rigs operate 24 hours a day and they are well lit. The lights may attract fish and may explain part of the "reef" effect observed around the rigs. The major impact of lights is on sea birds, and the EIAs address the mitigation measures set out by CWS.
Other Potential Activities	Sand and gravel mining, and hydrate extraction are two other activities that are in the planning stages, but will have a significant impact if a management process is not established. Both involve what is basically an open-pit mining operation on the seabed. Sand and gravel mining would be conducted from a suction dredge with standard mitigation techniques to minimize turbidity. The benthic community would be destroyed in the removal area and could recolonize on any surface substrate requested. A change from sand to hard-bottom substrate changes the benthic community from infauna to epifauna, so this alteration has been presented as habitat improvement. The removal of bedforms such as large sand waves, gravel piles or moraines can represent a major loss to the benthic community and fish that depend on it. These operations are capable of deepening the water significantly (20–30m), which could remove small banks critical for spawning. These projects will have to be given careful review. Methane hydrates are a type of natural formation that contains large amounts of methane (natural gas), and water in the form of ice. Hydrates are plentiful in nature, both underwater and under permafrost, and have been found in the Beaufort Sea. They are a potential source of energy for the future; however, little is currently known about cost-effective ways to turn hydrates into an energy resource. Hydrates affect the strength of the sediments in which they are found. Areas with hydrates appear to be less stable than other areas of the seabed. Consequently, it is important to assess their presence prior to the construction of underwater structures related to military defence and to gas and oil exploration and production.	

Appendix 12 – Canadian science and research projects selected for International Polar Year 2007–2008 funding from the Government of Canada and relevant to understanding climate change in the Beaufort Sea.

Project Title	Project Leader	Description	Location(s):
The Circumpolar Flaw Lead System Study	David Barber, University of Manitoba	This project will examine the importance of climate processes in changing the nature of a flaw lead system (a unique area where open water persists throughout the winter) in the Northern Hemisphere, and the effect these changes have on the marine ecosystem, contaminant transport, carbon fluxes and greenhouse gases. The project requires the Canadian Research Icebreaker *CCGS Amundsen* to spend the winter in the Banks Island flaw lead in the Southern Beaufort Sea.	Southern Beaufort Sea
C3O – Canada's Three Oceans	Eddy Carmack, Fisheries and Oceans Canada	C3O will use two Canadian Coast Guard icebreakers, whose current mission tracks encircle Canada, to obtain a snapshot of large-scale ocean and ecosystem properties, and thus establish a scientific basis for sustained monitoring of Canada's sub-Arctic and Arctic seas in the wake of climate change.	C3O will measure ocean and ecosystem properties from Vancouver Island to Nova Scotia, including the Gulf of Alaska, the Bering, Chukchi and Beaufort seas, the deep Canada Basin, the Northwest Passage from Amundsen Gulf to Lancaster Sound, Baffin Bay and the Labrador Sea. In all, approximately 12,000 km of ocean track will be covered.
Impacts of Severe Arctic Storms and Climate Change on Coastal Areas	William Perrie, Fisheries and Oceans Canada	The focus of this project is to understand coastal oceanographic processes in the southern Beaufort Sea, and the related waters of the western Canadian Arctic, driven by intense storms and severe weather. This area is important because the use of the coastal marine and terrestrial environment by Canadian Northerners is an integral part of their life style, and these environments are being impacted by coastal erosion processes, related to marine storms that tend to be growing stronger.	Beaufort Sea, and coastal areas of the Yukon and Northwest Territories
Permafrost Conditions and Climate Change	Antoni Lewkowicz, University of Ottawa	The goal of this project is to provide a snapshot of permafrost conditions during the International Polar Year that we can use to make predictions about the future. Permafrost and the ice it contains make it difficult to build houses, roads and pipelines in the North. However, permafrost thawing may cause new problems. Research is needed to understand the rapidity of change and to help prepare northern residents and communities—as well as industry and governments—for the future.	Yukon, Northwest Territories and Nunavut

Project Title	Project Leader	Description	Location(s):
Variability and Change in the Canadian Cryosphere (Snow and Ice)	Anne Walker, Environment Canada	Research activities involve investigating the current state and past change of the cryosphere (snow, lake and river ice, sea ice, frozen ground, glaciers and ice caps) through analysis of satellite data and images, field measurements, and historical data. Projections of future climate change will be evaluated and enhanced by improving the representation of the cryosphere in Canadian climate models. This project will provide new satellite-derived information products to meet the needs of a wide variety of users including northern communities and water-resource management and operations. It will also support climate impact studies and the development of adaptation strategies.	Yukon Territory, Northwest Territories, Nunavut and northern Quebec
The Carbon Cycle in the Canadian Arctic and Sub-Arctic Continental Margin	Charles Gobeil, Université du Québec	The intent of this project is to collect sediment cores along sections on the margin of Canada's three oceans, with the view that these sections span the present-day marginal ice zone. The change in ice conditions of the Arctic Ocean's margin can then be assessed against other margins that will not exhibit any change. With this work, the Canadian science community will take a leadership role in understanding the interactions between climate change and elemental cycles in the Arctic Ocean.	Sub-Arctic Pacific (margin leading up to the Aleutians), the Bering, Chukchi and Beaufort seas, Baffin Bay and Davis Strait, and the Canadian Archipelago

Appendix 13 – Canadian science and research projects selected for International Polar Year 2007–2008 funding from the Government of Canada and relevant to social, cultural and economic assessment.

Project Title	Project Leader	Description	Location(s)
Arctic Resiliency and Diversity	Inuit Tapiriit Kanatami with universities and northern organizations	Northern Aboriginal organizations will guide the development of a study on Arctic resiliency and diversity to examine the factors that determine resiliency in northern communities, and how northern communities are adapting to a changing world. This study will consider how the health of northern communities is expected to evolve with changing climate, as well as environmental, technological and social changes in the North.	Northern Canada
Dynamic Inuit Societies in Arctic History	Trevor Friesen, University of Toronto	Archaeologists and other scientists from across Canada will collaborate with Inuit community and heritage organizations to better understand how Inuit culture has developed and changed over the past 1000 years. Research teams will bring together Inuit knowledge, the excavation of important archaeological sites, and information about changing Arctic environments	Across the Canadian Arctic
The Impacts of Oil and Gas Activity on Peoples in the Arctic	Dawn Bazely, York University	Over centuries, people in the Arctic have learned to adapt and thrive in an uncertain, harsh environment. Today, change is occurring at an unprecedented rate. Local peoples' capacity to cope and adapt is under pressure. Natural and social scientists will join with members of Arctic communities in Canada, Norway, Alaska and Russia to study the impacts of oil and gas activity on the health, traditional livelihoods, economic development and ecosystem change in the Arctic. The research will develop a broad range of community-driven grassroots indicators and methods to assess future change. The research will also broaden international collaboration and communication among circumpolar communities through focus-group workshops on oil and gas impacts on local communities.	Various locations throughout Canada's Territories