Fisheries and Oceans Canada Pêches et Océans Canada

Science Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2012/149

Central and Arctic Region

Document de recherche 2012/149

Région du Centre et de l'Arctique

An Ecological and Oceanographic Assessment of the Beaufort Sea Region: Evaluation of the Risks Associated with Ballast Water Exchange

Évaluation écologique et océanographique de la région de la mer de Beaufort : évaluation des risques liés à l'échange des eaux de ballast

David Fissel[1], William Cross[2] and Kimberly Howland[3]

[1]ASL Environmental Sciences Inc., 1986 Mills Road, Sidney, BC V8L 5Y3

[2]LGL Ltd., Environmental Research Associates, 22 Fisher St., P.O. Box 280, King City, ON L7B 1A6

[3]Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, MB R3T 2N6

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Correct citation for this publication:

Fissel, D., Cross, W., and Howland, K. 2013. An Ecological and oceanographic assessment of the Beaufort Sea region: evaluation of the risks associated with ballast water exchange. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/149. vi + 64 p.

ABSTRACT

This work considers the ecological risks of non-indigenous species introductions associated with ballast water exchange in the Beaufort Sea region of the Canadian Arctic. Normally foreign vessels are required to conduct mid-ocean ballast exchange outside the Canadian Exclusive Economic Zone, however in the event that this is not possible due to safety concerns, ships may conduct emergency ballast exchange in one of two designated alternate ballast water exchange zones (ABWEZs) within Canadian Arctic waters. To date, ABWEZs have been identified in the Hudson Strait and Lancaster Sound regions of the eastern Arctic for vessels traveling westbound to the Port of Churchill or the Northwest Passage, respectively. A need for a third zone in the western Arctic has been identified, and is considered a priority given the renewed interest in hydrocarbon development in this region.

Information on the ecology, oceanography, and shipping patterns in the Beaufort Sea region were reviewed to assess the potential risks of non-indigenous species introductions associated with ballast water exchange.

In the Canadian Beaufort Sea there are extensive areas of ecological significance associated with upwelling in the Mackenzie Trough and the outer shelf and slope regions of the Mackenzie, as well as over the middle and inner portions of the Mackenzie Shelf due to the influence of the Mackenzie River plume and frontal features. Based on these features, ballast water exchange should be avoided from the longitude of Herschel Island (139°W) eastward to the entrance to Amundsen Gulf (125°W) and from the coastline to approximately the 1000-m water depth contour.

Given the spatial constraints related to water depths and ecologically important areas, the potential locations for an ABWEZ are very limited, given the need to accommodate a linear ship track of 200–400 km long. Within these constraints, the waters to the west of Herschel Island at depths of 20–100 m along the route of most transiting vessels are incompatible with a potential AWBEZ because the distance from the Canada/US border is <100 km. Farther offshore at water depths of 100–1000 m, starting from the Canada/US border there is an area that extends in a WSW to ENE orientation, however, travel eastward along this track is limited in early August by the presence of significant ice concentrations. Although a sufficient linear transit track (> 200 km) becomes feasible in this location by mid-September, this is well beyond the entry dates of most commercial shipping in August.

Under present ice conditions combined with the water depths and ecologically sensitive area constraints, there are presently no feasible ABWEZ sites in the Canadian Beaufort Sea.

In the event that future sea ice conditions are reduced and ice retreats farther offshore in early to mid-summer, an ABWEZ site from the Canada/US border east-northeastward in water depths of 1000 m or more north of the Mackenzie Trough would become possible. This area would be reasonably feasible for ships that may be travelling to far offshore oil and gas license areas for which exploration is presently getting underway, and for transit to McClure Strait north of Banks Island, which represents the deepwater northern route of the Northwest Passage through the Canadian Arctic Islands.

RÉSUMÉ

Cette étude se penche sur les risques écologiques des introductions d'espèces non indigènes liées aux échanges d'eaux de ballast dans la région de la mer de Beaufort dans l'Arctique canadien. Normalement, les navires étrangers sont obligés d’effectuer un échange d'eau de ballast en haute mer en dehors de la zone économique exclusive du Canada. Toutefois, si cela n'est pas possible pour des raisons de sécurité, les navires ont la possibilité d'effectuer un échange d’urgence dans une des deux zones alternatives d'échange des eaux de ballast (ZAEEB) dans les eaux de l'Arctique canadien. À ce jour, on a identifié des zones de ce type dans les régions des détroits d'Hudson et de Lancaster de l'est de l'Arctique à l'intention des navires qui se dirigent vers l'ouest respectivement vers le port de Churchill et vers le passage du Nord-Ouest. On a également besoin d'une troisième zone dans l'ouest de l'Arctique; il s'agit d'une priorité vu le regain d'intérêt pour l'exploitation des hydrocarbures dans cette région.

L'information sur l'écologie, l'océanographie et les trajets habituels de navigation dans la région de la mer de Beaufort a été examinée afin d'évaluer les risques potentiels des introductions d'espèces non indigènes liées aux échanges d'eau de ballast.

Dans la partie canadienne de la mer de Beaufort, il y a des zones étendues d'importance écologique liées à la remontée des eaux dans la dépression du Mackenzie ainsi que les régions de la zone externe du plateau et le talus continental du Mackenzie, ainsi que les parties du milieu et de l'intérieur du plateau du Mackenzie en raison de l'influence du panache fluvial et les caractéristiques du front du fleuve Mackenzie. Pour cette raison, on doit éviter l'échange d'eaux de ballast à partir de la longitude de l'île Herschel (139 °O) vers l’est jusqu'à l'entrée du golfe Amundsen (125 °O) et de la côte jusqu'à l'isobathe de 1000 m environ.

Étant donné les contraintes spatiales associées aux profondeurs d'eau et aux zones d'importance écologique, le nombre d’emplacements possibles d’une ZAEEB est très limité, compte tenu du besoin de garantir une trajectoire linéaire de 200 à 400 km pour les navires. Tout en respectant ces contraintes, les eaux à l'ouest de l'île de Herschel avec des profondeurs entre 20 et 100 m le long de la route empruntée par la plupart des navires sont incompatibles avec une possible ZAEEB, car la distance entre celle-ci et la frontière canado-américaine est moins de 100 km. Plus loin en mer, à des profondeurs entre 100 et 1000 m, à partir de la frontière canado-américaine, il y a une zone qui s'étend de l'OSO à l'ENE. Cependant, la navigation vers l'est le long de cette trajectoire est limitée au début du mois d'août par la présence de fortes concentrations de glace. Même si une route linéaire suffisamment longue (de plus de 200 km) devient faisable à cet emplacement à partir de la mi-septembre, c'est bien après les dates d'entrée d'une grande partie de la navigation commerciale en août.

Les contraintes associées à l'état présent des glaces de mer, aux profondeurs de l'eau et aux zones d'importance écologique, font qu’il n’y a pas d’emplacements possibles pour l'établissement d’une ZAEEB dans la partie canadienne de la mer de Beaufort à l’heure actuelle.

Si jamais l'état des glaces de mer se modifie et la glace régresse plus loin en mer entre le début et le milieu de l'été, une ZAEEB allant de la frontière canado-américaine vers l'est-nord-est dans des eaux de 1000 m de profondeur ou davantage au nord de la dépression du Mackenzie deviendra alors possible. Cette zone serait raisonnablement à la portée de navires se dirigeant vers des zones en haute mer visées par des permis pour l'exploration pétrolière et gazière déjà en cours, et vers le détroit de McClure au nord de l'île Banks, qui représente la route nord en eau profonde du passage du Nord-Ouest à travers les îles de l'Arctique canadien.

1. INTRODUCTION

Transport Canada has identified a need for sound scientific data to assess the ecological risk of introducing non-indigenous species (NIS) into Canadian Arctic waters in the event that foreign vessels bound for Arctic ports need to conduct emergency ballast water exchange in designated alternate ballast exchange zones (ABWEZ) within the Canadian Exclusive Economic Zone (EEZ). Normally vessels containing ballast from foreign waters are required to conduct ballast water exchange (BWE) in waters outside the EEZ, which extends up to 370 km (200 nautical miles) offshore (*Canada Shipping Act*, P.C. 2006-495 June 8, 2006). BWE replaces the coastal water in the ballast tanks with water from a mid-ocean region where the salinity is above 30 and the water is at least 2000 m deep (Ruiz and Reid 2007). In cases where ballast exchange cannot be completed outside the EEZ, Transport Canada states that ships bound for ports in eastern Canada north of 60 degrees latitude may conduct ballast exchange in one of two designated ABWEZs within Canadian Arctic waters.

To date, ABWEZs have been identified in the Hudson Strait and Lancaster Sound regions of the eastern Arctic for vessels traveling westbound to the Port of Churchill or the Northwest Passage, respectively. A need for a third zone in the western Arctic has been identified, and is considered a priority given the renewed interest in hydrocarbon development in this region. This report provides a review and summary of relevant information on the ecology, oceanography, and shipping patterns in the Beaufort Sea region to assess the ecological risks of NIS introductions associated with ballast water exchange, and make recommendations regarding suitable areas (if any) for emergency ballast water exchange.

2. ECOLOGICAL RISKS OF BALLAST WATER

2.1 INTRODUCTION

Non-indigenous species (NIS) are species that have formed self-propagating, isolated populations outside of their historic range (Levings et al. 2002), and are currently seen as the largest threat to global biological diversity (Claudi et al. 2002). NIS were known to be a problem in terrestrial and freshwater habitats long before their potential impact in marine environments was considered (Ruiz et al. 1997). Even now, more is known about NIS in the Great Lakes than off the Atlantic, Pacific, or Arctic coasts of Canada (Wiley and Claudi 2002). In fact, the history, composition, extent, and impacts of marine invasions along most of the world's coasts are not well known (Bax et al. 2001).

The release of ballast water from commercial ships is recognized as the most significant vector of aquatic NIS (e.g., Carlton 1985; Carlton et al. 1995; Carlton and Geller 1993). Ballast water is taken up by empty or partially-full vessels to add stability, and is released prior to taking on cargo. When taking on ballast water in port, vessels also take on whole assemblages of plankton, then typically transport them quickly across large distances and release them, often into similar coastal habitats (Carlton and Geller 1993). The world's deep-sea fleets have been estimated to transport over 3000 species a day in their ballast tanks, and 10,000 or more species each week, resulting in a prevalence of invasive species in ports around the world (Carlton et al. 1995; Carlton 1999 *in* Bax et al. 2001). Despite multiple examples of major and irreversible ecological effects of NIS, as well as associated economic costs, limited information exists on ballast water biology or factors affecting invasion success (Hines and Ruiz 2000).

2.2 FACTORS CONRIBUTING TO RISK OF SUCCESSFUL INVASIONS

There are some factors that are currently thought to contribute to the risk of successful invasions by NIS. Larger quantities, higher quality, and higher frequency of "inoculations", especially from the same source port, can increase the chances of a NIS becoming established. Larger vessels, such as tankers, can transport larger quantities of ballast water (>150,000 metric tons; Ruiz et al. 1997) and therefore, more invasive organisms per trip (Hines and Ruiz 2000). As travel time increases, organism survival and densities in ballast water decrease, thus increases in average speed and shorter voyage distances can be expected to increase the viability of discharged organisms (Williams et al. 1988; Hines and Ruiz 2000). Regular vessel routes will increase the chances of NIS becoming successfully established through multiple "inoculations" of organism assemblages from the same source ports (Hines and Ruiz 2000). NIS will have a greater chance of survival if they are discharged in an area with similar temperature and salinity characteristics to the area where they originated (Smith et al. 1999; Hines and Ruiz 2000). Also, a marine ecosystem can be more vulnerable to NIS invasions if there are multiple stressors on the system, such as increased human disturbance or changing environmental conditions related to global warming (Bax et al. 2003).

Areas where ballast water is discharged have a greater risk of NIS becoming established if vessels have not undertaken mid-ocean exchange (MOE). The rationale for MOE is that it should replace foreign coastal species contained in the ballast water with oceanic species that are less likely to survive when the ballast is discharged into receiving coastal waters, and that oceanic communities are less diverse and abundant than coastal communities (Williams et al. 1988; Hines and Ruiz 2000; Wonham et al. 2005). Estimates of the efficacy of MOE vary, with estimates of anywhere from 50–90% reduction in larvae and plankton concentrations (Locke et al. 1993; Smith et al. 1996). A limited study showed similar microorganism (bacteria and viruses) abundance and biomass between ballast tanks that had original water, and those that had exchanged for mid-ocean water, although the composition of these microorganism assemblages was not studied and the overall biomass decreased with voyage duration (Drake et al. 2002). Ballast-tank sediments can also transport NIS (Williams et al. 1988), so the proper disposal of accumulated sediments is important.

2.3 INVASIVE SPECIES

Most vessels take on ballast in coastal waters, transporting and discharging a diverse assemblage of viable planktonic and nektonic organisms (e.g., Carlton and Geller 1993). Taxa that have been identified in ballast waters include representatives of all major marine taxa and trophic groups (Carlton and Geller 1993; Ruiz et al. 1997). The majority of taxa identified from ballast waters destined for Oregon from Japan were in five phyla: crustaceans, annelids (mainly polychaetes), plantyhelminthes (mainly turbellarians), cnidarians, and molluscs (Carlton and Geller 1993). Other taxa included dinoflagellates, ctenophores, ectoprocts (or bryozoans), and fish (Carlton and Geller 1993). Some taxa are less frequent in ballast water, such as benthic organisms with no planktonic life stage or very limited planktonic life stages, or nektonic organisms, such as fish, that are able to resist ballast water uptake (Carlton and Geller 1993).

Species with broad temperature and salinity tolerances, such as the invasive European green crab (*Carcinus maenas*), have been able to invade many parts of the world (Levings et al. 2002; Wiley and Claudi 2002). Indeed, many NIS are reported to be euryhaline, or able to tolerate a wide range of salinity levels (Ruiz et al. 2000). An example is the Asian clam *Corbula amurensis,*

a highly tolerant species found in virtually all salinities and in all sediment types, from tropical to cold temperate waters (NIMPIS 2012).
In a study on NIS found along the Pacific, Atlantic, and Gulf Coasts of the U.S., most identified NIS taxa were crustaceans or mollusks, ranging from 41% to 50% of total NIS on each coast (Ruiz et al. 2000). Large numbers of arthropod, mollusk, and annelid NIS organisms are found in most locations along the west coast of North America (Hines and Ruiz 2000).

Often there is a lack of baseline surveys to show historical species ranges, leading some species to be classified as “cryptogenic”, since they could be either native or non-native species (Carlton and Geller 1993; Carlton 1996; Ruiz et al. 1997; Levings et al. 2002; Wiley and Claudi 2002). Some introduced species may go unrecognized, and are subsequently assumed to be native to the region (Carlton and Geller 1993). Therefore, the number of NIS in a given region almost certainly will always be underestimated (Ruiz et al. 1997; Bax et al. 2001).

Even with these difficulties, large numbers of NIS and cryptogenic species have been identified worldwide. In Australia, 252 NIS and cryptogenic marine and estuarine species have been identified, and in New Zealand, 159 marine NIS have been identified (Bax et al. 2003). Over 240 NIS have been found in the Mediterranean Sea, the majority likely attributable to invasions through the Suez Canal; approximately 52 NIS have been recorded around Great Britain; and 35 NIS have been identified in the Baltic Sea (Ruiz et al. 1997 and references therein).

Approximately 400 NIS have been recorded along the outer coasts of the continental U.S, with a total of 298 invertebrate and algal NIS established in North American marine and estuarine waters (Ruiz et al. 1997; Ruiz et al. 2000). Along the west coast of North America, >80 NIS have been identified in southern California, >40 in the northwest region of Washington, and almost 250 in San Francisco Bay alone (Hines and Ruiz 2000). In the Strait of Georgia, B.C., 89 potentially invasive species were identified (Levings et al. 2002). Estimates for southern Alaska are 24 definite/probable NIS (Hines and Ruiz 2000), with 10 of those recorded as established in Prince William Sound (Ruiz et al. 2000). Currently, it seems that there are fewer NIS recorded with increasing latitude (Ruiz et al. 2000).

2.4 PATTERNS OF INVASION

Along the west coast of North America, there are several locations where the same NIS have invaded, showing that some species can occur across a range of latitudes (Hines and Ruiz 2000). NIS can invade multiple regions through an effect called “leap-frogging”, where an NIS that has invaded one area can in turn be taken up and transported to further areas (Ruiz et al. 1997 and references therein; Hines and Ruiz 2000; Wiley and Claudi 2002).

Coastal waters are thought to be more susceptible to NIS invasions. Along coastlines, there is also variation in patterns of invasion, with estuaries and bays invaded more frequently than outer rocky and sandy coasts, which may be related to the frequency and quantities of ballast water released, as most ports are located in bays and estuaries (Ruiz et al. 1997; Reise et al. 1999). Within estuaries, there are more reported NIS in brackish-water than marine or freshwater (Reise et al. 1999; Leppäkoski 1991).

The rate of NIS invasions could be increasing worldwide, because of increases in shipping volume, vessel size, and vessel speeds (Ruiz et al. 1997). However, in most regions, part of the increase in the recorded rate of invasions seems to be related to an increase in awareness and study effort (Ruiz et al. 1997; Ruiz et al. 2000; Levings et al. 2002).

Overall, there are a small number of microorganisms classified as NIS, such as protists and diatoms, but many groups are not recorded, e.g., bacteria and viruses, and their impacts are largely unknown (Reise et al. 1999; Ruiz et al. 2000; Drake et al. 2007). The fact that the frequency of taxa identified in ballast water does not match the frequency of taxa reported as NIS is thought to be caused by a general bias, in that invasions by larger organisms, such as fish and mollusks, are more readily noticed (Carlton and Geller 1993). Polychaetes, platyhelminthes and diatoms, which tend to be prevalent in ballast water, could in fact have higher invasion levels than are currently recorded (Carlton and Geller 1993). Again, the number of NIS in regions will be an underestimate, because of the taxonomical challenges of studying and identifying these smaller organisms or poorly known taxa (Bax et al. 2001). It should also be noted that the presence of NIS *per se* does not imply threat or impact (Molnar et al. 2008).

2.5 IMPACTS OF NIS INVASIONS

NIS invasions can have effects on ecological processes, such as competition, predation, herbivory, hybridization, parasitism, toxicity, habitat change, and bioturbation (Levings et al. 2002). Through these processes, native species can be displaced, and locally-adapted gene pools can be diluted or lost through inter-breeding or decreased native species survivorship, affecting biodiversity levels (Ruiz et al. 1997; Claudi et al. 2002). Invasions by small planktonic organisms can shift the ecological balance between benthic and pelagic food webs or modify transfers of energy and material between ecosystem compartments. There is also the potential for introduction of species that can produce harmful algal blooms (Doblin et al. 2004; Vila and Masó 2005). Pathogenic bacteria and viruses are also potentially important and harmful invasive species that can infect humans and other vertebrates or have a detrimental effect on their food sources. However, recent reviews of the threat of NIS do not include bacteria and viruses due to a lack of information (Gollasch 2006; Molnar et al. 2008).

NIS that invade new environments can quickly become numerically dominant, because the new environment often lacks the native predators, competitors, parasites, and diseases that formerly limited their populations (Mack et al. 2000). If NIS become “numerically or aspect dominant”, they can cause significant changes to the function and structure of marine communities, changing food webs, nutrient cycles, and sedimentation rates (Ruiz et al. 1997).

There are multiple examples of catastrophic impacts of NIS on marine ecosystems (Bax et al. 2003 and references therein). There is the invasive comb jelly (*Mnemiopsis leidyi*), native to the eastern Atlantic Ocean, which caused a crash in populations of its copepod prey and subsequent instability in the zooplankton community; this species is blamed for the collapse of coastal Black Sea fisheries (Gubanova and Alukhov 2007). In San Francisco Bay, the Asian clam reaches densities of over 10,000/m^2 and is blamed for the collapse of local fisheries. The invasive European green crab is now found in Australia, Japan, South Africa, and on both coasts of North America. There is also the potential for the introduction of harmful algal-bloom species, the majority of which are dinoflagellates (75%) (Doblin et al. 2004; Vila and Masó 2005). Blooms of introduced dinoflagellates, known as “toxic red tides”, can threaten fisheries and public health, while introduced bacteria, such as cholera (*Vibrio cholerae*) may have caused past epidemics in South and Central America (McCarthy and Khambaty 1994; Cohen et al. 2012).

Trying to estimate the effect of a given NIS in a novel environment is difficult, as organisms can switch food sources or use different habitat types. For example, the European green crab seems to grow faster and larger in some invaded areas, and is found in different habitat types than in its native range (Grosholz and Ruiz 1996). This degree of uncertainty in estimating the impacts and success of NIS in new regions means that the release of organisms in ballast water can be considered “ecological roulette” (Carlton and Geller 1993).
“Niche limitation” is still just a theory and does not seem to hold for some heavily-invaded areas, such as San Francisco Bay, where there are still high rates of new invasions (Ruiz et al. 1997). Some researchers even think that initial invasions can make a region more susceptible to subsequent invasions by NIS (C. Hewitt, pers. comm. *in* Ruiz et al. 1997). As invasive species enter a new environment and change it through increased predation and habitat modification, there are increased opportunities for further invasion, a problem termed “invasional meltdown” (Simberloff and von Holle 1999). At least the large size of many marine populations, and the degree of dispersal between these populations, means that they could be less susceptible to local or regional extinctions (Ruiz et al. 1997).

2.6 BEAUFORT SEA

Currently, there are limited studies of NIS in polar marine ecosystems (Hines and Ruiz 2000). Some studies have occurred in high temperate latitudes (40–60º N and S), with numbers of NIS per location ranging from 32 to 80 and including a broad range of taxonomic groups (Hines and Ruiz 2000). There are also issues in properly identifying NIS in polar regions, because there is often a lack of historical baseline ecological surveys (Hines and Ruiz 2000, Niimi 2004).

Plankton collected from the ballast tanks of vessels arriving in Port Valdez, Prince William Sound, Alaska, showed a high rate of survival at temperatures and salinities comparable to those found in Port Valdez (Hines and Ruiz 2000). In general, temperature-salinity conditions at high latitudes can match conditions found at lower latitudes, particularly during the summer, and some species can also exist in a range of conditions (Hines and Ruiz 2000). For example, of 10 identified NIS in Prince William Sound, 6 were common between Prince William Sound and San Francisco Bay, 5 were common to other bays in Oregon and Washington, and 1 was common to a bay in Australia (Ruiz et al. 2000). Overall, however, numbers of NIS were lower in Port Valdez compared to other ports along the west coast of North America (Hines and Ruiz 2000; Ruiz et al. 2000).

Increasing sea temperatures are expected to reduce ice cover and open the Arctic to increased shipping, while also providing more favorable conditions for invasive species (Niimi 2004, Arctic Marine Council 2009). Currently, sea temperature is still a limiting factor for NIS such as the European green crab, which based on observed mortality and breeding rates, will be limited by average winter sea surface temperatures of approximately 0–1 ºC (Wiley and Claudi 2002).

3. ECOLOGICALLY IMPORTANT OR SENSITIVE AREAS AND RESOURCES

3.1 TRADITIONAL USE

Subsistence harvest and traditional patterns of land use associated with subsistence harvesting are important parts of the lives of the people of the Inuvialuit Settlement Region (ISR). There are six communities in the ISR area: Aklavik, Ulukhaktok, Inuvik, Paulatuk, Sachs Harbour, and Tuktoyaktuk (Fig 3.1).

Subsistence use was defined in the Inuvialuit Final Agreement (IFA) as "the taking of wildlife by Inuvialuit for their personal use for food and clothing and includes the taking of wildlife for the purpose of trade, barter and sale among Inuvialuit and trade, barter and sale to any person of the non-edible by-products of wildlife that are incidental to the taking of wildlife for their personal use." Many of the wildlife species taken in the subsistence harvest inhabit or feed in the Beaufort Sea, including marine mammals, sea-associated birds, and fish. Four marine mammals, six marine or anadromous fish, and five sea-associated birds are the main species harvested; the numbers and species taken vary considerably among communities (Table 3.1).

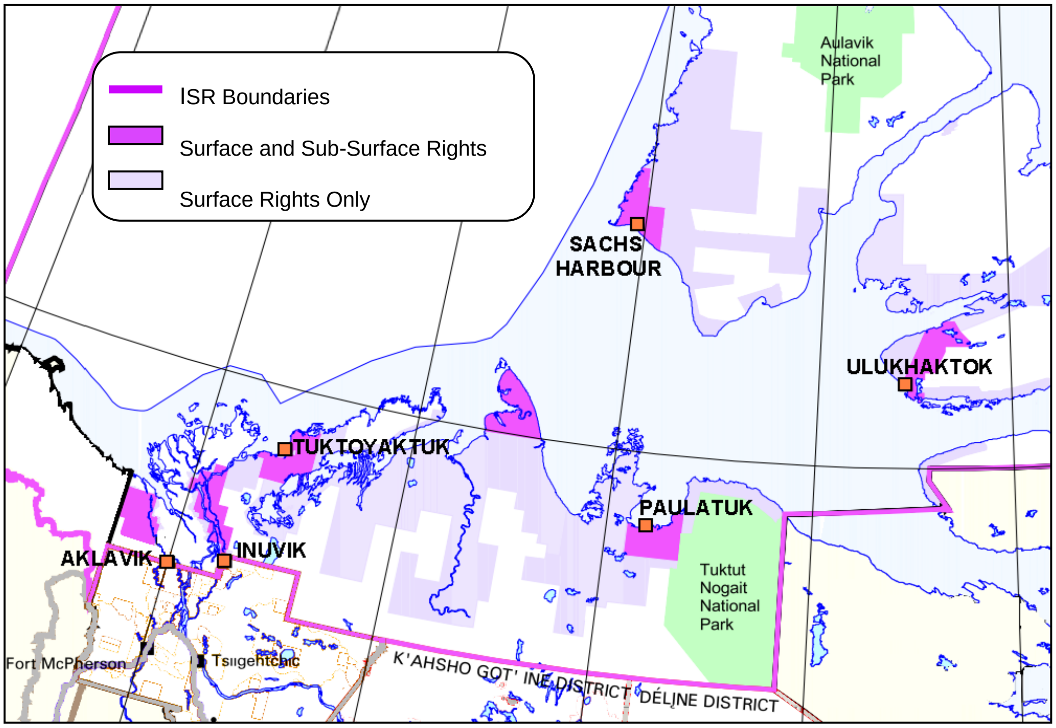

Figure 3.1. Location of the six ISR communities.(Source: GNWT, Dept. of Aboriginal Affairs and Inter-governmental Relation).

Table 3.1. Average numbers of the most important marine or sea-associated species harvested annually in the six communities in the ISR. Data are from Joint Secretariat (2003).

Average annual harvest of the most important marine or sea-associated species during 1988–1997						
Species	**Aklavik**	**Ulukhaktok**	**Inuvik**	**Paulatuk**	**Sachs Harbour**	**Tuktoyaktuk**
Bearded seal	0	8	0	5	9	1
Ringed seal	1	839	0	83	143	19
Beluga	19	0	54	10	0	47
Polar Bear	2	14	0	7	11	10
Burbot	1399	0	1998	15	0	284
Arctic char/Dolly Varden	1110	7300[1]	55	2446	591	3
Cisco (unspecified)	4803	11	425[1]	52	3	12000[1]
Pacific herring	969	0	98[1]	100	1	4750[1]
Inconnu	1409	0	1277	0	0	2647
Broad whitefish	5828	0	6635	1294	0	9500[1]

Brant	2	7	2	11	24	443
Eider	2	3244	0	12	16	8
Canada goose	18	256	72	296	2	14
Greater white-fronted goose	130	1	246	355	1	1028
Snow goose	148	53	314	1342	1817	2196

[1] Estimates because counted differently over the 10-year period

3.2 IMPORTANT AREAS

3.2.1 Special Designated Lands

For each community in the ISR, traditional land and continuing subsistence use by the Inuvialuit are documented within Community Conservation Plans (CCPs): AICCP (2008); IICCP (2008); OCCP (2008); PCCP (2008); SHCCP (2008); TCCP (2008). Areas of importance in each community planning area have been given letter designations corresponding to one of five management categories, from A (no known significant and sensitive cultural or renewable resources; managed according to current regulatory practices) to E (cultural or renewable resources are of extreme significance and sensitivity; no development). Special designated lands have been identified by community working groups, Inuvialuit organizations (e.g., Fisheries Joint Management Committee), and government agencies and assigned management categories. These lands are described and mapped in the CCPs.

3.2.2 Ecologically and Biologically Significant Areas

DFO is authorized under Canada's *Oceans Act* to provide enhanced protection to areas of the oceans and coasts that are ecologically or biologically significant (DFO 2004). A total of 26 ecologically and biologically significant areas (EBSAs) have been identified in the Western Arctic biogeographic region from the Beaufort Sea Large Ocean Management Area (LOMA) exercise (Paulic 2009) and a later Arctic EBSA exercise (DFO 2011; Figure 3.2a, Table 3.2). Additional EBSAs were also identified in the Arctic Basin (Figure 3.2b and Table 3.2) and the Arctic Archipelago (Figure 3.2c and Table 3.2) biogeographic regions (DFO 2011).

3.2.3 Conservation Areas

The Canadian Beaufort Sea region 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 two islands (Garry and Pelly islands) established as International Biological Program sites because of their importance to waterfowl (Figure 3.3). It also has a Marine Protected Area (MPA) called the Tarium Niryutait (TNMPA) (Cobb et al. 2008; Canada Gazette II 2010; Fig 3.3), which consists of the three beluga management areas zoned (FJMC 2001).

Table 3.2. Ecologically and biologically significant areas (EBSAs) within the Western Arctic, Arctic Basin and Arctic Archipelago biogeographic region (source Paulic 2009; DFO 2011).

#	EBSA	#	EBSA	#	EBSA
3.1	Lambert Channel	3.12	Husky Lakes	3.23	Thesiger Bay
3.2	Bathurst Inlet	3.13	Kugmallit Corridor	3.24	Viscount Melville Sound
3.3	Queen Maud Gulf Coastline	3.14	Cape Bathurst Polynya	3.25	Horton River
3.4	Chantrey Inlet	3.15	Banks Island Shorelead	3.26	Liverpool Bay

3.5	King William Island	3.16	Pearce Point	4.1	Arctic Basin Multi-year Pack Ice
3.6	Southern Victoria Is. Coastline	3.17	Hornaday River	5.1	Ellesmere Island Ice Shelves
3.7	Yukon North Slope	3.18	Kagloyuak River	5.2	Nansen-Eureka-Greely Fjord
3.8	Mackenzie Trough	3.19	Prince Albert Sound	5.3	Archipelago Multi-year Pack Ice
3.9	Beaufort Shelf	3.20	Walker Bay (DD)	5.4	Norwegian Bay
3.10	Shallow Bay	3.21	Minto Inlet (DD)	5.5	Princess Maria Bay
3.11	Beluga Bay	3.22	De Salis Bay		

a)

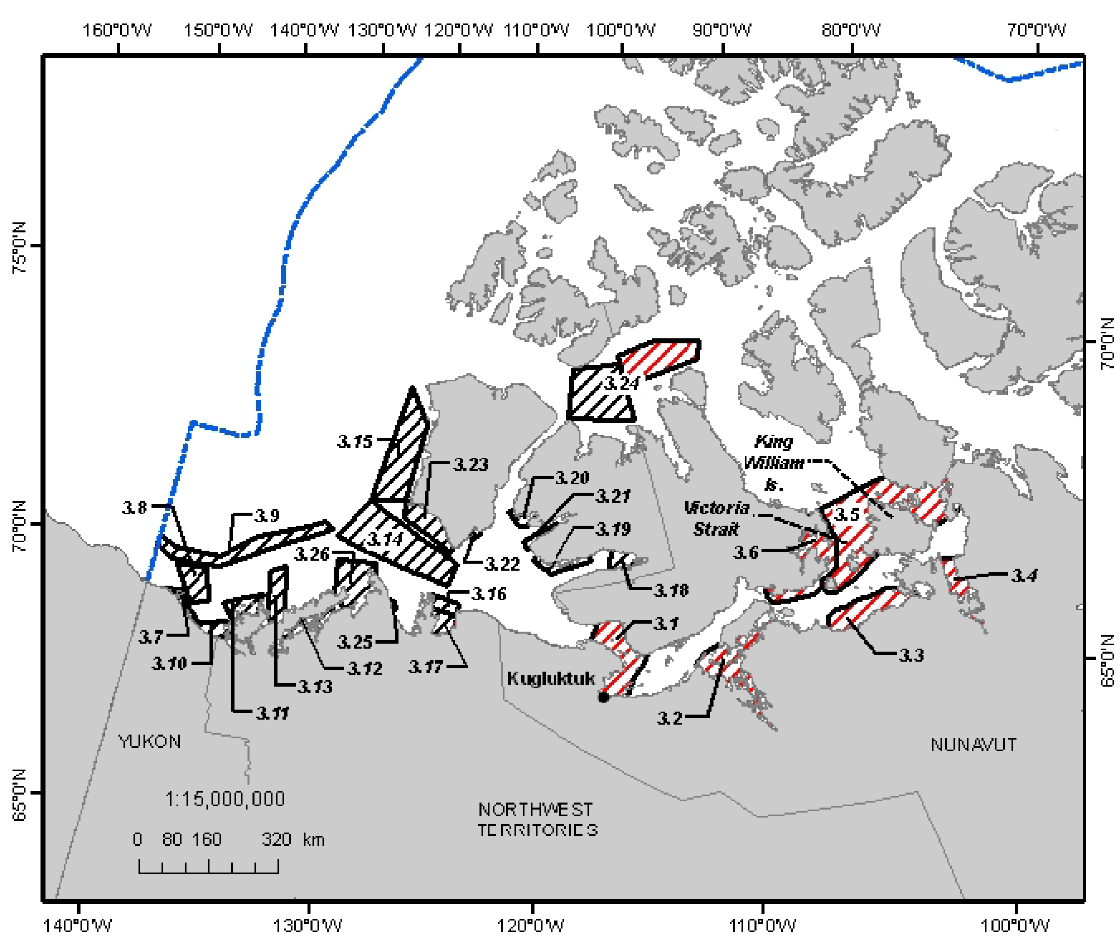

Figure 3.2. Ecologically and biologically significant areas (EBSAs) within the a) Western Arctic, b) Arctic Basin and c) Arctic Archipelago biogeographic regions. Black hatched areas were identified as part of the Beaufort Sea LOMA exercise (Paulic 2009) and red hatched areas were identified through the Arctic EBSA exercise. The red arrow indicates the Beaufort Gyre, an important oceanographic feature contributing to ecosystem structure and functioning in the Arctic Basin and the Western Arctic biogeographic regions. The Canadian international boundary is indicated by the blue dashed line. (from DFO 2011).

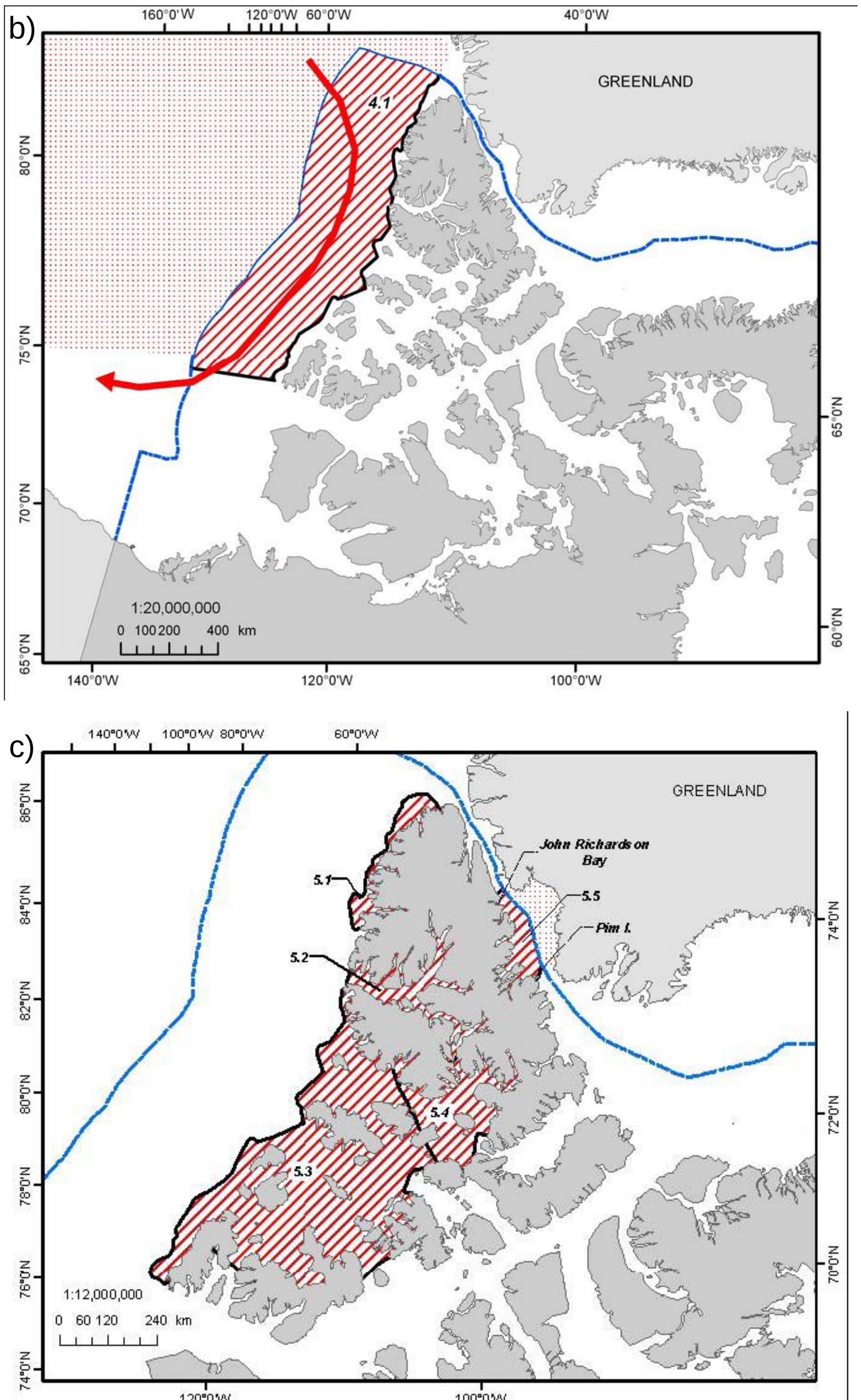

Figure 3.2. Ecologically and biologically significant areas (EBSAs) within the a) Western Arctic, b) Arctic Basin and c) Arctic Archipelago biogeographic regions. Black hatched areas were identified as part of the Beaufort Sea LOMA exercise (Paulic 2009) and red hatched areas were identified through the Arctic EBSA exercise. The red arrow indicates the Beaufort Gyre, an important oceanographic feature contributing to ecosystem structure and functioning in the Arctic Basin and the Western Arctic biogeographic regions. The Canadian international boundary is indicated by the blue dashed line. (from DFO 2011).

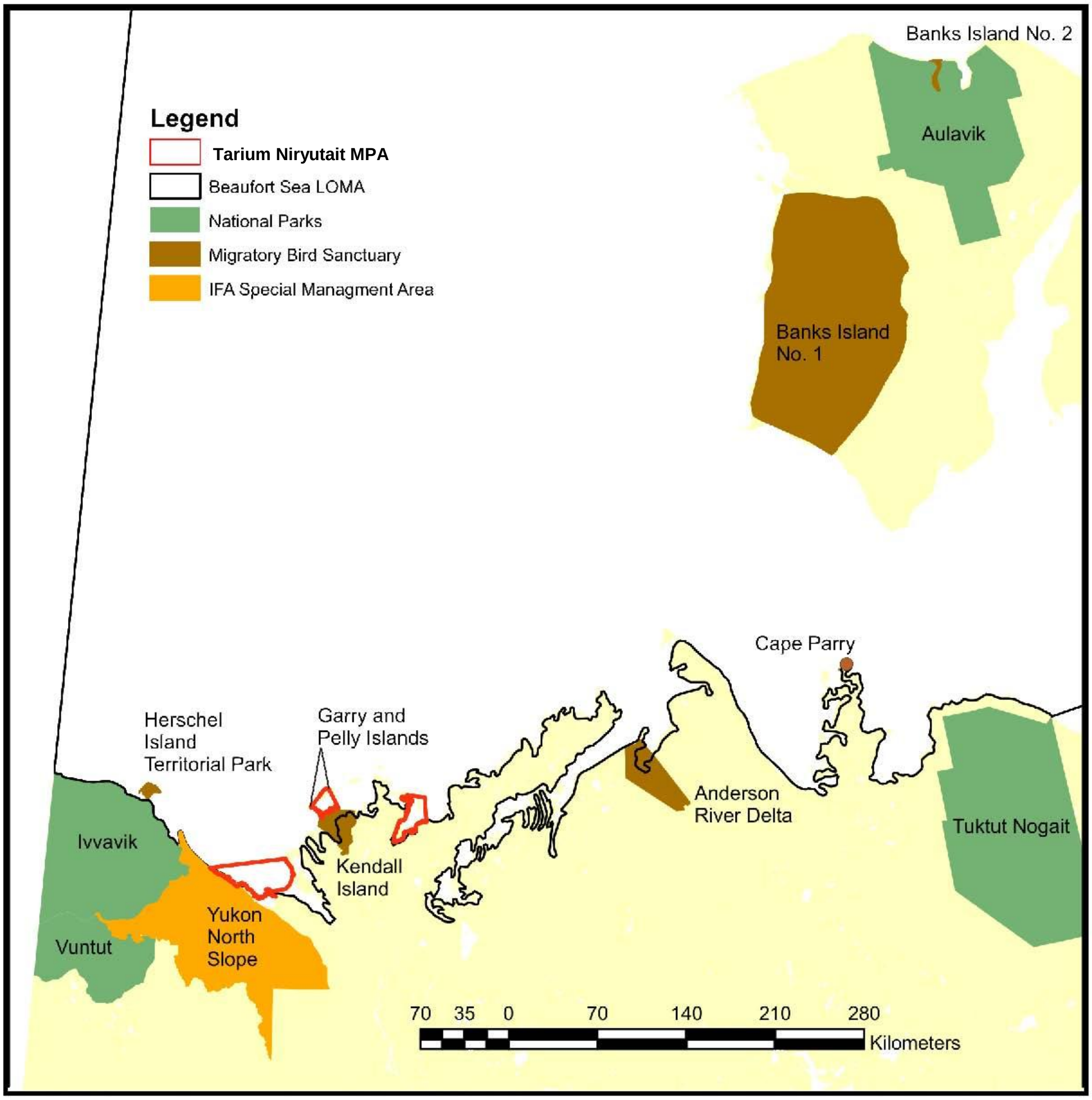

Figure 3.3. Conservation and protected areas in the Canadian Beaufort Sea region (after Cobb et al. 2008).

3.3 PLANKTON

The productivity and abundance of phytoplankton, zooplankton, and benthos will determine the carrying capacity of the environment for fish, birds, and marine mammals. The amount of primary productivity is variable, and depends on the physical oceanographic regime and the advection of nutrients into the euphotic zone. The large freshwater inflow from the Mackenzie River and ice melt cause stratification of the water column that limits productivity (Carmack and MacDonald 2002). Zooplankton biomass is generally low in waters of the Mackenzie River plume (Bradstreet et al. 1987). Thus, it is likely that abundance and productivity of phytoplankton is also low in this area. The location of the plume (and associated areas of low productivity) is variable and determined by wind direction (Thomson et al. 1986). Easterly winds induce upwelling (Carmack and MacDonald 2002), which brings nutrients to the surface and increases primary productivity. These winds also cause dispersion of the plume offshore over deep water (Carmack and MacDonald 2002). Westerly winds cause downwelling, which decreases productivity and causes the plume to flow eastwards along the Tuktoyaktuk Peninsula.

Zooplankton biomass tends to be higher in oceanic water than in waters of the Mackenzie River plume (Bradstreet et al. 1987). Although occurrence is highly variable in time and space, it is possible to document where areas with high productivity and/or concentrations of plankton are most likely to occur (Belkin et al. 2003). Such areas with high concentrations of zooplankton are ecologically important in the Beaufort Sea and can have a strong influence on the distribution of organisms that feed on them. For example, biomass of zooplankton near feeding bowhead whales approached 2 g/m^3 and was an order of magnitude higher than in areas where whales were absent (Bradstreet et al. 1987). Fish, ringed seals, and some birds also feed on zooplankton, and many species feed on polar cod, which depends on zooplankton.

Oceanic fronts, in particular are often associated with high concentrations of plankton (Flint et al. 2002) and their vertebrate predators (Munk et al. 1995; Bluhm et al. 2007; Seminoff et al. 2008). The most stable oceanic fronts within the Beaufort Sea are associated with the Shelf Break/Shelf-Slope (SSFs; Figure 3.4) (Belkin and Cornillon 2007). Maximum stability along this front occurs where the shelf is steepest in the area of the Cape Bathurst Polynya, a biological "hotspot" for marine life where birds and marine mammals are known to congregate (Belkin et al. 2003, Belkin and Cornillon 2007).

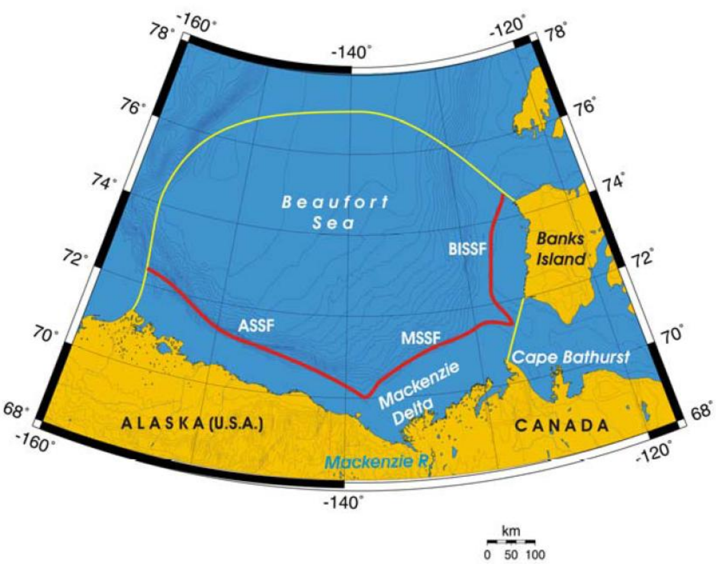

Figure 3.4. Fronts of the Beaufort Sea Large Marine Area (LME): ASSF=Alaskan Shelf-Slope Front; MSSF=Mackenzie Shelf-Slope Front; BISSF=Banks Island Shelf-Slope Front. LME boundary indicated by yellow line (after Belkin and Cornillon 2007)

3.4 BENTHOS

The Beaufort Sea benthos is poorly studied compared to other Canadian waters (Cobb et al. 2008). Before 1970, most studies of benthic fauna conducted in the western Canadian and Alaskan Arctic concerned taxonomy and zoogeography. Those studies were summarized by Wacasey (1975) and Curtis (1975). Since that time, site-specific data on diversity and abundance of benthic fauna have been collected during a number of studies funded by the petroleum industry or conducted by government. Wong (2000) and Cobb et al. (2008) summarized the literature on benthos in the southeastern Beaufort Sea.

Benthic fauna are divided into two main groups based on the habitat that they occupy: epifauna and infauna (Thorson 1957). Epifauna (also called epibenthos) generally inhabit the upper surface of the substrate, and are separated into sessile forms (e.g., sea anemones) and mobile forms (e.g., mysids and some amphipods). Infauna (e.g., bivalves, polychaetes, and some amphipods) are generally found in the bottom sediments, and are usually sedentary.

Sessile epifauna are rare in the Beaufort Sea because of the predominance of soft bottoms. Where rocks are present, such as the Boulder Patch in Stefansson Sound (offshore near the Sagavanirktok River delta; Figure 3.5), dominant and conspicuous sessile animals include sponges, soft corals, sea anemones, stalked hydrozoans, bryozoans, molluscs, bryozoans, and urochordates, attached to rocks and other biota. Mobile epifauna are often abundant in inshore areas during the open-water period, including the barrier-island lagoon systems found along parts of the northern Alaskan coast (Griffiths and Dillinger 1981; Bradstreet and Fissel 1987). Reported biomasses (dry or estimated dry weight) have been as high as 3.78 g/m^2 in Simpson Lagoon (Griffiths and Dillinger 1981). The most abundant groups and species were the mysids *Mysis litoralis* and *M. relicta*, the amphipods *Onisimus glacialis* and *Gammarus setosus*, and the isopod *Saduria entomon*. These epifauna of the shallow inshore zone of the Beaufort Sea are important ecologically because they comprise major components of the diets of fish, birds, and marine mammals (Griffiths et al. 1975, 1977; Kendel et al. 1975; Divoky and Good 1979; Lowry et al. 1978; Craig et al. 1984).

In the Beaufort Sea, infaunal species diversity and biomass generally increase with depth and distance from shore, at least from beyond the 20-m depth contour to the edge of the continental shelf (Wacasey 1975). Minimum numbers occur at depths of 15–20 m, which correspond closely to the shear zone, the boundary between landfast ice and the moving ice pack. Low densities also occur in depths <2 m, primarily because the landfast ice freezes to the bottom.

The abundances and biomasses of infauna in soft sediment at depths 5–30 m are similar along the southern coast of the Beaufort Sea: means of 2873/m^2 and 25.0 g/m^2 off Banks Island (Heath and Thomas 1984); 871–1361/m^2 and 2.9–12.5 g/m^2 in Mackenzie Bay (Thomas et al. 1982); 176–1320/m^2 and 0.3–14.4 g/m^2 west of the Mackenzie Delta between King Point and Herschel Island (Wacasey 1975); means of 1350/m^2 and 33.3 g/m^2 off Prudhoe Bay (Carey et al. 1974), and 1500–6000/m^2 and 10–50 g/m^2 off Narwhal Island and Barter Island in the western Beaufort Sea (Carey 1978). The three dominant taxa were polychaetes, crustaceans, and molluscs (Carey et al. 1974; Carey 1978). Carey et al. (1984) concluded that the bivalves in the Alaskan Beaufort Sea are broadly distributed throughout the region, and that there are no strong spatial or depth patterns in overall abundance, species richness, or species composition. His results did show that suspension feeders decreased, and that the proportion of deposit feeders increased, with increasing depth from 5 to 15 m. Broad et al. (1979:363) concluded that except for the Boulder Patch, “there is no known unique or unusual benthic habitat in the Beaufort, inshore or nearshore.”

3.5 FISH RESOURCES

Fishes of the Beaufort Sea are characterized by three basic life-history patterns: freshwater, marine and anadromous/amphidromous. Freshwater species largely remain within river, stream, and lake systems year round, although they may venture out during summer into coastal areas where waters are brackish (e.g., Percy 1975; Bond and Erickson 1992). One freshwater species, the ninespine stickleback, is very tolerant of salinity, and can often be found in nearshore brackish or marine water (Scott and Crossman 1973; Morrow 1980).

Most marine fishes remain offshore in cold marine waters, although there are some species like fourhorn sculpin (*Myoxocephalus quadricornis)*, Arctic flounder (*Pleuronectes glacialis)*, starry flounder (*Platichthys stellatus*), and saffron cod (*Eleginus gracilis)* that migrate inshore during summer (Morrow 1980; Craig 1984).

The Arctic cod has a circumpolar distribution and is ubiquitous in marine waters of arctic Canada and Alaska (Bradstreet et al. 1986; Welch et al. 1993; Gillespie et al. 1997; Hop et al. 1997), occurring farther north than any other marine fish. In nearshore coastal waters, arctic cod abundance during summer is linked to salinity. Cod abundance is highest where salinities are highest (e.g., Underwood et al. 1995), and Arctic cod are rare where conditions are more brackish. The movement of large schools into coastal areas can be dramatic (Craig and Haldorson 1981). Arctic cod are an important food item in the diets of marine mammals, birds, and fish, and they are considered to be a primary component of the arctic marine food chain (Bradstreet et al. 1986; Hobson and Welch, 1992).

The fourhorn sculpin is one of the most common marine species found in coastal waters. It is a demersal species that has a circumpolar nearshore distribution in brackish and moderately saline waters (Scott and Crossman 1973; Morrow 1980). Fourhorn sculpin live permanently near the coast, are most common in shallow (<20 m) waters, and do not undergo any extensive migrations (Andriyashev 1954).

The arctic and starry flounders are bottom-dwelling marine species, typically found in shallow coastal waters during summer when they commonly enter low-salinity habitats (Walters 1955; Morrow 1980). As with fourhorn sculpin, arctic and starry flounder are not found far offshore (Morrow 1980). These species are common and widely distributed along the Beaufort Sea coast, and have been taken in small to moderate numbers in virtually every coastal fishery survey conducted in Alaska and Canada.

The saffron cod is found in brackish and marine waters of the Beaufort Sea east to Bathurst Inlet in Canada (Walters 1955). They frequently enter rivers and can go considerable distances upstream (Morrow 1980). Unlike fourhorn sculpin and arctic flounder, saffron cod can be found both nearshore and offshore during summer (Percy 1975; Galbraith and Hunter 1975; Byers and Kashino 1980). It has been reported throughout the Beaufort Sea, but is the least abundant of the "onshore" marine species.

Large but variable numbers of capelin have been reported in the Amundsen Gulf region, and they are known to spawn at Herschel Island (Hunter 1981 in Stewart et al. 1993), in Sachs Harbour on Banks Island, and in the Ulukhaktok (formerly known as Holman) area of Victoria

Island (Figure 3.5; Cobb et al. 2008). Pacific herring are common in the Canadian Beaufort Sea, especially east of the Mackenzie Delta. They are not a common catch of the Alaskan Beaufort Sea subsistence fishery (Craig 1989b). They spawn in protected waters such as Tuktoyaktuk Harbour and the Fingers area of Liverpool Bay (Figure 3.5), about the time of ice break-up from early June to mid-July (Cobb et al. 2008). Larval and juvenile Pacific herring larvae occur along the Tuktoyaktuk Peninsula from mid-July into September (Stewart et al. 1993).

Surveys of demersal fish in the offshore waters (>50 km offshore) of the western and central Beaufort Sea have identified 17 species (Frost and Lowry 1983). Incidental takes from nearshore studies have identified an additional dozen or so "deepwater species". They include ten species of sculpin, two poachers, four snailfish, ten eelpouts, five pricklebacks, two wolffishes, and one species of gunnel. They reflect a numerically low, yet geographically extensive, marine faunal assemblage throughout arctic marine waters. McAllister (1962) suggested that this faunal assemblage extends continuously from the central Canadian Arctic westward through the Beaufort, Chukchi, East Siberian, Laptev, Kara, and Barents seas.

The main species of anadromous/amphidromous fish that inhabit the Beaufort Sea are least cisco (*Coregonus sardinella*), arctic cisco (*Coregonus autumnalis*), broad whitefish (*Coregonus nasus*), humpback whitefish (*Coregonus autumnalis*), inconnu (*Stenodus leucichthys),* arctic char (*Salvelinus alpinus*), and Dolly Varden (*Salvelinus malma*)[1] (Figure 3.5). Fry of all species (with the exception of arctic char and Dolly Varden which stay in their natal rivers and do not migrate to coastal areas until the age of at least 3-4; Craig 1977a,b,c) are carried downstream in spring where they enter summer nursery areas, and tend to remain in and near the low-salinity river deltas and/or coastal areas throughout much of the open-water season. Following the time of first entry to coastal areas, all species tend to cycle annually between freshwater and coastal marine environments; they spawn and overwinter in rivers and streams but migrate out into coastal waters for several months each summer to feed.

The Arctic cisco is one of the most abundant and widely distributed coregonids found in the coastal waters of the Beaufort Sea during summer (e.g., LGL 1989; Bond and Erickson 1993; Underwood et al. 1995; Fechhelm et al. 2000). The species supports subsistence fisheries in the Mackenzie River (Stein et al. 1973; Joint Secretariat 2003) and subsistence and commercial fisheries in the lower Colville River, Alaska (Craig 1989b). Most Arctic cisco found in the Beaufort Sea are believed to originate from spawning grounds in the Mackenzie River system, with newly-hatched young flushed downriver into ice-free coastal waters of the Beaufort Sea in spring (Gallaway et al. 1983).

Least cisco and humpback whitefish have discontinuous distributions; western populations are associated with the Colville River and smaller tundra rivers to the west, whereas eastern populations are associated primarily with the Mackenzie River watershed. In Canada, anadromous inconnu are present in most of the Mackenzie River drainages and east to the Anderson River (Morrow 1980) while broad whitefish are associated with large rivers systems from the Mackenzie east to the Coppermine (Scott and Crossman 1973). Broad whitefish is one of the more restricted in terms of summer dispersal from overwintering rivers. Young fish tend to remain in and near the low-salinity river deltas and coastal areas throughout much of the open-water season (Bond 1982; Griffiths et al. 1992; Bond and Erickson 1991, 1992). In

[1] Meristic and genetic analyses show that "char" (anadromous, residual, and isolated stream resident forms) from the continental slope west of the Mackenzie River are Dolly Varden (Reist et al. 1997)

contrast, Dolly Varden spawn in many of the mountain river systems between and including the Colville and Mackenzie rivers (Bain 1975; Craig and McCart 1974, 1975; Craig 1984; Everett et al. 1997) and are common along much of the Beaufort Sea coast during summer (Griffiths et al. 1975; Kendel et al. 1975; Craig and Haldorson 1981; Bond and Erickson 1989; Fechhelm et al. 2000). East of the Mackenzie River, the Dolly Varden is replaced by the arctic char which are associated with rivers and nearby coastal areas both throughout the mainland coast and island in the archipelago.

3.6 MARINE MAMMALS

Five species of marine mammals occur regularly in the Beaufort Sea: the bowhead whale (*Balaena mysticetus*), beluga whale (*Delphinapterus leucas*), ringed seal (*Phoca hispida*), bearded seal (*Erignathus barbatus*), and polar bear (*Ursus maritimus*) (Figure 3.5). Gray whales (*Eschrichtius robustus*) have been sighted occasionally there, but only a few enter the Beaufort Sea east of Point Barrow in most years. Most summering gray whales congregate in the northern Bering Sea and in the southern Chukchi Sea, and the north-easternmost of the recurring feeding areas is southwest of Barrow (Clarke et al. 1989). Rare sightings of narwhal (*Monodon monoceros*) have been made in the Beaufort and Chukchi seas (Geist et al. 1960; Smith 1977; Reeves 1978). Orcas (*Orcinus orca*) can migrate to the Chukchi Sea during summer, but they rarely move east of Point Barrow (Leatherwood and Dahlheim 1979).

3.6.1 Bowhead Whale

One stock of the bowhead whale is found in the Beaufort Sea: the Bering-Chukchi-Beaufort Sea stock (BCB, i.e., the western Arctic stock). The latest abundance estimate for 2004 based on photo identification data is 11,000 (Koski et al. 2010). This population has been increasing in recent decades; the estimated annual rate of increase from 1978 to 2001 was 3.4% (George et al. 2004).

Bowhead whales of the BCB stock winter in the central and western Bering Sea, and most of the stock summers in the Canadian Beaufort Sea and Amundsen Gulf (Moore and Reeves 1993). The spring migration across the western Beaufort Sea occurs through offshore ice leads, generally from mid-April to mid-June, depending on ice conditions (Braham et al. 1984; Gentleman and Zeh 1987; Moore and Reeves 1993). A few bowhead whales arrive in coastal areas of the eastern Beaufort Sea and Amundsen Gulf in late May and June (Fraker et al. 1978; Fraker 1979; Fraker and Bockstoce 1980), but most remain in offshore waters (>200 m deep) among the offshore pack ice in the central and eastern Beaufort Sea until late July to mid-August, when they begin to move gradually toward coastal and nearshore areas (Davis et al. 1982). The distribution of feeding bowhead whales is dependent on the location of food concentrations, which varies from year to year (Thomson et al. 1986). Generally, adults move into Amundsen Gulf into water depths 50–200 m off Bathurst Peninsula, small (<10 m) sub adults move into coastal and nearshore waters at water depths 10–50 m along the Yukon coast, and large sub adults move into nearshore and shelf waters at water depths 20–200 m off the Yukon coast, Mackenzie Delta, and Tuktoyaktuk Peninsula (Cubbage and Calambokidis 1987; Koski et al. 1988).

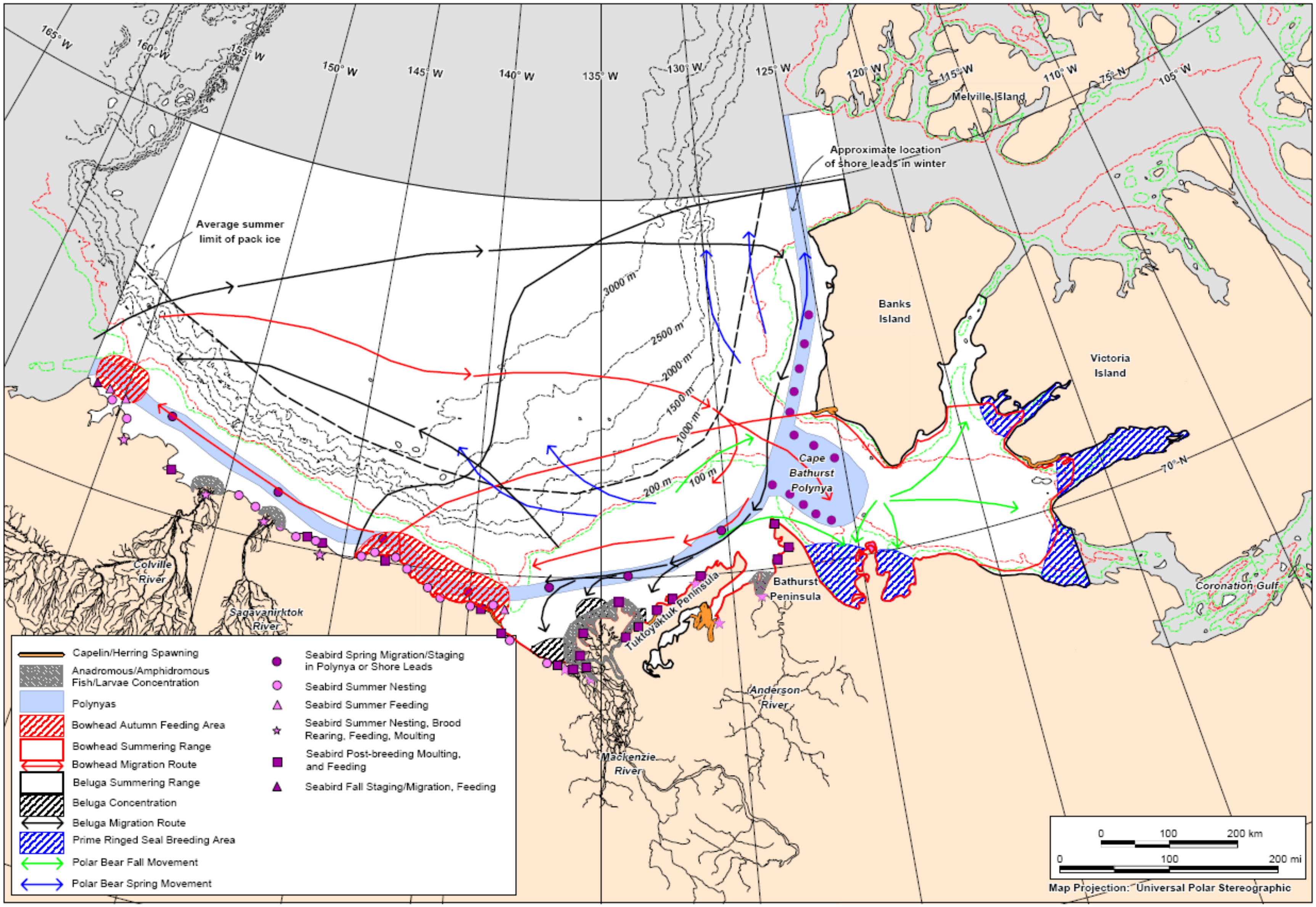

Figure 3.5. Distribution of fish, marine mammals and seabirds in the Beaufort Sea (LGL, unpublished).

The fall migration of bowheads out of the Canadian Beaufort Sea typically begins in early September with the last animals leaving by late October. They swim westward through nearshore waters of the Beaufort Sea, past northern Alaska, and south through the Bering Strait to the Bering Sea. The Inupiat of northern Alaska hunt bowhead whales during the spring and fall migrations. Inuvialuit in Canada have not hunted bowheads since 1996 (Dr. S. Stephenson, DFO, 2008 pers. comm.)

3.6.2 Beluga Whale

The Eastern Beaufort Sea population of beluga whales summers in the Beaufort Sea (Finley et al. 1987; COSEWIC 2004; Angliss and Outlaw 2008). Based on surveys in 1992, the estimated stock size is 39,258 (Angliss and Outlaw 2008). Belugas of this stock migrate annually between the Bering Sea, where they winter, and the eastern Beaufort Sea and Amundsen Gulf, where they summer (Finley et al. 1987).

The spring migration occurs primarily in April and May through leads off the northern coasts of Alaska and the Yukon. Belugas begin arriving in the Canadian Beaufort Sea in mid-May, and off the western coast of Banks Island and Cape Bathurst in late spring (Fraker 1977, 1979). During late June and early July, there is a southwestward movement back along the seaward edge of the landfast ice along the Tuktoyaktuk Peninsula toward the Mackenzie River estuary (Fraker and Fraker 1982; Norton and Harwood 1986). Typically, whales begin arriving in the area in late June or early July (FJMC 2001) after which they concentrate in the generally ice-free Mackenzie River estuary in greatest numbers from late June to mid-July. By late July and early August, relatively few whales are present in the estuary.

Some belugas leave the estuary and travel long distances to the east and north before beginning their westward migration to the wintering range (Richard et al. 2001). Most (11 of 14) males satellite-tagged in the Mackenzie delta in 1993 and 1995 traveled to Viscount Melville Sound via McClure Strait, and others traveled by way of Amundsen Gulf and Prince of Wales Strait. Most (4 of 6) females satellite-tagged in the Mackenzie River delta in 1993 and 1995, and most males (6 of 7) and females (2 of 3) tagged in 1997 traveled to Amundsen Gulf, where they moved in a clockwise loop before returning to the delta or to the shelf break north of the delta (Richard et al. 2001). Some of the highest observed densities of whales occurred in Amundsen Gulf (Davis and Evans 1982). Both males and females travel far into the permanent pack ice during both the summer and autumn (Richard et al. 2001).

The autumn migration of beluga whales from the Canadian Beaufort Sea begins during late August or early September, with the majority of autumn migrants traveling through offshore waters, near and within the pack-ice edge (Davis and Evans 1982; Hazard 1988; Clarke et al. 1993; FJMC 2001).

There are several traditional coastal harvesting/concentration areas for the Beaufort Sea population of beluga whales including 4 locations west of the Mackenzie Delta to Shingle Point, Gary and Kendall Island in the outer Mackenzie Delta, and 5 locations east of the Mackenzie Delta in Kugmalllit Bay (Harwood et al. 2002).

3.6.3 Ringed Seal

Ringed seals have a continuous northern circumpolar distribution, and they are the most abundant marine mammal in the Canadian Arctic. Estimates based on surveys of numbers of visible seals hauled out on the ice in spring, which may underestimate substantially the actual size of the populations, are at least 40,000 in the Canadian Beaufort Sea (Stirling et al. 1981), 50,000 in northern Amundsen Gulf (Kingsley 1990), and 49,000 in Prince Albert Sound (Kingsley 1990). There can be large natural variations in the numbers of ringed seals e.g., between 1974 and 1975 and again between 1982 and 1985, there were marked decreases in the abundance and productivity of seals in the Canadian Beaufort Sea and Amundsen Gulf (Stirling et al. 1977; Smith and Stirling 1978; Harwood and Stirling 1992).

During the spring breeding and moulting seasons, ringed seals are dispersed at low densities on top of the ice throughout the southeastern Beaufort Sea (Kingsley 1986). Density indices for the Canadian Beaufort Sea and Amundsen Gulf were 0.1–0.7 seals/km^2 during 1974–1979 (Stirling et al. 1982). Prime breeding habitat in the Canadian Beaufort Sea is around Cape Parry, Dolphin and Union Strait, and Prince Albert Sound and Minto Inlet on western Victoria Island (Cobb et al. 2008). Ringed seals seemed to prefer areas with a high proportion of ice cover and moderate water depths of 50–75 m (Stirling et al. 1982), areas that provide optimal feeding habitat.

During summer, ringed seals are dispersed throughout open-water areas. Some disperse to offshore areas after the landfast ice breaks up in summer, and in some regions, they move into coastal waters. Seasonal concentrations related to food sources are known in offshore waters of the Canadian Beaufort Sea off the Tuktoyaktuk Peninsula and off Cape Dalhousie (McLaren and Davis 1985; Harwood and Stirling 1992). Ringed seals encountered in the Alaskan Beaufort Sea during open-water seismic exploration were broadly dispersed as individuals or small groups (Lawson and Moulton 1999, 2001; Moulton and Lawson 2000, 2001; Moulton et al. 2002). Harwood and Stirling (1992) estimated densities in the Beaufort Sea of 0.42, 0.15, 0.08, and 0.19/km^2 in 1982, 1984, 1985, and 1986, respectively.

3.6.4 <u>Bearded Seal</u>

Bearded seals have a northern circumpolar distribution, and they are distributed throughout the Canadian Arctic in relatively low densities. The most recent population size estimates for the eastern Beaufort Sea population are 1200–3100 animals (Stirling et al. 1977, 1981, 1982). The Bering/Chukchi population was estimated at 300,000 (Burns 1981), and some of those summer in the Beaufort Sea.

The bearded seal is a benthic feeder that is most abundant in areas where it can reach the bottom to feed, usually in waters <200 m deep (Burns and Frost 1979; Finley and Evans 1983). In the Canadian Beaufort Sea, the bearded seal is most abundant over depths 25–50 m (Stirling et al. 1981). Thus, bearded seals prefer shallow-water areas with some amount of pack ice cover on which to haul out. The bearded seal’s preferred habitat is areas with thin, broken, or rotten ice, or the floe edge (Kingsley 1985). This species also prefers less stable ice during break-up (Cleator and Stirling 1990).

During the summer open-water period, much of the Canadian Beaufort is unsuitable for feeding because the pack-ice habitat preferred by bearded seals typically retreats north to waters deeper than those preferred by bearded seals. During seismic exploration off the Mackenzie Delta and Tuktoyaktuk Peninsula in late July to early October 2001, low numbers of bearded seals were observed by marine mammal monitors (Moulton et al. 2002). However, bearded seals are relatively common in certain nearshore areas along southern Banks Island, Cape Parry, and Herschel Island during summer.

3.6.5 Polar Bear

Polar bears are distributed throughout the Arctic in a number of relatively discrete populations (Stirling et al. 1984). Fourteen polar bear populations are identified in Canada (Stirling and Taylor 1999; Lunn et al. 2002), of which two occur in the Beaufort Sea: the Northern Beaufort Sea (1200) and Southern Beaufort Sea (1800) populations. Current information on the status of the populations suggests that they are stable (Stirling and Taylor 1999; Lunn et al. 2002).

The local distribution and abundance of polar bears vary through the year, and are strongly influenced by those of their principal prey, the ringed seal, and by the presence or absence, distribution, and quality of sea ice. During winter and spring, most polar bears are found on the sea ice (Amstrup 2000), tending to concentrate along pressure ice that parallels the coasts, and in the vicinity of floe edges. In summer, when the pack ice retreats offshore, polar bears are found along the edge of the pack ice (DeMaster and Stirling 1981; Amstrup 1995). During years with little or no pack ice near the coast, polar bears are often found along the coastline and on barrier islands (Stirling 1974). Polar bears usually exhibit fidelity to spring feeding and denning areas (Ramsay and Stirling 1990; Wiig 1995; Born et al. 1997).

Most of the recent information on movements of polar bears in the Beaufort Sea is from studies of female bears equipped with satellite tags. Most denning occurs on the heavy pack ice (Lentfer 1975). Annual movements of tagged female polar bears were 1406–6203 km over ranges of 7264–596,800 km^2 (Amstrup et al. 2000). In the southern Beaufort Sea, polar bears had the highest movement rates in June and July, when the ice was breaking up. In both the southern and northern Beaufort Sea, polar bears also had high rates of movement in early winter when ice was consolidating (Amstrup et al. 2000).

In late March and early April, females with cubs return to the sea ice to hunt seals, usually concentrating in places where ringed seals are pupping (Davis et al. 1980). In summer, they are relatively concentrated in areas with irregular coastlines such as bays, particularly those within which ice remains longer than in other areas (Stirling et al. 1979).

3.7 SEA-ASSOCIATED BIRDS

Sea-associated birds are widespread in substantial numbers in coastal, nearshore, and offshore waters of the Beaufort Sea (Johnson and Herter 1989; Cobb et al. 2008). However, the greatest numbers of marine birds, at least several million (Johnson and Herter 1989) occur in coastal and nearshore zones (Alexander et al 1988 a, b; Johnson and Herter 1989; Dickson and Gilchrist 2002; Noel et al. 2003; Fischer and Larned 2004; Johnson et al. 2005; North/South Consultants 2005; Cobb et al. 2008) (Figure 3.5).

The coastal islands, wetlands/marshes, and mud/sand-flats in the estuaries of the Mackenzie, Colville, Sagavanirktok, and Canning rivers, and numerous other smaller rivers and streams support large numbers of nesting, brood-rearing, moulting, and feeding waterfowl and shorebirds (Alexander et al. 1988b; Johnson and Herter 1989; Dickson and Gilchrist 2002; Latour et al. 2006; Cobb et al. 2008).

During spring, large numbers (10^5–10^6) of seaducks, mainly eiders and long-tailed ducks, migrate along open-water lead systems extending westward from Point Barrow to Banks Island, the outer Mackenzie River delta, and Amundsen Gulf (Alexander et al. 1988b; Dickson and

Gilchrist 2002; Latour et al. 2006). Many of these spring migrants (10^4–10^5) stop over or stage during spring migration in coastal leads and polynyas in the Canadian Beaufort Sea. Particularly large spring stop-over locations exist in Amundsen Gulf and farther east (Alexander et al. 1993). They remain in these marine environments until inland habitats are snow-free and available for nesting (Alexander et al. 1988a, 1997; Mallory and Fontaine 2004; Latour et al. 2006; Cobb et al. 2008).

During summer, loons, waterfowl, and seabirds are found generally within 50–70 km of the coast. Bird densities are generally lowest in offshore areas and highest along the coast in barrier island-lagoon habitats (Johnson and Herter 1989; Dickson and Gilchrist 2002; Fischer and Larned 2004; Cobb et al. 2008). Barrier islands provide important nesting habitat for common eiders (*Somateria mollissima*), glaucous gulls (*Larus hyperboreus*), Arctic terns (*Sterna paradisaea*), and black guillemots (*Cepphus grylle),* whereas adjacent brackish lagoon habitats provide shelter and abundant food resources for sea ducks, mainly long-tailed ducks (*Clangula hyemalis*), and shorebirds, mostly phalaropes (Johnson and Richardson 1981; Craig et al. 1984; Johnson et al. 2005).

After hatching, common eider young often aggregate in creches of varying size along coastal barrier islands in the Beaufort Sea, particularly where eiders nest in colonies (Johnson 2000b; Noel et al. 2005; Latour et al. 2006).

Black guillemots nest on some barrier islands in the western Beaufort Sea, i.e., on Cooper Island, Alaska (Butler and Buckley 2002), in buildings and other artificial structures on Herschel Island, Canada (Eckert et al. 2006), and on sea cliffs farther east, e.g., at Cape Parry (Johnson and Ward 1985; Johnson and Herter 1989; Latour et al. 2006).

Long-tailed ducks are the most abundant and widespread sea duck throughout the Beaufort Sea region. During post-breeding, 10^3–10^4 males and non-breeding females aggregate in coastal lagoons and bays where they undergo an extensive feather moult (Fischer and Larned 2004; Noel et al. 2004; Johnson et al. 2005). Together with lesser numbers of scoters, scaup, red-breasted mergansers, and some common eiders, these moulting birds are flightless and vulnerable during this period (Johnson et al. 2005; Robertson and Savard 2002; Cobb et al. 2008).

Nesting colonies of lesser snow geese (*Chen caerulescens)* and black brant (*Branta bernicla nigricans)* are found in some tundra-covered coastal islands (Johnson 2000a; Ritchie et al. 2000; Noel et al. 2004; Latour et al. 2006 and in coastal salt-marshes and wetlands in both the Canadian and Alaskan Beaufort Sea (Alexander et al. 1988a; Johnson 2000a; Ritchie et al. 2000; Latour et al. 2006).

Probably three-quarters of Beaufort Sea king eiders (*Somateria spectabilis*) occupy western Canada and northeastern Alaska during the breeding season (Johnson and Herter 1989; Dickson et al. 1997; Suydam et al. 2000; Dickson and Gilchrist 2002).

Red-throated and Pacific loons (*Gavia stellata* and *G. pacifica* respectively) nest on the arctic coastal plain of Alaska and Canada and make regular trips to coastal and nearshore Beaufort Sea marine habitats to feed (Johnson and Herter 1989; Gotthardt 2001; Russell 2002). Yellow-billed loons (*Gavia adamsii)* also nest on the coastal plain, mainly near large rivers or freshwater lakes, and also travel to coastal Beaufort Sea habitats to feed (North 1994).

The only thick-billed murre (*Uria lomvia*) colony in the Beaufort Sea consists of several hundred pairs nesting on cliffs at Cape Parry (Johnson and Ward 1985; Latour et al. 2006).

The post-breeding westward moult-migration of seaducks, primarily long-tailed ducks, eiders, and scoters, occurs during late June through late July–early August in the eastern and central portions of the Beaufort Sea (Johnson and Richardson 1982). Post-breeding king eiders spend several weeks staging in the nearshore Beaufort Sea before starting their moult migration (Powell et al. 2005). The peak of the westward fall migration of king and common eiders out the Beaufort Sea occurs during late July through early September, with peak numbers passing Point Barrow during August (Suydam et al. 1997). Some late-fall migrant eiders have been recorded migrating westward past the Colville River delta as late as November (Johnson and Herter 1989).

4. GENERAL ICE CONDITIONS, CIRCULATION PATTERNS, CURRENTS, AND BATHYMETRY

4.1 ICE CONDITIONS

4.1.1 Large Scale Patterns of Ice Movement

The seasonally navigable portions of the Beaufort Sea extend along the mainland Yukon and Northwest Territories coasts and through areas west and south of Banks Island, which in principle connect with the Northwest Passage via either McClure Strait or Prince of Wales Strait. These areas are occupied by upper Arctic Ocean waters, often strongly modified by the discharges of major rivers, and lie under or close to overlying bodies of pack ice generally associated with the southern portion of the anti-cyclonic Beaufort Gyre (Figure 4.1). Distinctions between the characteristics of ice movements can be made according to positioning in areas, respectively, in and offshore of the shallower sections of the coastal shelves. Movements in the latter, offshore, areas tend to be west-southwestward (acquiring a more southerly direction west of Banks Island), reflecting the influence of the offshore gyre (Figure 4.1), which dominates ice and water flows in the Canadian Basin portion of the Arctic Ocean. Ice drift speeds range upward from 0 to 10 or 15 km/day and average ~3 km/day. Periods of gyre reversal and persistent east-northeast flow occasionally occur in response to intervals of strong cyclonic atmospheric flow in the region.

Nevertheless, the integrity and long-term persistence of the gyral flow is such that the Beaufort Gyre and adjacent areas immediately north of the Canadian Arctic Archipelago act as the Arctic Ocean’s major reservoirs of ice that has survived one or more annual growth /melt cycles (Figure 4.2).

Ice movements on the middle and inner shelves are much more closely tied to synoptic wind conditions, and to the circumstance that large scale ice mobility essentially disappears locally between ~November and June in the vast zone of ice that forms around the Beaufort Sea periphery. This landfast ice feature extends out to ~20 m depth along the mainland and Banks Island coastlines. It spans Amundsen Gulf, extending out to one of a series of annually and intra-annually varying western fast-ice boundaries that link the mainland coast to Banks Island, more or less smoothly connecting with the immobile ice fields characteristic of the winter channels of the Canadian Archipelago.

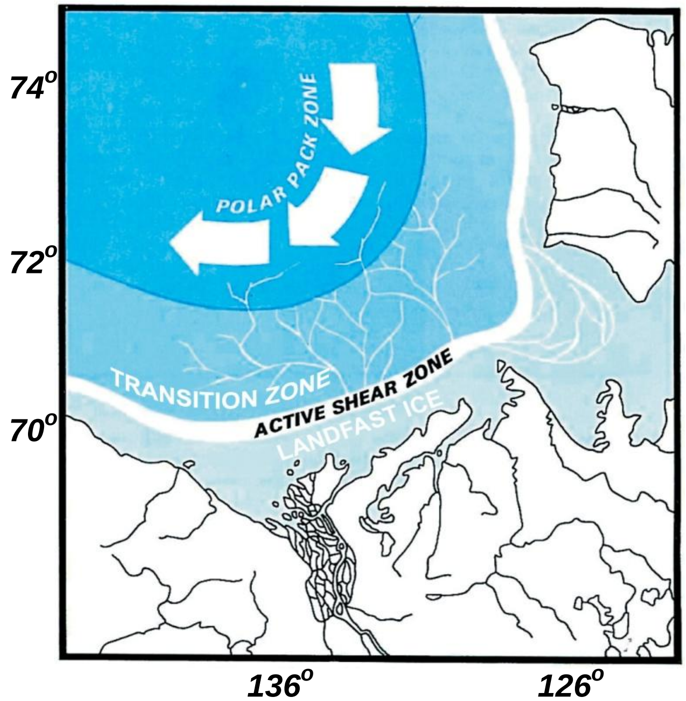

Figure 4.1. Schematic representation of the major features of ice cover in the southeastern Beaufort Sea.

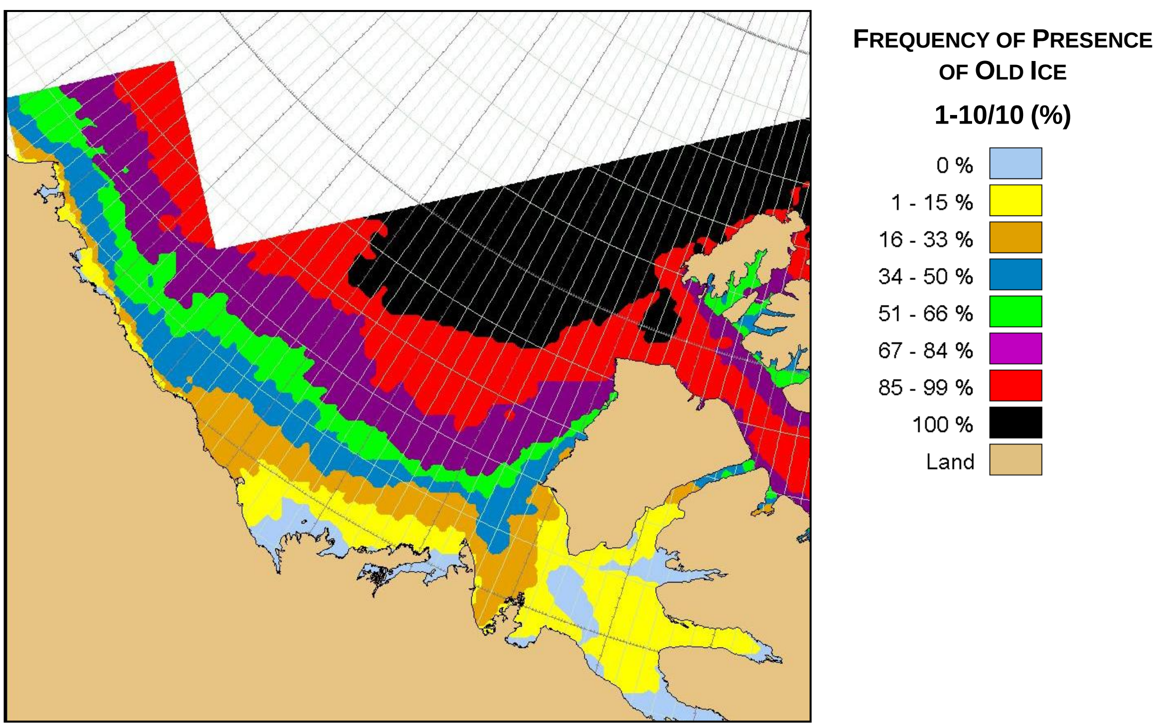

Figure 4.2. Probabilities for multiyear ice presence on 20 August (based on 30 years of Environment Canada ice chart data, 1971–2000).

4.1.2 Winter Ice Regime: Landfast Ice and Shear Zone

The annual growth of the landfast ice begins in September and October, with the appearance and development of new ice and its intermixing with shoreward advancing elements of the offshore pack ice that have survived at least one annual melt season. During this process, the offshore edge of the zone irregularly advances seaward and retreats through alternating steps of growth and deformation, until its outer boundary becomes stabilized in early winter in waters close to the 20-m bathymetric contour (Marko 1975). Stabilization is produced by physical contact between the sea floor and deep ice keels embedded in the outer portion of the landfast ice. These deep keels are produced by strong interactions between the landfast ice and adjacent portions of the gyral pack ice, which also increases its areal extent and thicken during the fall and winter months.

A well-developed flaw or “active shear lead” with widths ~10 km usually can be seen seasonally marking the outer limits of the landfast ice (Figure 4.1), and hence, the start of a “transition zone” where deviations from a more purely gyral flow are introduced by interactions with nominally stationary, more shoreward, ice. These deviations, evident in the fracturing of massive floes, generation of numerous additional, northward- and eastward-extending leads, and the irregular openings, closings, and position shifts of the flaw lead, dictate the dynamic nature of the transition zone regime (Dome 1982), which can extend 100 km or more beyond the edge of the landfast ice. The landfast ice itself thickens and remains in place until early summer, when it clears by melting and dispersal, usually in conjunction with the northward retreat of a shrinking offshore ice pack. This clearance process is strongly dependent upon wind conditions, but generally proceeds east to west (south to north off Banks Island), and its character and rate of progress are closely tied to the discharges of the Mackenzie and other rivers.

The thickest level ice is primarily found in the old-ice dominated regions of the gyral zone. Heavy ridging is a common but not ubiquitous feature in all ice regimes, with the greatest occurrence frequencies occurring in the transition zone and the outer landfast ice.

4.1.3 Sea Ice and Navigation

Realistically, commercial navigation in the region of interest is likely to be confined to the summer season when clearance in the landfast, transition, and gyral zones eventually produces a continuous stretch of open or, at worst, moderately ice-infested water along the mainland coast, throughout Amundsen Gulf and northward along the west coast of Banks Island, to latitudes close to those associated with the entrance to McClure Strait. An initial appreciation of a typical seasonal progression can be obtained from charts of median ice conditions in the Beaufort Sea (Figure 4.3). The charts show both the heavy southern and eastern bias of the clearing process and, consequently, the narrow spatial and temporal windows associated with shipping routes west of ~142° W and off the west coast of Banks Island.

Although useful to illustrate recent environmental tendencies, the median condition data of Figure 4.3 must be supplemented by information that reflects the region’s characteristically large ranges of variability. Some measure of this variability can be gained from Figure 4.4, which presents data on the frequencies of local ice presence in the same areas considered in Figure 4.3 and based upon the same ice chart compilations. Data are presented for times in the middle of the July–September months, which are most likely to be associated with navigable conditions. These results show that significant probabilities for (mostly) ice-free conditions exist even in the most ice-infested western and northern portions of potential transportation routes. Past examples of extremes in navigation route coverage are illustrated in Figure 4.5 by charts depicting mid-September conditions in 1996 and 2007. Variations in ice conditions such as those depicted in Figure 4.5 are clearly not random or stochastic, but reflect changes occurring on a variety of temporal scales.

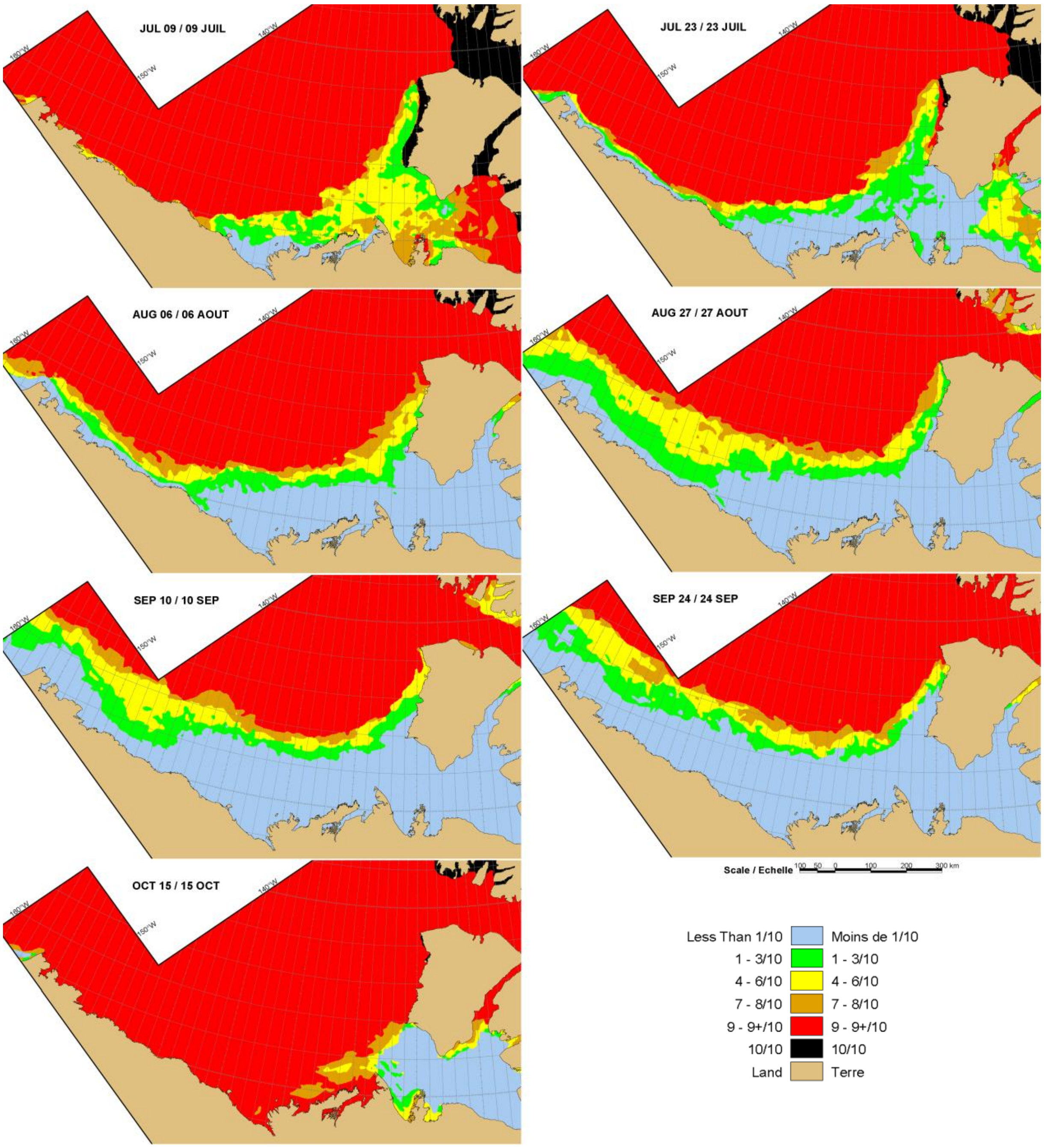

Figure 4.3. Median (1971–2000) distributions of ice concentration in the Beaufort Sea at weekly intervals between 25 June and 15 October (Environment Canada, Canadian Ice Services).

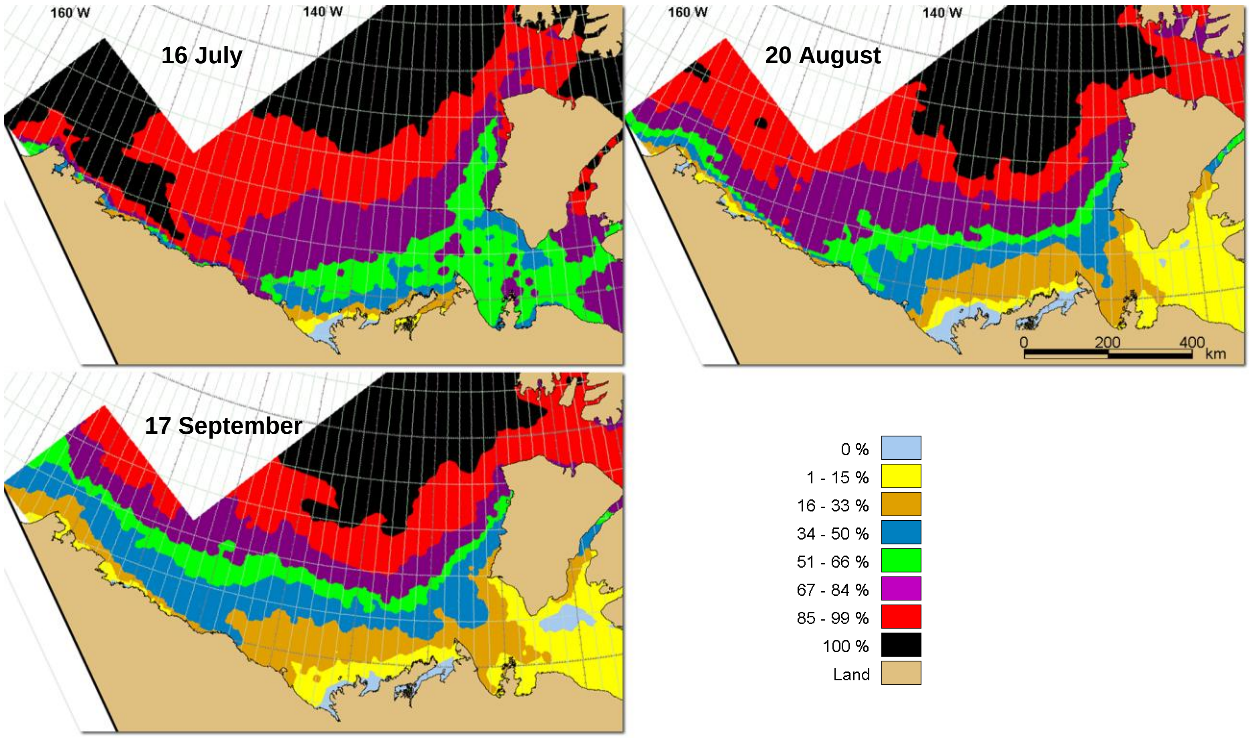

Figure 4.4. Frequencies of sea ice presence (%) on 16 July, 20 August, and 17 September for a 30-year period (1971–2000) (Environment Canada, Canadian Ice Services).

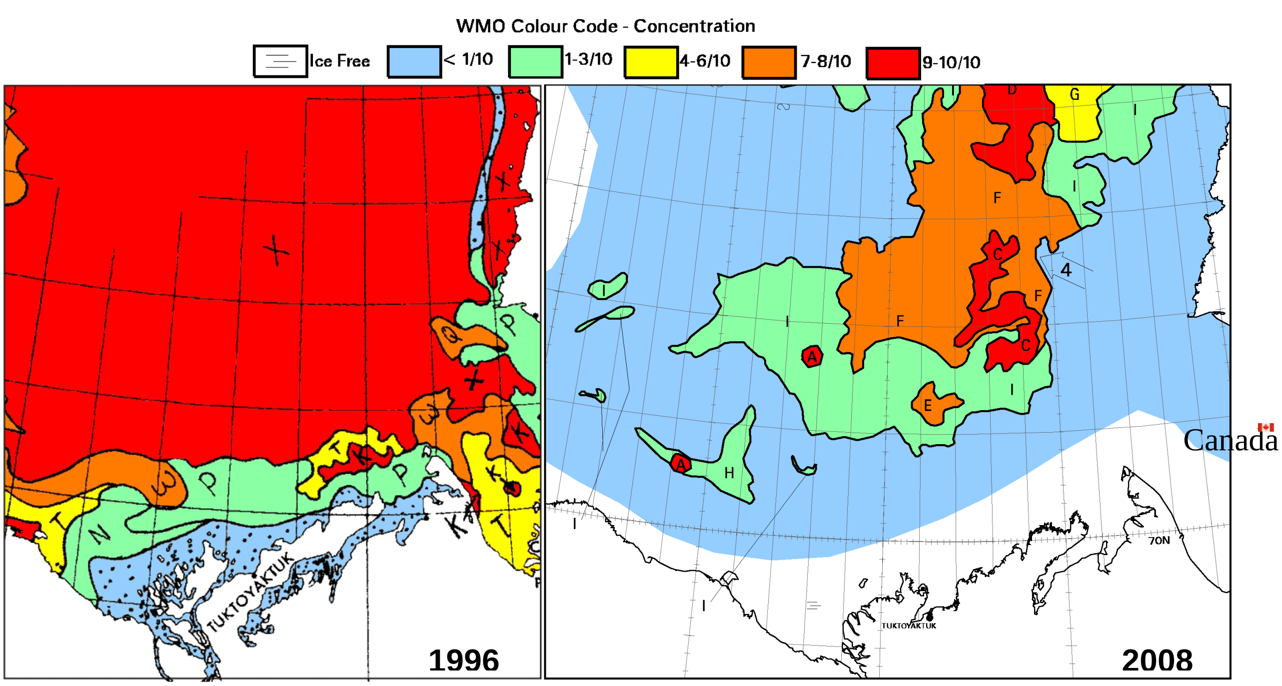

Figure 4.5. Environment Canada ice chart for 17 September in 1996 (left panel) and 2008 (right panel).

4.1.4 Interannual Variability of Summer Ice Conditions

The presence of temporal patterns in interannual variability of sea ice is apparent in Figure 4.6, as derived from Canadian Ice Service ice charts over the 41 year period of 1968 to 2008, for the Alaskan Beaufort Sea, the Mackenzie shelf, and the deeper waters north of the Mackenzie Shelf. From these data, general patterns are evident as (1) the general dominance of the clearing in eastern areas and (2) that year-to-year variations in clearing rates usually, but not always, tend to follow each other fairly closely in the eastern and western portions of the mainland coastal region. The results can be taken as representative of cyclic variations that almost certainly exist independently of much longer-term trends associated with more global natural or anthropogenic influences. They suggest that difficult summer navigation conditions, i.e., small areal extents of open water, can be expected to occur along the navigation routes at, on average, 6–7 year intervals. Also, clearance rates in adjacent years are usually fairly closely correlated.

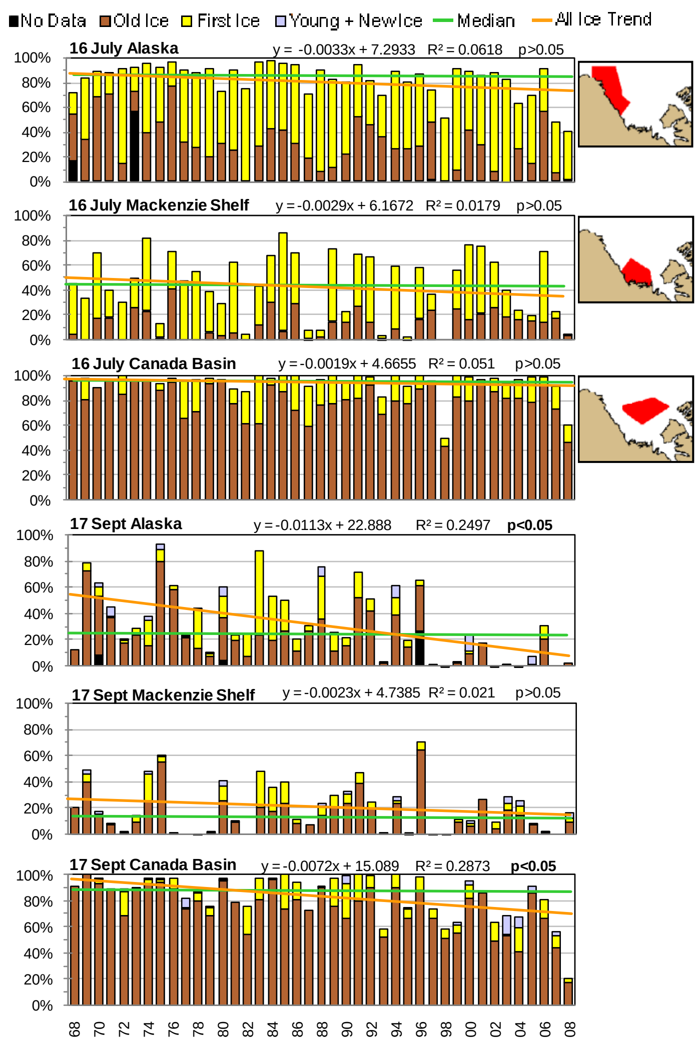

Figure 4.6. Sea ice concentrations by ice type for Alaskan Beaufort Sea, the Mackenzie Shelf and the deep waters north of the shelf, for mid-July and late-September, 1968–2008 (derived from Canadian Ice Service ice chart data).

Any evaluation of ice conditions to be encountered over the next few decades must consider the diminishing presence of ice in the Arctic as a whole, and also as seen to a lesser degree, in the trend computed for some of the areas shown in Figure 4.1. The decreasing trend in the Arctic Ocean sea ice coverage and ice thickness has been occurring for at least two decades, but very large observed reductions in Arctic areal ice extents have been observed within the past decade (Stroeve et al. 2007). However, the Beaufort Sea has experienced much smaller areal reductions (-6% and -8%/decade in all ice and multiyear ice, respectively), as deduced by Melling (2005) from data gathered in "Zone A" (Figure 4.7), a large region in the southern part of the gyral feature (see Figure 4.1) and also seen in the deeper water "Canada Basin" area on Figure 4.6.

Decadal trends identified in adjacent areas shoreward of the ~100 m bathymetric contour have shown negligible decreases (0% and -1% for all ice and multiyear ice, respectively). Other evidence indicative of the absence of significant decreases in drift in the latter areas and the negligible or much lower (relative to summer month data) decreases in areal extent in the late winter months (see the ice extent data from the study area and the western Canadian Archipelago during the extreme 2008 ice season in Figure 4.8) suggest that the bulk of recent shrinkage in the Arctic sea ice cover has occurred through decreases in coverage by its multiyear or old ice component, which is highly concentrated in offshore gyral pack areas (Figure 4.2). In this view, the recent melt-back of the older, thicker ice component has been countered by winter expansions of first year ice coverage. The higher probability for first year ice floes to have melted away in summer, relative to old ice, underlies the observed preferential decreases in late summer/early fall ice coverage. The absence of decreases in areal extent and ice drift in areas shoreward of the 100-m bathymetric contour reflect the usual dominant presence of first year ice in such areas.

Within this picture, regional air temperature decreases as large as a few ºC are unlikely to have major impacts on late winter first-year ice thickness, which is largely determined by wind-forced deformation processes (Melling 2005). Warmer temperatures, on the other hand, would be expected to increase the rates of summer melt-back in such ice, further lowering overall areal coverage in summer and fall and increasing the corresponding fractional contents of multiyear ice.

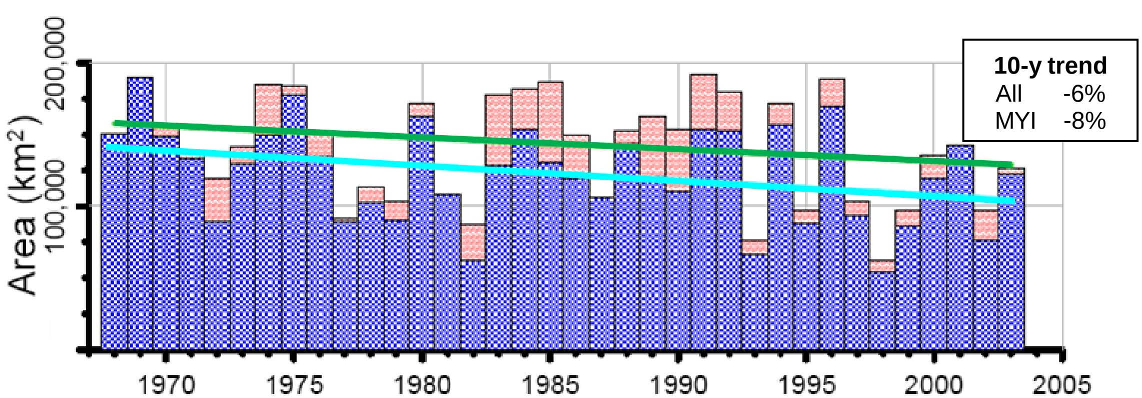

Figure 4.7. Annual minimum (September) ice extents in offshore Beaufort Sea "Zone A" (from Melling 2005, 2007). Areal coverage is presented for all (blue) and multiyear (pink) ice types, accompanied by linear trend estimates.

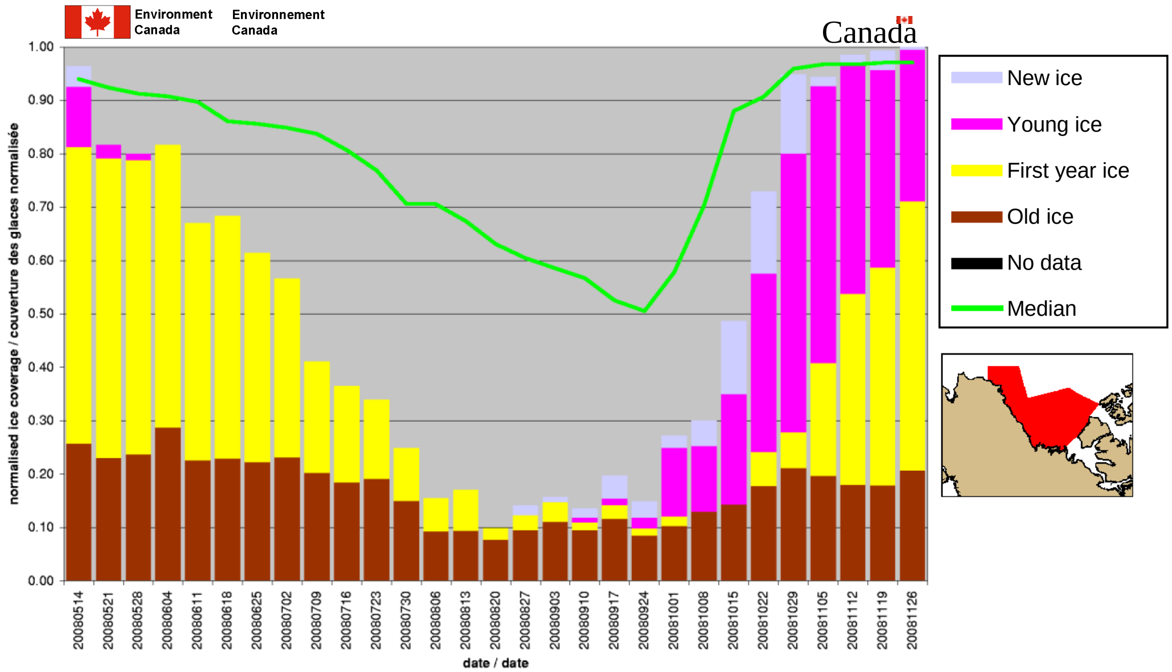

Figure 4.8. Ice cover in the Beaufort Sea during the 2008 ice season and comparisons with long term median coverage.

At this point, the existing knowledge and understandings of changes in the Beaufort sea ice climate is not sufficient to determine if the observed recent trends will continue or even accelerate or reverse. It is certainly possible, however, that the continued melting away and lack of replacements for the Arctic Ocean's content of old ice could lead to a situation in which ice free conditions would be ubiquitous during the mid to late summer period and into early autumn allowing for greater shipping activity during this period.

4.2 OCEANOGRAPHY

Currents in the Beaufort Sea come in many forms, driven by a combination of various oceanographic processes including large-scale circulation features, the effects of wind, the major rivers draining into this area (particularly the Mackenzie and Colville Rivers), the role of sea ice formation and break-up, and tidal forcing.

4.2.1 Large-Scale Circulation Features over the Continental Slope and Deeper Waters

In the deeper waters of the Beaufort Sea (Canada Basin) and over the continental margin and slope, large-scale circulation features include the Beaufort Gyre, the Beaufort Undercurrent, and the intrusion of Atlantic Waters. These geophysical features, combined with the effects of regional winds and the Mackenzie River plume coalesce to create a complex of surface currents, as represented in Figure 4.9. Upwelling, a process that brings deeper, nutrient-rich waters to the surface, occurs along the continental shelf edge and slope under winds blowing from the east. In the vicinity of the Mackenzie Trough underwater canyon (Figure 4.12), upwelling is enhanced by canyon circulation features and the effects of ice (when present).

Currents at the continental slope represent large-scale flow features driven by the influence of waters from the Pacific and Atlantic Oceans. Water masses consist of Arctic Surface Water in the upper 250 m, below which Atlantic Water is present (Figure 4.10).

The Arctic Surface Water is characterized by very low temperatures (<0ºC) except in summer, when solar heating of open water and river discharges can raise the temperature near the surface. The Arctic Surface Water has relatively low salinity because of the effect of Arctic river runoff and summer ice melt.

Pacific water enters the Arctic Ocean through the Bering Strait, moves through the Chukchi Sea and Barrow Canyon off the northwest Alaskan coastline, and travels eastward along the upper portion of the continental slope (Pickart 2004). Because this Pacific water has a slightly greater density than that of the Arctic Surface Water, it descends beneath the surface at typical water depths of 50–175 m, and is characterized by slightly higher temperatures. This flow of Pacific water, called the Beaufort Undercurrent (Aagaard 1984), moves eastward along the upper portion of the Alaskan continental slope and then onto the continental slope off the Mackenzie Shelf (Weingartner 2006). Because of inherent instabilities in the flow dynamics, the Beaufort Undercurrent is present intermittently with interruptions because of the formation of eddies that spin off into the deeper waters or the complex dynamics of the Mackenzie Trough, as discussed below. Nevertheless, the Pacific water of the Beaufort Undercurrent represents an important oceanographic influence on the lower levels of the food chain.

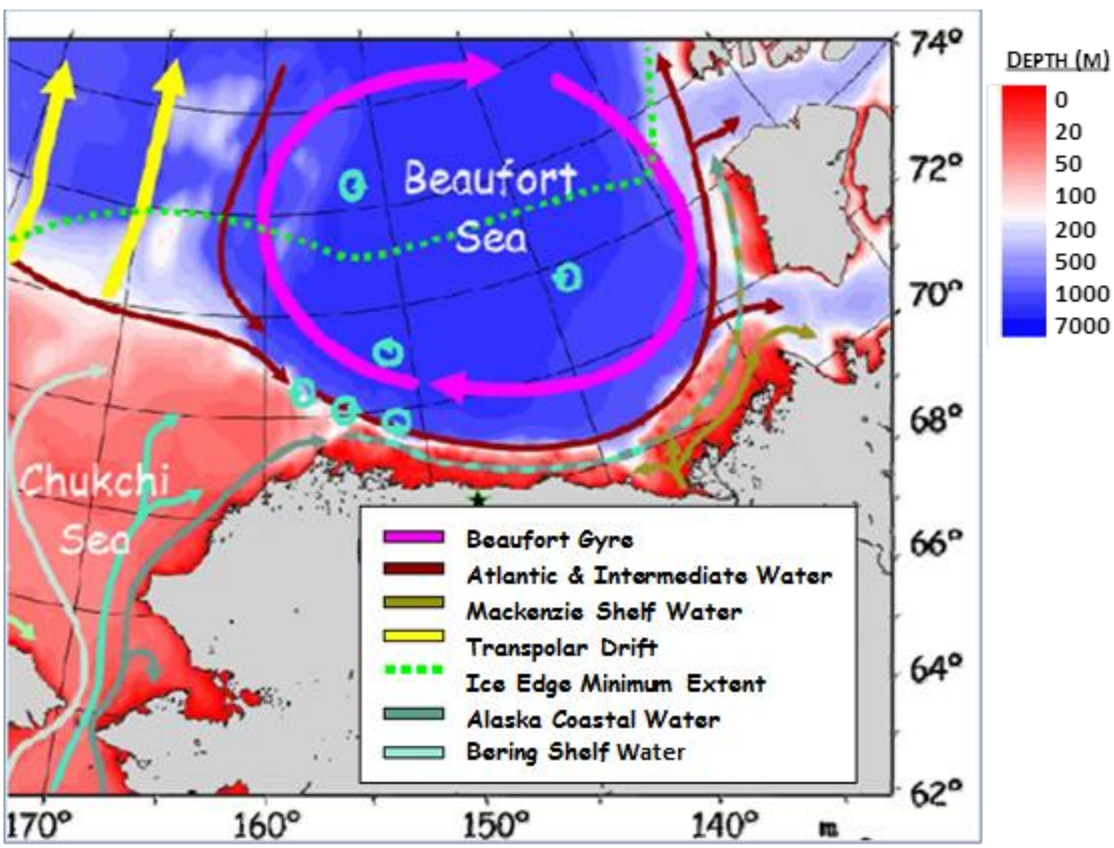

Figure 4.9. Schematic summary of ocean currents in the Beaufort Sea (from Weingartner 2006).

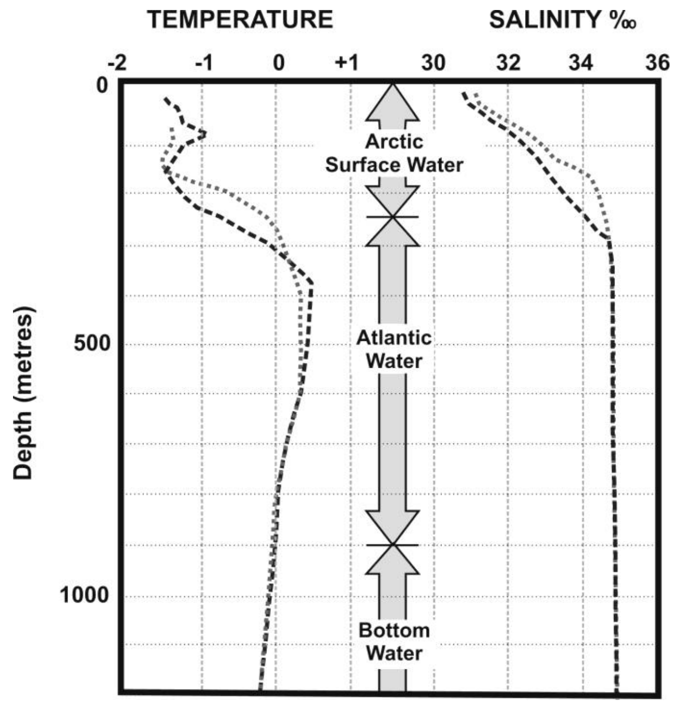

Figure 4.10. Temperature, salinities, and depths of Arctic Surface Water and Atlantic Water in the Beaufort Sea.

At depths of 250–750 m, warmer, more saline waters that originate in the Greenland Sea of the Atlantic Ocean flow along the continental slope and the major topographic ridges of the Arctic Ocean. This water flow then turns eastward along the deeper portion of the continental slope along the Chukchi Sea and off the Alaskan and Canadian portions of the Beaufort Sea (Weingartner 2006) before exiting the Arctic Ocean and returning to the Greenland Sea.

The surface waters over the continental slope and the Canada Basin move slowly westward, following in the large-scale clockwise flow pattern of the Beaufort Gyre. The Beaufort Gyre is driven by the high pressure atmospheric system permanently situated over the western Arctic Ocean.

4.2.2 Continental Shelf Circulation Dominated by Wind-Driven Currents

In the shallower waters over the continental slope, the ocean currents are predominantly wind-driven. The winds blow in two main directions, from the east and from the west-northwest. An analysis of 14 years (1994–2007) of wind data measured at Pelly Island on the Mackenzie Shelf show that winds blowing from the east occur most frequently, nearly twice as often as winds blowing from the west-northwest. However, the largest winds (those exceeding 12 m/s) nearly always blow from the west-northwest, with a maximum recorded wind speed of 24 m/s. The surface currents generated by the two dominant wind directions (Figure 4.11) generally track the wind direction with a 15–30º rightward deflection. Current speeds are ~2–3% of the wind speed with typical speeds of 0.25–0.4 m/s (up to 0.8 m/s).

Farther to the west, the Alaskan and Yukon Territory portion of the Beaufort Continental Shelf is narrower in width, typically 50–100 km, than the >100 km width of the continental shelf off the Northwest Territories (Figure 4.12). The currents over the outer shelf and continental slope are characterized by mean flows amounting to only a few cm per second, whereas the variable, wind-driven flows can be large (10–50 cm/s). Although swift flows can occur throughout the year, they tend to be strongest in late fall and winter. In contrast, the magnitude of the flows on the inner shelf is strongly seasonal; during summer, current speeds can exceed 50 cm/s, but are more typically ~20 cm/s and coherent with the along-shore winds (Dunton et al. 2006).

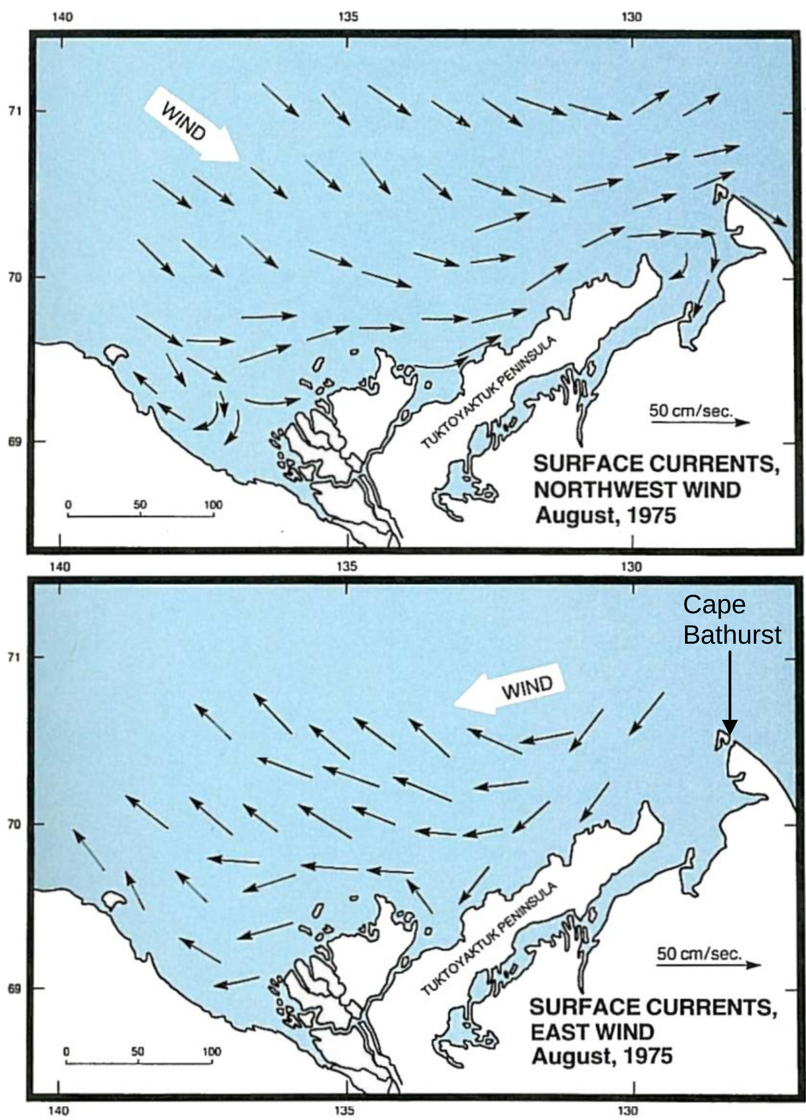

Figure 4.11. Current patterns resulting from the two dominant wind directions (W–NW, upper panel), and winds from the east (lower panel) (from McNeil and Garrett 1975).

On the inner shelf, the surface current pattern is more complicated because of the presence of the more intense Mackenzie River plume waters (discussed in section 4.2.3), and to a more localized extent, the plumes from the Colville and other major Arctic rivers. The effect of shoreline features such as headlands and islands, especially barrier islands along the Alaskan coast, also can result in enhanced surface currents over small local areas.

The winds from the west result in strong alongshore currents, and move the sea-ice and river waters closer to shore. Winds from the east result in an offshore displacement of Mackenzie River water and pack ice. Easterly winds cause upwelling of colder, nutrient-rich water from deeper water over the continental slope. This water moves upward into the surface layer on the shelf edge, which can result in plankton blooms in otherwise nutrient-deficient surface waters. Upwelling is especially evident north of Cape Bathurst (Figure 4.11), as evidenced by the frequent appearance of a tongue of cold saline water extending north along the western shelf break (Dunton et al. 2006).

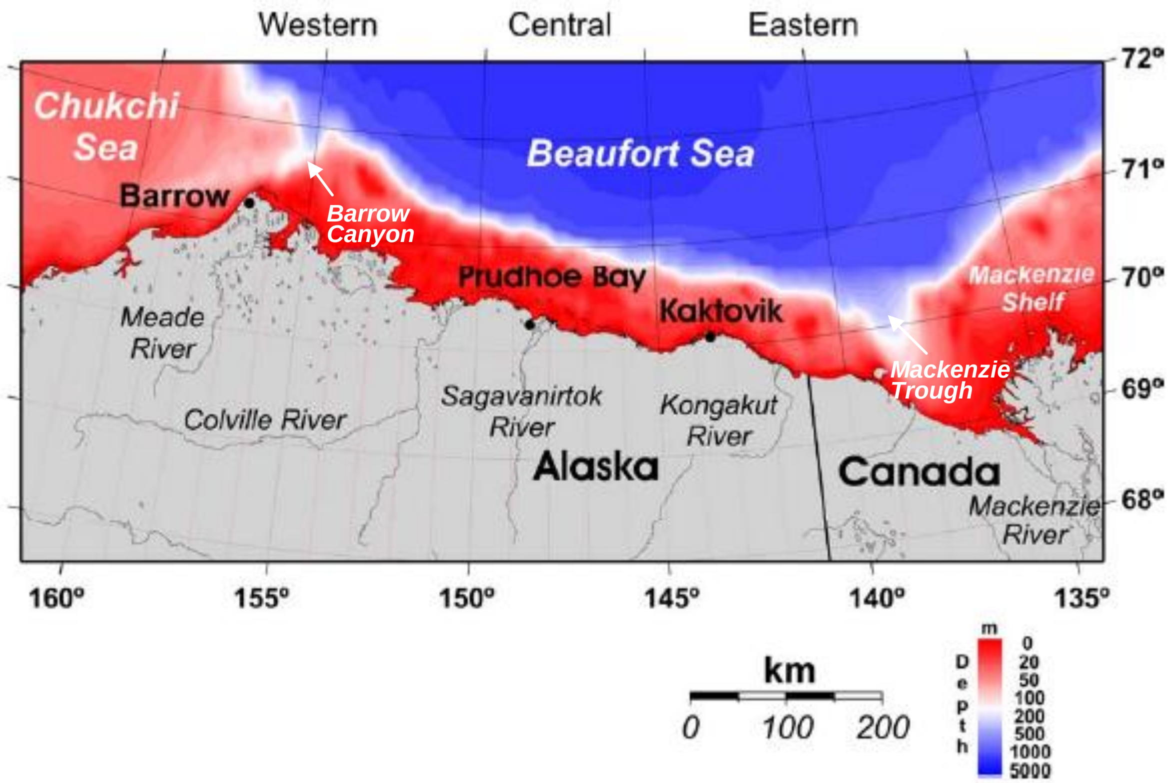

Figure 4.12. Map of the Alaskan Beaufort Sea and North Slope with place names and subdivisions indicated (from MBC Applied Environmental Sciences 2003).

4.2.3 <u>Mackenzie River</u>

In contrast to the Arctic rivers of the Alaskan Beaufort Shelf, the Mackenzie River drains both temperate and pan-Arctic watersheds, and flows year-round. The large annual freshwater discharge from the Mackenzie River (~330 km^3) spreads over a relatively small shelf area of ~64,103 km^2; this results in an annual freshwater burden of ~5 m, making it the most ‘estuarine’ of the panarctic shelves (Dunton et al. 2006).

Within the inner portion of the Mackenzie Shelf (Figure 4.12), the Mackenzie River discharge into the Beaufort Sea dominates circulation and water properties during peak river discharge beginning in mid-May to mid-June. Mackenzie River discharge continues to dominate circulation through the summer months of ice breakup and open water conditions. The Mackenzie River plume tends to move eastward along the Tuktoyaktuk Peninsula, although the dominant wind patterns alter the location of the plume (Figure 4.13).

Intense fronts occur along the edge of, and within, the plume proper as water mixes from below and alongside. Mackenzie River water, after mixing with shelf waters, can be detected at much greater distances from the river mouth, extending as much as 400 km from shore (Carmack and Macdonald 2002). Enhanced concentrations of plankton can occur in the fronts and boundaries of the Mackenzie River-influenced surface waters, which can be important feeding habitat for baleen whales (Thomson et al. 1986).

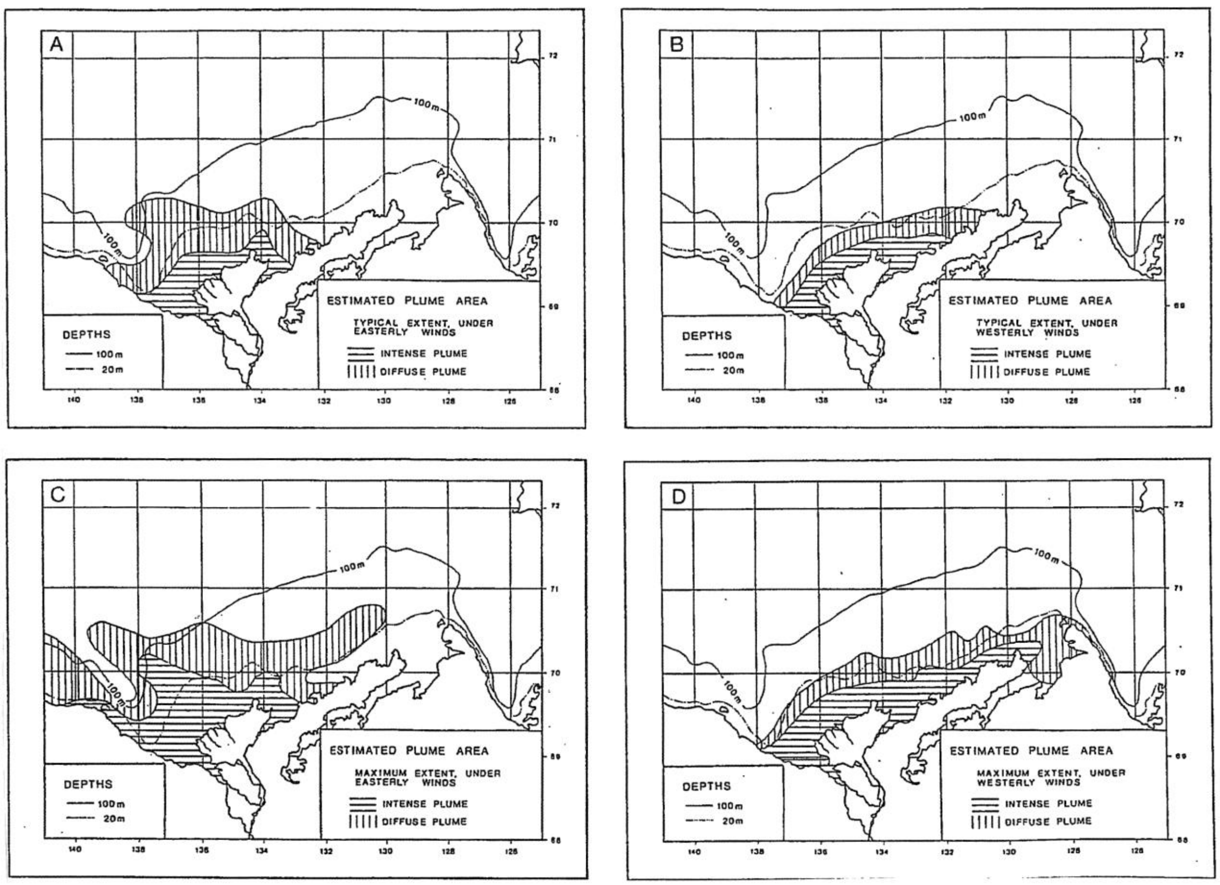

Figure 4.13. Map of the Mackenzie River Plume area under easterly and westerly wind conditions (from Thomson et al. 1986).

4.2.4 Tidal Currents

Tidal heights in the Beaufort Sea are generally small (<0.5 m), and tidal currents are weak through most of the area, typically <0.05 m/s throughout most of the region (Kulikov et al. 2004). However, tidal modeling studies (Kowalik and Proshutinsky 1994) reveal that significantly larger (5–10 cm/s) semidiurnal (M2) tidal currents occur on the outer shelf zone of the Beaufort Sea, bordered by the 100-m isobath between Mackenzie Trough and Amundsen Gulf. Especially, strong currents (>10 cm/s) are predicted for the area northwest of Cape Bathurst and on the southwestern shelf of Banks Island. The simulated diurnal currents have two areas of high intensity: northwestward from Cape Bathurst, and westward from Banks Island (Figure 4.14)

4.2.5 **Shelf Break and Mackenzie Trough Currents**

Enhanced exchanges of nutrient-rich water from deep water onto the shelf break via upwelling are known to occur in cross-shelf underwater canyons throughout the world. Large-amplitude upwelling was found to occur in the Mackenzie Trough from moored current meter observations in the late 1980s (Carmack and Kulikov 1998). Upwelling occurred during northeasterly winds followed by eastward movement of the nutrient-rich, upwelled waters eastward along the slope and outer shelf as the winds abated. A more extensive current meter mooring program in the 1990s revealed that upwelling near the head of the Mackenzie Trough extends upwards from approximately 360-m water depths. Ice motion causes the largest amplitude upwelling, indicating that ice motion tends to amplify the effects of wind forcing (Williams et al. 2006). Further research on these processes is ongoing with the Canadian Arctic Shelf Exchange Study (CASES; Fortier et al. 2008) and two Canadian International Polar Year (IPY) projects in the Canadian Beaufort Sea (Carmack et al. 2008; DFO 2007).

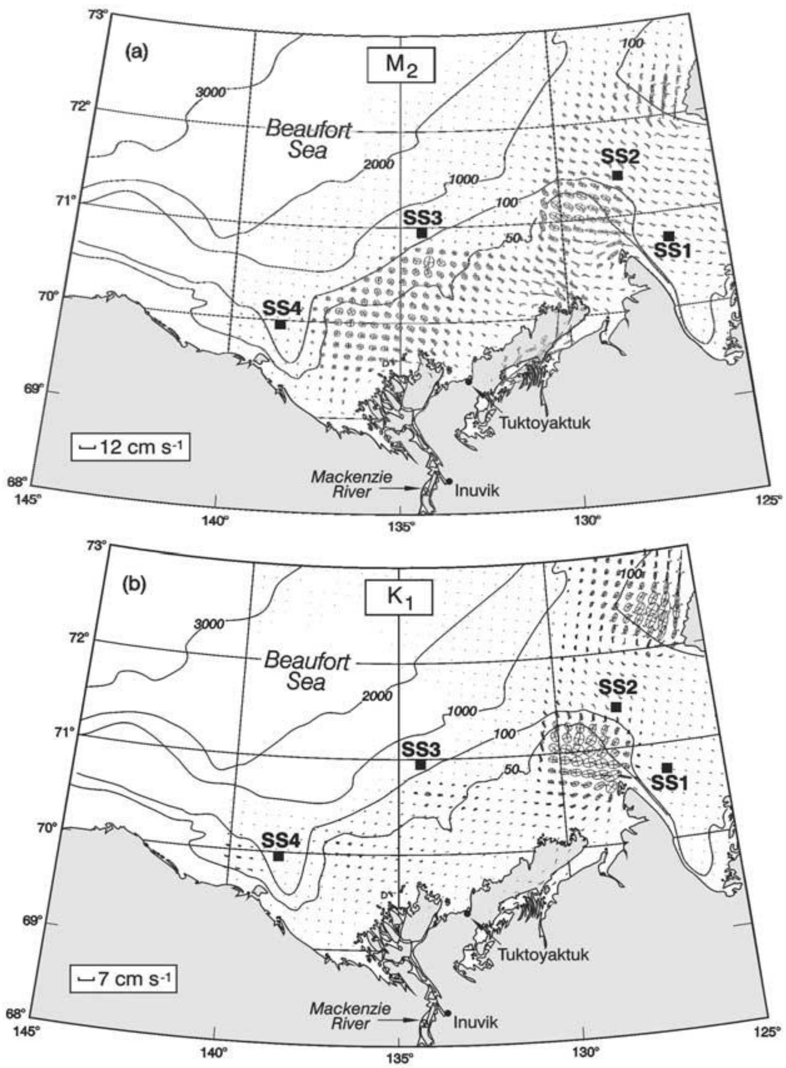

Figure 4.14. Map showing (a) semidiurnal (M2) and (b) diurnal (K1) tidal currents, computed by Kowalik and Proshutinsky (1994).

5. CURRENT AND EXPECTED FUTURE VESSEL TRAFFIC PATTERNS AND VOLUME

Vessel traffic in the Beaufort Sea includes, or will include in the future, traffic within the Beaufort Sea and Canadian Arctic archipelago, and traffic to and from waters outside the Beaufort Sea. Current traffic within the region is mostly barge traffic (Figure 5.1), much of which originates from other areas of the Arctic (Figure 5.2) (Chan et al. 2012), mainly the Mackenzie River and Tuktoyaktuk, and is bound for other Western Canadian Arctic communities (Judson 2010; Figure 5.3). For example, in 2006, Northern Transportation Company Limited (NTCL) scheduled 7 trips by tug and barge from Tuktoyaktuk to resupply communities in Coronation Gulf and as far as Taloyok in Spence Bay, to the east of King William Island. Between 2005 and 2008 an average of 9 non-merchant vessels per year arrived in Tuktoyaktuk, the most frequently used port in the Western Arctic (Chan et al. 2012). Vessel traffic along the Alaskan north coast is also associated with community supply or with oil field developments; in 2007, three barges made ten trips across the Beaufort Sea.

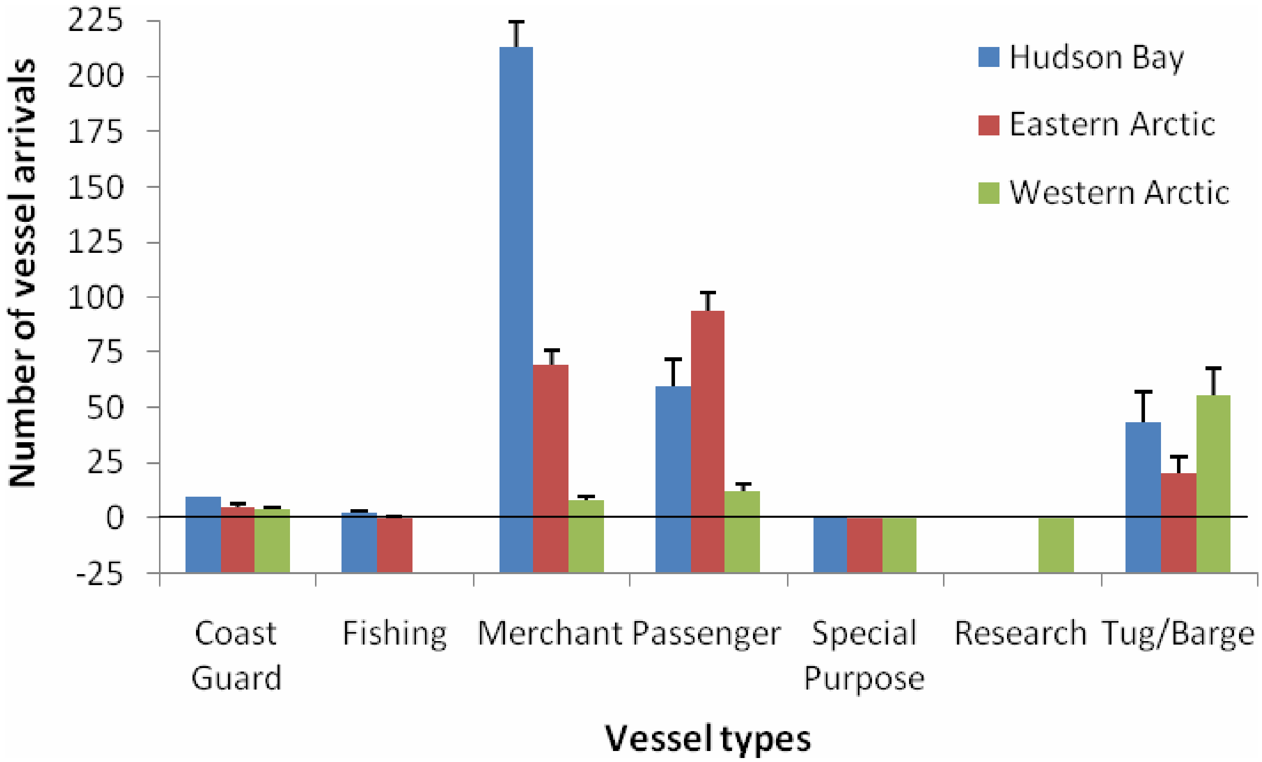

Figure 5.1. Mean (+ S.E.M.) annual number of vessel arrivals from 2005-2008 by vessel type and Arctic region. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero (from Chan et al. 2012)

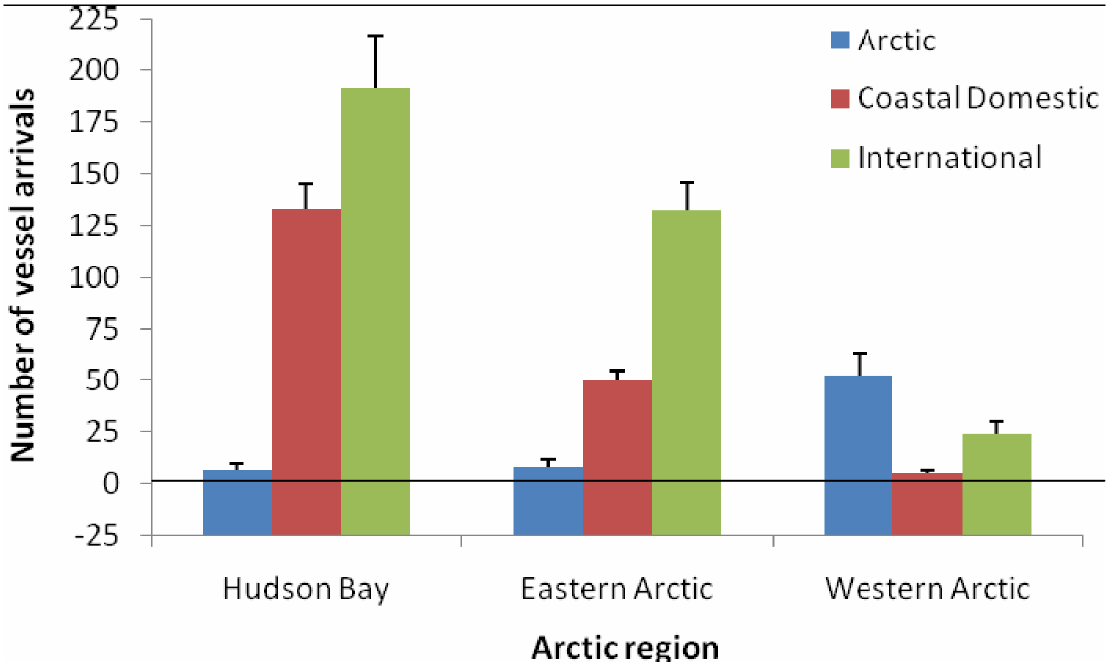

Figure 5.2. Mean (+ S.E.M.) annual number of vessel arrivals by vessel operational region and Arctic region. The x-axis has been lowered to differentiate zero (no bar presented) from values close to zero (from Chan et al. 2012).

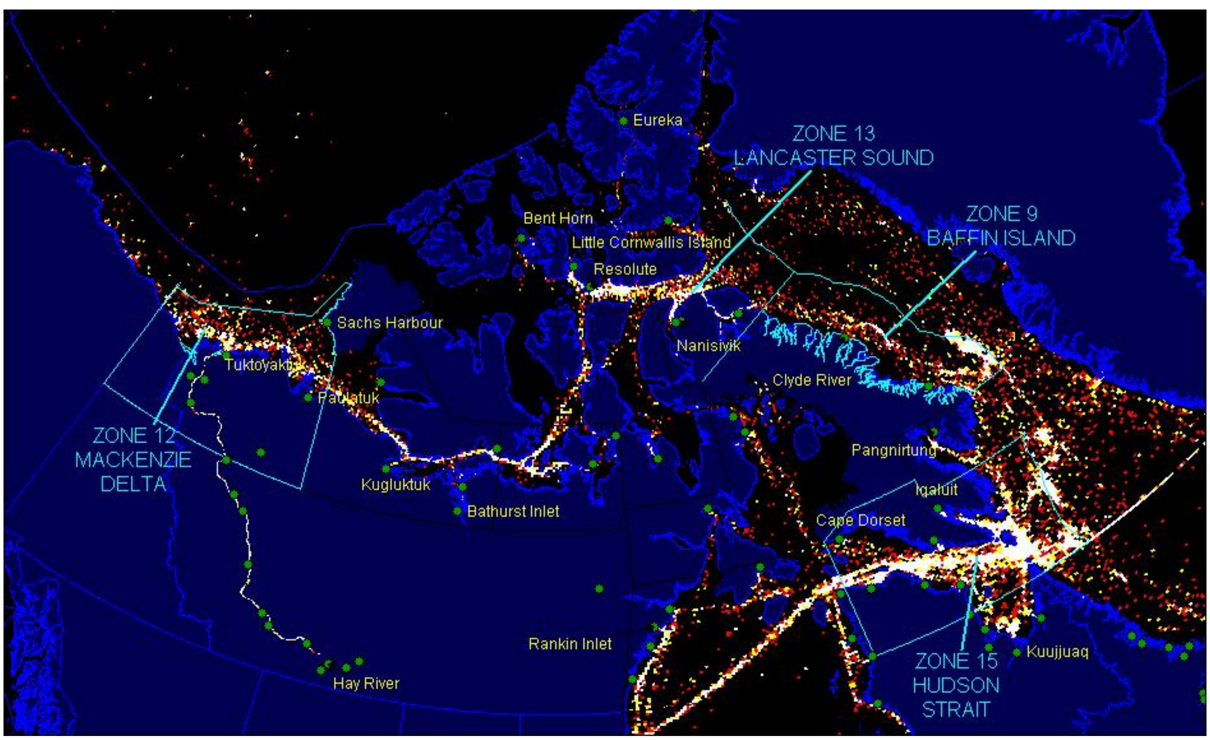

Figure 5.3. Traffic Density (Ship-days), 1991-2008, Red:<=2 ship-days, Yellow: 3 ship-days, White = 4+ ship days (from Judson 2010).

A study of vessel-related exotic species to the Arctic region by Niimi (2004) indicated that international cargo movements to domestic ports in the western Arctic were limited to U.S. vessels from Alaskan waters. Recent exploration for and plans for development of oil, gas, and mineral resources indicates that large vessel traffic into and out of the Beaufort Sea will increase, probably markedly, in the not too distant future (Arctic Marine Council 2009). Examples are the seismic exploration in the Canadian Beaufort Sea by GX Technology (2006–2008), Imperial Oil (2008), and a proposed seismic survey by BP (2009); the High Lake and Izok mines south of Coronation Gulf; the Bathurst Inlet Port and Road Project; Imperial Oil's proposed Ajurak exploration well and BP Canada' proposed Pokak well in the Canadian Beaufort Sea north of the Mackenzie Delta, and seismic exploration by Shell (2007–2008) and GX Technology in the Alaskan Beaufort Sea. Current oil well development off the Alaskan North Slope is supplied by tug and barge from Kodiak in the Gulf of Alaska.

Shipping routes into the Beaufort Sea are largely dictated by ice conditions (see Figure 4.3), and are closer to shore off the North Slope than in the central and eastern Beaufort Sea (Figure 5.3). At present, the typical time of entry of vessels into the Beaufort Sea from the west past Point Barrow is late July, although mid-July is possible in very favorable ice years. Ships normally leave the Beaufort Sea by mid-October in response to the deteriorating ice conditions, worsening weather conditions, and reduced daylight hours (Figure 4.3, Figure 5.4). There has been a general trend toward increasing length in the shipping season in the Beaufort Sea between 1953 and 2005 (Figure 5.4).

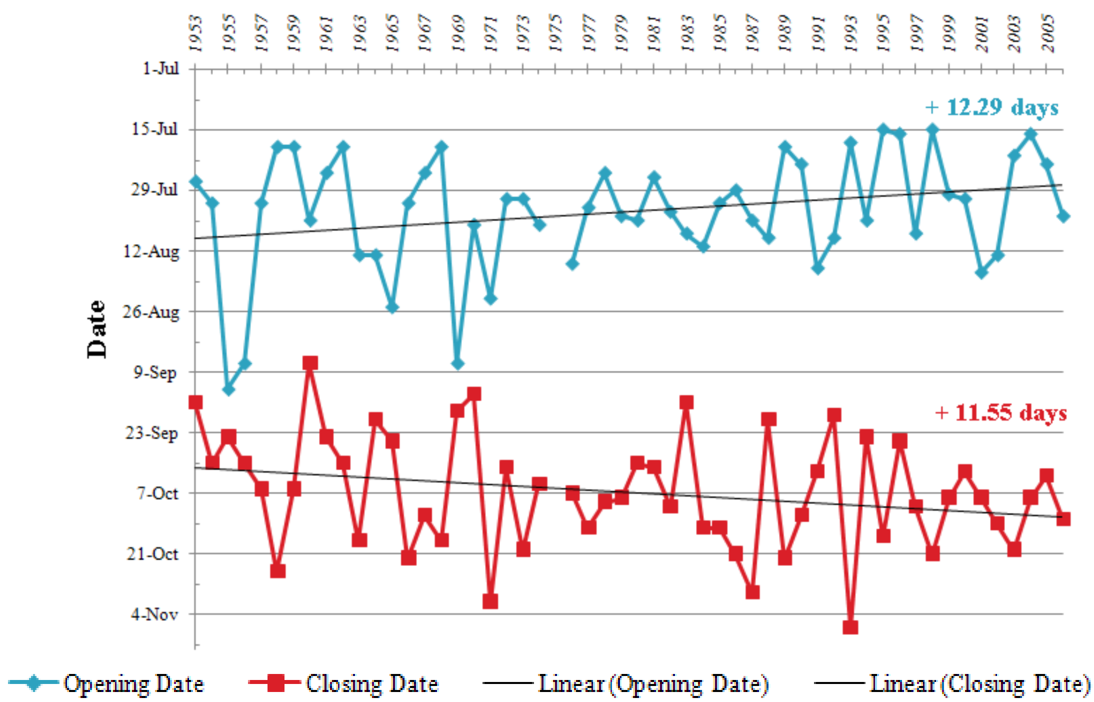

Figure 5.4. The opening and closing dates for shipping from Pt. Barrow to Prudhoe Bay, Alaska, as derived from a review of historical ice charts from 1953 to 2006 and a trend analysis (Todd Arbetter, 2008, National Ice Service).

Tugs, barges, and seismic vessels are typically not ballasted; a recent assessment of shipping activity found that none of the vessels visiting ports in the Beaufort Sea region between 2005 and 2008 were in ballast (Figure 5.5; Chan et al. 2012). The large cargo vessels that are planned for future shipments of resources out of the Beaufort Sea could enter in ballast, however, most of the vessels associated with the planned developments have yet to be built, and in all likelihood would be built after ratification of the International Maritime Organization (IMO) Ballast Water Convention, thus should have the required ballast water treatment facilities installed.

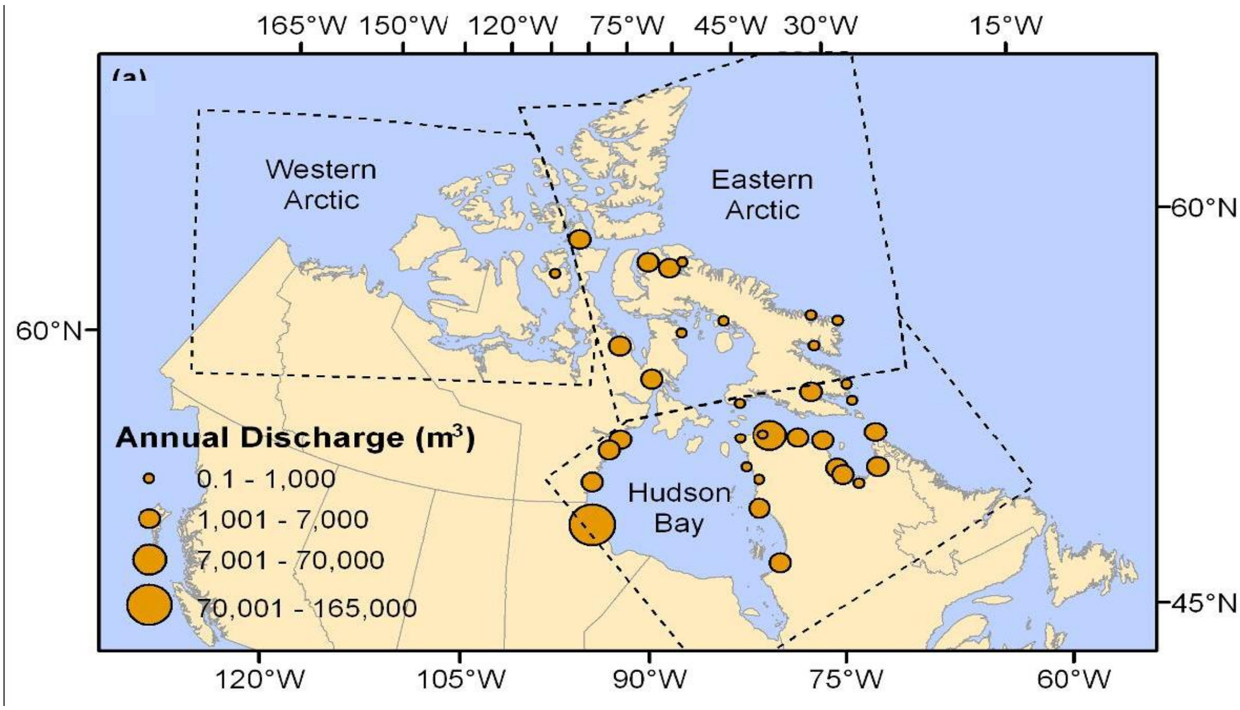

Figure 5.5. Map illustrating spatial patterns of annual ballast water discharges in the Canadian Arctic by Arctic regions: Hudson Bay, Eastern Arctic and Western Arctic (from Chan et al. 2012).

6. CONSIDERATION OF ALTERNATIVES TO BALLAST WATER EXCHANGE IN THE BEAUFORT SEA

Ideally, ballast water would be discharged far away from any ecologically sensitive species and habitats, in locations where water currents will keep the ballast water away from such species and habitats. To be realistic, however, a discharge strategy must identify one or more discharge locations (AWBEZ) that offer options for safe accessibility to ballasted vessels during the seasons associated with shipping activity in the region.

The principal impediments to accessibility are shallow water depths and ice coverage en route to the vessel's destination. In the areas of interest, the vessel draft for larger vessels that have ballast water systems dictate that the ship route is in water depths greater than ~10–15 m. This constraint results in ship routes that are at the outer edge of the landfast ice edge or farther offshore in the ice shear zone during the winter-spring season of heaviest ice conditions (Figure

4.1). Such a route would facilitate early (May–June) accessibility for vessels capable of navigating in the flaw lead that in most years is present just offshore from the deteriorating landfast ice. However, currently there is no shipping before late July because of difficulties in accessing the southeastern Beaufort Sea from the much more severe ice conditions off the western Alaskan Beaufort Sea at Point Barrow to the west and in the Northwest Passage to the east.

As the offshore pack ice retreats northward, clearance of the landfast ice by early July followed by slower clearing in coastal waters west of 141°W should allow, in ~4 out of 5 years, accessibility by ships to sites in the Canadian Beaufort Sea from the west by the beginning of August. Accessibility by ships from the east through the Northwest Passage is highly variable, with access as early as August in the most favourable ice conditions in the myriad of channels making up the Northwest Passage. Coverage by thin ice begins in all potential shipping zones by mid-October. If recent tendencies toward earlier clearance and later ice formation linked to persistent climate change persist, site accessibility might eventually be expected to extend somewhat outside the present August-early October time access window for shipping.

Even in summer, ice conditions in the present shipping corridors can quickly deteriorate as a result of episodic occurrences of sustained west and northwest winds. These west-northwesterly winds can dramatically narrow shipping corridors by pushing the offshore pack ice edge shoreward at rates of 10–15 km/day. Fortunately, such periods of reduction of the amount of open water in the shipping corridor are relatively predictable, allowing some accommodation through altered route planning. Given the effect of ice conditions on shipping corridors, operational times and locations of potential AWBEZ sites must be based not only on protecting the area from invasive species, but on the degree to which the sites offer ballast-water discharge options that are safe and convenient.

A basic strategy to minimize the survival of invasive species is to maximize the contrast between the characteristics of the ballast waters and the discharge-receiving water body. Thus, in the most obvious case, ballast taken on in warm brackish coastal regions at southern ports should be discharged in cold, saline, deep ocean waters. Alternatively, cold, high-salinity ballast water would favour disposals at sites in the warm, brackish waters of the Mackenzie River plume. Unfortunately, more ambiguous situations are also likely to arise in which choices among discharge alternatives are less obvious.

Avoiding potential adverse effects of exotic species on important species and ecological processes in the Beaufort Sea is possible by achieving adequate dilution of ballast water when discharged, and by selecting ballast exchange zones such that the discharges are kept away from sensitive and valued portions of the region. Given stratification of the water column typical of the summer Canadian Beaufort Sea in the worst case, discharges would be confined to the uppermost 5 m of the water column. Thus, a 190,000-m^3 discharge, the ballast capacity of an empty bulk carrier (Carlton 1992), would initially spread out to a radius of 110 m from the discharge point assuming no dilution. Simple dilutions to 1% and 0.01% of local water would require the spreading of this discharge out to radii of 1.1 and 11 km, respectively.

The spreading process is rarely omnidirectional and, in the case of the Canadian Beaufort Sea, would be highly dependent upon the largely wind-driven surface-current patterns. The directions of these patterns can be inferred from the schematic sketches of the intense and diffuse surface plumes associated with the most commonly occurring east/southeast and north/northwest regional wind fields (see Figure 4.13). For this assessment, the scales of the shorter term distributions were evaluated with a simple model based upon 15 years of wind data measured at Environment Canada's Pelly Island in eastern Mackenzie Bay. Computations of the cumulative displacement of the wind (based on vector summations of wind velocity/time interval products) were scaled downward to produce equivalent surface water displacement plots based on the long-standing approximation for Arctic waters that surface currents attributable to wind drift are 2–2.5% of the wind speed and the directions are 20–25º degrees to the right of the direction towards which the wind is blowing (Ekman 1905). Adjustments were made for the effects of regional surface currents (Figure 4.11), which reflect influences on water movement of driving forces other than the wind, such as local bathymetric steering and large scale current systems found at the shelf edge.

It was found that over periods of 1–4 days associated with shorter-term weather changes, surface water velocities averaged ~10 km/day and were up to 20 km/day. The most common directions of these flows were toward the southeast and northwest. Over month-long time intervals, net velocities were <2 km/day ~50 % of the time. Periods of sustained drift were also observed, such as in September 2007, when the computed monthly average surface velocity was slightly greater than 10 km/day. All these directions only apply to offshore waters. Translation into velocities appropriate for Mackenzie Bay and north of the Tuktoyaktuk Peninsula requires reference to the patterns depicted in Figure 4.13 whereby northwest winds drive currents to the southeast and east, and east winds drive currents to the southwest, west, and, close to shore in Mackenzie Bay, to the northwest. In general, net displacements of discharged ballast water tend to be on the order of a few tens of km over periods of a few weeks. During periods of sustained wind direction, which occur with approximately 10% probability, unidirectional displacement at typical velocities of ~10 km/d can be expected. Such intervals might be expected to be associated with lessened dilution and potential delivery of detectably modified water to sites many tens of km distant from the discharge area. In most cases, however, day-to-day variations in drift speed and direction would be expected, within our simple dilution model, to quickly (within a few days) distribute a given discharge over the approximately10 km^2 area required to achieve dilution to 0.01% levels.

7. UNCERTAINTIES, RESEARCH GAPS, AND FURTHER RECOMMENDED RESEARCH

There are a number of uncertainties and research gaps regarding the introduction of exotic species into the Beaufort Sea through exchange of ballast water. Although there is considerable knowledge about certain ecological aspects of the Beaufort Sea, information in other areas is lacking. For example, Beaufort Sea benthos is relatively poorly studied in comparison with other Canadian waters, as are marine fish outside of the Mackenzie Delta area, especially in deep, offshore waters. Cobb et al. (2008) discussed such data gaps.

Cobb et al. (2008) presented a general view of energy flow through various food chains. They state that a comprehensive, quantitative model of the Beaufort Sea food web is needed, including quantities for each trophic level and for each arrow between ecosystem components, such as those presented by Thomson (1987) and Welch et al. (1992) for other arctic areas. These kinds of exercises are very useful in identifying ecosystem components that are important, poorly understood, or require further investigation. For example, Welch et al. (1992) underestimated abundance of arctic cod in the Eastern NW Passage because their estimate could not support consumption by birds and marine mammals. Thomson (1987) found that primary and secondary productivity of the North Aleutian Shelf could not support the ecosystem that was dependent on it. Advection of excess productivity from the outer shelf found by (Walsh and McRoy 1986) made up the shortfall in nearshore productivity. Construction of a preliminary quantitative energy budget that includes what is known about plankton biomass and productivity and consumption by vertebrates would help focus research on important linkages and components.

The southeastern Beaufort Sea is a very dynamic environment. Geographic location may not be as important as meteorological and physical oceanographic regime in determining areas where high and low productivity or important processes and linkages occur. Some effort has been expended in identifying these, but a longer time-series of data is needed to refine the relationships.

Once important processes, linkages, and areas are identified, it would be possible to identify those that could be impacted by NIS and to design specific mitigation measures to protect them.

8. RECOMMENDATIONS FOR BALLAST WATER EXCHANGE IN THE BEAUFORT SEA

- Minimizing safety risks for transiting vessels requires that potential AWBEZ sites be located in water depths >20 m and in areas where sea ice concentrations are low or zero in most years.

- To avoid the risk of adverse ecological effects from non indigenous species, the discharge of ballast water should be avoided in ecologically significant areas. In the Canadian Beaufort Sea, such areas have been shown to have a large areal extent taking into account both the west-northwesterly and easterly wind drift of ocean waters as well as the important areas of episodic upwelling in Mackenzie Trough and over the outer shelf and slope regions of the Mackenzie Shelf and over the middle and inner portions of the Mackenzie Shelf due to the influence of the Mackenzie River plume and frontal features. The area of avoidance extends eastward from the longitude of Herschel Island (139°W) to the entrance to Amundsen Gulf (125°W) and from the coastline out to approximately the 1000-m water depth contour.

- Given the spatial constraints related to water depths and ecologically important areas, the potential locations of an ABWEZ becomes very limited, given the need to accommodate a linear ship track of 200–400 km long. Within these constraints, the waters to the west of Herschel Island at depths of 20–100 m along the route of most transiting vessels are incompatible with a potential AWBEZ because the distance from the Canada/US border is <100 km. Farther offshore at water depths 100–1000 m, starting from the Canada/US border there is an area that extends ~120 km in distance in a WSW to ENE orientation. However, travel farther to the east along this track is limited in early August by the presence of 4/10 or more ice concentration at a frequency of 1 in 4 years (Figure 8.1).

- In the eastern portions of the Canadian Beaufort Sea, sea ice concentrations in the areas offshore of the Mackenzie Shelf are much higher in most years (Figure 8.1) and there are no suitable locations for an AWBEZ measuring even 50 km in length.

- Note that by mid-September, the presence of ice concentrations of 4/10 or more is far offshore in water depths of 2000 m or more (in 3 years out of every 4; see Figure 8.2) in the western half of the Canadian Beaufort Sea, so a linear transit track extending well over 200 km becomes feasible. However, the timing of the clearing of sea ice well into September is well past the entry dates of most commercial shipping in August.

- Under present ice conditions combined with the water depths and ecologically sensitive area constraints, there are presently no feasible ABWEZ sites in the Canadian Beaufort Sea.

- In the event that future sea ice conditions are reduced and ice retreats farther offshore in early to mid-summer, an ABWEZ site from the Canada/US border east-northeastward in water depths of 1000 m or more north of the Mackenzie Trough would become possible. This area would be reasonably feasible for ships that may be travelling to the far offshore oil and gas license areas for which exploration is presently just getting underway, and for transit to McClure Strait north of Banks Island, which represents the deepwater northern route of the Northwest Passage through the Canadian Arctic Islands.

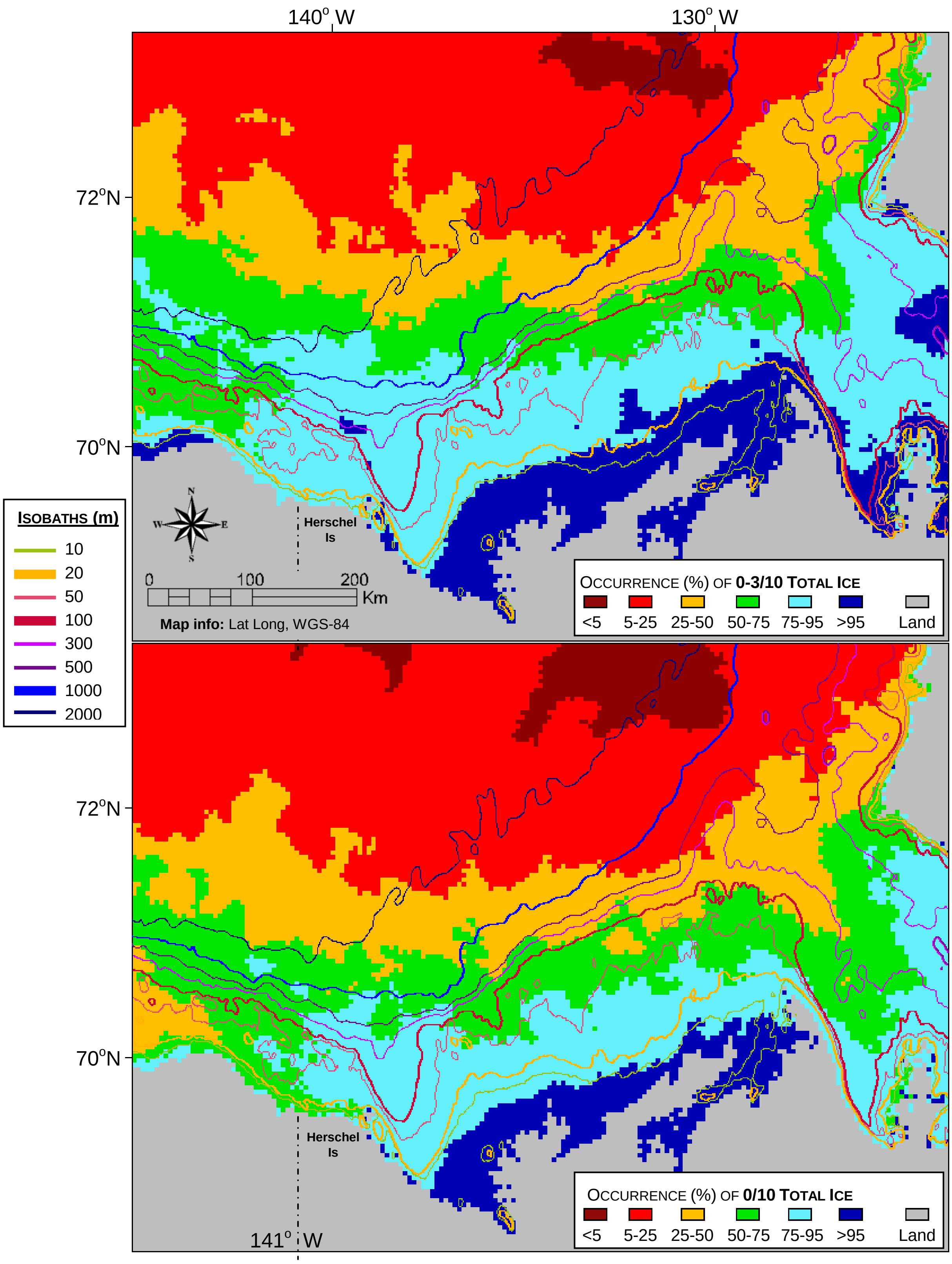

Figure 8.1. Frequency occurrence (%) of 0–3/10 total ice (top) and 0/10 total ice (bottom) in the Beaufort Sea during the second week of August 1992-2008.

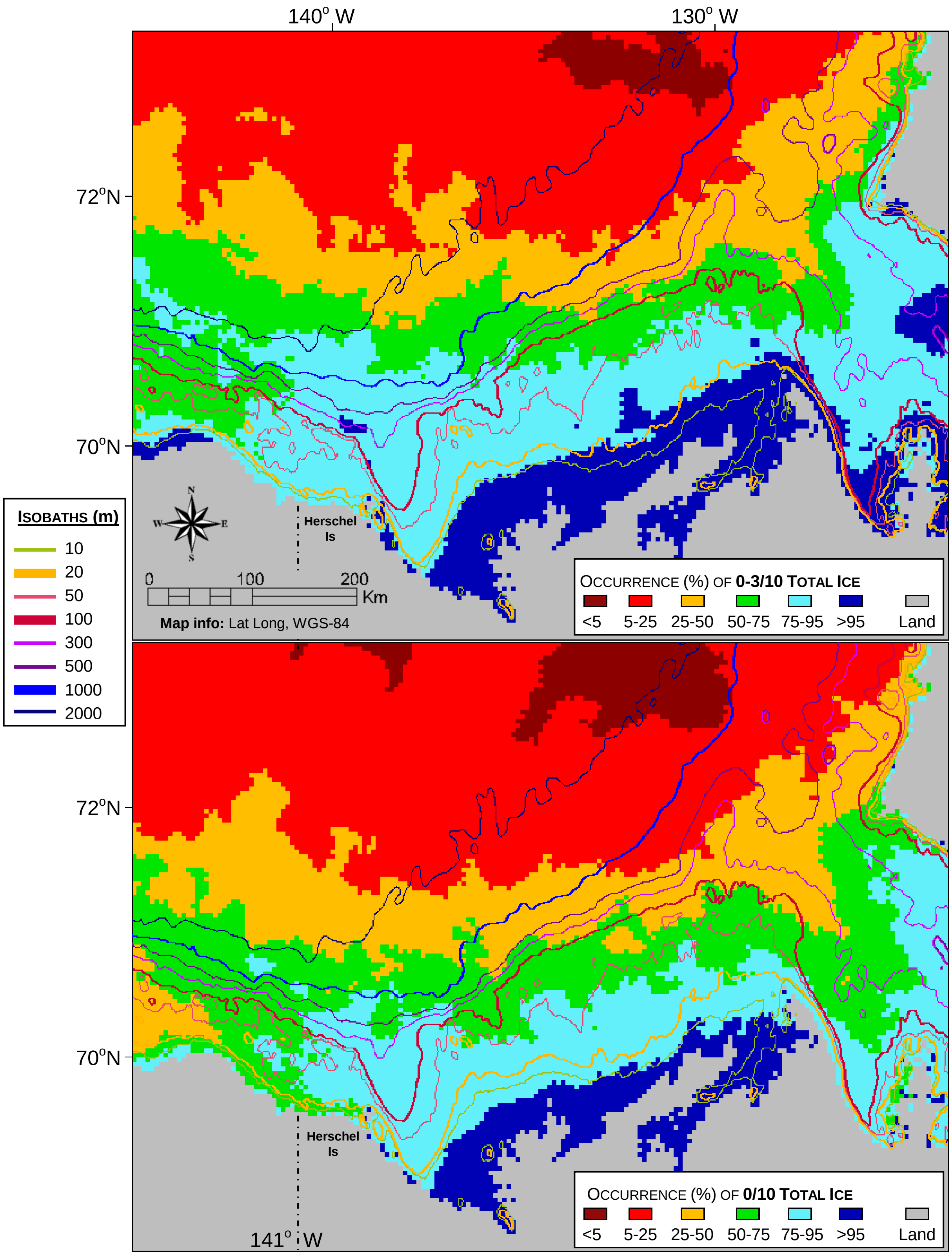

Figure 8.2. Frequency occurrence (%) of 0–3/10 total ice (top) and 0/10 total ice (bottom) in the Beaufort Sea during the second week of September 1992-2008.

LITERATURE CITED

Aagaard, K. 1984. The Beaufort undercurrent. *In* The Alaskan Beaufort Sea: ecosystems and environment. Edited by P. Barnes and E. Reimnitz. Academic Press, New York, NY. p. 47-71.

AICCP (Aklavik Inuvialuit Community Conservation Plan). 2008. A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Aklavik, Northwest Territories. Prepared by the Community of Aklavik, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 155 p. http://www.screeningcommittee.ca/pdf/ccp/Aklavik_CCP.pdf [accessed on Oct 19, 2012]

Alexander, S.A., Ealey, D.M., and Barry, S.J. 1988a. Spring migration of eiders, oldsquaws, and glaucous gulls along offshore leads of the Canadian Beaufort Sea. Tech. Rep. Ser. 56, Canadian Wildlife Service, Environment Canada, Edmonton, AB.

Alexander, S.A., Barry, T.W., Dickson, D.L., Prus, H.D., and Smyth, K.E. 1988b. Key areas for birds in coastal regions of the Canadian Beaufort Sea. Canadian Wildlife Service, Environment Canada, Edmonton, AB. vii + 146 p. [accessed on October 19, 2012]

Alexander, S.A., Westover, S.E., and Dickson, D.L. 1993. Spring migration of waterbirds in the Beaufort Sea, Amundsen Gulf, and Lambert Channel polynya, 1992. Tech. Rep. Ser. 171, Canadian Wildlife Service, Environment Canada, Edmonton, AB.

Alexander, S.A., Dickson, D.L., and Westover, S.E. 1997. Spring migration of eiders and other waterbirds in offshore areas of the western Arctic. *In* King and common eiders of the western Canadian Arctic. Edited by D.L. Dickson. Occ. Pap. 94. Canadian Wildlife Service, Environment Canada, Ottawa, ON. p. 6-20.

Amstrup, S.C. 1995. Movements, distribution and population dynamics of polar bears in the Beaufort Sea. PhD thesis, University of Alaska, Fairbanks, AK.

Amstrup, S.C. 2000. Polar bear. *In* The natural history of an Arctic oil field: development and biota. Edited by J.C. Truett and S.R. Johnson. Academic Press, San Diego, CA. p. 133-157.

Amstrup, S.C., Durner, G.M., Stirling, I., Lunn, N.J., and Messier, F. 2000. Movements and distribution of polar bears in the Beaufort Sea. Can. J. Zool. 78: 948-966.

Andriyashev, A.P. 1954. Fishes of the northern seas of the U.S.S.R. Keys to the fauna of the U.S.S.R. Zoological Institute of the U.S.S.R. Academy of Sciences No. 53. Translated from Russian by Israel Program for Scientific Translations 1964. 617 p.

Angliss, R.P. and R.B Outlaw. 2008. Alaska Marine Mammal Stock Assessments, 2007. NOAA Tech. Memo. NMFS-AFSC-180. 252 p. http://www.nmfs.noaa.gov/pr/pdfs/sars/ak2007.pdf [accessed October 19, 2012]

Arctic Marine Council. 2009. Arctic marine shipping assessment 2009 report. 194 p. http://www.pame.is/images/stories/AMSA_2009_Report/AMSA_2009_Report_2nd_print.pdf [accessed October 19, 2012]

Bain, L.H. 1975. Life histories and systematics of Arctic char, *Salvelinus alpinus* (Linnaeus) in the Babbage River system, Yukon Territory. Thesis (M.Sc.) University of Calgary, Calgary, AB. 162 p.

DFO 2007. The circumpolar flaw lead system study. 2 p. http://www.ipy-api.gc.ca/_docs/cfl_e.pdf [accessed on November 7, 2012]

Bax, N., Carlton, J.T., Mathews-Amos, A., Haedrich, R.L., Howarth, F.G., Purcell, J.E., Rieser, A., and Gray, A. 2001. The control of biological invasions in the world's oceans. Conserv. Biol. 15: 1234-1246.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., and Geeves, W. 2003. Marine invasive alien species: a threat to global biodiversity. Conserv. Biol. 27: 313-323.

Belkin, I.M. and Cornillon, P.C. 2007. Fronts in the world ocean's large Marine ecosystems. ICES CM 2007/D:21. 33 p. http://www.ices.dk/products/CMdocs/CM-2007/D/D2107.pdf [accessed Oct 19, 2012]

Belkin, I.M., Cornillon, P., and Ullman, D. 2003. Ocean fronts around Alaska from satellite SST data. *In* Seventh Conference on Polar Meteorology and Oceanography and Joint Symposium on High-Latitude Climate Variations, Hyannis, MA. American Meteorological Society, Boston, MA. 15p.

Bluhm, B.A., Coyle, K.O., Konar, B., and Highsmith, R. 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. Deep-Sea Research II 54 (23-26): 2919-2933.

Bond, W.A. 1982. A study of the fishery resources of Tuktoyaktuk Harbour, southern Beaufort Sea coast, with special references to life histories of anadromous coregonids. Can. Tech. Rep. Fish. Aquat. Sci. 1119: vii + 90 p. http://www.dfo-mpo.gc.ca/Library/24486.pdf [accessed October 19, 2012]

Bond, W.A. and Erickson, R.N. 1989. Summer studies of the nearshore fish community at Phillips Bay, Beaufort Sea coast, Yukon. Can. Tech. Rep. Fish. Aquat. Sci. 1676: vi + 102 p. http://www.dfo-mpo.gc.ca/Library/110294.pdf [accessed October 19, 2012]

Bond, W.A. and Erickson, R.N. 1991. Fishery data from the Anderson River estuary, Northwest Territories, 1989. Can. Data Rep. Fish. Aquat. Sci. 849: vi +59 p. http://www.dfo-mpo.gc.ca/Library/123690.pdf [accessed October 19, 2012]

Bond, W.A. and Erickson, R.N. 1992. Fishery data from the Anderson River estuary, Northwest Territories, 1990. Can. Man. Rep. Fish. Aquat. Sci. 2171: vi + 46 p. http://www.dfo-mpo.gc.ca/Library/143394.pdf [accessed October 19, 2012]

Bond, W.A., and Erickson, R.N. 1993. Fisheries investigations in coastal waters of Liverpool Bay, Northwest Territories. Can. Man. Rep. Fish. Aquat. Sci. 2204: vi + 51 p. http://www.dfo-mpo.gc.ca/Library/148743.pdf [accessed October 19, 2012]

Born, E.W., Wiig, Ø., and Thomassen, J. 1997. Seasonal and annual movements of radio-collared polar bears (*Ursus maritimus*) in northeast Greenland. J. Mar. Systems (1-4): 67-77.

Bradstreet, M.S.W. and Fissel, D.B. 1987. Zooplankton of a bowhead whale feeding area off the Yukon Coast in August 1985. *In* Bowhead whale food availability characteristics in the southern Beaufort Sea: 1985 and 1986. Edited by M.S.W. Bradstreet, D.H Thomson, D.B. Fissel, Northern Affairs Program (Canada), L.G.L. Limited, and Environmental Research Associates. Department of Indian Affairs and Northern Development, Canada, Ottawa, ON. Environ. Stud. 50. 155 p. [available in the DFO library]

Bradstreet, M.S.W., Finley, K.J, Sekerak, A.D., Griffiths, W.B., Fabijan, M.F., Evans, C.R., and Stallard, H.E. 1986. Aspects of the biology of Arctic cod (*Boreogadus saida*) in Arctic marine food chains. Can. Tech. Rep. Fish. Aquat. Sci. 1491: viii + 193 p. http://www.dfo-mpo.gc.ca/Library/36638.pdf [accessed October 19, 2012]

Bradstreet, M.S.W., Thomson, D.H., and Fissel, D.B. 1987. Zooplankton and bowhead whale feeding in the Canadian Beaufort Sea, 1986. *In* Bowhead whale food availability characteristics in the southern Beaufort Sea: 1985 and 1986. Edited by M.S.W. Bradstreet, D.H Thomson, D.B. Fissel, Northern Affairs Program (Canada), L.G.L. Limited, and Environmental Research Associates. Department of Indian Affairs and Northern Development, Canada, Ottawa, ON. Environ. Stud. 50. 155 p. [available in the DFO library]

Braham, H.W., Krogman, B.D., and Carroll, G.M. 1984. Bowhead and white whale migration, distribution and abundance in the Bering, Chukchi, and Beaufort seas, 1975–78. NOAA Tech. Rep. NMFS SSRF-778. NTIS PB84-157908. 39 p. [available in the DFO library]

Broad, A.C., Benedict, A., Dunton, K., Koch, H., Mason, D.T., Schneider, D.E. Schonberg, S.V. 1979. Environmental assessment of selected habitats in the Beaufort and Chukchi littoral system. *In* Envir. Assess. Alaskan Cont. Shelf, Ann. Rep., March 1979, Vol. 3., BLM/NOAA, Outer Continental Shelf Environmental Assessment Program, Boulder, CO. pp. 361-542. http://www.arlis.org/docs/vol1/OCSEAP2/Annual/5721406/A1979%20V03.pdf#page=367 [accessed November 7, 2012]

Burns, J.J. 1981. Bearded seal (*Erignathus barbatus*, Erxleben, 1777). *In* Handbook of marine mammals, Vol.2: Seals. Edited by S.H. Ridgway and R.J Harrison. Academic Press, London, UK. p. 145-170.

Burns, J.J. and Frost, K.J. 1979. Natural history and ecology of the bearded seal, *Erignathus barbatus*. U.S. Dep. Commer., BLM/NOAA, Outer Continental Shelf Environmental Assessment Program. Final Rep. 19: 311-392. http://www.arlis.org/docs/vol1/OCSEAP2/Final/6515301/F%20v19.pdf#page=321 [accessed November 7, 2012]

Butler, R.G. and D.E. Buckley. 2002. Black guillemot (*Cepphus grylle*), No. 675. *In* The birds of North America. Edited by A. Poole and F. Gill. The Birds of North America, Inc., Philadelphia, PA.

Byers, S.C. and Kashino, R.K. 1980. Survey of fish populations in Kugmallit Bay and Tuktoyaktuk Harbour, N.W.T. Rep. by Dobrocky Seatech Limited for Dome Petroleum Limited, Calgary, AB. vii + 77 p. [available in the DFO library]

Canada Gazette II. 25 August 2010. Tarium Niryutait Marine Protected Areas Regulations. SOR/2010-190 vol. 144, no. 19. http://www.gazette.gc.ca/rp-pr/p2/2010/2010-09-15/html/sor-dors190-eng.html. [accessed November 9, 2012]

Carey, A.G. Jr. 1978. The distribution, abundance, diversity and productivity of the western Beaufort Sea benthos. *In* Environ. Assess. Alaskan Cont. Shelf. Ann. Rep. Prin. Invest., March 1978, Vol. 4. BLM/NOAA, OCSEAP, Boulder, CO. p. 127-252.

Carey, A.G. Jr., Ruff, R.E., Castillo, J.G., and Dickinson, J.J. 1974. Benthic ecology of the western Beaufort Sea continental margin: preliminary results. *In* The coast and shelf of the Beaufort Sea. Edited by J.C. Reed and J.E. Sater. Arctic Institute of North America, Arlington, VA. p. 665-680.

Carey, A.G. Jr., Scott, P.H., and Walters, K.R. 1984. Distributional ecology of shallow southwestern Beaufort Sea (Arctic Ocean) bivalve Mollusca. Mar. Ecol. Prog. Ser. 17: 125-134.

Carlton, J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Ocean. Mar. Biol. Annu. Rev. 23: 313-371.

Carlton, J.T. 1992. Marine species introductions by ship's ballast water: an overview. *In* Introductions and transfers of marine species. Edited by M.R. DeVoe. Proceedings of the conference and workshop, 30 October–2 November, 1991. Hilton Head Island, SC. p. 23-26.

Carlton, J.T. 1996. Biological invasions and cryptogenic species. Ecology 77: 1653-1655.

Carlton, J.T. and Geller, J.B. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261: 78-82.

Carlton, J.T., Reid, D.M., and van Leeuwen, H. 1995. Shipping study. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options: final report. The National Sea Grant College Program/Connecticut Sea Grant Project R/ES-6. U.S. Department of Transportation• United States Coast Guard• Washington• DC and Groton, Connecticut. Report CG-D-11-95. Government Accession Number ADA294809, 213 p. and Appendices A-I (122 pages). [available in the DFO library]

Carmack, E.C., McLaughlin, F., Vagle, S. and Melling, H. 2008. Canada's Three Oceans (C3O): A Canadian contribution to the International Polar Year. PICES Press 16(2): 22-25. https://www.pices.int/publications/pices_press/volume16/v16_n2/pp_22-25_Arctic_f.pdf [accessed November 7, 2012]

Carmack, E. and Kulikov, Y. 1998. Wind-forced upwelling and internal Kelvin wave generation in Mackenzie Canyon, Beaufort Sea. J. Geophys. Res. 103: 18,447-18,458.

Carmack, E.C. and Macdonald, R.W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: a setting for marine life. Arctic 55(Suppl. 1): 29-45.

Chan, F.T., J.E. Bronnenhuber, J.N. Bradie, K.L Howland, N. Simard and S.A. Bailey. 2012. Risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/105. vi + 93 p.

Clarke, J.T., Moore, S.E., and Ljungblad, D.K. 1989. Observations on gray whale (*Eschrichtius robustus*) utilization patterns in the northeastern Chukchi Sea, July-October 1982-1987. Can. J. Zool. 67: 2646-2654.

Clarke, J.T., Moore, S.E., and Johnson, M.M. 1993. Observations on beluga fall migration in the Alaskan Beaufort Sea, 1982-87, and northeastern Chukchi Sea, 1982-91. Rep. Int. Whal. Comm. 43: 387-396.

Claudi, R., Nantel, P., and Muckle-Jeffs, E. (eds.). 2002. Alien invaders in Canada's waters, wetlands, and forests. Natural Resources Canada, Canadian Forest Service, Science Branch, Ottawa, Ont. 320 p.

Cleator, H.J. and Stirling, I. 1990. Winter distribution of bearded seals (*Erignathus barbatus*) in the Penny Strait area, Northwest Territories, as determined by underwater vocalizations. Can. J. Fish. Aquat. Sci. 47: 1071-1076.

Cobb, D., Fast, H., Papst, M.H., Rosenberg, D., Rutherford, R., and Sareault, J.E. 2008. Beaufort Sea large ocean management area: ecosystem overview and assessment report. Can. Tech. Rep. Fish. Aquat. Sci. 2780: xi + 188 p. http://www.dfo-mpo.gc.ca/Library/331896.pdf [accessed October 19, 2012]

Cohen, N.J., Slaten, D.D., Marano, N., Tappero, J.W., Wellman, M., Albert, R.J., Hill, V.R., Espey, D., Handzel, T., Henry, A., and Tauxe, R.V. 2012. Preventing Maritime transfer of toxigenic Vibrio cholera. Emerging Infectious Diseases 18: 1680-1682.

COSEWIC 2004. COSEWIC assessment and update status report on the beluga whale *Delphinapterus leucas* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 70 p. [accessed November 8, 2012]

Craig, P.C. 1977a. Ecological studies of amphidromous and resident populations of Arctic char in the Canning River drainage and adjacent coastal waters of the Beaufort Sea, Alaska. Chap. 1 *In* Studies of fisheries investigations along the North Slope and Beaufort Sea coast in Alaska with emphasis on Arctic char. Edited by P. McCart. Arctic Gas Biological Report Series, Volume 41. Rep. by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 173 p.

Craig, P.C. 1977b. Arctic char in Sadlerochit Spring, Arctic National Wildlife Refuge. Chap. 2 *In* Studies of fisheries investigations along the North Slope and Beaufort Sea coast in Alaska with emphasis on Arctic char. Edited by P. McCart. Arctic Gas Biological Report Series, Volume 41. Rep. by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 173 p.

Craig, P.C. 1977c. Fisheries research in the Shaviovik Drainage, Alaska, with emphasis on Arctic char in the Kavik River. Chap. 3 *In* Studies of fisheries investigations along the North Slope and Beaufort Sea coast in Alaska with emphasis on Arctic char. Edited by P. McCart. Arctic Gas Biological Report Series, Volume 41. Rep. by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 173 p.

Craig, P.C. 1984. Fish use of coastal waters of the Beaufort Sea: a review. Trans. Amer. Fish. Soc. 113: 265-282.

Craig, P.C. 1989a. An introduction to amphidromous fishes in the Alaskan Arctic. Biol. Pap. Univ. Alaska 24: 27-54.

Craig, P.C. 1989b. Subsistence fisheries at coastal villages in the Alaskan Arctic, 1970–1986. Biol. Pap. Univ. Alaska 24:131-152.

Craig, P.C. and Haldorson, L. 1981. Beaufort Sea barrier island-lagoon ecological process studies: Final report, Simpson Lagoon. Part 4, fish. *In* Environmental Assessment of the Alaskan Continental Shelf. Bureau of Land Management and National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Final Report, Vol. 7. p. 384-678.

Craig, P.C. and McCart, P. 1974. Fall spawning and overwintering areas of fish populations along routes of proposed pipeline between Prudhoe Bay, Alaska, and the Mackenzie Delta. Chap.3 *In* Fisheries research associated with proposed gas pipeline routes in Alaska, Yukon and Northwest Territories. Edited by P. McCart. Arctic Gas Biological Report Series, Volume 15. Rep. by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 450 p.

Craig, P.C. and McCart. P. 1975. Classification of stream types in Beaufort Sea drainages between Prudhoe Bay, Alaska, and the Mackenzie Delta, N.W.T. Arctic Alpine Res. 7: 183-198.

Craig, P.C., Griffiths, W.B., Johnson, S.R., and Schell, D.M. 1984. Trophic dynamics in an Arctic lagoon. *In* The Alaskan Beaufort Sea: ecosystems and environments. Edited by P.W. Barnes, D.M. Schell, and E. Reimnitz. Academic Press Inc., New York, NY. p. 347-401.

Cubbage, J.C. and Calambokidis, J. 1987. Size-class segregation of bowhead whales discerned through aerial stereophotogrammetry. Mar. Mamm. Sci. 3: 179-185.

Curtis, M.A. 1975. The marine benthos of arctic and sub-arctic continental shelves. Polar Record 17: 595-626.

Davis, R.A. and Evans ,C.R. 1982. Offshore distribution and numbers of white whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. by LGL Ltd., Toronto, Ont., for Sohio Alaska Petrol. Co., Anchorage, AK, and Dome Petroleum Limited, Calgary, AB. Xii + 75 p. [available in the DFO library]

Davis, R.A., Finley, K.J., and Richardson ,W.J. 1980. The present status and future management of Arctic marine mammals. Science Advisory Board of the Northwest Territories Report No. 3. Department of Information, Government of the Northwest Territories, Yellowknife, NWT. 93 p. [available in the DFO library]

Davis, R.A., Koski, W.R., Richardson, W.J., Evans, C.R., and Alliston, W.G. 1982. Distribution, numbers and productivity of the Western Arctic Stock of bowhead whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. by LGL Ltd., Toronto, Ont., for Sohio Alaska Petrol. Co., Anchorage, AK, and Dome Petroleum Limited, Calgary, AB. xii + 134 p. [available in the DFO library]

DeMaster, D.P. and Stirling, I. 1981. *Ursus maritimus*. Mamm. Species 145: 1-7.

DFO. 2004. Identification of ecologically and biologically significant areas. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2004/006.

DFO. 2011. Identification of Ecologically and Biologically Significant Areas (EBSA) in the Canadian Arctic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/055.

Dickson, D.L. and Gilchrist, H.G. 2002. Status of marine birds of the southeastern Beaufort Sea. Arctic 55(Suppl. 1): 46-58.

Dickson, D.L., Cotter, R.C., Hines, J.E., and Kay, M.F. 1997. Distribution and abundance of king eiders in the western Canadian Arctic. *In* King and common eiders of the western Canadian Arctic. Edited by D.L. Dickson. Occ. Pap. 94. Canadian Wildlife Service, Environment Canada, Ottawa, Ont. p. 29-39.

Divoky, G. and Good, A.E. 1978. The distribution, abundance, and feeding ecology of birds associated with pack ice. *In* Envir. Assess. Alaskan Cont. Shelf, Annu. Rep., March 1978. Vol. 2. BLM/NOAA, Outer Continental Shelf Environmental Assessment Program, Boulder, CO. pp.167-509. http://www.arlis.org/docs/vol1/OCSEAP2/Annual/5721406/A1979%20V01.pdf#page=338 [accessed November 7, 2012]

Doblin, M.A., Popels, L.C., Coyne, K.J., Hutchins, D.A., Cary, S.C., and Dobbs, F.C. 2004. Transport of the harmful bloom alga *Aureococcus anophagefferens* by oceangoing ships and coastal boats. Appl. Environ. Microbiol. 70(11): 6495-6500.

Dome (Dome Petroleum Limited, Esso Resources Canada Limited, and Gulf Canada Resources Inc.). 1982. Environmental impact statement. Hydrocarbon development in the Beaufort Sea-Mackenzie Delta Region. Volume 3A: Beaufort Sea-Delta Setting. Prepared for Landholders in the Beaufort Sea–Mackenzie Delta Region.

Drake, L.A., Ruiz, G.M., Galil, B.S., Mullady, T.L., Friedmann, D.O., and Dobbs, F.C. 2002. Microbial ecology of ballast water during a transoceanic voyage and the effects of open-ocean exchange. Mar. Ecol. Prog. Ser. 233: 13-20.

Drake, L.A., Doblin, M.A. and Dobbs, F.C. 2007. Potential microbial bioinvasions via ships' ballast water, sediment, and biofilm. Mar. Pollut. Bull. 55: 333-341.

Dunton, K.H., Weingartner, T., and Carmack, E.C. 2006. The nearshore western Beaufort Sea ecosystem: Circulation and importance of terrestrial carbon in Arctic coastal food webs. Progr. Oceanogr. 71: 362–378.

Eckert, C.D., Cooley, D., and Gordon, R.R. 2006. Monitoring black guillemot population and nesting success at Herschel Island, Yukon Territory - 2005. Yukon Department of Environment, Whitehorse, YK.Tech. Rep. Ser. TR-06-01. 15 p. [accessed October 19, 2012]

Ekman, V.W. 1905. On the influence of the earth's rotation on ocean currents. Ark. Mat. Astron. Fys. 2: 1-53.

Everett, R.J., Wilmot, R.L., and Krueger, C.C. 1997. Population genetic structure of Dolly Varden from Beaufort Sea drainages of northern Alaska and Canada. Amer. Fish. Soc. Symp. 19: 240-249.

Fechhelm, R.G., Wilson, W.J., Haley, B.E., and Griffiths, W.B. 2000. The 1999 Point Thomson fish study. Rep. by LGL Alaska Research Associates, Inc., Anchorage, AK, for BP Exploration (Alaska) Inc., Anchorage, AK, and Point Thomson Unit Owners. iv + 71 p. http://www.arlis.org/docs/vol2/point_thomson/1057/1057A_1999%20pt%20thomson%20fish%20study%20may%2031%202000.pdf [accessed Oct 19, 2012]

Finley, K.J. and Evans, C.R. 1983. Summer diet of the bearded seal (*Erignathus barbatus*) in the Canadian High Arctic. Arctic 36: 82-89.

Finley, K.J., Hickie, J.P, and Davis, R.A. 1987. Status of the beluga (*Delphinapterus leucas*) in the Beaufort Sea. Can. Field-Nat. 101: 271–278.

Fischer, J.B. and Larned ,W.L. 2004. Summer distribution of marine birds in the western Beaufort Sea. Arctic 57: 143-159.

FJMC (Fisheries Joint Management Committee). 2001. Beaufort Sea beluga management plan. Inuvik, NWT. http://fishfp.sasktelwebhosting.com/publications/Beluga%20Management%20Plan%20(%202001)as%20printed%20with%20covers.pdf [accessed Oct 19, 2012]

Flint, M.V., Sukhanova, I.N., Kopylov, A.I., Poyarkov, S.G., and Whitledge, T.E. 2002. Plankton distribution associated with frontal zones in the vicinity of the Pribilof Islands. Deep Sea Research Part II 49: 6069-6093.

Fortier, L. Barber, D. and Michaud, J. 2008. On thin ice: a synthesis of the Canadian Arctic Shelf Exchange Study (CASES). Aboriginal Issues Press, Winnipeg, Manitoba, Canada. 215 p.

Fraker, M.A. 1977. The 1976 white whale monitoring program, Mackenzie River estuary, N.W.T. Rep. by F.F. Slaney and Co. Ltd., Vancouver, B.C., for Esso Resources Canada Ltd., Calgary, AB. [available in the DFO library]

Fraker, M.A. 1979. Spring migration of bowhead (*Balaena mysticetus*) and white whale (*Delphinapterus leucas*) in the Beaufort Sea. Fish. Mar. Serv. Tech. Rep. 859. vi + 36 p. . [available in the DFO library]

Fraker, M.A. and Bockstoce, J.R. 1980. Summer distribution of bowhead whales in the eastern Beaufort Sea. Mar. Fish. Rev. 42(9-10): 57-64.

Fraker, P.N. and Fraker, M.A. 1982. The 1981 white whale monitoring program, Mackenzie River estuary. Rep. by LGL Ltd., Sidney, B.C., for Esso Resources Canada Ltd., Calgary, AB. 74 p. [available in the DFO library]

Fraker, M.A., Sergeant, D.E., and Hoek, W. 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Project, Tech. Rep. 4. Sidney, BC. http://www.dfo-mpo.gc.ca/Library/49579.pdf [accessed Oct 19, 2012]

Frost, K.J. and Lowry, L.F. 1983. Demersal fishes and invertebrates trawled in the northeastern Chukchi Sea and Western Beaufort seas, 1976–1977. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Tech. Rep. NMFS SSRF-764. 22 p. [available from the DFO library]

Galbraith, D.F. and Hunter, J.G. 1975. Fishes of offshore waters and Tuktoyaktuk vicinity. Fisheries and Marine Service, Environment Canada. Beaufort Sea Tech. Rep. 7. 47 p. http://www.dfo-mpo.gc.ca/Library/317290.pdf [accessed October 19, 2012]

Gallaway, B.J., Griffiths, W.B., Craig, P.C., Gazey, W.J., and Helmericks, J.W. 1983. An assessment of the Colville River delta stock of Arctic cisco–migrants from Canada? Biol. Pap. Univ. Alaska 21: 4-23.

Geist, O.W., Buckley, J.L., and Manville, R.H. 1960. Alaskan records of the narwhal. J. Mamm. 41: 250-253.

Gentleman, R. and Zeh ,J.E. 1987. A statistical model for estimating the number of bowhead whales, *Balaena mysticetus*, passing a census point from combined visual and acoustic data. Rep. Int. Whal. Comm. 45: 313-327.

George, J.C., Zeh, J., Suydam, R., and Clark, C. 2004. Abundance and population trend (1978–2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. Mar. Mamm. Sci. 20: 755-773.

Gillespie, J.A., Smith, R.L., Barboue, E., and Barber, W.E. 1997. Distribution, abundance, and growth of Arctic cod in the northeastern Chukchi Sea. Amer. Fish. Soc. Symp. 19: 81-89.

Gollasch, S. 2006. Overview on introduced aquatic species in European navigational and adjacent waters. Helgol. Mar. Res. 60(2): 84-89.

Gotthardt, T. 2001. Status report on the red-throated loon (*Gavia stellata*). Report for the U.S. Fish and Wildlife Service, Ecological Services. Alaska Natural Heritage Program, Environment and Natural Resources Institute, University of Alaska at Anchorage, Anchorage, AK. 142 p.

Griffiths, W.B. and Dillinger, R.E. 1981. Beaufort Sea barrier island-lagoon ecological process studies: Final report, Simpson Lagoon. Part 5, Invertebrates. *In* Environ. Assess. Alaskan Cont. Shelf, Final Rep. Prin. Invest., Vol. 8, Biol. studies. BLM/NOAA, OCSEAP, Boulder, CO. p. 1-198. http://www.arlis.org/docs/vol1/OCSEAP2/Biological/8498344/FB%20v08.pdf#page=9 [accessed November 7, 2012]

Griffiths, W.B., Craig, P.C., Walder, G.L., and Mann, G.J. 1975. Fisheries investigations in the coastal region of the Beaufort Sea (Nunaluk Lagoon, N.W.T.). Chap.2 (219 p.) *In* Fisheries investigations in a coastal region of the Beaufort Sea. Edited by P.J. McCart. Arctic Gas Biological Report Series, Vol. 34. Rep. by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 420 p. [available in the DFO library]

Griffiths, W.B, DenBeste, J.J., and Craig, P.C. 1977. Fisheries investigations in a coastal region of the Beaufort Sea (Kaktovik Lagoon, Alaska). Arctic Gas Biol. Rep. Ser. 40(2). 190 p.

Griffiths, W.B., Gallaway, B.J., Gazey, W.J. and Dillinger R.E. 1992. Growth and condition of Arctic Cisco and Broad Whitefish as indicators of causeway-induced effects in the Prudhoe Bay region, Alaska. Trans. Am. Fish. Soc. 121: 557-577.

Grosholz, E.D. and Ruiz, G.M. 1996. Predicting the impact of introduced marine species: Lessons from the multiple invasions of the European green crab *Carcinus maenas*. Biol. Conserv. 78: 59-66.

Gubanova, A. and Altukhov, D. 2007. Establishment of *Oithona brevicornis* Giesbrecht, 1892 (Copepoda: Cyclopoida) in the Black Sea. Aquat. Invasions 2(4): 407-410.

Harwood, L.A. and Stirling, I. 1992. Distribution of ringed seals in the southeastern Beaufort Sea during late summer. Can. J. Zool. 70: 891-900.

Harwood, L.A., Norton, P., Day, B. and Hall, P.A. 2002. The harvest of beluga whales in Canada's Western Arctic: hunter-based monitoring of the size and composition of the catch. Arctic 55: 10-20.

Hazard, K. 1988. Beluga whale (*Delphinapterus leucas*). In Selected marine mammals of Alaska: species accounts with research and management recommendations. Edited by J.W. Lentfer . Marine Mammal Commission, Washington, DC. NTIS PB88-178462. p. 195-235

Heath, W.A. and D.J. Thomas. 1984. The impact of gravel dredging on benthos near Banks Island, Northwest Territories, 1981 and 1983. Rep. by Arctic Laboratories Limited for Dome Petroleum Limited and Gulf Canada Resources Inc. 54 p + appendices. [available in the DFO library]

Hobson, K.A. and H.E Welch. 1992. Determination of trophic relationships within a high-Arctic marine food web using $\delta^{13}C$ and $\delta^{15}N$ analysis. Mar. Ecol. Progr. Ser. 84: 9-18.

Hop, H., H.E. Welch, and R.E. Crawford. 1997. Population structure and feeding ecology of Arctic cod schools in the Canadian high Arctic. Amer. Fish. Soc. Symp. 19: 68-80.

IICCP (Inuvik Inuvialuit Community Conservation Plan). 2008. A plan to provide guidance regarding the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Inuvik, Northwest Territories. Prepared by the Community of Inuvik, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 150 p. http://www.eirb.ca/pdf/ccp/Inuvik_CCP.pdf [Accessed October 19, 2012]

Johnson, S.R. 2000a. Lesser snow goose. In The natural history of an Arctic oil field: development and the biota. Edited by J.C. Truett and S.R. Johnson. Academic Press, San Diego, CA. p. 233-257.

Johnson, S.R. 2000b. Pacific eider. *In* The natural history of an Arctic oil field: development and the biota. Edited by J.C. Truett and S.R. Johnson. Academic Press, San Diego, CA. p. 259-275.

Johnson, S.R. and Herter, D.R. 1989. The birds of the Beaufort Sea. BP Exploration (Alaska) Inc., Anchorage, AK. 372 p.

Johnson, S.R. and Richardson, W.J. 1981. Barrier island-lagoon ecological process studies: final report, Simpson Lagoon. Part 3, birds. *In* Environmental Assessment of the Alaskan Continental Shelf, Final Report of Principal Investigators Vol. 7. Bureau of Land Management/National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program (BLM/ NOAA-OCSEAP), Boulder, CO.

Johnson, S.R. and Richardson ,W.J. 1982. Waterbird migration near the Yukon and Alaskan coast of the Beaufort Sea. II. Moult migration of seaducks. Arctic 35: 291-301.

Johnson, S.R., and Ward, J.G. 1985. Observations of thick-billed murres (*Uria lomvia*) and other seabirds at Cape Parry, Amundsen Gulf, N.W.T. Arctic 38: 112-115.

Johnson, S.R., Noel, L.E., Gazey, W.J., and Hawkes, V.C. 2005. Aerial monitoring of marine waterfowl in the Alaskan Beaufort Sea. Environ. Monit. Assess. 108: 1-43.

Joint Secretariat. 2003. Inuvialuit harvest study data and methods report 1988–December 1997. 202 p. http://www.jointsecretariat.ca/pdf/js/IHS10yrDataMethodsReport.pdf [accessed November 7, 2012]

Judson, B. 2010. Trends in Canadian Arctic shipping traffic – myths and rumors. *In* Proceedings of the 20th International Offshore and Polar Engineering Conference. Edited by J.S. Chung, A. Raghaven, S. Prinsenerg, S. Won Hong, and I. Langen. Volume I. p. 1292-1299.

Kendel, R.E., Johnson, R.A.C., Lobsinger, U., and Kozak, M.D. 1975. Movements, distribution, populations, and food habits of fish in the coastal Beaufort Sea. Beaufort Sea Project Tech. Rep. No. 6. Dept. of the Environment, Victoria, B.C. 114 p.

Kingsley, M.S.C. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980–82. Can. J. Fish. Aquat. Sci. 42: 1189-1210.

Kingsley, M.S.C. 1986. Distribution and abundance of seals in the Beaufort Sea, Amundsen Gulf, and Prince Albert Sound, 1984. Environmental Studies Revolving Funds, Rep. 25. Ottawa, ON. [available in the DFO library]

Kingsley, M.S.C. 1990. Status of ringed seal, *Phoca hispida*, in Canada. Can. Field Nat. 104: 138-145.

Koski, W.R., Miller, G.W., and Davis ,R.A. 1988. The potential effects of tanker traffic on the bowhead whale in the Beaufort Sea. Environ. Stud. 58. Rep. by LGL Ltd., King City, Ont., for Indian Affairs and Northern Development, Hull, Que. NTIS MIC-90-04552. [available in the DFO library]

Koski, W.R., Zeh, J., Mocklin, J., Davis, A.R., Rugh, D.J., George, J.C., and R. Suydam. 2010. Abundance of Bering-Chukchi-Beaufort bowhead whales (*Balaena mysticetus*) in 2004 estimated from photo-identification data. J. Cetacean Res. Manage. 11(2): 89-99.

Kowalik, Z., and Proshutinsky, A.Y. 1994. The Arctic Ocean tides. *In* The polar oceans and their role in shaping the global environment. Edited by O.M. Johannessen, R.D. Muench, and J.E. Overland. Geophys. Monogr. Ser., vol. 85, AGU, Washington, D.C. p. 137-158.

Kulikov, E.A., Rabinovich, A.B., and Carmack, E. 2004. Barotropic and baroclinic tidal currents on the Mackenzie shelf break in the southeastern Beaufort Sea. J. Geophys. Res. 109. C05020, doi:10.1029/2003JC001986.

Latour, P.B., Leger, J., Hines, J.E., Mallory, M.L., Mulders, D.L., Gilchrist, H.G., Smith, P.A., and Dickson, D.L. 2006. Key migratory bird terrestrial habitat sites in the Northwest Territories and Nunavut, 3rd edition. Canadian Wildlife Service, Environment Canada, Edmonton, AB. Occ. Pap. 114. http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=4625F589-01A1-4A7B-BBCE-C8E36573B657 [accessed October 19, 2012]

Lawson, J.W. and Moulton, V.D. 1999. Seals. *In* Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. Edited by W.J. Richardson . LGL Rep. TA2230-3. Rep. by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. [available from ARLIS, http://www.arlis.org]

Lawson, J.W. and Moulton, V.D. 2001. Seals. *In* Marine mammal and acoustical monitoring of WesternGeco's open-water seismic program in the Alaskan Beaufort Sea, 2001: 90-day report. Edited by W.J. Richardson. LGL Rep. TA2564-3. Rep. by LGL Ltd., King City, Ont., for WesternGeco, LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. http://www.arlis.org/docs/vol2/point_thomson/1101/1101A_marine%20mammal%20monitoring%20of%20western%20Gecos.pdf [accessed November 8, 2012]

Leatherwood, J.S. and Dahlheim, M.E. 1979. The world-wide distribution of pilot whales and killer whales. NOSC Tech. Rep. 295. 30 p.

Lentfer, J.W. 1975. Polar bear denning on drifting sea ice. J. Mammal. 56: 716-718.

Leppäkoski, E., 1991. Introduced species – resource or threat in brackish-water seas? Examples from the Baltic and the Black Sea. Mar. Poll. Bull. 23: 219–223.

Levings, C., Kieser, D., Jamieson, G.S., and Dudas, S. 2002. Marine and estuarine alien species in the Strait of Georgia, British Columbia. *In* Alien invaders in Canada's waters, wetlands, and forests. Edited by P. Nantel, R. Claudi, and E. Muckle-Jeffs. Natural Resources Canada, Canadian Forest Service, Science Branch, Ottawa, Ont. p. 111-131.[available in the DFO library]

LGL (LGL Alaska Research Associates, Inc.). 1989. The 1988 Endicott Development fish monitoring program. Volume II: Recruitment and population studies, analysis of 1988 fyke net data. Rep. by LGL Alaska Research Associates, Inc., Anchorage, AK, for BP Exploration (Alaska) Inc., Anchorage, AK. 317 p. [available in the DFO library]

Locke, A., Reid, D.M., van Leeuwen, H.C., Sprules, W.G., Carlton, J.T. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Can. J. Fish. Aquat. Sci. 50: 2086-2093.

Lowry, L., K. Frost, and J. Burns. 1978. Trophic relationships among ice inhabiting phocid seals. Envir. Assess. Alaskan Cont. Shelf, Annu. Rep. Prin. Invest., March 1978, Vol. 1. BLM/NOAA, OCSEAP, Boulder, CO. 211 p.

Lunn, N.J., Atkinson, S., Branigan, M., Calvert, W., Doidge, B., Elliot, C., Nagy, J., Obbard, M., Otto, R., Stirling, I., Taylor, M., and Vandal, D. 2002. Polar bear management Canada 1997–2000. *In* Polar bears: Proceedings of the 13th working meeting of the IUCN/SSC Polar Bear Specialist Group, 23–28 June 2001, Nuuk, Greenland. Edited by N.J. Lunn, S. Schliebe, and E.W. Born. Occ. Pap. 26, IUCN Species Survival Commission. IUCN Publication Services, Cambridge, U.K. p. 41-52.

Mack, R.N, Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., and Bazzaz, F.A. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689-710.

Mallory, M.L. and Fontaine, A.J. 2004. Key marine habitat sites for migratory birds in Nunavut and Northwest Territories. Occ. Pap. 109, Canadian Wildlife Service, Environment Canada, Ottawa, Ont. 93 p. http://www.ec.gc.ca/Publications/3CF6D6D9-A460-4348-9C10-79648C948B2E/KeyMarineHabitatSitesForMigratoryBirdsInNunavutAndTheNorthwestTerritories.pdf [accessed October 19, 2012]

Marko, J.R. 1975. Satellite observations of the Beaufort Sea ice cover. Beaufort Sea Project Tech. Rep. No. 34. 137 p.

MBC Applied Environmental Sciences. 2003. Physical oceanography of the Beaufort Sea–Workshop proceedings. OCS Study MMS 2003-045. Rep. by MBC Applied Environmental Sciences, Costa Mesa, CA, for the U.S. Dept. of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage AK. 26 p.

http://www.ims.uaf.edu/beaufort/FinalPhysicalOceanographyBFProceedings.pdf [accessed November 8, 2012]

McAllister, D.E. 1962. Fishes of the 1960 "*Salvelinus*" program from western arctic Canada. Nat. Mus. Can. Bull. 185: 17-39. [available in the DFO library]

McCarthy, S.A. and Khambaty, F.M. 1994. International dissemination of epidemic Vibrio cholerae by cargo ship ballast and other nonpotable waters. Appl. Environ. Microbiol. 60: 2597-2601.

McLaren, P.L. and Davis, R.A. 1985. The distribution of bowhead whales in the southeastern Beaufort Sea, August–September 1983. Environ. Stud. Revol. Funds Rep. No. 001, Ottawa, Ont. 62 p.

McNeil, M.R. and Garrett, J.F. 1975. Open water surface currents. Beaufort Sea Project Tech. Rep. No. 17. Beaufort Sea Project, Department of the Environment, Victoria, BC. 113 p. http://www.restco.ca/BSPTR/BSP_TR17_MacNeill&Garrett.pdf [accessed November 8, 2012]

Melling, H. 2005. Sea ice, climate and Beaufort development. Presentation at PERD/INAC Workshop, Inuvik, N.W.T. http://www.bsstrpa.ca/pdf/nogr/iceproperties_melling.pdf [accessed November 8, 2012]

Melling, H. 2007. Pack-ice hazards, thoughts on designing for an uncertain future. Presentation to PERD/CCTII Workshop held in Calgary, AB. November 2007. ftp://ftp2.chc.nrc.ca/CRTreports/PERD_CCTII_Workshop_07_Session_3.pdf [accessed November 8, 2012]

Molnar, J.L., Gamboa, R.L., Revenga, C., and Spalding, M.D. 2008. Assessing the global threat of invasive species to marine biodiversity. Front. Ecol. Environ. 6(9): 485-492.

Moore, S.E. and Reeves, R.R. 1993. Distribution and movement. *In* The bowhead whale. Edited by J.J. Burns, J.J. Montague and C.J. Cowles. Spec. Pub. No. 2. Soc. Mar. Mammal., Lawrence, KS. p. 313-386.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, AK. 248 p.

Moulton, V.D. and Lawson, J.W. 2000. Seals, 1999. *In* Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. Edited by W.J. Richardson. LGL Rep. TA2313-4. Rep. by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. [available from ARLIS, http://www.arlis.org].

Moulton, V.D. and Lawson, J.W. 2001. Seals, 2000. *In* Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Edited by W.J. Richardson. LGL Rep. TA2424-4. Rep. by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. . [available from ARLIS, http://www.arlis.org].

Moulton, V.D., Miller, G.W., and Serrano, A. 2002. Vessel-based monitoring, 2001. *In* Marine mammal and acoustical monitoring of Anderson Exploration Ltd.'s open-water seismic program in the southeastern Beaufort Sea. Edited by G.W. Miller and R.A. Davis. Final rep. by LGL Ltd., King City, Ont., and JASCO Research Ltd., Victoria, B.C., for Devon Canada Corporation, Calgary, AB. [available in the DFO library]

Munk, P., P. O. Larsson, D. Danielsen, and E. Moksness. 1995. Larval and small juvenile cod Gadus morhua concentrated in the highly productive areas of a shelf break front. Mar. Ecol. Progr. Ser. 125(1-3): 21-30.

Niimi, A.J. 2004. Environmental and economic factors can increase the risk of exotic species introductions to the Arctic region through increased ballast water discharge. Environ. Manage. 33: 712-718.

NIMPIS. 2012. *Potamocorbula amurensis* general information, National Introduced Marine Pest Information System. http://www.marinepests.gov.au/nimpis [accessed November 8, 2012]

Noel, L.E., O'Doherty, G.M., and Johnson, S.R. 2003. Atlas of activity areas for marine birds, waterfowl and human activity in the barrier island-lagoon systems between Spy Island and Brownlow Point, Alaska: 1998–2002. Rep. by LGL Alaska Research Associates, Inc., Anchorage, AK, for BP Exploration (Alaska) Inc., Anchorage, AK. http://www.arlis.org/docs/vol2/point_thomson/1023/1023A_~1.pdf [accessed November 8, 2012]

Noel, L.E., Johnson, S.R., and Butcher, M.K. 2004. Snow goose nesting and brood-rearing distribution in the Sagavanirktok River Delta, Alaska, 1980–2002. Waterbirds 27: 388-395.

Noel, L.E., Johnson, S.R., O'Doherty, G.M., and Butcher, M.K. 2005. Common eider (*Somateria mollissima v. nigrum*) nest cover and depredation on central Alaskan Beaufort Sea barrier islands. Arctic 58: 129-136.

North, M.R. 1994. Yellow-billed loon (*Gavia adamsii*), No. 121. *In* The Birds of North America. Edited by A. Poole and F. Gill. The Birds of North America Inc., Philadelphia, PA. 24 p.

Norton, P. and Harwood, L.A. 1986. Distribution, abundance and behaviour of white whales in the Mackenzie River Estuary. Environ. Stud. Revol. Funds, Rep. 36. Ottawa, ON. [available in the DFO library]

OCCP (Olokhaktomiut Community Conservation Plan). 2008. A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Holman, Northwest Territories. Prepared by the Community of Holman, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 127 p. http://www.eirb.ca/pdf/ccp/Ulukhaktok_CCP.pdf [accessed October 19, 2012]

Paulic, J.E., Papst, M.E. and Cobb, D.G. 2009. Proceedings for the Identification of Ecologically and Biologically Significant Areas in the Beaufort Sea Large Ocean Management Area. Can. Manuscr. Rep. Fish. Aquat. Sci. 2865: ii + 46 p.

PCCP (Paulatuk Community Conservation Plan). 2008. A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Paulatuk, Northwest Territories. Prepared by the Community of Paulatuk, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 140 p. http://www.eirb.ca/pdf/ccp/Paulatuk_CCP.pdf [accessed October 19, 2012]

Percy, R.J. 1975. Fishes of the outer Mackenzie Delta. Freshwater Institute, Fisheries and Marine Service, Environment Canada, Beaufort Sea Tech. Rep. 8. 114 p.

Pickart, R.S. 2004. Shelfbreak circulation in the Alaskan Beaufort Sea: mean structure and variability. J. Geophys. Res. 109 (C04024). doi: 0.1029/2003JC001912.

Powell, A.N., Phillips, L., Rexstad, E.A., and Taylor, E.J. 2005. Importance of the Alaskan Beaufort Sea to king eiders (*Somateria spectabilis*). OCS Study MMS 2005-057 by Coastal Marine Institute, University of Alaska, Fairbanks, AK, for U.S. Mineral Management Service, Anchorage, AK. http://www.arlis.org/docs/vol1/70702448.pdf [accessed November 8, 2012]

Ramsay, M.A. and Stirling, I. 1990. Fidelity of female polar bears to winter-den sites. J. Mammal. 71: 233–236.

Reeves, R.H. 1978. Narwhal. *In* Alaska whales and whaling. Edited by R.E. Stevens. Alaska Geographic Society, Anchorage, AK. Vol. 5(4): 108-114.

Reise, K., Gollasch, S., and Wolff, W.J. 1999. Introduced marine species of the North Sea coasts. Helgol. Meer. 52: 219-234.

Reist, J.D., Johnson, J.D. and Carmichael, T.J. 1997. Variation and specific identity of char from northwestern Arctic Canada and Alaska. Am. Fish. Soc. Symp. 19: 25-261.

Richard, P.R., Martin, A.R., and Orr, J.R. 2001. Summer and autumn movements of belugas of the eastern Beaufort Sea stock. Arctic 54: 223-236.

Ritchie, R.J., Burgess, R.M., and Suydam, R.S. 2000. Status and nesting distribution of lesser snow geese, *Chen caerulescens caerulescens*, and brant, *Branta bernicla nigricans*, on the western Arctic coastal plain, Alaska. Can. Field-Nat. 112: 700-701.

Robertson, G.J. and Savard, J.-P.L. 2002. Long-tailed duck (*Clangula hyemalis*). No. 651. *In* The birds of North America. Edited by A. Poole and F. Gill. The Birds of North America, Inc., Philadelphia, PA.

Ruiz, G.M. and Reid, D.F. (ed.). 2007. Current state of understanding about the effectiveness of ballast water exchange (BWE) in reducing aquatic nonindigenous species (ANS) introductions to the Great Lakes basin and Chesapeake Bay, USA: synthesis and analysis of existing information. NOAA Tech. Memo. GLERL-142: xiv + 126 p.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D., and Hines, A.H. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent, and consequences. Amer. Zool. 37: 621-632.

Ruiz, G.M., P.W. Fofonoff, J.T. Carlton, M.J. Wonham, and A.H. Hines. 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. Annu. Rev. Ecol. Syst. 31:481-531.

Russell, R.W. 2002. Pacific loon (*Gavia pacifica*) and Arctic loon (*Gavia arctica*). No. 657. *In* The birds of North America. Edited by A. Poole and F. Gill. The Birds of North America, Inc., Philadelphia, PA.

Scott, W.B. and Crossman, E.J. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 p.

Seminoff, J.A., Zarate, P., Coyne, M., Foley, D.G., Parker, D., Lyon, B.N., and Dutton, P.H. 2008. Post-nesting migrations of Galapagos green turtles *Chelonia mydas* in relation to oceanographic conditions: integrating satellite telemetry with remotely sensed ocean data. Endang. Spec. Res. 4(1-2): 57-72.

SHCCP (Sachs Harbour Community Conservation Plan). 2008. A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region and in the vicinity of Banksland, Northwest Territories. Prepared by the Community of Sachs Harbour, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 109 p. http://www.eirb.ca/pdf/ccp/SachsHarbour_CCP.pdf [accessed November 6, 2012]

Simberloff, D. and Von Holle, B. 1999. Positive interactions of nonindigenous species: invasional meltdown? Biol. Invasions. 1: 21–32.

Smith, T.G. 1977. The occurrence of a narwhal (*Monodon monoceros*) in Prince Albert Sound, western Victoria Island, Northwest Territories. Can. Field-Nat. 92: 299.

Smith, T.G. and Stirling, I. 1978. Variation in the density of ringed seal (*Phoca hispida*) birth lairs in the Amundsen Gulf, Northwest Territories. Can. J. Zool. 56: 1066-1070.

Smith L.D., Wonham, M.J., McCann, L.D., Reid, D.M., Ruiz, G.M., and Carlton, J.T. 1996. Shipping study II. Biological invasions by nonindigenous species in United States waters: quantifying the role of ballast water and sediments, parts I and II. The National Sea Grant College Program/Connecticut Sea Grant Project R/ES-6. United States Department of Transportation, United States Coast Guard, Washington, DC and Groton, Connecticut. Report number CG-D02-97. Government accession number AD-A321543.

Smith L.D., Wonham M.J., McCann L.D., Ruiz G.M., Hines A.H., Carlton J.T. 1999. Invasion pressure and inoculant survival in a ballast-flooded estuary. J. Biol. Inv. 1: 67-87.

Stein, J.N., Jessop, C.S., Porter, T.R., and Chang-Kue, K.T.J. 1973. An evaluation of the fish resources of the Mackenzie River valley as related to pipeline development, Vol. I. Rep. by Fisheries and Marine Service, Department of the Environment, for Environmental-Social Program Northern Pipelines, Task Force on Northern Oil Development. Report 73-1. Ottawa, Ont. 121 p.

Stewart, D.B., Ratynski, R.A., Bernier, L.M.J., and Ramsey, D.J. 1993. A fishery development strategy for the Canadian Beaufort Sea-Amundsen Gulf area. Can. Tech. Rep. Fish. Aquat. Sci. 1910: v + 127 p.

Stirling, I. 1974. Midsummer observations on the behaviour of wild polar bears. Can. J. Zool. 52: 1191-1198.

Stirling, I., and Taylor, M.K. 1999. Update COSEWIC status report on polar bear (*Ursus maritimus*). Committee on the Status of Endangered Wildlife in Canada. Canadian Wildlife Service, Environment Canada, Ottawa, Ont.

Stirling, I., Archibald, W.R., and DeMaster, D. 1977. Distribution and abundance of seals in the eastern Beaufort Sea. J. Fish. Res. Board Can. 34: 976-988.

Stirling, I., Schweinsburg, R.E., Calvert, W., and Kiliaan, H.P.L. 1979. Population ecology of the polar bear along the proposed Arctic Islands gas pipeline route. Dep. Indian and Northern

Affairs, Environmental-Social Program, Northern Pipelines Rep No. AI-24, Ottawa, ON. 82 p. [available in the DFO library]

Stirling, I., Kingsley, M.C.S., and Calvert, W. 1981. The distribution and abundance of ringed and bearded seals in the eastern Beaufort Sea, 1974–1979. Rep. for Dome Petroleum Ltd, Esso Resources Canada Ltd., and Department of Indian and Northern Affairs, Edmonton, AB. 70 p. [available in the DFO library]

Stirling, I., Kingsley, M., and Calvert, W. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974–79. Occ. Pap. 47. Canadian Wildlife Service, Environment Canada, Ottawa, Ont. [available in the DFO library]

Stirling, I., Calvert, W., and Andriashek, D. 1984. Polar bear (*Ursus maritimus*) ecology and environmental considerations in the Canadian High Arctic. *In* Northern ecology and resource management. Edited by R. Olson, University of Alberta Press, Edmonton, AB. p. 201-222.

Stroeve, J., Holland, M.M., Meier, W., Scambos, T., and Serreze, M. 2007. Arctic sea ice decline: Faster than forecast. Geophys. Res. Lett. 34, L09501, doi:10.1029/2007GL029703

Suydam, R.S., Quakenbush, L.T., Johnson, M., George, J.C., and Young, J. 1997. Migration of king and common eiders past Point Barrow, Alaska, in spring 1987, spring 1994, and fall 1994. *In* King and common eiders of the western Canadian Arctic. Edited by D.L. Dickson, Occ. Pap. 94. Canadian Wildlife Service, Environment Canada, Edmonton, AB p. 21-28.

Suydam, R.S., Dickson, D.L., Fadely, J.B., and Quakenbush, L.T. 2000. Population declines of king and common eiders of the Beaufort Sea. Condor 102: 219-222.

TCCP (Tuktoyaktuk Community Conservation Plan). 2008. A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Tuktoyaktuk, Northwest Territories. Prepared by the Community of Tuktoyaktuk, the Wildlife Management Advisory Council (NWT), and the Joint Secretariat. 168 p. http://www.eirb.ca/pdf/ccp/Tuktoyaktuk_CCP.pdf [accessed October 19, 2012]

Thomson, D.H. 1987. Patterns of energy flow. *In* Environmental characterization and biological utilization of the North Aleutian Shelf nearshore zone. Edited by J.C. Truett. U.S. Dept. Commerce. NOAA OCSEAP Final Rep. 60(1989). p. 489-522. [available from NTIS http://www.ntis.gov/help/ordermethods.aspx or ARLIS http://www.arlis.org]

Thomas, D.J., Heath, W.A., Koleba, J.M., Perry, B.M., and Ethier, A.G. 1982. A study of the benthos and sediment chemistry at Tarsiut N-44 artificial island and south Tarsiut borrow area, 1981. Rep. by Arctic Laboratories Limited for Dome Petroleum Limited and Gulf Canada Resources Inc. 160 p. [available in the DFO library]

Thomson, D.H., Fissel, B.D., Marko, J.R., Davis, R.A., and Borstad, G.A. 1986. Distribution of bowhead whales in relation to hydrometeorological events in the Beaufort Sea. Environ. Stud. Revol. Funds Rep. 028. Ottawa, Ont. http://www.esrfunds.org/pdf/28.pdf [assessed October 19, 2012]

Thorson, G. 1957. Bottom communities. *In* Treatise on marine ecology and paleoecology. Vol. 1, Ecology. Edited by J.W. Hedgepeth, Memoir 67, Geol. Soc. Amer., New York, NY. p. 461-534.

Underwood, T.J., Gorden, J.A., Millard, M.J., Thorpe, L.A., and Osborne, B.M. 1995. Characteristics of selected fish populations of Arctic National Wildlife Refuge coastal waters, final report, 1988-1991. U.S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Fairbanks, AK. Alaska Fish. Tech. Rep. No. 28. 590 p. http://www.arlis.org/docs/vol1/A/34254212a.pdf and http://www.arlis.org/docs/vol1/A/34254212b.pdf [accessed November 8, 2012]

Vila, M. and Masó, M. 2005. Phytoplankton functional groups and harmful algal species in anthropogenically impacted waters of the NW Mediterranean Sea. Sci. Mar. 69(1): 31-45.

Wacasey, J.W. 1975. Biological productivity of the southern Beaufort Sea: Zoobenthic studies. Beaufort Sea Project Tech. Rep. 126. Dept. of the Environment, Victoria B.C. 39 p. http://www.restco.ca/BSPTR/BSP_TR12B_Wacasey.pdf [assessed October 19, 2012]

Walsh, J.J. and McRoy, P. 1986. Ecosystem analysis in the southeastern Bering Sea. Cont. Shelf Res. 5(1-2): 259-288.

Walters, V. 1955. Fishes of western arctic America and eastern arctic Siberia: taxonomy and zoogeography. Bull. Amer. Mus. Nat. Hist. 106: 259-368.

Weingartner, T. 2006. Circulation, thermohaline structure, and cross-shelf transport in the Alaskan Beaufort Sea. OCS Study MMS 2006-031. Minerals Management Service, Alaska OCS Region. Available from http://www.sfos.uaf.edu/cmi/publications.html [assessed October 19, 2012]

Welch, H.E., Bergmann, M.A., Siferd, T.D., Martin, K.A., Curtis, M.F., Crawford, R.E., Conover, R.J., and H. Hop. 1992. Energy flow through the marine ecosystem of the Lancaster Sound region, arctic Canada. Arctic 45(4): 343-357.

Welch, H.E., Crawford, R.E., and Hop, H. 1993. Occurrence of Arctic cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. Arctic 46: 331-339.

Wiig, Ø. 1995. Distribution of polar bears (*Ursus maritimus*) in the Svalbard area. J. Zool. 237: 515–529.

Wiley, C.J. and Claudi, R. 2002. Alien species transported in ships' ballast water: from known impact to regulations. *In* Alien invaders in Canada's waters, wetlands, and forests. Edited by R. Claudi, P. Nantel, and E. Muckle-Jeffs. Natural Resources Canada, Canadian Forest Service, Science Branch, Ottawa, Ont. 320 p. 233-241.

Williams, R.J., Griffiths, F.B., Van der Wal, E.J., and Kelly, J. 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. Estuar. Coast. Shelf Sci. 26: 409-420.

Williams, W.J., Carmack, E.C., Shimada, K., Melling, H., Aagaard, K., Macdonald, R.W., and Ingram, R.G. 2006. Joint effects of wind and ice motion in forcing upwelling in Mackenzie Trough, Beaufort Sea. Cont. Shelf Res. 26: 2352-2366.

Wong, P.L. 2000. A summary and synthesis of benthic literature from southeastern Beaufort Sea. 30 p.

Wonham, M.J., Lewis, M.A., and MacIsaac, H.J. 2005. Minimizing invasion risk by reducing propagule pressure: a model for ballast-water exchange. Front. Ecol. Environ. 3: 473-478.