10.1.1 BACKGROUND DATA

Imperial has a large volume of baseline information to draw on for developing the program. The joint venture partners conducted field data collection programs (FDCPs) in 2009, 2010 and 2011. The scientific collaboration between ArcticNet, Imperial and BP has increased the understanding of the physical, chemical and biological oceanography, contaminants in seawater and sediment, ice climatology and surface and near-surface geohazards in the Beaufort Sea.

In addition to the FDCPs, the BREA provides more background data.

10.1.2 PHYSIOGRAPHY AND MARINE SETTING

The Beaufort Sea is a marginal sea of the Arctic Ocean, located off the western Arctic coast of North America. It is characterized by a continental shelf that extends 150 to 200 km from the coast, in contrast to the Eurasian side of the basin where the shelf extends much further from the coast. The Beaufort Sea shelf is incised by a small number of underwater canyons and is anchored or bounded by the Amundsen Gulf on the east.

The Canadian part of the Beaufort Sea is a Large Ocean Management Area (LOMA) under federal government jurisdiction, subject to exceptions in the IFA relating to wildlife management and environmental screening and assessment. This setting is described from a physical environment, biological environment, and cultural and historical resources perspective, including coastal and shoreline, and Mackenzie River and Mackenzie Delta components.

10.1.3 PHYSICAL, CHEMICAL, GEOLOGICAL AND BIOLOGICAL OCEANOGRAPHY

The oceanography of the Canadian sector of the Beaufort Sea involves many physical, chemical, geological and biological processes that are linked within the context of different oceanographic regimes:

- the inshore area, which is heavily influenced by freshwater and sediment discharges of the Mackenzie River
- the mid- and outer-shelf area, where wind forcing of the ocean current is more dominant
- the outer shelf and continental slope region, where large-scale ocean current systems of Pan-Arctic, Atlantic and Pacific origin play an important role

10.1.3 PHYSICAL, CHEMICAL, GEOLOGICAL AND BIOLOGICAL OCEANOGRAPHY (cont'd)

The seasonality of the oceanographic regime is an important factor that is best expressed in terms of the sea-ice conditions. Ice is prevalent during the fall to spring months and then retreats in late spring to mid-autumn although heavy polar pack ice can persist throughout the summer in the offshore outer shelf and slope region.

The seasonal characteristics of sea-ice formation have a major influence on the shelf and slope water properties through the uptake of salt brine as sea ice forms in autumn and winter, and the discharge of salt brine as sea ice melts in late spring and summer.

Between 1958 and 2007, sea-ice thickness in the Beaufort Sea declined by over 1 m, or 50 % of its volume (Kwok and Rothrock 2009).

10.1.3.1 Physical and Geochemical Processes

An understanding of marine life in the Beaufort Sea requires knowledge of the linkages to physical and geochemical processes, and their large spatial variations and temporal changes, especially on synoptic, seasonal and interannual time scales (Carmack and Macdonald 2002). Primary production (i.e., new organic matter produced, such as phytoplankton) is controlled by the highly variable physical, chemical and sea-ice conditions in these waters, which differ considerably by spatial regime and with the seasons. The seasonal peaks in primary productivity levels are different from one regime to another in terms of the timing and composition (species distribution) of the phytoplankton in or on the bottom of sea ice, or in the water column.

Understanding the higher marine trophic levels begins with the primary productivity patterns in time and space, which are further modulated by biophysical and geochemical processes. For example, the abundance of zooplankton is affected by ocean properties in the upper part of the water column, including vertical stratification, mixing, and formation of frontal features where abundances are higher. Animals that feed on zooplankton are drawn to areas where the zooplankton develops. The habitat and behaviour of animals that feed on zooplankton are strongly influenced by the physical, chemical and biological processes that occur in these waters.

10.1.4 OCEAN CIRCULATION AND CURRENTS IN THE BEAUFORT SEA

Currents in the Beaufort Sea are driven by a combination of various oceanographic processes including:

- large-scale circulation features
- winds
- the Mackenzie River discharges
- tidal forcing

The program EL areas (EL 476 and EL 477) lie along the continental slope between two major underwater canyons, the Mackenzie Trough and Kugmallit Valley. Large-scale circulation features in this area include:

- the clockwise Beaufort Gyre that is driven by the high-pressure atmospheric system, which results in a westward movement of the near-surface waters
- the eastward transport of Pacific Ocean water (Pacific water) that originates in the Bering Sea, thought to occur as an episodic eastward-flowing shelf-break jet along the edge of the Beaufort Shelf at depths of 50 to 200 m (Schulze and Pickart 2012)
- a deeper (greater than 200 m) eastward movement of Atlantic Ocean water (Atlantic water)

These geophysical features, combined with the effects of regional winds and the Mackenzie River plume, create a complex of surface currents (Fissel and Melling 1990). A schematic overview of major circulation elements is shown in Figure 10-1.

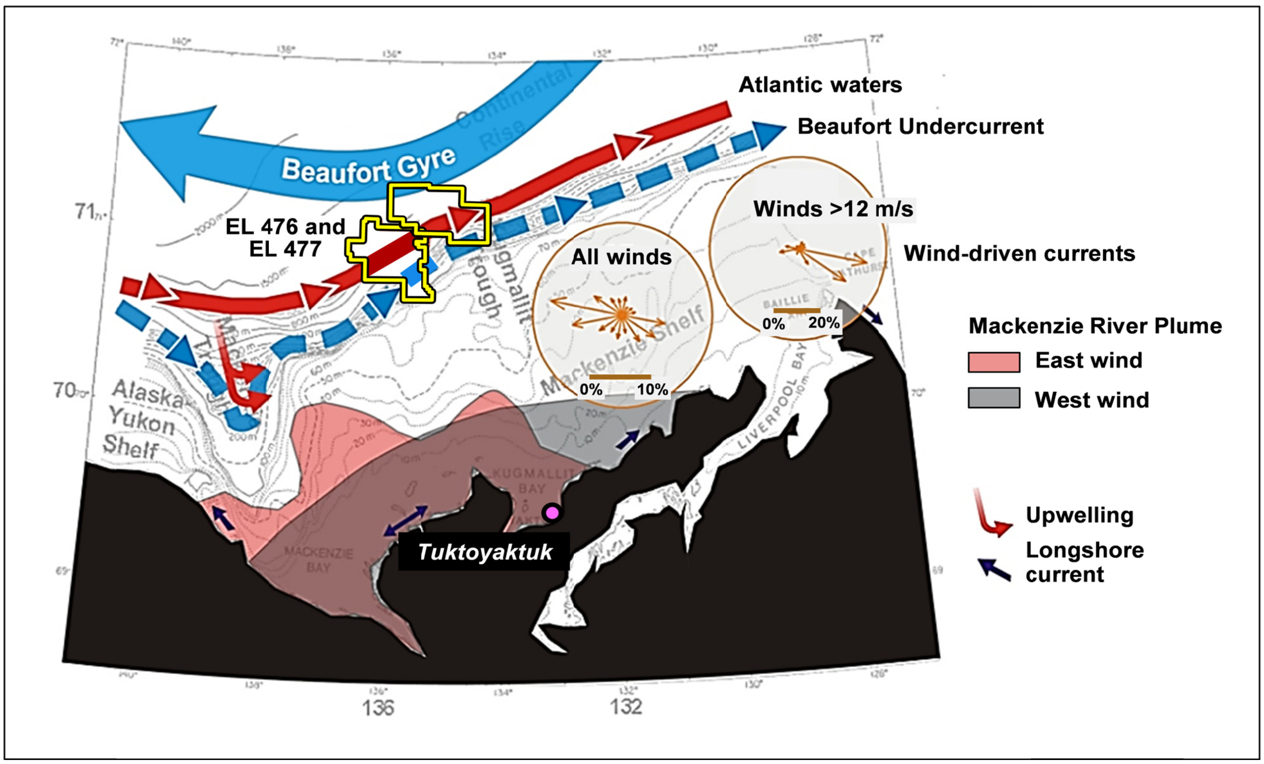

Figure 10-1: Ocean Currents in the Canadian Beaufort Sea

The currents over the shelf edge and continental slope are highly episodic with events occurring over a few days, largely in response to wind forcing as modulated by the local sea-ice cover, topographic waves and mesoscale eddies (Carmack and Kulikov 1998). Current meter measurements from the 2009 to 2011 FDCPs in the exploration licence areas identified events with current speeds as high as 99 cm/s in the upper 200 m of the water column and up to

10.1.4 OCEAN CIRCULATION AND CURRENTS IN THE BEAUFORT SEA (cont'd)

47 cm/s in the deeper (greater than 250 m) Atlantic water layer (Fissel et al. 2012c, Osborne et al. 2012). Such strong current events are associated with northeasterly winds and resulted in ocean upwelling, a process that brings more saline nutrient-rich waters to the surface along the Beaufort Shelf edge and slope (Williams et al. 2006, Williams and Cormack 2008).

Upwelling is enhanced near the Mackenzie Trough and influences the currents along the entire shelf-break area (Carmack and Kulikov 1998). Strong episodic currents over the continental slope have been observed, that include a few large current speed events from 2004 to 2006 that were characterized by large sediment fluxes in the water column, indicative of erosion and redistribution of bottom sediments in the region (Forest et al. 2008).

In the shallower waters on the Beaufort Shelf, ocean currents are predominantly wind-driven (Fissel and Melling 1990). Wind direction is primarily from the east and from the west-northwest (Cobb et al. 2008). Environment Canada data obtained at the weather station on Pelly Island indicates that wind direction is most frequently from the east and that significant wind speeds (i.e., those exceeding 12 m/s) are most common from the west-northwest. The surface currents generated by the two dominant wind directions generally follow the wind direction with a 15 to 30 degree rightward deflection. Current speeds are roughly 2 to 3% of the wind speed, with typical velocities of 0.25 to 0.4 m/s (up to a maximum velocity of 0.8 m/s).

On the inner shelf, the surface currents are influenced by the Mackenzie River plume and the effects of shoreline features, such as islands and headlands. The winds from the west result in strong alongshore currents. Winds from the east result in an offshore displacement of water from the Mackenzie River and pack ice (Carmack and Macdonald 2002). Water from the Mackenzie River was observed in the southern Canada Basin in:

- 1993 and 1994 (Guay and Falkner 1997)
- 1997 (Macdonald et al. 1999)
- 2007 (Yamamoto-Kawai et al. 2009)

However, the water observed from the Mackenzie River was constrained to the coastline, likely exiting the Arctic through the Arctic Archipelago in:

- 1974 (Macdonald et al. 2002)
- 2000 to 2006 (Yamamoto-Kawai et al. 2009)

This suggests that the fate of water from the Mackenzie River depends on interannual climate variability provided by the Arctic oscillation. Observations that are relevant to this situation were also obtained during the FDCPs in 2009, 2010 and 2011.

Tidal currents in the Canadian sector of the Beaufort Sea are weak, typically less than 5 cm/s, with small tidal heights (less than 0.5 m) (Kulikov et al. 2004). However, inertial oscillations, which have a 12-hour period (similar to semidiurnal tides), can have current speeds of up to 40 cm/s, thereby obscuring tidal currents and having important implications for ice floes. Considering the large magnitude and circular nature of inertial oscillations, anticipating when they occur is important to the ice management required to support drilling operations.

10.1.5 WATER MASSES AND OCEAN STRUCTURES

Water properties in the program area are shown in Figure 10-2. They consist of:

- relatively cold, fresh Arctic Ocean surface water in the upper 250 m
- warmer, salty Atlantic water from about 250 to 900 m
- cold, salty water from about 900 m to the bottom

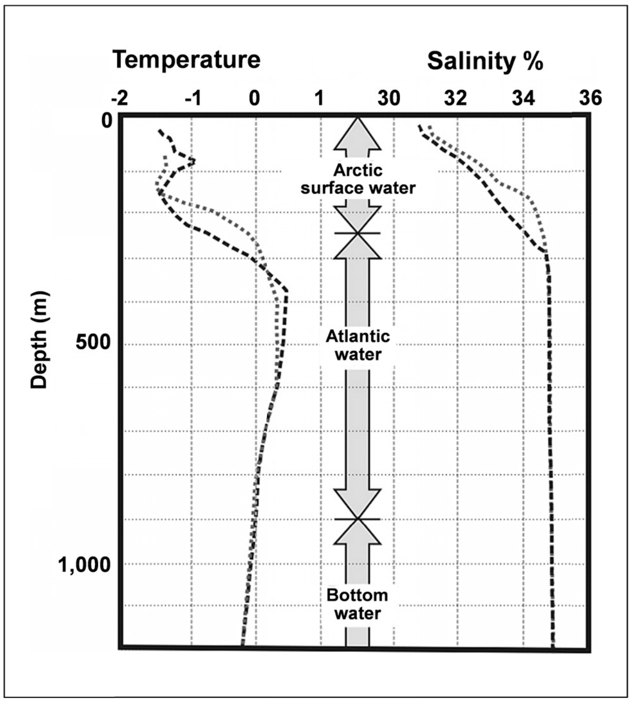

Figure 10-2: Water Properties of Arctic Surface Water and Atlantic Water in the Program Area

10.1.5.1 Water Composition in the Program Area

Arctic surface water is composed of water from the Mackenzie River, melted sea ice, winter polar mixed layer water or surface mixed layer water, and upper halocline water that can include Pacific water (Lansard et al. 2012). The inputs of fresh water from melted sea ice and river runoff results in surface water that is fresher in summer than winter.

The properties of Pacific water vary depending on whether it is modified in the Chukchi Sea in summer or winter (Coachman and Barnes 1961). Pacific summer water is warm with temperatures up to 1°C, fresh (salinity 31 to 33%), with a

10.1.5.1 Water Composition in the Program Area (cont'd)

temperature maximum in the depth range of 30 to 90 m. Pacific winter water is colder with temperatures from -1.6 to -1.5°C, salty (salinity 33.1%), with a temperature minimum in the depth range of 90 to 200 m (Steele et al. 2004). Because of the episodic nature of the Beaufort Shelf-break jet (Schulze and Pickart, 2012), the transport of Pacific summer water and Pacific winter water into the southern Beaufort Sea varies according to regional oceanographic and ice conditions and surface wind patterns.

Atlantic water and Pacific water are likely transported as a boundary current along the continental slope (Aksenov et al. 2011). Consequently, except for upwelling events, Atlantic water is not transported on the continental shelf.

The large discharges of fresh water from the Mackenzie River onto the shelf areas and beyond, and the wind-dependent advection of these river waters lead to frontal features with distance scales of tens of metres to tens of kilometres over the shelf and outer slope regions (Thomson et al. 1986, Carmack and Macdonald 2002). The frontal features from the Mackenzie River are important because they can act as a mechanism capable of concentrating plankton (and other passive water properties) that can result in an abundance of food sources for marine life (Thomson et al. 1986).

10.1.6 WAVES AND STORM SURGES

Between 1985 and 2005, the maximum statistical calculations of probable past significant wave heights (in 60 m water depth) in the EL areas was 5.66 m in October, compared to 0.53 m in July, increasing to 1.4 m in October (Swail et al. 2007). Maximum and mean wave heights vary considerably with water depth and distance offshore. The maximum significant wave height in the deepest area of the EL areas was 7.58 m in October, with average significant wave height values of 0.71 m in July, increasing to 1.63 m in October.

Direct measurements of wave heights taken in the EL areas during the FDCPs yielded wave height measurements of up to 4.9 m. Changes in ocean wave properties might have been occurring over the past decade as a consequence of reduced ice concentrations and increased wind fetches, resulting in a longer duration of ocean wave activity in recent years (Fissel et al. 2012a). In recent years, there is also evidence of moderate to large wave events starting in early June and extending into November, which is longer than the previous wave season observed in the 1980s (Fissel et al. 2012a).

Storm surges occur most commonly in late summer and fall. Typical water level changes associated with positive storm surges have durations of one to two days and do not normally exceed 0.5 m (Henry and Heaps 1976). The largest recorded storm surge was measured in September 1970 with peak surge values of 2.4 m at Tuktoyaktuk and values of 1.1 to 1.9 m along the Yukon coastline (Murty et al. 1995). A similar event occurred in 1999 (Kokelj et al. 2012). At a model grid location near EL 476, the largest surge level each year was calculated at 0.2 m.

From this finding an expected 10-year maximum value of 0.4 m and an expected 100-year maximum of 0.6 m can be extrapolated.

10.1.7 ACOUSTIC CONDITIONS

The acoustic environment in the Beaufort Sea is characterized by acoustic propagation conditions and the ambient noise regime. Acoustic propagation is governed by the water mass properties, the topography and the acoustic properties of the bottom and surface. Ambient acoustic conditions have been studied by the joint venture partners and ArcticNet, in association with Cornell University, during the 2009 and 2010 FDCPs. Marine autonomous recording units were deployed and recovered from Canadian Coast Guard Ship (CCGS) *Amundsen* to record ambient sound levels and marine mammal vocalizations in the program area.

The water mass structure in the exploration licence areas reflects colder, lower salinity Arctic surface water overlying warmer, more saline Atlantic water (see Figure 10-2 shown previously). When ice cover is present, the sound speed minimum is at the surface. Summer heating or river discharge can result in warmer temperatures near the surface, which will displace the sound speed minimum below the surface to a depth of up to 50 m. For typical sound speed profiles in the local study area (LSA), see Figure 10-3.

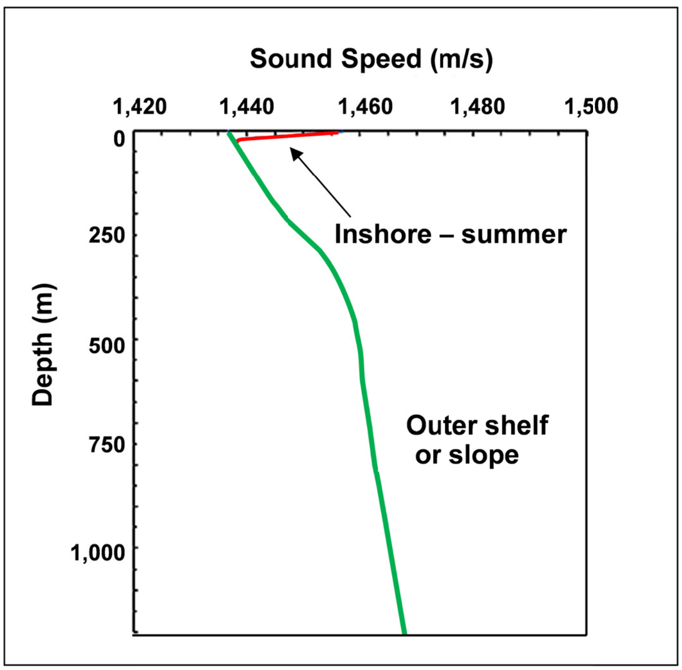

Figure 10-3: Typical Sound Speed Profiles in the LSA

In the deep water of the outer shelf and slope, the sound speed minimum forms a surface sound channel where sound can travel long distances with relatively low losses. The rate of loss depends on the roughness and scattering properties of the surface. This includes the underside or bottom of the ice cover and the air-water

10.1.7 ACOUSTIC CONDITIONS (cont'd)

interface (Milne 1967, Thode et al. 2010). In the nearshore and shallow shelf waters, sound propagation will be more variable in summer, influenced by the Mackenzie River plume with its warmer, fresher water, which is both spatially and temporally variable. In the shallow shelf waters, sound propagation involves multiple surface and bottom reflections, and losses with distance are more dependent on the acoustic properties of the seafloor. Various sources of climatological sound speed data and geoacoustic properties of the seafloor in EL 477 were documented as a component of a 3-D seismic survey carried out in the program area in 2009 for BP by JASCO.

Under ice-free conditions, the ambient noise in the Beaufort Sea is attributed to wind over the ocean surface, precipitation, biological sources and, to the extent that they are present, shipping and industrial sources. When ice cover is present, the character and level of ambient noise differs significantly compared with ice-free conditions. Under a mobile pack ice, ambient noise can be several decibels (dB) higher, while under landfast ice, noise levels might be very low (Milne 1967). Recent measurements conducted during the FDCPs with marine autonomous recording unit equipment provided data on summer and fall low-frequency ambient noise on the shelf and over the slope in the EL areas, including instances of seismic survey activity (Cornell University 2011a).

10.2.1 ICE ZONES

As shown in Figure 10-4, sea ice in the Canadian sector of the Beaufort Sea can be divided into distinct categories or regimes, the:

- landfast ice zone
- active shear zone
- transition zone
- offshore polar pack zone

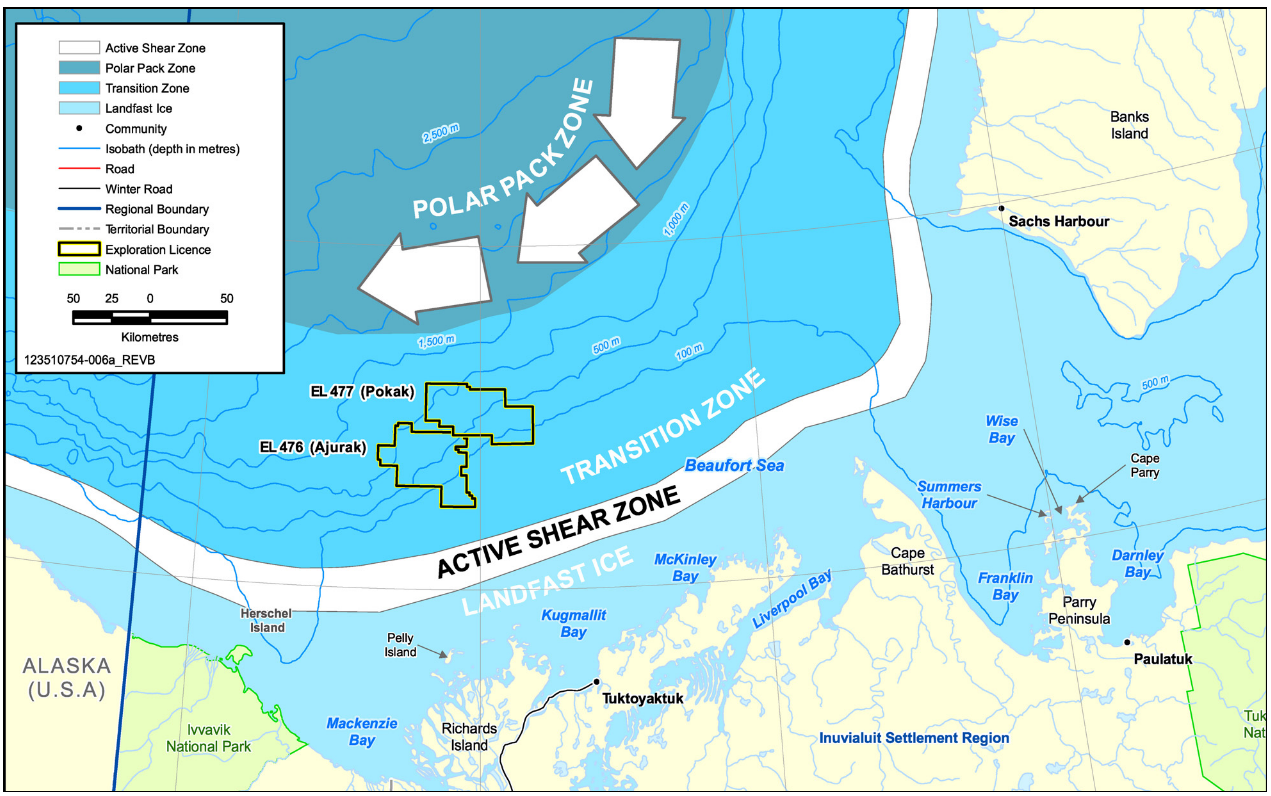

Figure 10-4: Schematic Representation of Zones of Ice Dynamics in the Beaufort Sea

The seasonal first-year landfast (largely immobile) ice cover forms in the shallow water portions of the continental shelf in the fall, and disperses and melts in the following summer.

A transition zone lies landward of the polar pack ice that might be present in the EL areas at some times of the year, as well as over the outer and mid-shelf.

10.2.1 ICE ZONES (cont'd)

Typically, this transition zone is associated with high concentrations of first-year ice and a gradual degradation of the anticyclonic (clockwise) average flow. Degradation appears most strongly in the form of higher variability and lower average ice drift in the most southern areas, where a dynamic shear zone is often separately designated to denote regions of intense ice deformation near the flow discontinuity defining the offshore edge of the landfast ice zone.

The offshore, mobile polar pack ice of the Arctic Ocean describes a large anticyclonic pattern of ice movement related to the Beaufort Gyre.

10.2.1.1 Ice Zone Dynamics

The EL areas are largely situated in the transition zone for sea ice, between the landfast ice on the inner shelf and the Arctic Ocean polar pack ice further offshore. In the transition zone, local navigation and operating conditions are highly sensitive to fluctuations in the character of the offshore ice pack and its seasonal interactions with landfast ice.

According to ice chart information obtained from the Canadian Ice Service for the years 1981 to 2010, ice formation in the EL areas has typically occurred in the middle of October, with ice formation developing seaward from the coastline about two weeks earlier. Ice breakup does not usually occur until late August, although ice can clear as much as four weeks earlier in locations along the shoreline. However, Canadian Ice Service observations from 2000 to 2009 reveal a trend toward sea ice forming later (i.e., the end of October to early November) and clearing earlier (i.e., July). This shift in timing is supported by data on ice conditions obtained with ice profiling (upward-looking) sonars installed on current meter moorings during the 2009, 2010 and 2011 FDCPs (Fissel et al. 2012c) and during a BREA-funded program in 2012.

For nearshore areas, ice formation begins in late September or early October when the outer edge of the offshore ice pack can be as much as several hundred kilometres north of the coastline. In the fall and early winter, ice development is characterized by outward extension and thickening of the nearshore ice cover, punctuated by localized ice deformations generating increasingly deep first-year ice keels. This first-year ice development can be associated with intrusions of thick second-year and older ice (Kovacs and Mellor 1974). Simultaneously, new growth also appears in the offshore ice pack, primarily in areas of open water and thin ice. Rapid deformation of this new and young ice into large first-year ice keels is generally followed by its incorporation into the mixtures of new first year, second year and multi-year-ice, which are typical of the offshore Beaufort Sea ice cover.

10.2.2 LANDFAST ICE

The landfast ice zone forms in the late fall and grows in place until late spring. The thickness and seasonal duration of landfast ice within the Canadian Arctic depends strongly on air temperature and snow cover (Brown and Cote 1992). The outer boundary of the landfast ice is marked by a rubble ice field (stamukhi) formed by grounded ice ridge fragments in winter. Their presence increases significantly with offshore distance at roughly the 10 to 20 m bathymetric contour. Through contacts between their keels and the seafloor, these features inhibit local ice movement, playing a key role in establishing the seaward boundary of the effectively immobile landfast ice. In deeper waters, grounding events tend to occur during periods of negligible or slow gyre-related drift, giving rise to the temporary outward extensions of the seasonal landfast ice boundary.

10.2.3 ACTIVE SHEAR AND TRANSITION ZONES

Shoreward incursions of mobile first-year ice present in the shear and transition zones result in episodic large ice deformation. The shear zone represents the shoreward edge of the transition zone. The episodic ice deformation, driven by strong winds usually from the northwest, results in high ice stresses as the drifting ice of the polar pack ice zone encounters the landfast ice and the shallower waters adjoining it. Individual ice floes impinge upon each other or push against weaker ice, producing areas of ice that are ridged, rafted or rubbled further. In some cases, this ice becomes grounded and pushed upward, embedding itself in the outer part of the landfast ice zone. This highly deformed ice, often referred to as stamukha, might take the form of an elongated hummock or series of hummocks. When the scale of the hummocked sea ice becomes massive, the resulting features are referred to as floebergs, which can extend over distances of many kilometres parallel to the coastline with sail heights of 5 to 25 m. The remnants of such grounded sea-ice features can persist as significant ice hazards during the summer navigation period.

10.2.4 MULTI-YEAR ICE

While first-year ice is predominant in the Arctic Ocean, some of the sea ice is older, having survived at least one summer. In recent years, this older ice has been limited to the polar pack zone. Old sea ice is classified into two categories:

- second-year ice
- multi-year ice

Multi-year ice is predominant throughout the year in the deeper waters of the Canada Basin and is less frequent on the outer portions of the Mackenzie Shelf in late summer.

As sea ice ages from year to year its physical, chemical and other properties change (Wadhams 2000). The salinity is reduced as brine channels are evacuated and frozen over, increasing ice hardness. This change accounts for the more hazardous nature of encounters with multi-year ice as compared to first-year ice. The topography of multi-year ice also changes, becoming smoother on the top and bottom as a result of partial melting in the summer. For shipping operations, including those associated with stationkeeping during drilling unit operations,

10.2.4 MULTI-YEAR ICE (cont'd)

occasional incursions of multi-year ice under the influence of onshore winds are predicted, especially in a less favourable ice year.

The properties and behaviour of multi-year ice in the Beaufort Sea, especially in areas north and northeast (or upstream) of the EL areas, have been studied with ship-based and airborne methods during the 2009, 2010 and 2011 FDCPs. This work and projects carried out by other groups has led to (and provided justification for) major BREA programs on multi-year ice. These BREA programs, which are ongoing, and supported by other agencies or groups, are summarized by Barber et al. (2013), Haas et al. (2013) and Johnston (2013).

10.2.5 EXTREME ICE FEATURES

Hazardous sea-ice features in the Canadian sector of the Beaufort Sea include large individual ice keels and segments of highly concentrated large hummocky (rubbled) ice. Individual large ice keels can be up to 20 m thick or more, while large hummocky ice features, including floebergs, have greater horizontal scales of 100 m to several hundred metres with lesser ice thicknesses ranging from a few to several metres (Fissel et al. 2012b). Upward-looking sonar data sets obtained in the EL areas during the FDCPs involved full-year measurements at multiple locations (Fissel et al. 2012c) and yielded several observations of ice keels exceeding 15 m in draft (thickness below sea surface).

Ice island fragments are infrequent in the offshore waters of the Canadian sector of the Beaufort Sea. They have their origins in parent ice islands which are large detached sections of glacial ice shelves formed from tidewater glaciers and ice sheets. They usually appear first off northern Greenland and the northernmost Arctic Islands (Ellesmere and the Axel Heiberg islands) and drift south-westward through offshore portions of the Canadian Arctic Archipelago and into the Canadian sector of the Beaufort Sea. This large continuous shelf ice began to break up at much increased rates early in the last decade with complete loss of the Markham and Ayles ice shelves and significant mass loss of the Ward Hunt, Milne, Petersen and Serson ice shelves (e.g., Copland et al. 2007). The features were very thick (greater than 40 m) and extend in area from hundreds of metres to kilometres in radius (D.G. Barber, personal communication). The larger ice islands are often marked with air-droppable satellite beacons to facilitate tracking these hazards. Ice islands are typically present further north than the EL areas. For example, during the 2011 FDCP, three ice island fragments were observed and tagged with position-tracking beacons off the northwest coast of Banks Island. These extreme ice features were not observed in the LSA during the 2009 and 2011 FDCP ice studies, nor were they present in this area during the BREA program work conducted in 2012 (Barber et al. 2013).

10.3.1 BACKGROUND

In general, the low average air temperatures over the Beaufort Sea and along the western Arctic coast (associated with the high northern latitudes and the high degree of seasonality) are linked to the formation of sea ice and permafrost conditions. The large-scale atmospheric circulation over the Western Arctic Ocean is the most important factor in determining oceanographic and sea ice movement patterns.

10.3.2 TEMPERATURE, PRECIPITATION AND FOG

Despite the low incidence angle of sunlight, the meteorology of the Beaufort Sea is driven by the cyclical amount of daylight (Overland 2009). Observations at the Tuktoyaktuk ‘A’ meteorological station show that the mean air temperature exhibits a large seasonal cycle between -27°C in the winter and 10°C in the summer (EC 2013). By October, mean temperatures are generally well below freezing at -7°C and remain at subfreezing values until June. Further to the northeast at Sachs Harbour, the air temperature is typically a few degrees colder with the minimum reaching -29°C.

Cold Arctic air holds little moisture resulting in low overall precipitation rates with much of the precipitation occurring in the form of snow (NSIDC 2013). At the Tuktoyaktuk ‘A’ station the mean annual total rain is 8 cm with most of this occurring from June to September (EC 2013). Snowfall occurs year-round with 97% of it occurring between September and May.

Fog occurs in late spring and onwards through the summer, in association with warmer air masses (influenced by coastal areas and large areas of open water) that are advected over the sea or with low air temperatures. During the spring and fall shoulder seasons when open water persists longer in the presence of cold air temperatures, fog can occur more frequently.

10.3.3 WIND CLIMATOLOGY AND STORMS

Atmospheric patterns in the Arctic have significantly changed since 2007 and are now characterized by high seasonal, interannual, and regional variability (Liu et al. 2012, Serreze and Barry 2011).

Since 1996, the Beaufort Sea high-pressure system has become stronger, enhancing the predominant easterly winds in the Beaufort Sea with larger increases at more offshore locations (Moore and Pickart 2012, Schulze and

10.3.3 WIND CLIMATOLOGY AND STORMS (cont'd)

Pickard 2012). These changes in high pressure are shown in Figure 10-5. Inshore surface winds have exhibited only small or negative trends over the last 50 years (Fissel et al. 2009 and 2013, Hakkinen et al. 2008, Martinez et al. 2011).

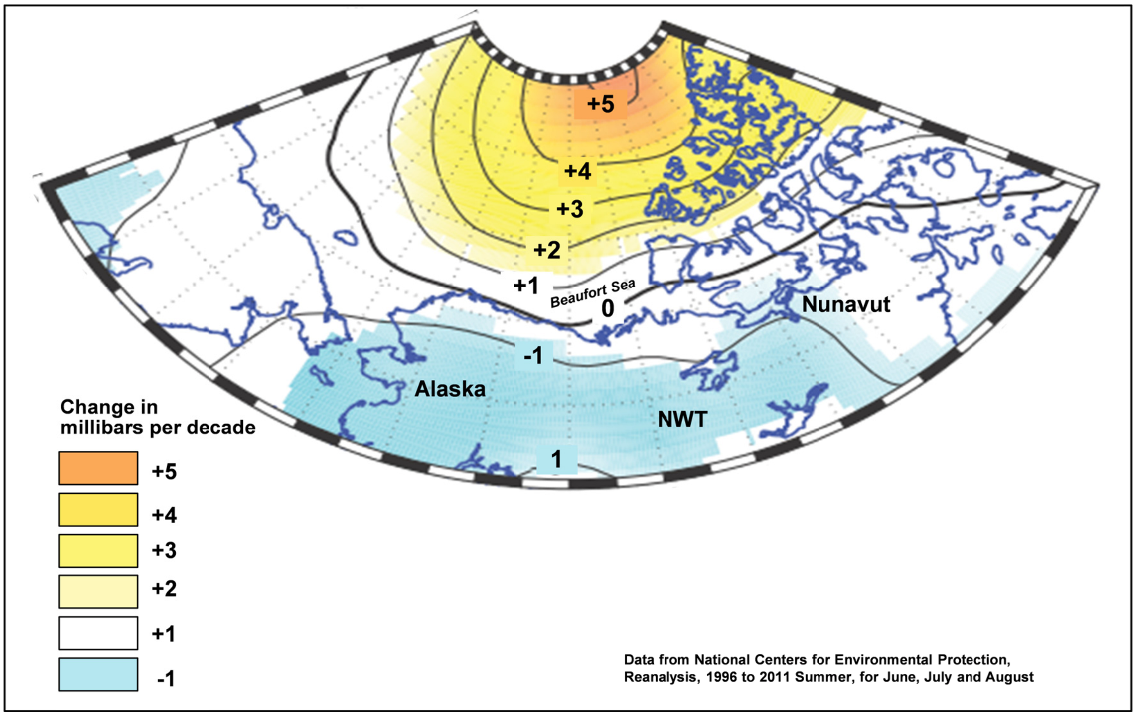

Figure 10-5: Atmospheric Pressure Trends in Sea-Level Pressure in the Program Area, 1996 to 2011

Cyclonic low-pressure systems are important in the Arctic, especially during the summer and fall. Typical Canadian summer storm tracks are shown in Figure 10-6. Several distinct systems have been identified (Asplin et al. 2009, Zhang et al. 2013). More cyclones tend to follow the sea ice–ocean interface, causing ice edge retreats as these storms move further offshore (Hakkinen et al. 2008, Moore and Pickart 2012, Overland et al. 2012). There has been an increase in the depth of offshore low-pressure systems but not an increase in the frequency of cyclones (Lukovich and Barber 2006, Lukovich et al. 2009, Barber 2012 personal communication).

Polar lows, which are an uncommon occurrence in the Beaufort Sea, are low-level and small-scale features that form near the ice edge or in coastal regions where cold air flows from ice or land surfaces over open water. As the cold air warms and rises, the pressure falls and a cyclonic circulation is created, often generating strong winds. The duration of polar lows over a particular location can be less than other low-pressure systems, often one day or less.

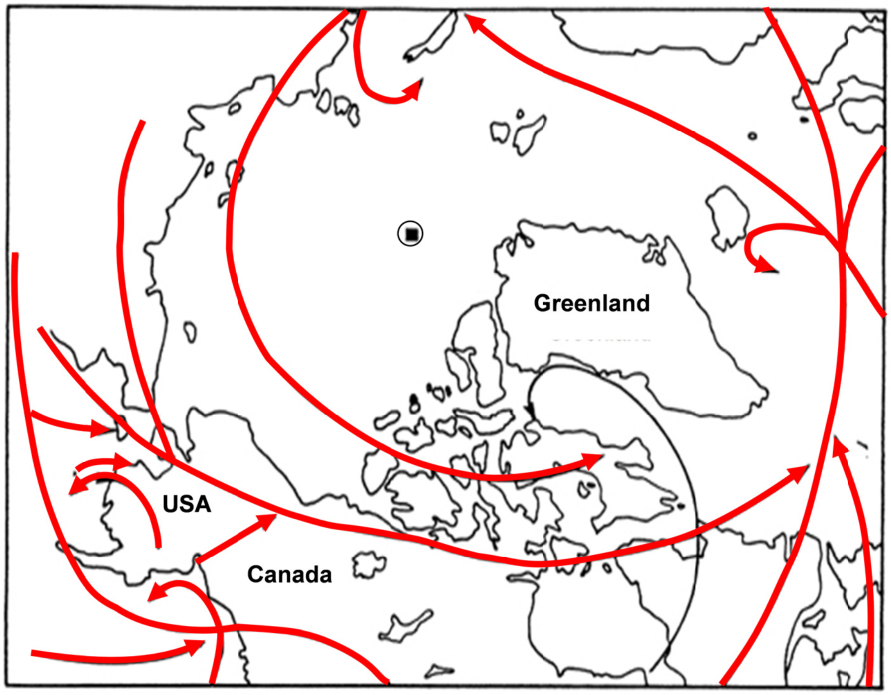

Figure 10-6: Typical Canadian Summer Storm Tracks

10.3.4 ICING FROM FREEZING PRECIPITATION OR SEA SPRAY

The accretion of ice on marine vessels and superstructures occurs when water droplets produced by freezing rain, drizzle, wet snow, super-cooled fog or sea spray in the atmosphere are present in below-freezing air temperatures (Overland 1990).

Generally, freezing spray has the greatest potential for marine icing incidents during the fall. During this period the air temperatures are significantly below 0°C and open water is still prevalent in Baffin Bay, Davis Strait and the northern portions of the Labrador Sea. Although it occurs less frequently, incidents of freezing spray in the western Arctic and Beaufort Sea have been reported, with extreme cases of ice accumulation exceeding 15 cm (Canadian Coast Guard 2013). As shown in Figure 10-7, the potential for freezing spray increases with the degree of subfreezing air temperatures and the wind speed (Overland et al. 1986, Overland 1990).

10.3.5 AIR QUALITY

Ambient air quality over the Beaufort Sea (in offshore and nearshore environments) is influenced by local, regional and non-regional air emissions, which are subject to various physical processes, such as:

- atmospheric transport and dispersion

10.3.5 AIR QUALITY (cont'd)

- wet and dry removal
- surface exchange between the atmosphere and terrestrial or marine environment
- chemical transformation processes

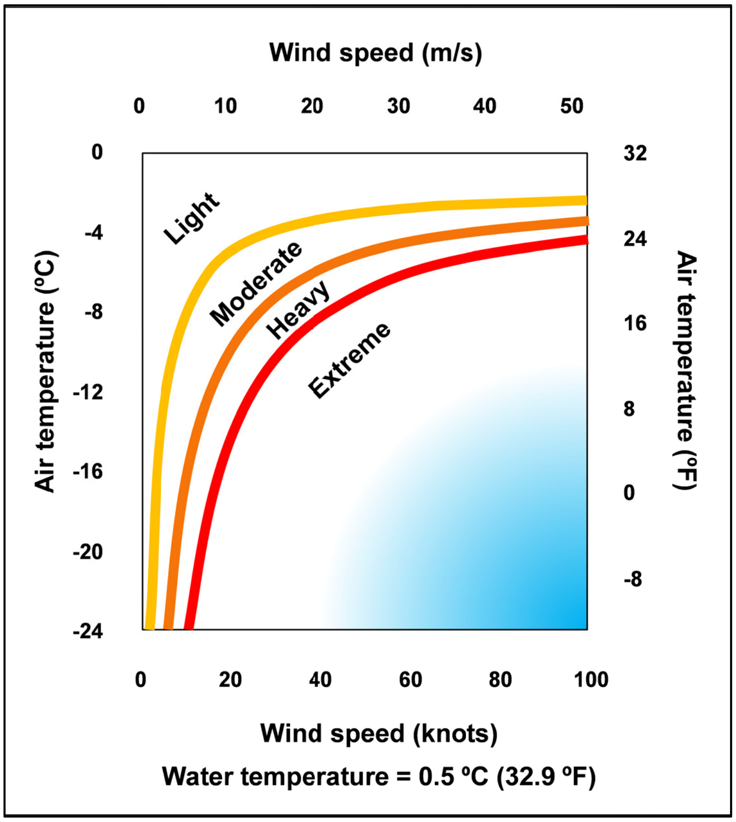

Figure 10-7: Freezing Spray Air Temperatures and Wind Speeds for Typical Water Temperatures During the Fall in the Canadian Beaufort Sea

Most contaminants found within the Arctic result from the long-range transport of pollutants from the industrialized areas of Europe, North America and Asia (AMAP 1998). Atmospheric contaminants include:

- black carbon, i.e., soot
- persistent organic pollutants, e.g., organochlorine pesticides and industrial chemicals
- combustion products, e.g., polycyclic aromatic hydrocarbons (PAHs)
- heavy metals

Emissions from sources beyond the Arctic also result in low but widespread levels of sulphur and nitrogen compounds within Arctic regions (AMAP 1998).

This sulphur, in the form of sulphate, augmented by humidity effects and ice crystals, can result in the formation of Arctic haze (Shaw 1995), which can reduce visibility to a few kilometres or less. Arctic haze is most common during the winter because of inversions that are typical of the cold and stable conditions during Arctic winters (AMAP 2006). However, fall and winter surface inversions are weakening under warming air temperatures, which has the potential to increase the amount of surface air temperature increases resulting from climate change (Bintanja et al. 2011).

In Tuktoyaktuk, local emission sources include:

- home heating and cooking
- power generation
- fuel storage
- transportation

Ambient air quality information is not available for Tuktoyaktuk. However, the GNWT collects ambient air quality data in Inuvik. The Inuvik monitoring station has been operating since 2003 and measures particulates (GNWT 2011a):

- less than 10 microns (PM_{10}), such as:
    - sulphur dioxide (SO_2)
    - ozone (O_3)
    - nitrogen dioxide (NO_2)
    - hydrogen sulphide (H_2S)
- less than 2.5 microns ($PM_{2.5}$)

10.4.1 SEDIMENT TYPES AND PROCESSES

Sediments in the Beaufort Sea are generally thick and span the full range of grain sizes from clays to sands and gravels. Sedimentation has been strongly influenced by:

- glacial processes
- the deposition of suspended material from the Mackenzie River plume and resuspension, transportation and redeposition at some locations along the shelf break
- sea-level change over geological timescales

10.4.1.1 Sediment Dispersal

In the upper part of the sediment column there is evidence from multi-beam and sub-bottom profiling surveys that recent sedimentation has buried glacial landforms, shorelines and outwash deposits when the sea level was about 120 m lower than present during the last ice age (Törnqvist et al. 2006).

The Mackenzie River plume, consisting of fresh water, dissolved material and suspended sediment, flows across and along the shelf to the northeast, under the influence of the Coriolis and the regional wind field during ice-free periods. Some of the plume, as it mixes with seawater on the middle and outer shelf during summer and fall, particularly during prolonged periods of easterly or northeasterly wind, can be transported to the west or southwest when these waters become part of the surface circulation driven by the Beaufort Gyre. In some cases, eddies generated by meanders in the plume can transport suspended material even further offshore.

Typical estimated sedimentation rates determined from age dating on recovered cores range from 0.1 mm/yr to 1.3 mm/yr within the EL areas (Fugro 2011, Bringue and Rochon 2008). Rates of 0 to 2 mm/yr are typical for the Beaufort Shelf, with some evidence that the sedimentation rate has slowed in recent times (Richerol et al. 2008, Scott et al. 2008). In the EL areas, work conducted as part of the FDCPs identified that on the outer shelf and slope, sediments are typically silt and clay, which can also include ice-rafted debris in the form of pebbles, sand and clay balls (Fugro 2011).

10.4.1.2 Geotechnical Properties

Geotechnical properties of samples obtained in the upper sediments in the EL areas have a high plasticity index of 35 to 50 and water content of 65 to 110% consistent with a normally to lightly over-consolidated marine clay. The measured undrained shear strength and compressibility are within the expected range for such sediments (Fugro 2011).

10.4.1.3 Ice Scour

Ice scouring is a particular feature of sediments in ice-covered waters that are identified as almost linear grooves on the seafloor. Observed ice keels appear to be limited to about 60 m, but relict scours are apparent in deeper waters on the slope and outer shelf. During the 2010 FDCP, a paleo-scour zone was identified within the upper slope area of EL 477, in which grooves on the seafloor are interpreted to be the expression of a buried ice keel-scoured surface, generally between 5 and 40 m below the seafloor. There is evidence that disturbance related to ice scouring completely remoulds near-surface sediments (depending on water depth, sediment type and ice regime) to depths of 2 to 4 m.

Bottom-fast ice in coastal areas, such as along the Tuktoyaktuk Peninsula, can rework sediment as well. Ice-bonded sediment can include marine soils that are attached or frozen into or onto the ice bottom. This bottom-fast sediment is mobilized during melting or ablation and breakup when the ice detaches from the bottom and either continues to melt in place, or drifts to another location under the influence of wind and surface currents.

10.4.1.4 Sediment Studies

To study contaminants within sediment, samples were collected during the 2009 FDCP in EL 476 for analysis of:

- metals
- parent and alkylated PAHs
- alkanes

During the 2010 FDCP in EL 477, samples were obtained for analysis of:

- metals
- parent and alkylated PAHs
- alkanes
- polychlorinated biphenyls
- acid base neutral extractable organic compounds
- petroleum hydrocarbons (benzene, toluene, ethylbenzene and xylene F1 and F2 to F4)

Large volume seawater sampling for analysis of parent and alkylated PAHs and alkanes in solution and on particulate was also carried out each year. The sediment results indicated that:

- concentrations of metals, PAHs and polychlorinated biphenyls were relatively low compared to available sediment quality guidelines
- alkane and PAH concentrations were within the range of concentrations previously reported for uncontaminated Beaufort Sea surficial sediments (Yunker et al. 1996, AMAP 1998 and 2007, Devon 2004)
- the predominant source of the PAHs in the sediment samples collected appeared to be petrogenic, which is consistent with AMAP (1998) and Yunker et al. (1993) recognizing that the Mackenzie River delivers petroleum hydrocarbons to the southern Beaufort Sea after flowing through a drainage basin rich in petroleum hydrocarbon deposits

During the 2009 FDCP, surficial sediment samples were collected from coastal stations in the Beaufort Sea area and in Tuktoyaktuk Harbour and its approaches, for analysis of metals and hydrocarbons (PAHs and alkanes). Concentrations of metals and PAHs in these nearshore areas were relatively low compared to the *Canadian Interim Sediment Quality Guidelines*. However, they were higher than the results obtained in the EL areas in 2009 and 2010.

10.5.1 DESCRIPTION

The bathymetry of the Beaufort Sea is dominated by an extensive shallow shelf, which gradually slopes north to a depth of 200 m before rapidly dropping off to several thousand metres.

Bottom morphology and associated sub-bottom features have been identified using a combination of multi-beam and sub-bottom profiling systems on the CCGS *Amundsen* during the 2009, 2010 and 2011 FDCPs. The sub-bottom features result from several different processes, such as those related to:

- glaciation
- river or stream discharges to the ocean during periods of lower sea level during the last ice age
- scouring or gouging by pressure ridges and other extreme features
- other localized and clustered features, both active and inactive, related to natural seafloor venting processes of gas and fluids that originate from shallow and potentially deeper sources

These sub-bottom features and processes have also been extensively studied by the Geological Survey of Canada, and they continue to be investigated for their potential as geohazards as a component of the multi-year BREA program that is supported by other government programs.

10.5.2 BATHYMETRIC MAPPING

Bathymetric mapping in the Beaufort Sea at the regional scale is acceptable for navigation and planning purposes, and continues to improve. A deep-draft shipping channel has been charted through the Beaufort Sea at mid-shelf depth by the Canadian Hydrographic Service, largely to avoid a dense distribution of underwater pingo-like features that pose a hazard to shipping. In the EL areas, accurate, high-resolution data on water depths was obtained during the 2009, 2010 and 2011 FDCPs, and during 3-D seismic surveys conducted by Imperial in 2008 and BP in 2009.

10.6.1 CURRENTS AND CIRCULATION

The currents in the inshore and coastal areas are dominated by wind forcing, but are also affected by the Mackenzie River plume, tides and ice extent (Thomson et al. 1986, Carmack and Macdonald 2002). Current measurements obtained during the 2009 FDCP, included one-day to two-day studies of four harbours (Tuktoyaktuk Harbour, Summers Harbour, Wise Bay and McKinley Bay) (Fissel et al. 2012c). The measurements from these studies indicated strong horizontal gradients in the currents (i.e., 40 cm/s to less than 10 cm/s over just a few hundred metres) in relation to large horizontal salinity, temperature and turbidity gradients associated with density fronts related to Mackenzie River plume waters (Fissel et al. 2012c).

Extensive historical ocean current data sets for inshore areas are also available, mostly from the late 1970s to late 1980s.

10.6.2 WATER PROPERTIES

Water in the inshore portion of the Mackenzie Shelf is a combination of fresh water from the Mackenzie River along with incursions of Arctic Ocean waters (Thomson et al. 1986). The water properties vary over short distances and over a few days according to the dominant river discharge and wind forcing. These dynamic conditions lead to the formation of large frontal features in the nearshore waters, especially between the Mackenzie River plume and the shelf Arctic waters. The fresh waters mix with marine waters and a relatively fresh mixed layer forms along the coastal areas and maintains a strong thermohaline (or temperature-salinity) gradient in the southern Beaufort Sea. These conditions are largely responsible for the basin’s surface-water stratification. This can be important in the aggregation of plankton and zooplankton for feeding by fish and marine mammals (e.g., Thomson et al. 1986, Carmack and Macdonald 2002). These processes, and other aspects of coastal oceanography in this area, are well described in a synthesis by Macdonald and Yu (2006).

The Mackenzie River is the largest river system that influences the Beaufort Sea. It annually transports about 130 million tonnes of sediment and 18 million km^3 of fresh water into the Beaufort Sea. The Mackenzie River does not form a single coherent plume. Consequently, several distinct temperature, salinity and turbidity fronts might be present on the Mackenzie Shelf as a diffuse plume at any given time (Carmack et al. 1989). Oceanographic surveys show the plumes that form as surface layers of turbid freshwater discharge extending seaward over the saline

10.6.2 WATER PROPERTIES (cont'd)

Beaufort Sea water (Carmack and Macdonald 2002). However, the size, shape and direction of the plumes are strongly influenced by winds.

Easterly winds create upwelling, causing plume waters to extend into offshore areas up to several hundred kilometres. However, westerly winds typically force plume waters against the coast and enhance the flow of this water along the Tuktoyaktuk Peninsula (Carmack and Macdonald 2002).

10.6.2.1 Spatial Variability

The extent and location of the Mackenzie River density fronts is variable and dependent on runoff, currents, winds and wave conditions. Belkin et al. (2003) note that: "under favourable ice/wind conditions, the Mackenzie River plume can spread across the Canadian shelf and extend well into the open ocean, as far as 400 km away from its source, being clearly visible in satellite imagery" (also noted in Borstad 1985, Thomson et al. 1986, Macdonald et al. 1999). The plume extent was investigated in the 1980s (Fissel et al. 1987) and again during the 2009 FDCP. Ship-based measurements of near-surface temperature, salinity and turbidity were obtained (Fissel et al. 2012c). The surface expression of the density fronts can be observed across the shelf, occurring in water depths of 20 to 80 m.

The intense Mackenzie River plume waters are characterized by salinities of less than 10 to 14% practical salinity unit and temperatures greater than 6 to 10°C. The diffuse plume waters have temperature and salinity values at intermediate ranges (Fissel et al. 1987). The diffuse plume can extend further offshore (up to 200 km in some cases) and along the shore as far as Cape Bathurst and across the Alaskan border (Thomson et al. 1986). In some years the Mackenzie freshwater discharge influence can be observed westward to the Alaskan Shelf.

Under-ice plumes have been traced west to Herschel Island and east to the tip of the Tuktoyaktuk Peninsula. During the winter, the plume spreads slowly under landfast ice and tends to move eastward along the Tuktoyaktuk Peninsula, extending seaward to the rough ice (stamukhi) zone (rubbled ice field), at about 20 m water depth (Carmack and Macdonald 2002).

10.6.2.2 Seasonal Variability

Seasonal variations in discharge from the Mackenzie River, ice formation, breakup and winds are reflected in the seasonal character of the river density fronts. The Mackenzie River flows year-round, with peak discharges from mid-May to June and with strong outflow during late May through September (Carmack et al. 1989, Carmack and Macdonald 2002). During the ice-free months, the density front reaches its maximum seaward extent. The reduced outflow during late fall and winter, along with formation of landfast and offshore ice, results in a narrower plume and density fronts nearer the shore.

Generally, fresh water input is lower in late winter (about 4,000 m^3/s) and accumulates behind an ice dam near the mouth of the Mackenzie River

(Macdonald et al. 1989). This damming results in the eventual formation of a large mass of fresh or brackish water, known locally as Lake Mackenzie. Lake Mackenzie floats above underlying marine water further out into the estuary. This mass of fresh water covers an area of about 12,000 km^2 and has a volume of about 70 km^3.

10.6.3 WAVES

During the 2009 FDCP, directional wave measurements were obtained in water depths of 15 m along the proposed marine resupply corridor between the EL areas and Tuktoyaktuk Harbour (Fissel et al. 2012c). The EC model wind-wave study (Swail et al. 2007) also provided wave results, although these results might not be fully representative of present conditions.

10.6.4 STORM SURGES

Changes in water levels associated with wind-driven storm surges in combination with the small tides of the region are important in terms of possible flooding of the low-lying coastal lands, especially in the coastal Mackenzie Delta area. Storm surges occur most commonly in late summer and fall, when strong and sustained winds are experienced in the area and the areas of open water are the highest.

Typical water level changes that are caused by positive storm surges (resulting from onshore winds) do not normally exceed 0.5 m, with a typical duration of one to two days (Henry and Heaps 1976). A storm surge that occurred in 1999 is regarded from a traditional knowledge and western science point of view as the largest surge that has affected water levels in the western part of the Mackenzie Delta. This surge had long-term impacts on flooded areas, including vegetation, and was observed more than 20 km up-river by residents of Aklavik (Kokelj et al. 2012).

The effects of storm surges are compounded by rising sea level and coastal subsidence, which is occurring in some areas of the western Arctic, such as Tuktoyaktuk and Sachs Harbor. Projections of a continuing rise in sea level and subsidence for some areas of the western Arctic increases the potential risks to infrastructure, such as the shore-based facility and docks.

10.6.5 SEDIMENT DYNAMICS NEARSHORE

In collaboration with other government agencies and industry, the Geological Survey of Canada collected information on sediment dynamics and coastal erosion from previous studies involving aerial reconnaissance and ground-based surveys in the 1980s, 1990s and 2000s. Some data relevant to this situation was collected during the 2009 FDCP and continues to be obtained and interpreted during a multi-year BREA program and other programs.

The present day Mackenzie River Delta started forming during the retreat of glaciers after the last glacial maximum, about 12,000 to 13,000 years ago (Cobb

10.6.5 SEDIMENT DYNAMICS NEARSHORE (cont'd)

et al. 2008). The Mackenzie River Delta includes wetlands, river channels, lakes, barrier islands, deltaic islands and Richards Island, encompassing more than 13,000 km^2 (Hirst et al. 1987). Continuous deposition of sediment over the last 65 million years has built up to a thickness of about 15 km under the southern part of the Mackenzie River Delta. Unlike much of the area to the west, this region was greatly affected by processes during and after the last glaciation (Cobb et al. 2008) and includes characteristic glacial topography and landforms (e.g., eskers, drumlins, moraines and terraces).

In addition to the significant regional role of the Mackenzie River and its delta, other rivers along the coast, including the Firth, Babbage, Blow, Anderson and Horton are locally important (Cobb et al. 2008). Many of these rivers have associated deltas, especially those that discharge through unconsolidated material along the coastal plain to the west and east (Hill et al. 1991, Welch 1993). The sediment that is being deposited on the Canadian Beaufort Shelf consists mostly of clay or silt, with relatively little gravel. Most gravel deposits probably originate from ice rafting or drowned beaches from which the finer sediments have been previously eroded (Carmack and Macdonald 2002). Shelf sediments are also resuspended and transported during storms, especially in late autumn (Carmack and Macdonald 2002).

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

Delta channels are also prone to extensive erosion as a result of high flow velocities and thermal niching (Dome et al. 1982). As a result of this erosion-related process, substantive quantities of suspended sediments are introduced to the southeastern Beaufort Sea.

The effects of coastal erosion are most pronounced along the Yukon North Slope, the western coastline of Banks Island and along the coast near Tuktoyaktuk Peninsula, although other areas of the Tuktoyaktuk Peninsula are likely also subject to increased erosion. The coastline of the southern Beaufort Sea exhibits retreat rates greater than 1 m/yr, although this rate might reach a maximum of 18 m/yr (observed at Shallow Bay in the Mackenzie Delta). These high rates of shoreline erosion can result in unstable and dynamic shoreline habitats. Cliffs located along the Beaufort Sea coast that are formed of unconsolidated frozen material typically erode at rates of 1 to 3 m/yr (Solomon and Forbes 1994).

Coastal erosion is an important local source of sediments, but the relative contribution of coastal erosion to sediment loading in the Beaufort Sea is minor compared to sediments originating from the Mackenzie River (Carmack and Macdonald 2002). However, coastal erosion will probably increase as a result of elevated temperatures resulting from climate change. Warmer temperatures can destabilize frozen sediments and ice that are found in coastal cliffs (Solomon and Forbes 1994).

10.7.1 PHYTOPLANKTON

In the Arctic, the occurrence of phytoplankton blooms is closely associated with the timing and movement of melting sea ice. In the spring, phytoplankton production on the Arctic shelves is often dominated by diatoms. During summer, nutrient limitation often induces a system shift to support the growth of smaller-celled flagellates over larger diatom species, although diatoms might remain abundant if sufficient nutrients are available. Other phytoplankton groups (Hsiao 1976) in the Beaufort Sea include:

- dinoflagellates
- chrysophytes
- blue-green algae (cyanobacteria)

From 2005 to 2007, measurements of phytoplankton production, biomass, and composition in the Beaufort Sea indicated that the eastern Beaufort Sea, including the Mackenzie Shelf, was characterized by low total chlorophyll *a* biomass (mean ± SD = 16.0 ± 5.5 mg m^{-2}) and production (73 ± 37 mg C m^{-2} d^{-1}) in the euphotic zone (Ardyna et al. 2011). The limiting factors influencing primary production in the Beaufort Sea are:

- temperature
- salinity
- nutrient availability
- the amount of light or solar radiation available for photosynthesis, known as photosynthetically active radiation

These factors vary considerably between estuarine areas, polynya zones and marine areas underlying consolidated sea ice.

10.7.1.1 Estuarine Waters

The estuarine region of the Beaufort Sea is characterized by nutrient-poor surface waters and low primary production resulting from strong vertical stratification created by fresh water input from the Mackenzie River and melting sea ice (Carmack and Macdonald 2002). Within the Mackenzie system, phytoplankton concentrations remain relatively level across the river-to-estuary transition, with a marked chlorophyll maximum observed offshore at a depth of about 25 m (Emmerton et al. 2008). Concentrations of nitrate and phosphate in freshwater discharge are lower than in marine waters, while silica and dissolved oxygen concentrations are higher (Holmes et al. 2012). Variations in dissolved nitrate

10.7.1.1 Estuarine Waters (cont'd)

and phosphate concentrations suggest that phosphorus limits total primary production at lower salinities (from between 0 to 10%) and nitrogen limits total primary production further offshore in the Beaufort system (McClelland et al. 2012).

10.7.1.2 Polynya Zones

Primary production in polynya zones is generally weak and dominated by flagellates (Hsiao 1976), except in areas with pronounced upwelling. As the ice breaks up to form a polynya, upwelling creates local nutrient enrichment at the surface, which supports greater primary production than in most nearshore areas (Carmack et al. 2004). Several biological hotspots occur in the Beaufort Sea, including the central Amundsen Gulf and the Cape Bathurst polynya (Williams and Carmack 2008). These areas support the highest abundance and biomass of phytoplankton in the Beaufort Sea (Ardyna et al. 2011).

10.7.1.3 Consolidated Sea Ice

For up to nine months of the year, short daylight hours and thick ice and snow cover strongly limit light availability in the water column. Primary production under the ice is limited to summer (May to August) and is restricted by light availability and by water column stratification (Boetius et al. 2013). During summer, the mixed layer depth is limited to 10 to 30 m (Bourgain and Gascard 2011, Rabe et al. 2011), which constrains the nutrient supply for algal growth (Tremblay and Gagnon 2009). Average estimates for primary production in the ice-covered central Arctic are low, on the order of 1 to 25 g C m^{-2} $year^{-1}$ (Wassmann et al. 2010). However, recent surveys completed in the Arctic suggest that warming trends might actually contribute to enhancing primary production under the ice (Arrigo et al. 2012).

Seasonal sea ice and snow cover were assumed to strongly limit incoming solar radiation (Arrigo et al. 2012) and subsequently impede any significant growth of phytoplankton in the sub-ice environment. Recent reports of extensive blooms beneath fully consolidated pack ice have been associated with increased trans-ice light transmission resulting from a thinning ice cover and proliferation of melt ponds in recent years (Mundy et al. 2009, Nicolaus et al. 2010, Arrigo et al. 2012). Zhange et al. (2010) reported that about 50% of the ice-covered ocean in the Arctic has surface nitrate concentrations greater than 10 µmol l^{-1} in early spring, which are conditions that are highly suitable for sub-ice primary production.

During the spring freshet, low nutrient river discharge displaces richer winter water under the ice. Carmack et al. (2004) demonstrated that landfast ice in the Mackenzie River region delays the onset of phytoplankton production in the water column by about one month over the inner shelf compared to the outer shelf. While this delay is largely a function of light availability, the offshore nutrient regime supports a higher incidence of primary production as well.

The contribution of ice algae to total primary production levels is not well understood, ranging from 0 to 80% in different studies (Hegsdeth 1998, Wassmann et al. 2006). Sea-ice algae are estimated to contribute between 4 and 26% of total primary production in seasonally ice-covered waters (Legendre et al. 1992) and more than 50% in regions covered by ice year-round (Gosselin et al. 1997).

10.7.2 ZOOPLANKTON

Biomass composition within the Beaufort Sea is dominated by three species of copepod (Darnis et al. 2008):

- *Metridia longa*
- *Calanus glacialis/marshallae*
- *Calanus hyperboreus*

Five other species are also abundant (Robert et al. 2009 and 2010) as also identified during the FDCPs:

- *Oithona similis*
- *Microcalanus pygmaeus*
- *Pseudocalanus spp.*
- *Cyclopina spp.*
- *Oncaea borealis*

The abundance and biomass of zooplankton varies seasonally with peaks that are generally observed in August. Total abundance, biomass and species richness increases offshore towards the slope (Robert et al. 2010). Biomass is highest in areas of increased salinity and outside the influence of the Mackenzie River outflow (Bradstreet et al. 1987).

Larval fish, or ichthyoplankton, were also captured at most plankton sampling stations. Larval fish abundance was dominated by Arctic cod (*Boreogadus saida*) and was more abundant at inshore locations than at sampling stations further offshore (Robert et al. 2009 and 2010), which was also the finding during the FDCPs.

10.8.1 SIGNIFICANCE OF BENTHIC INVERTEBRATES

For the purpose of this PD, benthos refers to benthic invertebrates living either on the seafloor (epifauna) or within the seafloor (infauna). In the Canadian Arctic, marine benthos is an important food source for many species of fish, marine birds and mammals (Frost and Lowry 1984). Benthic invertebrates affect the physical environment by redistributing sediment, breaking down pelagic waste and recycling nutrients back into the water column (Conlan et al. 2008). Benthic community composition is largely determined by near-bottom salinity, water temperature levels (Cusson et al. 2007) and other biophysical factors, such as:

- ice scour
- oxygen availability
- sediment particle size
- organic carbon availability from riverine and coastal erosion

Benthos diversity and abundance is also influenced by the degree of pelagic-benthic coupling, which describes the level of organic matter exchange between the pelagic and benthic environments (Renaud et al. 2007).

Data on benthic communities within the Canadian sector of the Beaufort Sea are sparse and originate from either early hydrocarbon exploration investigations (Wacasey 1975, Wacasey et al. 1977, Atkinson and Wacasey 1989) or relatively recent studies (Cusson 2007, Conlan et al. 2008, DFO 2008, Robert et al. 2009 and 2010), including surveys conducted in the program area FDCPs. Results from investigations demonstrate that diversity and abundance varies widely across the continental shelf, with crustaceans, gastropods, polychaetes and echinoderms being the most representative groups.

Benthos in Tuktoyaktuk Harbour is characterized by low abundance and diversity and is mostly dominated by polychaetes and amphipods (Hopky et al. 1994). Conversely, upwelling areas near Cape Bathurst support an increased level of benthos diversity with significantly higher densities observed (up to 17,127 individuals/m^2) than surrounding shelf and inshore areas (about 0 to 3,000 individuals/m^2) (Cusson et al. 2007, Conlan et al. 2008, DFO 2008).

10.8.1.1 Biogeographic Zones

The distribution of marine benthos can be divided into four key biogeographic zones (Wacasey 1975) based on differences in water depth, temperature, salinity and benthic community metrics (diversity and biomass):

10.8.1.1 Biogeographic Zones (cont'd)

- the estuarine
- the transitional
- the marine
- the continental slope

Reported occurrences of larger invertebrates in one or more of the biogeographic zones include giant Pacific octopus (*Enteroctopus dofleini apollyon*), North Atlantic octopus (*Bathypolypus acticus*), snow crab (*Chionoecetes opilio*), toad crab (*Hyas coarctatus alutaceus*) and several squid species (Arctic Laboratories and LGL 1987, Atkinson and Wacassey 1989, Siferd 2001). However, data on these species is scarce given that they routinely escape standard epibenthic sampling devices. Therefore, true distribution and densities of the larger invertebrates are unknown.

10.8.1.1.1 Estuarine Zone

The estuarine zone, which includes all coastal areas influenced by the Mackenzie River, including Tuktoyaktuk Harbour (Hopky et al. 1994), is characterized by water depths less than 15 m with salinity levels of less than 20 ‰ (parts per thousand). At these shallow depths, benthos is strongly influenced by the outflow of fresh water, which creates pockets of low salinity water within inshore areas (up to 0.1 ‰ near the mouth) (Wacasey 1975). Benthic communities in the estuarine zone are characterized by low diversity and low biomass, potentially because of a low species tolerance to fluctuating salinity levels (Wong 2000). Common species present in this zone include polychaetes (*Ampharete vega*), amphipods (*Boeckosimus affinis, Onisimus glacialis* and *Pontoporeia affinis*), cumaceans (*Diastylis sulcata*), mysids (*Mysis femorata* and *M. relicta*), isopods (*Mesidotea entomom*) and bivalves (*Macoma balthica, Cyrtodaria kurriana* and *Yoldiella intermedia*) (Percy et al. 1985, DFO 2008). Echinoderms are generally absent from this zone.

10.8.1.1.2 Transitional Zone

The transitional zone is characterized by water depths between 15 and 30 m with salinity levels fluctuating between 20 and 30 ‰ (Wacasey 1975). The benthic environment at these depths is affected by a high rate of ice scouring, which periodically disturbs local assemblages of benthic invertebrates (Percy et al. 1985). As a result, biomass is typically low in this zone (DFO 2008), although diversity is typically higher than the estuarine zone as it serves as a transitional area for many mobile invertebrates between the estuarine and marine zones. High species richness is also reported in this zone at about 15 m depth (DFO 2008). The bivalve *Portlandia arctica* is particularly abundant in areas where ice scouring rates are high (Conlan et al. 2008). Other common species in this zone include echinoderms, polychaetes (*Artacama proboscidea* and *Trochochaeta carica*) and isopods (*Mesidotea sibirica*) (Percy et al. 1985, DFO 2008).

10.8.1.1.3 Marine Zone

The marine zone is characterized by water depths ranging from 30 to 200 m where salinity fluctuations are minor, 30 to 33 ‰ (Wacasey 1975). The lack of fresh water influence and ice scouring events in this zone, as well as the wide range in water depth, results in higher productivity levels (biomass and diversity) in this zone than the estuarine and transitional zones. Common species include polychaetes (*Maldane sarsi, Aricidea suecica, Paraonis gracilis, Onuphis conchylega* and *Pectinaria hyperborea*), amphipods (*Haploops laevis*), isopods (*Mesidotea sabini*) and bivalves (*Astarte borealis, A. montagui, Macoma calcarea,* and *Macoma spp.*) (Percy 1985, DFO 2008). Other macrofauna observed within this zone include sea stars, octopus and squid.

10.8.1.1.4 Continental Slope Zone

The continental slope zone is characterized by water depths from 200 to 900 m where salinity levels range from 34 to 35 ‰ (Wacasey 1975). This zone supports a homogeneous physical environment marked by lower food availability because of weaker pelagic-benthic coupling than in shallower environments (Morata et al. 2008). Benthic productivity in this zone is variable. Epifaunal biomass is generally lower than in the marine zone while infaunal biomass is typically higher than in the marine zone (Robert et al. 2010). Both epifaunal and infaunal diversity are similar to that observed in the marine and transitional zones, and higher than that in the estuarine zone (DFO 2008). Many of the species occurring on the slope also inhabit the marine zone. However, several species are unique to this area, including the polychaetes *Onuphis quadricuspis* and *Laonice cirrata*, amphipods *Haploops tubicola* and *Hippomedon abyssi*, and the isopod *Gnathia stygia* (DFO 2008).

10.8.2 TRADITIONAL HARVEST

The community conservation plans indicate that edible crustaceans might be harvested along the coastline and the Mackenzie Delta shoreline between Aklavik and Tuktoyaktuk (Aklavik 2008, Inuvik 2008, Sachs Harbour 2008, Paulatuk 2008, Ulukhaktok 2008, Tuktoyaktuk 2008) but do not identify specific species or gathering locations. During interviews completed as part of the 2010 joint venture traditional knowledge study, Tuktoyaktuk participants indicated that crab is harvested (along with other fish species) and that harvesting locations include Tuktoyaktuk Harbour and along the shoreline (Golder 2011a).

10.9.1 PRINCIPAL HABITATS

The Canadian sector of the Beaufort Sea provides a diverse range of fish habitats for marine, freshwater and anadromous species (i.e., fish that travel from the sea up freshwater watercourses to spawn). Three principal habitats exist in the Beaufort Sea region, including:

- freshwater drainages
- nearshore coastal waters
- offshore marine waters

Freshwater streams and rivers, including the Mackenzie River, empty into the Beaufort Sea and are used by both freshwater and anadromous fish. The brackish, mixed waters along the nearshore coastal zone provide important habitat for both anadromous and marine fish. In the deeper offshore waters, varied assemblages of marine fish species can be found.

10.9.1.1 Presence, Distribution, Abundance and Habitat Use

Fish species presence, distribution, abundance and habitat use in the Canadian sector of the Beaufort Sea have been identified as important areas for ongoing research for environmental and social impact assessments (Kavik-Axys 2008, ArcticNet 2011, BREA 2012). According to varied lists compiled by Coad and Reist (2004), Cobb et al. (2008), the Working Group on General Status of NWT Species (2011) and Majewski et al. (2013), about 85 marine and anadromous fish species, consisting of 20 families are thought to occur in the Beaufort Sea LOMA. For a list of the common and scientific names of fish species present in the Beaufort Sea LOMA, see:

- Table 10-1, for anadromous and freshwater fish
- Table 10-2, for marine fish

Table 10-1: Scientific and Common Names of Anadromous and Freshwater Fish Species Present in the Beaufort Sea Large Ocean Management Area

Common Name	Scientific Name	COSEWIC Status	SARA Status
Lamprey	***Petromyzontidae***		
Arctic lamprey*	*Lethenteron camtschaticum**	—	—
Sucker	***Catostomidae***		
Longnose sucker	*Catostomus catostomus*	—	—
Pike	***Esocidae***		
Northern pike	*Esox Lucius*	—	—
Smelt	***Osmeridae***		
Pond smelt	*Hypomesus olidus*	—	—
Rainbow smelt	*Osmerus mordax mordax*	—	
Salmon and Whitefish	***Salmonidae***		
Arctic char	*Salvelinus alpinus*	—	—
Arctic cisco	*Coregonus autumnalis*	—	—
Arctic grayling	*Thymallus arcticus*	—	—
Bering cisco	*Coregonus laurettae*	Special concern (Yukon)	No status – no schedule
Broad whitefish	*Coregonus nasus*	—	—
Chinook salmon	*Oncorhynchus tshawytscha*	—	—
Chum salmon	*Oncorhynchus keta*	—	—
Cisco	*Coregonus artedi*	—	—
Coho salmon	*Oncorhynchus kisutch*	—	—
Dolly Varden	*Salvelinus malma malma*	Special concern	No status – no schedule
Inconnu	*Stenodus leucichthys*	—	—
Lake trout	*Salvelinus namaycush (brackish/freshwater)*	—	—
Lake whitefish	*Coregonus clupeaformis*	—	—
Least cisco	*Coregonus sardinella*	—	—
Pink salmon	*Oncorhynchus gorbuscha*	—	—
Round whitefish	*Prosopium cylindraceum*	—	—
Sockeye salmon	*Oncorhynchus nerka*	—	—
Cod/burbot	***Gadidae***		
Burbot	*Lota lota*	—	—
Stickleback	***Gasterosteidae***		
Nine-spined stickleback*	*Pungitius pungitius**	—	—
Three-spined stickleback	*Gasterosteus aculeatus*	—	—
Sculpin	***Cottidae***		
Slimy sculpin	*Cottus cognatus*	—	—
Spoonhead sculpin	*Cottus ricei*	—	—

Note:
Family names are in bold.
COSEWIC = Committee on the Status of Endangered Wildlife in Canada
SARA = *Species at Risk Act*
* = Larval fish
– = not listed

Table 10-2: Scientific and Common Names of Marine Fish Species Present in the Beaufort Sea Large Ocean Management Area

Common Name	Scientific Name	COSEWIC Status	SARA Status
Skate	***Rajidae***		
Arctic skate	*Amblyraja hyperborea*	—	—
Skates (unspecified)	*Bathyraja sp.*	—	—
Herring	***Clupeidae***		
Pacific herring*	*Clupea pallasii pallasii**	—	—
Smelt	***Osmeridae***		
Arctic cod*	*Boreogadus saida**	—	—
Capelin	*Mallotus villosus*	—	—
Cod	*Gadidae*		
Greenland cod	*Gadus ogac*	—	—
Saffron cod*	*Eleginus gracilis**	—	—
Sculpin	***Cottidae***		
Arctic hookear sculpin	*Artediellus uncinatus*	—	—
Arctic sculpin	*Myoxocephalus scorpioides*	—	—
Arctic staghorn sculpin*	*Gymnocanthus tricuspis**	—	—
Bigeye sculpin*	*Triglops nybelini**	—	—
Fourhorn sculpin*	*Myoxocephalus quadricornis**	Not at risk (salt water form)	No information in SARA list
Hamecon*	*Artediellus scaber**	—	—
Ribbed sculpin*	*Triglops pingelii**	—	—
Sculpin*	*Icelus sp.**	—	—
Shorthorn sculpin	*Myoxocephalus scorpius*	—	—
Spatulate sculpin	*Icelus spatula*	—	—
Twohorn sculpin	*Icelus bicornis*	—	—
Poacher	***Agonidae***		
Arctic alligatorfish*	*Ulcina olrikii**	—	—
Atlantic poacher*	*Leptagonus decagonus**	—	—
Lumpsucker	***Cyclopteridae***		
Atlantic spiny lumpsucker	*Eumicrotremus spinosus*	—	—
Leatherfin lumpsucker	*Eumicrotremus derjugini*	—	—
Snailfish	***Liparidae***		
Gelatinous snailfish*	*Liparis fabricii**	—	—
Greenland seasnail*	*Liparis tunicatus**	—	—
Sea tadpole	*Careproctus reinhardti*	—	—
Variegated snailfish	*Liparis gibbus*	—	—
Eelpout	***Zoarcidae***		
Archer eelpout	*Lycodes sagittarius*	—	—
Aurora pout	*Gymnelus retrodorsalis*	—	—
Canadian eelpout	*Lycodes polaris*	—	—
Eelpout*	*Lycodes sp.**	—	—
Glacial eelpout	*Lycodes frigidus*	—	—
Knipowitsch’s pout	*Gymnelus knipowitschi*	—	—
Longear eelpout	*Lycodes seminudus*	—	—
Saddled eelpout	*Lycodes mucosus*	—	—

Table 10-2: Scientific and Common Names of Marine Fish Species Present in the Beaufort Sea Large Ocean Management Area (cont'd)

Common Name	Scientific Name	COSEWIC Status	SARA Status
Eelpout (cont'd)	***Zoarcidae***		
Shulupaoluk	*Lycodes jugoricus*	—	—
Threespot eelpout	*Lycodes rossi*	—	—
Twolip pout	*Gymnelus viridis*	—	—
White sea eelpout	*Lycodes marisalbi*	—	—
Prickleback/Blenny	***Stichaeidae***		
Arctic shanny*	*Sticaeus punctatus punctatus**	—	—
Daubed shanny*	*Leptoclinus maculates**	—	—
Fourline snakeblenny	*Eumesogrammus praecisus*	—	—
Blackline prickleback Pighead prickleback	*Acantholumpenus mackayi*	Data deficient	Special concern – Schedule 3
Slender eelblenny*	*Lumpenus fabricii**	—	—
Stout eelblenny*	*Anisarchus medius**	—	—
Wolffish	***Anarhichadidae***		
Northern wolffish	*Anarhichas denticulatus*	Threatened	Threatened – Schedule 1
Sand lance	***Ammodytidae***		
Northern sand lance	*Ammodytes dubius*	—	—
Pacific sand lance	*Ammodytes hexapterus*	—	—
Sand lance*	*Ammodytes sp.**	—	—
Right-eyed flounder	***Pleuronectidae***		
Arctic flounder	*Pleuronectes glacialis*	—	—
Bering flounder	*Hippoglossoides robustus*	—	—
Greenland halibut	*Reinhardtius hippoglossoides*	—	—
Starry flounder*	*Platichthys stellatus**	—	—

Note:
Family names are in bold.
COSEWIC = Committee on the Status of Endangered Wildlife in Canada
SARA = *Species at Risk Act*
* = Larval fish
– = not listed

10.9.2 ANADROMOUS SPECIES

Brackish water habitats are found along the Yukon coast and Kugmallit Bay coast during summer (Carmack and Macdonald 2002, Cobb et al. 2008). These locations:

- support an important migration route for juvenile and adult anadromous fish species between the coastal lagoons and estuaries
- provide important nursery and feeding areas

This nearshore area has been characterized as an anadromous fish highway (Carmack and Macdonald 2002 - adapted from Gallaway et al. 1983, Loseto et al. 2010). Runs of anadromous fish species also extend east and west of the Mackenzie Delta during ice breakup and early spring, with fish returning to their natal rivers in the fall to overwinter in fresh water (LGL 1982, Cobb et al. 2008). Freshwater and anadromous fish species also use the northern portion of the Mackenzie Delta for feeding, spawning and rearing (LGL 1982).

The Mackenzie River and other Yukon North Slope Rivers discharge large volumes of fresh water into coastal areas of the southern Beaufort Sea, providing an influx of fresh water that creates low salinity habitats suitable for freshwater species, such as Arctic grayling, northern pike and round whitefish (LGL 1982). Arctic cisco, fourhorn sculpin and least cisco are among the most abundant fish species found along the nearshore area, with Dolly Varden and rainbow smelt also present in the area (Karasiuk et al. 1993, Cobb et al. 2008).

Seasonal changes in salinities influence fish assemblage along the coast. The open-water season is dominated by Dolly Varden, least cisco, broad whitefish, inconnu and other anadromous fish. During ice-cover periods, marine fish species dominate the area, including fourhorn sculpin, saffron cod and other marine species (Karasiuk et al. 1993, Cobb et al. 2008). Anadromous and freshwater fish species in the nearshore waters feed on the abundant small invertebrates and fishes living on or near the bottom substrates (Craig and Haldorson 1981).

Anadromous adult and large juvenile Dolly Varden migrate during the summer months to the coastal areas of the Beaufort Sea to feed (Cobb et al. 2008). Three and four-year-old Dolly Varden migrate and smolt in the estuaries of their natal streams, remaining at these locations during the summer, feeding and growing and following migration patterns along the coast (Sandstrom 1995). Local residents have reported that changes in the water and ocean currents along the Yukon North Slope coastline have resulted in Dolly Varden being found further offshore than in the past (Cobb et al. 2008).

10.9.2.1 Traditional Harvest

The following species are important to local Inuvialuit and Gwich'in harvesters, and are considered to be an important part of the food chain. They might also be considered as VECs:

- Arctic char
- Arctic cisco
- Bering cisco
- broad whitefish
- Dolly Varden
- inconnu
- lake whitefish
- least cisco
- rainbow smelt
- round whitefish

The Dolly Varden is of importance to both the local Inuvialuit and Gwich'in harvesters. Dolly Varden stocks have been declining throughout the Canadian Arctic and are an important management concern for the local communities

10.9.2.1 Traditional Harvest (cont'd)

and DFO. Integrated fisheries management plans and community-based plans are in place to help manage these stocks.

Subsistence fishing occurs all year along the Yukon North Slope coastal areas (especially in locations such as Shingle Point and Herschel Island) and Tuktoyaktuk. Commonly fished species include Dolly Varden, Arctic char, whitefish and Pacific herring (Aklavik 2008, Inuvik 2008, Sachs Harbour 2008, Paulatuk 2008, Ulukhaktok 2008, Tuktoyaktuk 2008). The joint venture traditional knowledge study conducted in 2010 also identified that traditional harvesting also takes place in Tuktoyaktuk Harbour and further north, overlapping the proposed marine resupply corridor to the EL areas.

10.9.3 MARINE SPECIES

There are about 50 species of marine fish in the Beaufort Sea, primarily shelf focused, with relatively few pelagic marine fish species and high benthic marine fish diversity (Majewski et al. 2013). Marine fish species presence in the deeper colder offshore area is known (see Table 10-1, shown previously). However, species distribution, abundance and habitat are not as clearly understood (Majewski et al. 2013). Skates, herring, smelt, sculpins, poachers, lumpfish, flounders, wolffish, sand lance, prickleback/blenny, lumpsucker snailfish and eelpout are found throughout the LOMA.

Cod (*Gadidae spp.*), snailfish (*Liparidae spp.*) and sculpin (*Cottidae spp.*) are among the most frequently reported marine fish collected from the western Beaufort Sea and Canadian High Arctic (Cobb et al. 2008). Similar to anadromous species, marine fish species also use nearshore coastal habitat for feeding during the summer (Bond 1982, Lawrence et al. 1984, Anderson Resources Ltd. 2001). Many marine fish species, such as Arctic cod and snailfish, are dependent on the influx of cold saltwater into the brackish coastal waters nearshore. Other marine species of fish can be found with relative consistency in coastal habitats including fourhorn sculpin and Arctic flounder (Bond 1982, Lawrence et al. 1984).

Pelagic marine fish, especially Arctic cod, are an important food source for marine mammals and birds in the Beaufort Sea ecosystem (Dome et al. 1982, Craig et al. 1982, Cobb et al. 2008). It is generally accepted that additional research is required to fully understand seasonal migrations, populations and distributions of Arctic cod and other marine fish species in the Canadian Arctic. Arctic cod are the most abundant pelagic fish species over the shelf and slope of the Canadian sector of the Beaufort Sea (Geoffroy et al. 2011). Recent studies (Geoffroy et al. 2011 and 2013) have reported aggregations of adult Arctic cod over the slope during fall and winter. During the ice-free season, Arctic cod (+1 year age class) are also distributed over the slope. There are clear segregations between young-of-the-year Arctic cod (less than 100 m depth) and age 1+ Arctic cod (greater than 200 m depth) (Geoffroy et al. 2011 and 2013). Age 1+ Arctic cod are present over the entire continental slope (1,400 to 9,200 m depths) as well as possibly even further offshore (Geoffroy et al. 2011 and 2013).

A higher biomass of Arctic cod was observed at bottom depths of 350 and 1000 m. Within the EL areas, young-of-the-year and adult Arctic cod were shown to have overlapping distributions (Geoffroy et al. 2011 and 2013).

Anadromous fish species make up the most of the local subsistence fisheries as compared to marine species (Bond 1982, Geoffroy et al. 2012). Marine fish species considered as VECs for the program for biological and ecological reasons include:

- Arctic cod
- Arctic flounder (abundant in nearshore coastal waters)
- blackline prickleback (noted as a marine benthic fish of uncertain status with potential vulnerability to disturbance)
- fourhorn sculpin
- northern wolffish (Schedule 1 SARA listing as threatened)
- Pacific herring
- starry flounder (abundant in nearshore coastal waters)

Marine fish species are harvested less in subsistence fisheries than the anadromous fish species (Bond 1982, Geoffroy et al. 2012).

10.9.4 HEARING ABILITY

All fish species can hear with varying degrees of sensitivity within the frequency range of sound produced by seismic sources and other industrial sound sources (Popper and Fay 1973, Fay 1988, Popper and Fay 1993, Fay and Popper 2000). Fish use sound for communication, to detect predators and prey and to learn about their environment (Popper and Fay 1999, Zelick et al. 1999, Fay and Popper 2000, Popper et al. 2003). The hearing range for most fish is believed to be in the frequency range of 100 to 1,000 Hz (Fay 1988). Behavioural responses and the susceptibility of fish to auditory trauma can vary. This is attributed to wide differences in hearing capability and morphologies among fish species (Popper and Fay 1993).

Fish can be divided into two broad categories (Popper et al. 2003, Ladich and Popper 2004):

- hearing generalists
- hearing specialists

10.9.4.1 Hearing Generalist Fish Species

Hearing generalists are fish species without any auditory system specializations. They have relatively poor auditory sensitivity characterized by a narrow bandwidth of hearing. Typically they can detect sounds from below 50 Hz up

10.9.4.1 Hearing Generalist Fish Species (cont'd)

to 1 or 1.5 kHz. Hearing generalist fish species include most bottom-dwelling species (Popper et al. 2003). Most fish species that fall into this category generally do not hear frequencies much above 1 kHz, with peak sensitivities around 300 to 500 Hz (Ladich and Popper 2004).

10.9.4.2 Hearing Specialist Fish Species

Hearing specialists have morphological adaptations that allow them to detect sound pressure with greater sensitivity (i.e., lowering their hearing threshold) and in a wider bandwidth than hearing generalist species. This makes hearing specialist species more sensitive to high-amplitude sound introduced into the marine environment (Popper and Fay 1993). Polar cod and Arctic cod are both hearing specialist species and are likely to be present in the program area. Cod fish can detect both sound acceleration and sound pressure over a substantial frequency range (e.g., 20 to 150 kHz). Sound pressure thresholds in cod fish are in the frequency range of 60 to 300 Hz and lie in the range of 80 to 90 dB re 1 μPa.

10.10.1 OVERVIEW

The Mackenzie River Delta and Beaufort Sea marine ecosystem provide important resources to resident and migrant marine birds throughout the year. Salter et al. (1980) documented 122 bird species using the Arctic Coastal Plain, including those that use the following habitats:

- offshore
- inshore
- intertidal
- salt marsh

These species can be categorized as:

- passerines (including corvids and ptarmigan, 40 species)
- raptors (including owls, 13 species)
- seabirds (29 species)
- shorebirds (24 species)
- waterfowl (16 species)

For the purposes of this PD, seabirds are considered those that feed in salt water and waterfowl are confined to those that feed primarily or exclusively in fresh water (e.g., most ducks and geese).

10.10.2 YEAR-ROUND SPECIES

Of these 122 species, only four are considered year-round residents (Salter et al. 1980):

- common raven (*Corvus corax*)
- gyrfalcon (*Falco rusticolus*)
- snowy owl (*Nyctea scandiaca*)
- willow ptarmigan (*Lagopus lagopus*)

10.10.3 MIGRATORY SPECIES

Most bird species use these locations during the summer for staging, moulting, nesting and brooding purposes (see Figure 10-8) before migrating to their traditional southerly wintering grounds, many of which are outside the ISR (e.g., Arctic terns).

For an overview of key migratory bird habitats in the southern Beaufort Sea region, see Figure 10-9. Figure 10-10 shows the offshore migratory bird sensitivity mapping for the region, as adapted from AECOM.

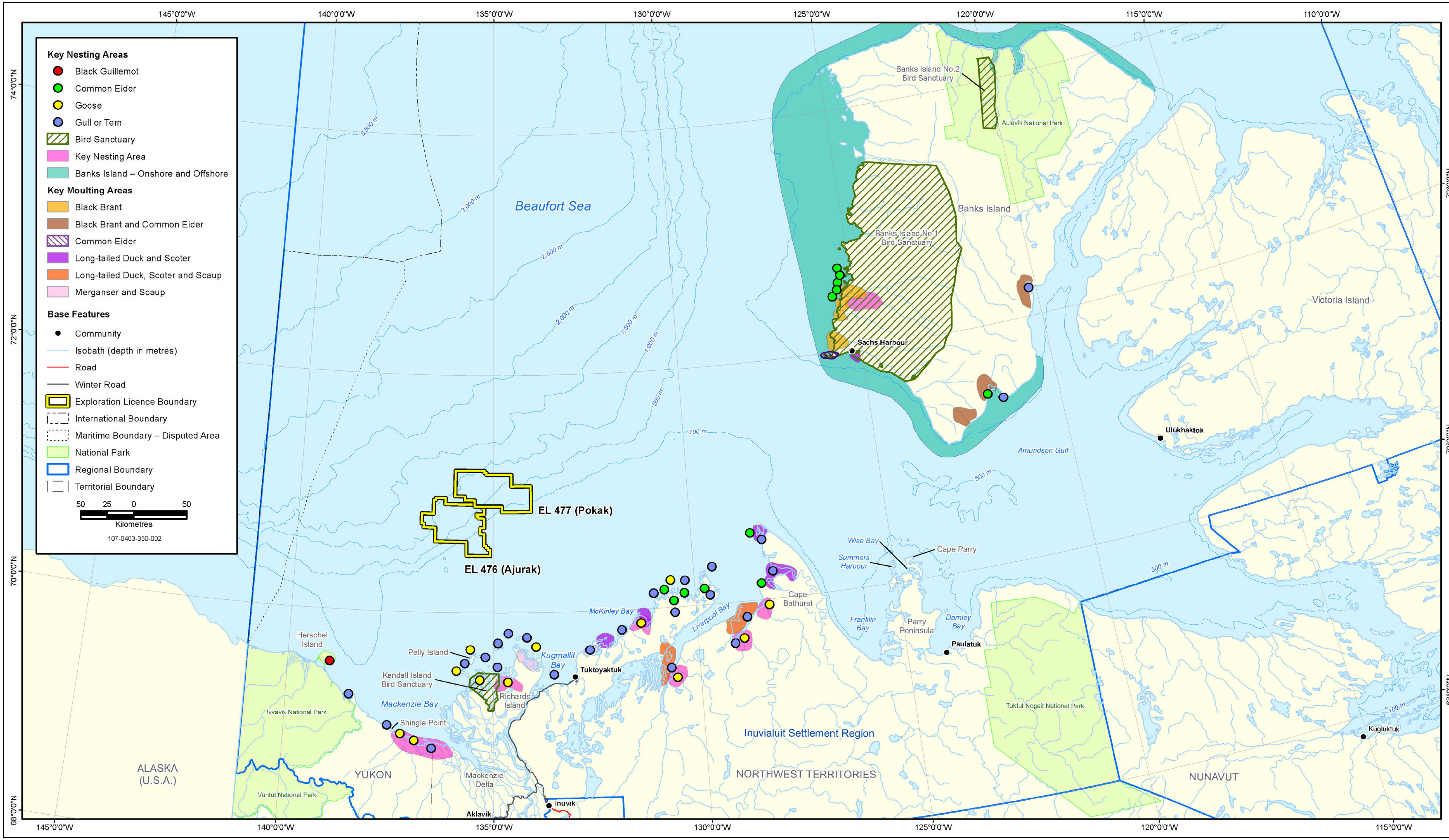

Figure 10-8: Overview of Key Nesting and Moulting Areas for Marine Avifauna in the Southern Beaufort Sea Region

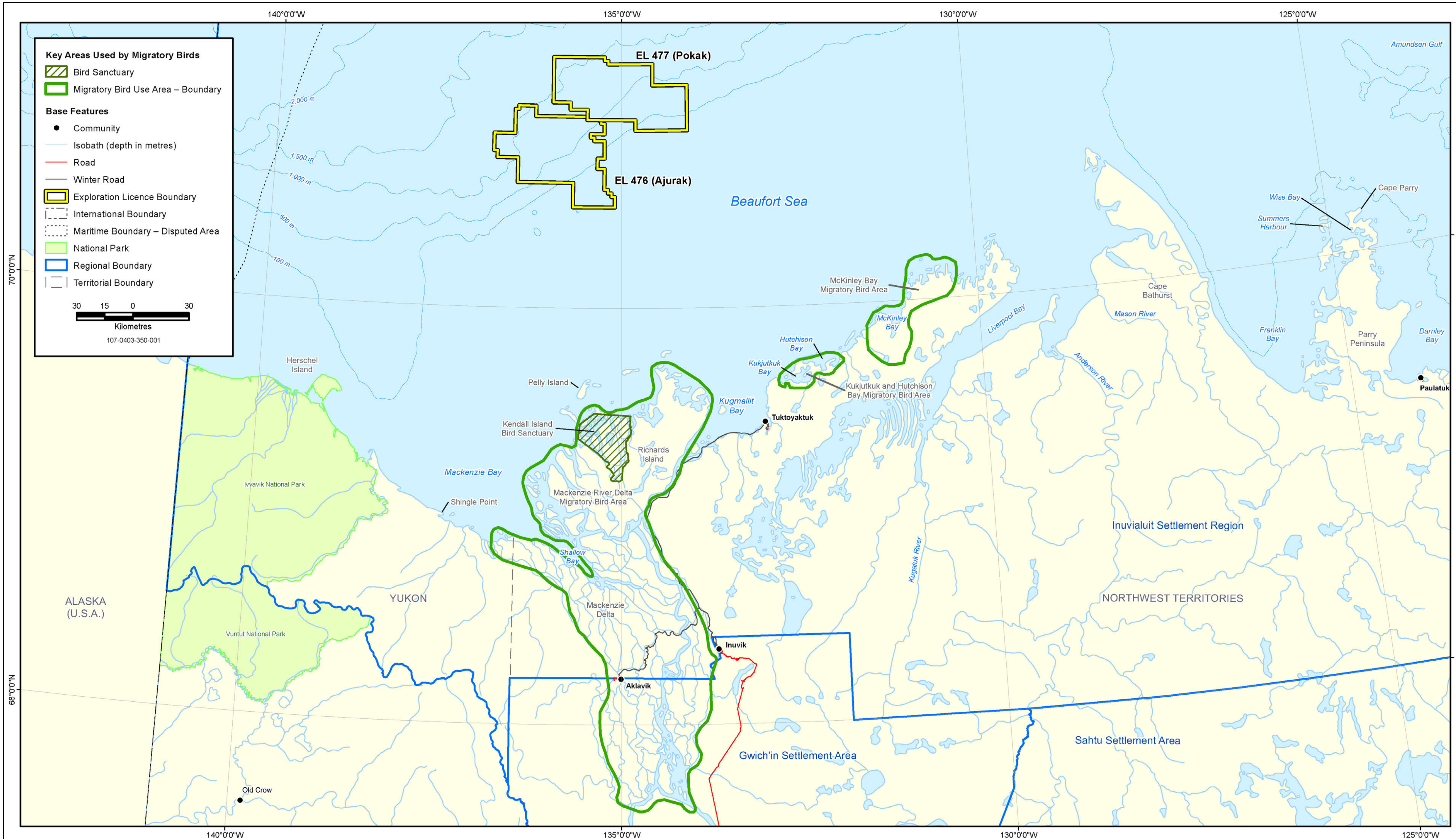

Figure 10-9: Overview of Key Areas Used by Migratory Birds in the Southern Beaufort Sea Region

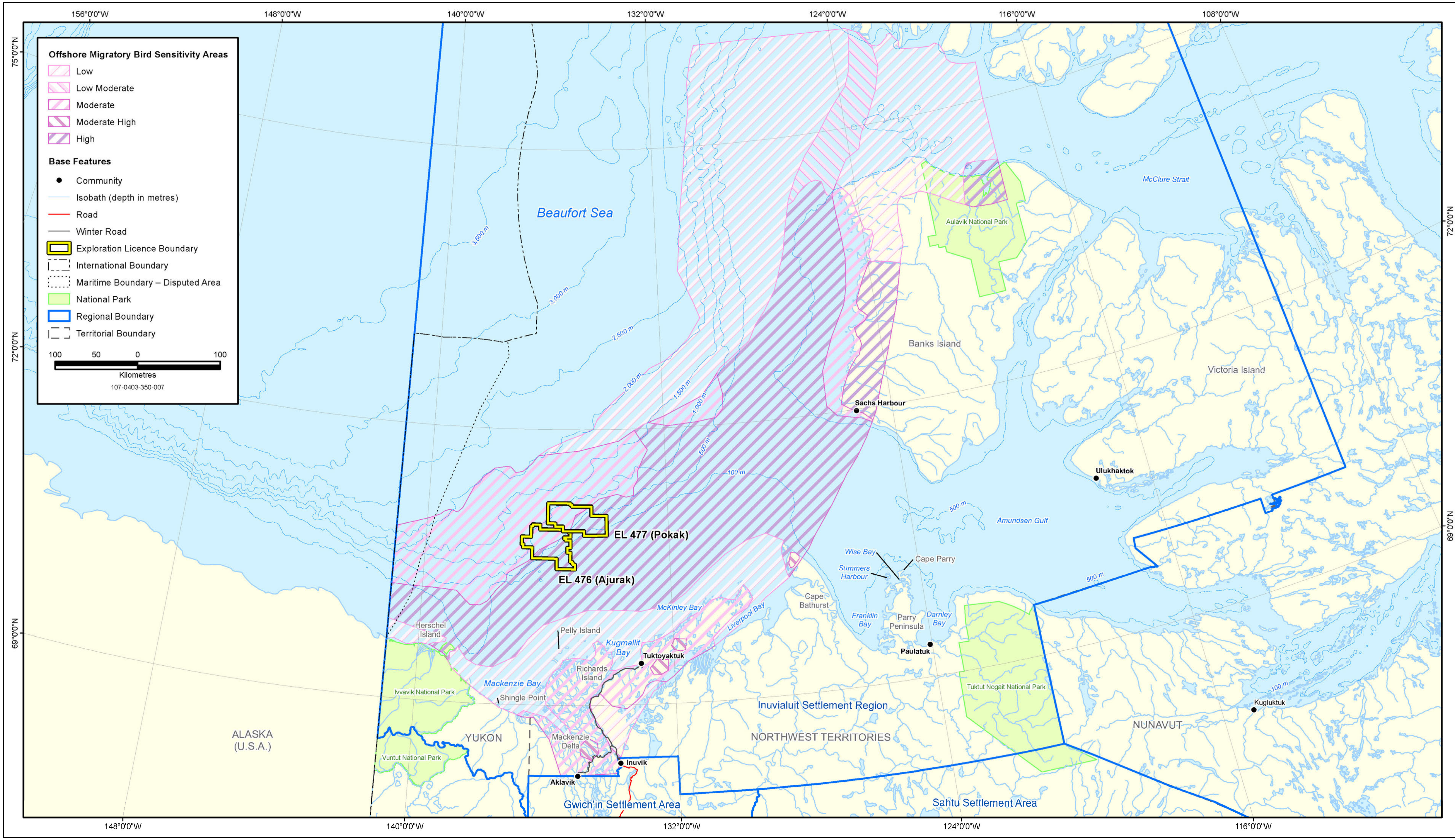

Figure 10-10: Offshore Migratory Bird Sensitivity Areas for the Beaufort Sea Region

10.10.4 MARINE AVIFAUNA SPECIES, DISTRIBUTION AND STATUS

Table 10-3 is a comprehensive list of marine avifauna species present in the Beaufort Sea and Mackenzie Delta ecosystem. This table provides detailed information for:

- seabirds
- waterfowl
- shorebirds
- raptors

Table 10-3: Marine Avifauna Species Present in the Southern Beaufort Sea and Mackenzie Delta Ecosystem

Common Name	Species	Seasonal Occurrence	Distribution	Other Relevant Information	COSEWIC Status	SARA Status
Seabirds						
Arctic loon	*Gavia arctica*	Summer	Coastal	Migratory species	Not assessed	No status
Arctic tern	*Sterna paradisaea*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Black guillemot	*Cepphus grylle*	Year-round	Coastal/offshore		Not assessed	No status
Black-legged kittiwake	*Rissa tridactyla*	Summer	Coastal/offshore		Not assessed	No status
Black scoter	*Melanitta americana*	Summer	Coastal	Migratory species	Not assessed	No status
Bonaparte's gull	*Chroicocephalus philadelphia*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Brant	*Branta bernicla*	April to October	Coastal	Migratory species	Not assessed	No status
Common eider	*Somateria mollissima*	Year-round	Coastal/offshore		Not assessed	No status
Common loon	*Gavia immer*	Summer	Coastal	Migratory species	Not at risk	No status
Glaucous gull	*Larus hyperboreus*	Summer	Coastal/offshore		Not assessed	No status
Harlequin duck	*Histrionicus histrionicus*	Summer	Coastal	Migratory species	Special concern	Special concern Schedule 1
Herring gull	*Larus argentatus*	April to November	Coastal/offshore	Migratory species	Not assessed	No status
Iceland gull	*Larus glaucoides*	Year-round	Coastal/offshore		Not assessed	No status
Ivory gull	*Pagophila eburnea*	Year-round	Coastal/offshore		Endangered	Endangered Schedule 1
King eider	*Somateria spectabilis*	Year-round	Coastal		Not assessed	No status
Little gull	*Larus minutus*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Long-tailed duck	*Clangula hyemalis*	May to October	Coastal		Not assessed	No status
Long-tailed jaeger	*Stercorarius longicaudus*	Summer	Coastal/offshore	Migratory species. Breeds along the coast.	Not assessed	No status
Mew gull	*Larus canus*	Year-round	Coastal/offshore		Not assessed	No status

Table 10-3: Marine Avifauna Species Present in the Southern Beaufort Sea and Mackenzie Delta Ecosystem (cont'd)

Common Name	Species	Seasonal Occurrence	Distribution	Other Relevant Information	COSEWIC Status	SARA Status
Seabirds (cont'd)						
Murre	*Uria sp.*	Summer	Coastal/offshore		Not assessed	No status
Northern fulmar	*Fulmarus glacialis*	Summer and fall	Coastal/offshore		Not assessed	No status
Pacific loon	*Gavia pacifica*	Summer	Coastal	Migratory species. Arctic-breeding species. Common and numerous along the mainland and island coasts.	Not assessed	No status
Parasitic jaeger	*Stercorarius parasiticus*	Summer	Coastal/offshore	Migratory species. Breeds along the coast and nearshore islands.	Not assessed	No status
Pomarine jaeger	*Stercorarius pomarinus*	Summer	Coastal/offshore	Migratory species. Breeds along the coast.	Not assessed	No status
Red-breasted merganser	*Mergus serrator*	Summer	Coastal	Migratory species. Males and non-breeding birds frequent coastal marine waters.	Not assessed	No status
Red-throated loon	*Gavia stellata*	Summer	Coastal	Migratory species. Arctic-breeding species. Common and numerous along the mainland and island coasts.	Not assessed	No status
Sabine's gull	*Xema sabini*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Surf scoter	*Melanitta perspicillata*	Summer	Coastal	Migratory species	Not assessed	No status
Thayer's gull	*Larus thayeri*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
White-winged scoter	*Melanitta deglandi*	Summer	Coastal	Migratory species	Not assessed	No status
Yellow-billed loon	*Gavia adamsii*	Summer	Coastal/offshore	Migratory species	Not at risk	No status
Waterfowl						
American wigeon	*Anas americana*	Summer	Coastal	Migratory species	Not assessed	No status
Barrow's goldeneye	*Bucephala islandica*	Summer	Coastal/offshore	Migratory species	Special concern	Special concern Schedule 1
Canada goose	*Branta canadensis*	Summer and fall	Coastal	Breeds in large numbers along the coasts and on nearshore islands.	Not assessed	No status
Canvasback	*Aythya valisineria*	Summer	Coastal	Migratory species	Not assessed	No status
Common goldeneye	*Bucephala clangula*	Summer	Coastal	Migratory species	Not assessed	No status
Greater scaup	*Aythya marila*	Summer	Coastal	Migratory species	Not assessed	No status

Table 10-3: Marine Avifauna Species Present in the Southern Beaufort Sea and Mackenzie Delta Ecosystem (cont'd)

Common Name	Species	Seasonal Occurrence	Distribution	Other Relevant Information	COSEWIC Status	SARA Status
Waterfowl (cont'd)						
Greater white-fronted goose	*Anser albifrons*	Summer	Coastal	Migratory species	Not assessed	No status
Green-winged teal	*Anas crecca*	Summer	Coastal	Migratory species	Not assessed	No status
Horned grebe	*Podiceps auritus*	Summer	Coastal	Migratory species. Breeds on freshwater lakes and ponds across western boreal forest.	Special concern (2009) – western population	No status
Lesser scaup	*Aythya affinis*	Summer	Coastal	Migratory species	Not assessed	No status
Mallard	*Anas platyrhynchos*	Summer	Coastal	Migratory species	Not assessed	No status
Northern pintail	*Anas acuta*	Summer	Coastal	Migratory species	Not assessed	No status
Northern shoveler	*Anas clypeata*	Summer	Coastal	Migratory species	Not assessed	No status
Red-necked grebe	*Podiceps grisegena*	Summer	Coastal	Migratory species. Breeds on freshwater lakes and ponds across western boreal forest.	Not at risk	No status
Snow goose	*Chen caerulescens*	May to September	Coastal	Migratory species. Breeding colonies occur along the coasts.	Not assessed	No status
Whistling swan	*Olor colombianus*	Summer	Coastal	Migratory species	Not assessed	No status
Shorebirds						
American golden plover	*Pluvialis dominica*	Summer	Coastal	Migratory species	Not assessed	No status
Baird's sandpiper	*Calidris bairdii*	Summer	Coastal	Migratory species	Not assessed	No status
Black-bellied plover	*Pluvialis squatarola*	Summer	Coastal	Migratory species	Not assessed	No status
Buff-breasted sandpiper	*Tryngites subruficollis*	Summer	Coastal/offshore	Migratory species	Special concern (2012)	No status – no schedule
Common snipe	*Capella gallinago*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Dunlin	*Calidris alpina*	Summer	Coastal	Migratory species	Not assessed	No status
Hudsonian godwit	*Limosa haemastica*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Killdeer	*Charadrius vociferus*	Summer	Coastal	Migratory species	Not assessed	No status
Least sandpiper	*Calidris minutilla*	Summer	Coastal	Migratory species	Not assessed	No status
Lesser yellowlegs	*Tringa flavipes*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Long-billed dowitcher	*Limnodromus scolopaceus*	Summer	Coastal/offshore	Migratory species	Not assessed	No status

Table 10-3: Marine Avifauna Species Present in the Southern Beaufort Sea and Mackenzie Delta Ecosystem (cont'd)

Common Name	Species	Seasonal Occurrence	Distribution	Other Relevant Information	COSEWIC Status	SARA Status
Shorebirds (cont'd)						
Northern phalarope	*Lobipes lobatus*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Pectoral sandpiper	*Calidris melanotos*	Summer	Coastal	Migratory species	Not assessed	No status
Red knot	*Calidris canutus*	Summer	Coastal	Migratory species	Endangered *(rufa spp.)* Special concern *(islandica spp.)*	No status
Red phalarope	*Phalaropus fulicarius*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Ruddy turnstone	*Arenaria interpres*	Summer	Coastal	Migratory species	Not assessed	No status
Sanderling	*Calidris alba*	Spring and summer	Coastal	Migratory species	Not assessed	No status
Sandhill crane	*Grus Canadensis*	Summer	Coastal	Migratory species	Not assessed	No status
Semi-palmated plover	*Charadrius semipalmatus*	Summer	Coastal	Migratory species	Not assessed	No status
Semi-palmated sandpiper	*Calidris pusilla*	Summer	Coastal	Migratory species	Not assessed	No status
Spotted sandpiper	*Actitis macularius*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Stilt sandpiper	*Calidris himantopus*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
Whimbrel	*Numenius phaeopus*	Summer	Coastal/offshore	Migratory species	Not assessed	No status
White-rumped sandpiper	*Calidris fuscicollis*	Summer	Coastal	Migratory species	Not assessed	No status
Raptors						
Peregrine falcon	*Falco peregrinus tundrius*	Summer	Coastal	Breeds and hunts along the coasts.	Special concern	No status
Snowy owl	*Bubo scandiacus*	Summer	Coastal	Breeds and forages along the coasts.	Not at risk	No status

Note: List adapted from Salter et al. 1980. Year of COSEWIC status assessment indicated in brackets.
COSEWIC = Committee on the Status of Endangered Wildlife in Canada
SARA = *Species at Risk Act*

10.10.5 SEABIRDS

In the spring, leads of open water in the southeastern Beaufort Sea are used by large numbers of seabirds. The most commonly observed species being (Frame 1973, Dickson and Gilchrist 2002):

- black-legged kittiwake

- common eider
- glaucous gull
- king eider
- long-tailed duck
- Pacific loon
- parasitic jaeger
- pomarine jaeger
- red-throated loon
- Sabine's gull
- surf scoter
- white-winged scoter
- yellow-billed loon

Spring migration occurs in May, peaking through late May to mid-June (Richardson and Johnson 1981, Dickson and Gilchrist 2002). Seabirds are likely to be present in the program area during May, June and intermittently through the remainder of the open-water season.

Common eider tend to concentrate in shallow water (less than 20 m deep) along the Tuktoyaktuk Peninsula, Cape Bathurst, and Dolphin and Union Strait, while king eider often stage in deeper waters (up to 50 m deep) off of Banks Island (Dickson and Gilchrist 2002). Long-tailed ducks feed within the water column, on bottom substrate, and on the undersurface of sea ice. They are not limited by water depth and are generally found in largest numbers in deeper water (Alexander et al. 1997). Gulls, kittiwakes, jaegers and terns can be found up to 750 km from the shore among the pack ice (Harwood et al. 2005) although their abundance is generally correlated inversely with distance from land (Frame 1973). Overall, sea duck abundance is highest off of Cape Bathurst, with lower numbers reported off the Mackenzie Delta (Dickson and Gilchrist 2002). The distribution of birds at sea is often associated with subsurface features, such as canyons, ridges and shelf breaks (Harwood et al. 2005).

By mid-June, most of the sea ducks that staged in the Beaufort Sea have dispersed to nest inland or to the east in the Central Arctic (Dickson and Gilchrist 2002). During the summer, the males, immatures and non-breeding females of several species (e.g., surf scoter, white-winged scoter, long-tailed duck, scaup, and red-breasted merganser) migrate to the southern Beaufort Sea (Johnson and Richardson 1982, Dickson and Gilchrist 2002). Sheltered coastal waters behind barrier beaches and spits, particularly around Herschel Island, are used throughout July and early August (Johnson and Richardson 1982). The Mackenzie Delta is not used by moulting sea ducks, presumably because of the turbid water impedes foraging during a time when they are unable to fly and seek out better food resources (Dickson and Gilchrist 2002).

In the fall, following summer brood rearing, moulting and feeding in the highly productive polar waters, birds begin their migratory movements out of the area, including seabirds, such as the long-tailed duck, scoters, eiders, Brant, glaucous gulls, red-breasted merganser, scaup, Pacific loons and red-throated loons (Dickson and Gilchrist 2002).

10.10.5 SEABIRDS (cont'd)

Between 2008 and 2011, about 350 hours of vessel-based marine avifaunal surveys were conducted in the program area, identifying a total of 31 bird species, including the SARA-listed ivory gull (Schedule 1, endangered). The most commonly observed birds during the surveys were glaucous gulls, black-legged kittiwakes, eider, loons, gulls (unidentified species) and waterfowl (unidentified species).

Populations of some seabird species, including common eider, king eider, long-tailed duck, surf scoter and white-winged scoter have all declined by about 50% between the 1970s and 1996 (Suydam et al. 2000, Dickson and Gilchrist 2002). Because the status of most of the marine bird species in the Beaufort Sea region is not routinely monitored, population trends for most species are uncertain (Dickson and Gilchrist 2002).

10.10.6 WATERFOWL

Waterfowl species primarily use freshwater lakes, ponds and rivers for feeding, nesting and rearing. Therefore, they are less likely to be directly affected by marine development. Some species (e.g., scaup and goldeneye) might use nearshore marine waters, but are considered predominately a freshwater species. In contrast to sea ducks and Brant, several waterfowl species that primarily inhabit fresh water in the Beaufort Sea region are not known to be in decline (Dickson and Gilchrist 2002).

10.10.7 SHOREBIRDS

Shorebirds use shallow coastal water and intertidal areas for feeding, and coastal areas above high tide for nesting.

10.10.8 ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREAS

The Beaufort Sea coastline is a major corridor for birds migrating easterly from the Bering and Chukchi Sea, and westward from the Central Arctic, during May and June (Barry 1976, Salter et al. 1980) (see Figure 10-9, shown previously). In particular, the area between Herschel Island and Tuktoyaktuk is used as a stopover by shorebirds (Gudmondsson et al. 2002). The barrier beaches and spits in this area provide critical protected waters for moulting seabirds (Johnson and Richardson 1982) and are also a major staging area for phalaropes, i.e., small wading birds (Dickson and Gilchrist 2002). Open-water leads and polynyas are important to migrating birds during spring because they provide access to potential foraging areas.

Alexander et al. (1988) compiled a series of maps that included both temporal and spatial resolution and identified bird use of coastal areas of the Beaufort Sea. The maps identify areas along the Tuktoyaktuk Peninsula considered important habitat locations because large numbers of birds congregate at these sites:

- six areas in early June to mid-July
- 11 areas in mid-July to mid-August
- 11 areas in mid-August to late September

The maps also identified various locations of important bird use within the Mackenzie Delta and along the coast toward the Yukon boundary. Similarly, Latour et al. (2008) identified important migratory bird terrestrial habitat sites, which include the areas of:

- the Lower Anderson River and Mason River
- the Kugaluk River
- McKinley Bay – Phillips Island
- Kukjutkuk Bay and Hutchison Bay

There are two small breeding bird colonies in the southeast Beaufort Sea, one of about 800 thick-billed murres (*Uria lomvia*) at Cape Parry and a second of about 100 black guillemots on Herschel Island (Dickson and Gilchrist 2002) (see Figure 10-9, shown previously).

Areas of higher sensitivity for marine avifauna during the open-water season are illustrated in Figure 10-10, shown previously. These areas are representative of key life stage areas, feeding areas, as well as movement and migratory corridors necessary for year-over-year survival (AECOM 2010).

10.10.9 TRADITIONAL HARVEST

The 2010 joint venture traditional knowledge study identified that ducks, ptarmigan and, especially, geese are hunted in the spring and summer months (May until late September) between Aklavik and Tuktoyaktuk. Hunting seasons vary by community, with most activity occurring during August and September (Aklavik 2008, Inuvik 2008, Sachs Harbour 2008, Paulatuk 2008, Ulukhaktok 2008, Tuktoyaktuk 2008, Golder 2011). In Ulukhaktok and Paulatuk, hunting season begins considerably earlier in May (Paulatuk, 2008, Ulukhaktok, 2008). While birds can be hunted along the entire coast, the Mackenzie Delta, Mackenzie Bay and Shallow Bay are particularly popular hunting grounds for all communities. Birds also provide communities with a source of eggs. Typically, eggs are gathered in the spring and early summer (Aklavik 2008, Inuvik 2008, Sachs Harbour 2008, Paulatuk 2008, Ulukhaktok 2008, Tuktoyaktuk 2008).

10.11.1 OVERVIEW

There are six species of marine mammals that have the potential to be present within the program area for variable periods of time and at different times throughout the year (see Table 10-4). This includes:

- three species of cetaceans:
  - two types of toothed whales
  - one type of baleen whale
- two species of pinnipeds (seals)
- polar bears

Table 10-4: Overview of Marine Mammal Species Potentially Occurring within the Program Area

Common Name	Species	Seasonal Occurrence	Habitat	COSEWIC Status	SARA Status
Ringed seal	*Phoca hispida*	Year-round	Landfast ice and pack ice	Not at risk	No status – no schedule
Bearded seal	*Erignathus barbatus*	Year-round	Pack ice	Data deficient	No status – no schedule
Polar bear	*Ursus maritimus*	Year-round	Spring: landfast ice Summer: pack ice Winter: landfast ice and coastal areas for denning	Special concern	Special concern Schedule 1
Beluga whale, eastern Beaufort Sea population	*Delphinapterus leucas*	Winter (November to May)	Spring: ice edges and leads Summer: shallow coastal areas Fall: deep water (foraging) Winter: offshore pack ice (Hudson Strait)	Not at risk	No status – no schedule
Bowhead whale	*Balaena mysticetus*	Winter (February to June)	Spring: along ice edge Summer: open water and pack ice Winter: heavy pack ice	Special concern	No status – no schedule
Killer whale	*Orcinus orca*	June to August	Coastal and offshore	Endangered	No status – no schedule

Note:
COSEWIC = Committee on the Status of Endangered Wildlife in Canada
SARA = *Species at Risk Act*

The largest stock of beluga whales (*Delphinapterus leucas*) in the world, and a large population of bowhead whales (*Balaena mysticetus*) are known to regularly inhabit the EL areas during the late spring, summer and early fall season. Ringed

10.11.1 OVERVIEW (cont'd)

seals (*Phoca hispida*) are year-round residents to the Beaufort Sea region. Polar bears can also be found in the program area, entering the pack ice in early November after their denning season. Other marine mammals are seasonal visitors, limited by the presence of landfast ice throughout the winter and spring. There is a geographical distribution bias for several species. For example, beluga whales are strongly associated with the southwest Beaufort Sea region in association with the Mackenzie River estuary. For a summary of marine mammal species harvested throughout the year by Inuvialuit communities in the ISR, see Table 10-5.

Table 10-5: Marine Mammal Species Harvested Throughout the Year by Inuvialuit Communities in the ISR

Target Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Ringed seal	–	x	x	x	x	x	x	x	x	x	x	x
Bearded seal	–	x	x	x	x	x	x	x	x	x	x	x
Beluga whale	–	–	–	–	–	x	x	x	x	–	–	–
Bowhead whale	Generally are no longer harvested in the ISR. Residents of Tuktoyaktuk, Ulukhaktok, and Sachs Harbour noted during the 2010 joint venture traditional knowledge study that bowhead whales are harvested in Alaska and in the Canadian eastern Arctic.											
Polar bear	x	x	x	x	x	–	–	–	–	–	–	x
X = harvesting information specific to Tuktoyaktuk Source: REF (Aklavik 2008, Ulukhaktok 2008, Sachs Harbour 2008, Paulatuk 2008, Inuvik 2008, Tuktoyaktuk 2008)												

10.11.2 BELUGA WHALE

10.11.2.1 Population Trend and Conservation Status

The eastern Beaufort Sea population of beluga whales (*Delphinapterus leucas*) is listed as not at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC 2004) and is not listed under the *Species at Risk Act* (SARA) and the US *Endangered Species Act*. This population is considered a non-strategic stock by the National Oceanic and Atmospheric Administration (Allen and Angliss 2011a). Duval (1993) reported an estimate of 21,000 beluga whales for the Beaufort Sea stock, similar to that reported by Burns and Seaman (1985). An aerial survey conducted in July 1992 estimated 19,629 beluga whales in the eastern Beaufort Sea (Harwood et al. 1996). A correction factor has been recommended for the Beaufort Sea beluga whale stock, resulting in a population estimate of 39,258 animals (Duval 1993). Annual monitoring studies conducted in the Beaufort Sea region do not indicate any significant changes in abundance (COSEWIC 2004).

10.11.2.2 Seasonal Distribution and Movement

Beluga whales winter in the Bering Sea and migrate into the Beaufort Sea in the spring of each year, passing Point Barrow, Alaska, in late March to early April (Norton and Harwood 1986, LGL and Greenridge 1996). They typically enter the Canadian sector of the Beaufort Sea in May to June (Fraker 1979), depending on ice and meteorological conditions. Beluga whale migration follows leads across the Beaufort Sea from about Point Barrow to Banks Island, with some migrating animals observed as far as 77°N (Fraker 1979, Norton and Harwood 1986). Later in the early summer, migrating individuals move along a more southerly route as the ice breaks up further south (Fraker 1979). Beluga whales migrate south at Banks Island and proceed to the Amundsen Gulf, where they spend four to six weeks before moving on to the Mackenzie River estuary in late June (Fraker 1979, Norton and Harwood 1986). For seasonal movements and concentrations of beluga whales, see Figure 10-11.

Beluga whales are common in the Mackenzie River estuary throughout the summer season, including waters near Tuktoyaktuk and the EL areas (Moore et al. 2002, Harwood and Smith 2002). They then move southwestward along the landfast ice edge off the Tuktoyaktuk Peninsula into Kugmallit Bay, East and West Mackenzie Bays, Shallow Bay and the Kendall Island area where they congregate for much of July (Harwood and Smith 2002) for feeding and calving (AECOM 2010). These areas are presumed to be of importance to beluga whales because they return to these areas each summer despite significant hunting pressures (North/South Consultants Inc. 2003). Figure 10-12 also shows the Beaufort Sea beluga whale management zones.

In late July, beluga whales begin moving further offshore or into Amundsen Gulf (Harwood et al. 1996). In September they migrate back to wintering areas in the Bering Sea. During fall, the migratory route is farther offshore (greater than 60 km) (LGL and Greenridge 1996), although there is evidence that they might also travel close to shore along the continental shelf and slope (Richard et al. 2001).

There can be considerable variation within the general migratory patterns. Most beluga whales can be found offshore rather than in the Mackenzie River estuary (Norton and Harwood 1986, Harwood et al. 1996, LGL and Greenridge 1996). Radiotelemetry studies have shown that beluga whales use the Mackenzie River estuary only intermittently (Richard et al. 2001).

Aerial surveys conducted in 1996 reported that beluga whale distribution during July was concentrated in four offshore areas (Harwood et al. 1996):

- 10 to 30 km northwest of west Mackenzie Bay
- within 5 to 10 km of the Tuktoyaktuk Peninsula, Baillie Island, and the mouth of the Horton River
- 50 to 80 km off Cape Bathurst in the area where the Bathurst polynya often recurs in winter
- in the central Amundsen Gulf

Although these areas do not overlap with boundaries of the EL areas, other proposed activities (e.g., vessel movements between the drill site and Tuktoyaktuk Harbour) will likely overlap with one or more of these areas during the proposed program.

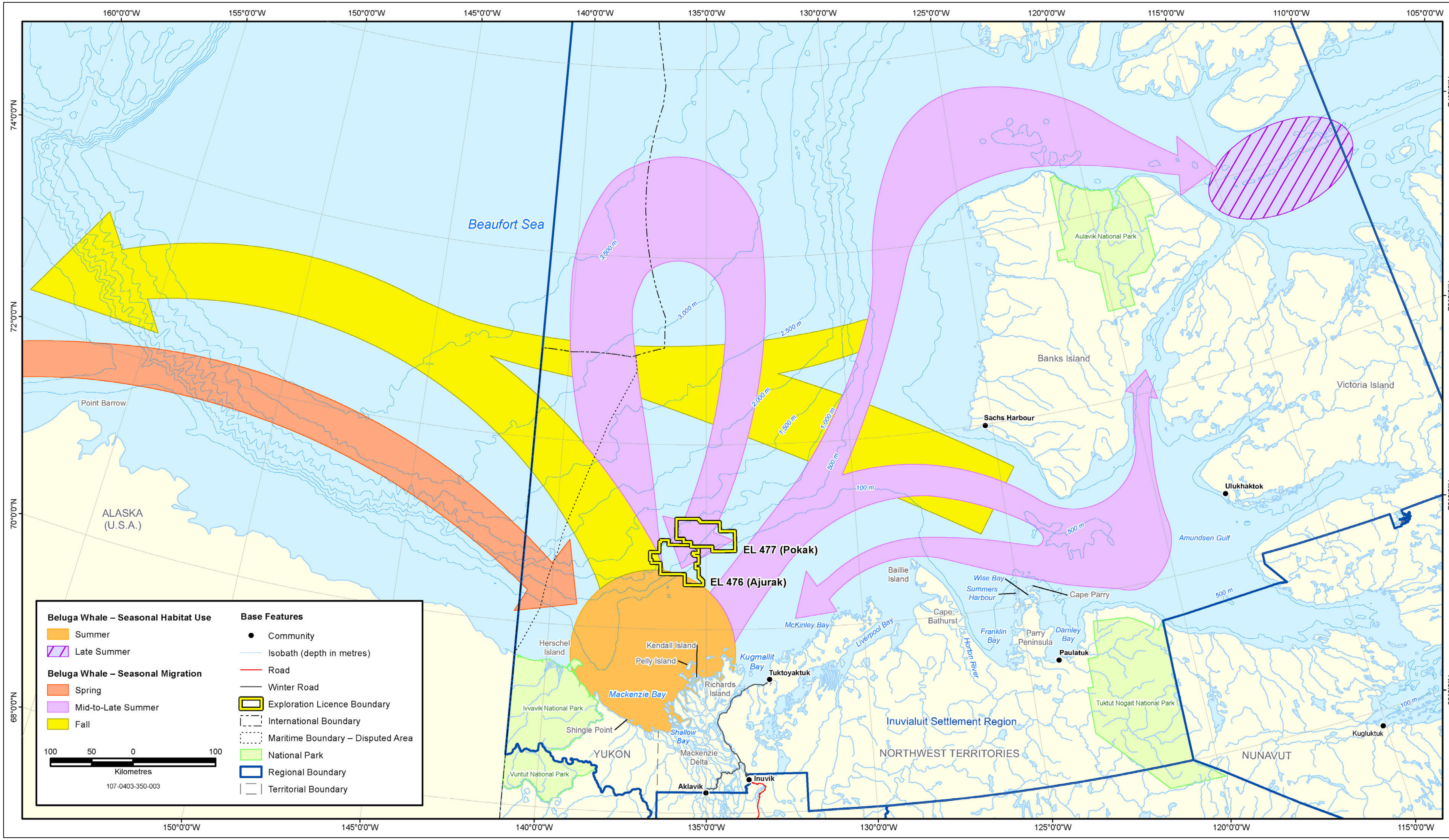

Figure 10-11: Beluga Whale Seasonal Movements and Concentration Areas in the Beaufort Sea

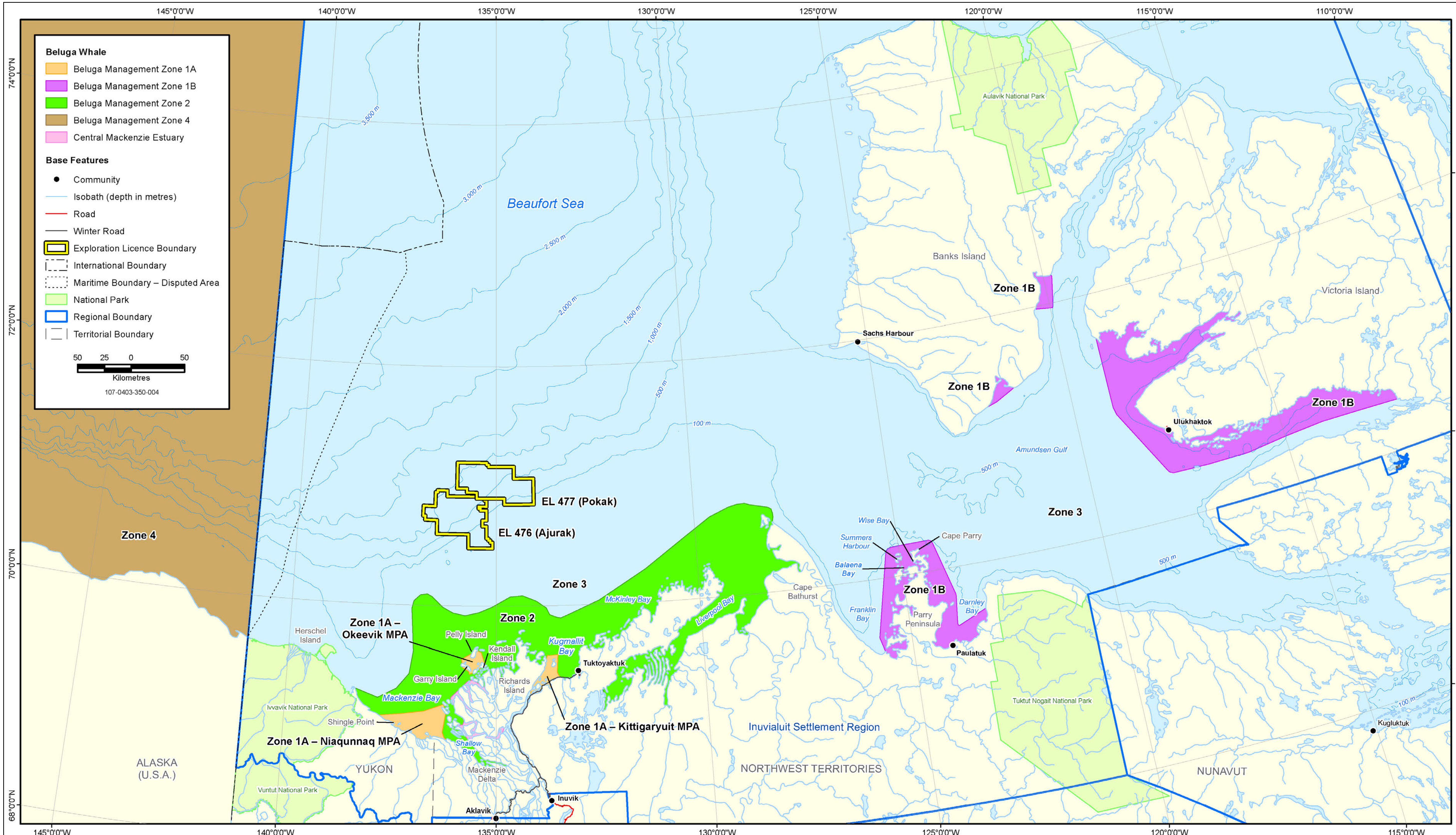

Figure 10-12: Beluga Whale Management Zones in the Beaufort Sea

10.11.2.2 Seasonal Distribution and Movement (cont'd)

Between 2008 and 2011, several vessel-based and aerial-based marine mammal surveys were conducted in the program area during the open-water season as part of the FDCPs. During the surveys, beluga whale sightings were recorded in the program area, including occurrences of mother and calf. Beluga whale sightings were most common in July and August, and sightings predominantly occurred in shallow, coastal waters and, to a lesser extent, in northern and ice environs.

During the summer and fall of 2010, Imperial worked with Cornell University to conduct passive acoustic monitoring in the program area. Twelve marine autonomous recording units were deployed in EL 477 for the purpose of quantifying beluga whale presence in the program area during the open-water season. Beluga whales were detected at one or more recording sites on 21 of 40 recording days (54%) and were less common at the shallower sites (Cornell University 2011b). This is consistent with known patterns of beluga whale migration (AECOM 2012) and habitat selection by depth (Moore et al. 2000).

Despite interannual variability in the extent and distribution of sea ice, beluga whales selected certain features (i.e., water depths of 200 to 500 m and heavy ice concentrations), frequenting regions of relatively significant seafloor slope with the potential for oceanographic upwellings (Asselin et al. 2011).

In 2001, the Fisheries Joint Management Committee (FJMC) issued an update of the Beaufort Sea Beluga Management Plan for the beluga whale population in the Canadian sector of the Beaufort Sea. Under this plan, there are various management zones and areas in the Beaufort Sea which are protected and should be avoided (see Figure 10-12, shown previously). The traditional summer locations for the eastern Beaufort Sea beluga whale population (i.e., Kugmallit Bay, east and west Mackenzie Bays, Shallow Bay and the Kendall Island area) are recognized as special designated lands under the Aklavik, Inuvik and Tuktoyaktuk community conservation plans (CCPs) as 711E, 714E and 716E – Beluga Management Zone 1A (WMAC 2000a, b, c). Category E consists of land and water where cultural or renewable resources are of extreme significance and sensitivity. The CCPs recommend the highest degree of protection for these types of lands, prohibiting development in these areas (WMAC 2000a b c, AECOM 2010).

Areas of higher sensitivity for beluga whales during the open-water season from May 1 to October 31 are shown in Figure 10-13, as extracted from AECOM 2010. These areas are representative of key life stage and feeding areas, and movement and migratory corridors necessary for year-over-year survival.

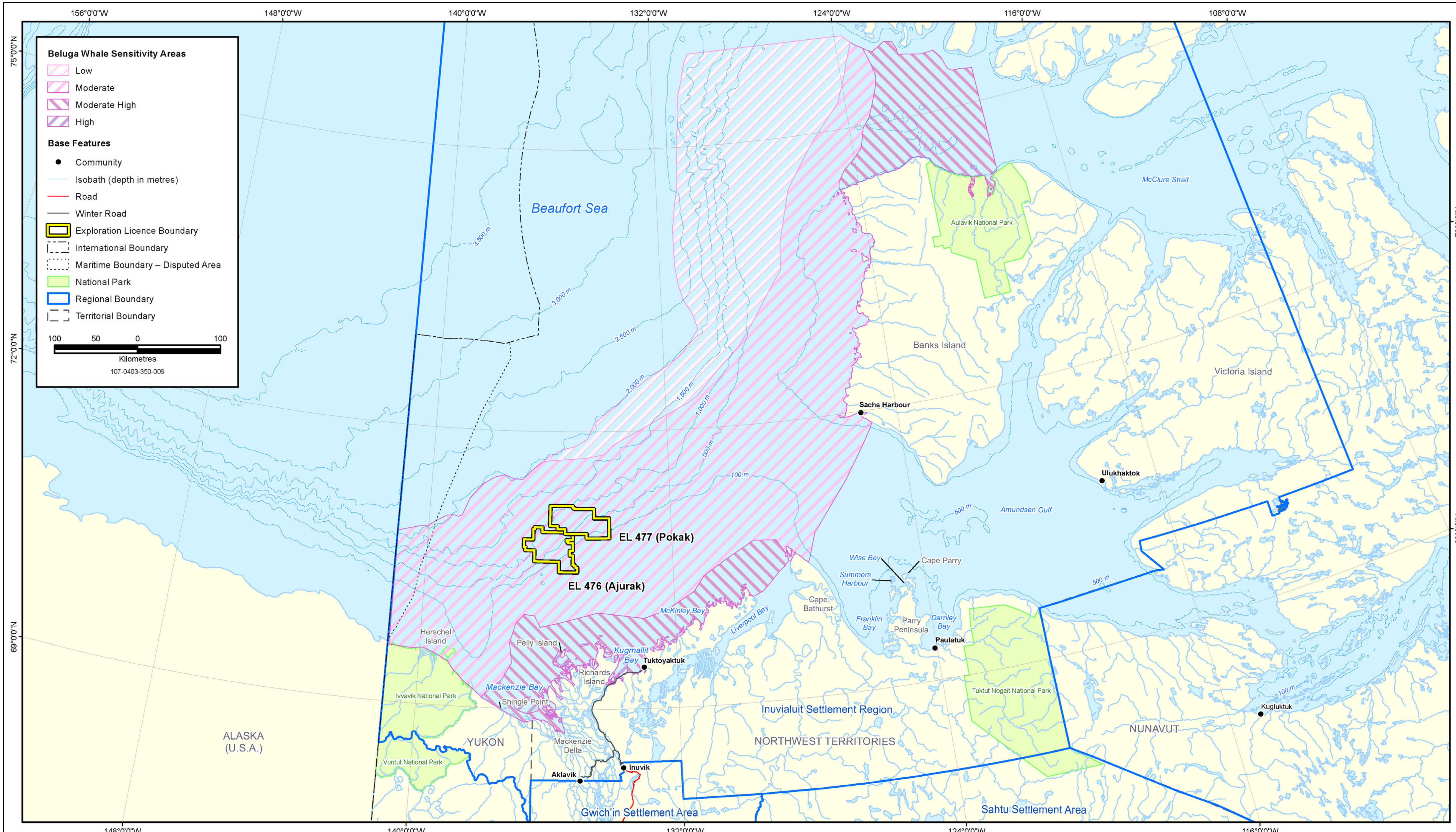

Figure 10-13: Beluga Whale Sensitivity Areas During the Summer Season

10.11.2.3 Subsistence Harvest

The 2010 joint venture traditional knowledge study identified beluga whales as an important subsistence species for local communities, providing muktuk (the outer skin and blubber) which is used as food and as a form of currency that is traded for other commodities, such as Arctic char and caribou. Communities harvest beluga whales during the summer, from June to late September, in the Beluga Management Zone 1A. The 2010 traditional knowledge study also identified the Mackenzie River Delta, Kugmallit Bay, the waters around Kendall Island and Garry Island and Balaena Bay as particularly popular subsistence harvesting locations.

10.11.2.4 Hearing Ability and Vocal Behaviour

Toothed whales, which include beluga whales, have been shown to echolocate, with beluga whales being considered the most vocal (Ketten 1992a, Karlsen et al. 2002). Echolocation is used for detection of prey and for navigation. Vocalizations are also used for social contact among pod members. Beluga whales are known for their rich vocal repertoire which includes different sound types (Panova et al. 2012, Chmelnitsky and Ferguson 2012), such as:

- whistles
- pulsed tones
- click series
- noise vocalizations

Beluga whales vocalize using a frequency range of 0.2 to 150 kHz (Ketten 1992b), with the greatest sensitivity around 32 and 108 kHz, and the least sensitivity at 54 kHz (Klishin et al. 2000). A lower threshold of 8 kHz was reported by Awbrey et al. (1988) who also found that juvenile beluga whales were slightly more sensitive to low frequencies than the adults. There does not appear to be any between-year variation in the vocal repertoire (Sjare and Smith 1986). However, beluga whales have been experimentally shown to change their signal frequency, bandwidth and intensity in a noisy environment (Au et al. 1985).

10.11.3 BOWHEAD WHALE

10.11.3.1 Population Trend and Conservation Status

The Bering-Chukchi-Beaufort subpopulation of bowhead whales (*Balaena mysticetus*) is listed as a population of special concern by COSEWIC (COSEWIC 2009) and SARA. The US *Endangered Species Act* also identifies this species as endangered. The most recent estimate of this population’s size was 10,545 animals in 2001 (Zeh and Punt 2005). There does not appear to be more recent, rigorous population estimates (Allen and Angliss 2012). However, the population of bowhead whales throughout their range has generally increased, reflecting an annual rate of increase of 3.4% through the early 2000s (Zeh and Punt 2005, COSEWIC 2009). Harwood et al. (2010) estimated 4,884 to 5,280 bowhead whales in the Beaufort Sea in the summer of 2007.

The remainder of Section 10 is in the PDF file called:

Beaufort Sea Proj Description Sec 10 Part 2 of 2.