Section 2

Affected Environment

2 AFFECTED ENVIRONMENT

This section discusses the affected environment in the vicinity of the proposed Liberty (SDI) Project area and alternatives. The discussion covers the physical, biological, cultural, and socioeconomic environments. The MMS updated the information and expanded on the information provided in the EIA, as needed.

2.1 AIR ENVIRONMENT

2.1.1 Climate and Meteorology

The North Slope of Alaska is bounded to the south by the Brooks Range and by the Arctic Ocean to the north. The mountains provide a natural barrier separating this region climatically from the rest of Alaska (Figure 2.1-1). This region is the coldest and driest of Alaska with a Köppen climatological classification of ET (polar tundra) and frequent high winds. The winters are cold and the summers are cool and short, with only 3 to 4 months with mean temperatures above freezing.

The following sections provide climatological data based on five locations (Barrow, Prudhoe Bay, Deadhorse, Kuparuk, and Barter Island) in Arctic Alaska (National Climatic Data Center [NCDC]). The climate stations are shown in Figure 2.1-1, while the characteristics are given in Table 2.1-1. No climate stations with long-term records are located in the immediate vicinity of the Liberty (SDI) Project area. However, the data at the five stations indicated above provide a reasonable depiction of the conditions anticipated at the Liberty site.

2.1.1.1 Air Temperature

Table 2.1-2 presents the air temperatures for Barrow, the station with the longest record of climatological data on the North Slope. These data are presented graphically in Figure 2.1-2. The data shown are for the period 1975 to 2004, as climatological normals are usually based on a 30-year period. July is on average the warmest month, with a mean temperature of 4.6 °C, while February is the coldest month with a mean of -26.0 °C. For most of Alaska, January is the coldest month, and this delay of 1 month in the Arctic is typical for a maritime climate. Only 3 months (June, July, August) have a mean temperature above the freezing point, and the average daily maxima are below 10 °C for all months. The record high, 26 °C, was measured on 13 July 1993. The lowest temperature recorded in Barrow during the last 30 years was -47 °C, and this occurred on 3 January 1975. This is a relatively benign value compared to the Statewide absolute minimum of -62 °C, measured at Prospect Creek south of the Brooks Range in northern Interior Alaska. The relatively strong winds experienced year-round in Arctic Alaska are a primary reason why temperatures do not go as low as in the Interior.

Table 2.1-3 presents climatological data for other stations on the North Slope. It should be noted, however, that the observational period is not identical for the different stations and slight differences in the climatological statistics might occur due to this fact.

In general, the two stations located directly at the Beaufort Sea coastline (Barrow and Barter Island) are somewhat cooler in the summer than the three other stations, which are located a distance inland. The period with mean temperatures above freezing also is extended at the inland stations. Alternatively, the winter temperatures at the coastal stations were somewhat warmer, a sign of the maritime influence of the Beaufort Sea.

2.1.1.1 Precipitation

Precipitation is light on the North Slope. The annual precipitation (water equivalent) for four of the stations is summarized in Table 2.1-4. Because the precipitation record for Deadhorse is incomplete, these data were not included. The mean annual precipitation ranges from 10.1 centimeters (cm) at Kuparuk to 15.7 cm at Barter Island. The precipitation maximum occurs in August for all stations while during the winter months (November through April), the precipitation is very light.

The annual snowfall for the four stations is presented in Table 2.1-5. The mean annual snowfall ranges from 78.2 cm at Kuparuk to 106.2 cm at Barter Island. The maximum snowfall, 211.7 cm, was recorded at Barter Island. A permanent snow cover normally is established in September. The increase in snow depth (Figure 2.1-3) is fairly rapid from the middle of September through the end of October, when about half of the seasonal maximum snow cover is reached. The snow depth increases slowly from November through March, with the maximum snow cover of about 30 to 40 cm reached in April. Thereafter, melting commences, and the snow depth declines quickly. By mid- to late June the seasonal snowpack has disappeared.

The depth of snow on the ground is influenced primarily by snowfall during the winter. However, due to blowing and drifting, the snow cover can be redistributed. Furthermore, densification of freshly fallen snow occurs. Both processes can result in a decrease in snow depth at a time when the temperature is far below the freezing point and no melt is possible. Figure 2.1-3 does not show such processes, as it is the average of many years of observations.

2.1.1.2 Wind

The winds are fairly strong on the North Slope, with monthly mean values around 10 knots (kt) (1 kt = 0.51 meter per second [m/sec]). There is no strong annual course in wind speed, but there is a slight indication of a maximum in the fall when the adjoining Beaufort Sea is still ice free and the land has already substantially cooled. This strong thermal contrast in the surface temperature of the ocean and land might at times enhance the wind speed. The mean monthly and annual wind-speeds for Barrow, Deadhorse, and Barter Island are presented in Table 2.1-6.

Winds are normally from an easterly direction, with westerly winds occurring more infrequently. The mean annual wind rose for Barrow (Figure 2.1-4) clearly shows the bi-modal wind direction distribution. Calms are very seldom, with annual values of less than (<) 2%.

Five years of wind speed and direction measurements at Endicott are available as part of the MMS Beaufort Sea Meteorological Monitoring and Data Synthesis Project (USDOI, MMS, 2007a). The average hourly mean wind speed measured between January 2001 and September 2006 was 5.3 m/sec, while the maximum hourly mean wind speed was 23.7 m/sec. The maximum instantaneous wind speed at the Endicott site during this period was 30.6 m/sec. Wind directions were bimodal, typically prevailing from an east northeasterly direction (approximately 45% of the time) or from a west northwesterly direction (approximately 25% of the time (USDOI, MMS, 2006c). It should be noted that the wind measurements at Endicott are known to be biased low during winter months due to icing problems (USDOI, MMS, 2006c)

2.1.1.3 Storminess

Storms are of special interest for many reasons, such as coastal erosion, visibility restrictions due to blowing snow, operational restrictions, and possible extremely low wind chill factors. Figure 2.1-5 presents the number of days during which the wind speed at Barrow exceeded 30 kt (15.4 m/sec) for at least 1 hour. On average, there are about 10 cases of such high wind events each year, with dramatic annual variability. There is an indication that the frequency has increased, but the change is not statistically critical. Further, such strong storms are least likely to occur in summer, but most likely to occur in the fall (Table 2.1-7).

2.1.1.4 Cloudiness

The mean cloudiness on the North Slope is high, especially in late summer/early fall, when Arctic stratus clouds are observed for most of the days. At Barrow, the long-term mean cloudiness value for September is 93%. The minimum in cloudiness is observed in winter with values around 50%.

2.1.1.5 Atmospheric Pressure

The atmospheric pressure reduced to sea level is nearly identical for both Barrow and Barter Island. The station pressure approximates the sea level pressure for these stations, as they are both less than 12 m above sea level. The lowest mean pressure (1012.2 millibars [mb]) is observed in late summer, which also is the time with the highest amount of cloud cover and the greatest amount of precipitation. The highest mean atmospheric pressure (1020.7 mb) is observed in March and is accompanied by a low amount of cloudiness and little precipitation.

2.1.1.6 Visibility

Visibility is measured continuously at the Deadhorse airport as part of the Automatic Surface Observing System (ASOS). The most restrictive category (visibility <1 mi) occurs on average about 10% over the year, with a minimum in summer and a maximum in winter. This distribution is likely caused by blowing snow, which can strongly impair visibility when severe. In the absence of snow cover (summer), such events cannot occur. In contrast, conditions of blowing or drifting snow take place nearly 25% of the time during the winter. Further, fog is more likely to occur in the summer, when it is formed over the cold ocean and drifts into the coastal area. In the winter, freezing fog may occur, especially in the presence of a temperature inversion.

2.1.1.7 Climate Change

Temperature Trends

Temperature trends from 1948 to 2004 are plotted in Figure 2.1-6 for the five climatological stations on the North Slope. The record extends to 1948 for only two stations (Barrow and Barter Island). In general, the time series of mean annual temperatures for the different stations are very similar. This finding is expected due to the fairly uniform surface conditions (tundra) found at each station.

While large variations in the annual temperatures occur from year to year, a general warming trend is apparent. The best-fit linear trend for the Barrow data indicates a temperature increase from -13 °C to -11 °C over the 56-year period. This increase of 2 °C over 56 years is substantial when compared to the global average of about 0.6 °C per century (IPCC, 2001), and is an often-observed enhancement of warming in polar regions. Furthermore, the warming trend is in general agreement with Stafford, Wendler, and Curtis (2000) and Shulski, Hartmann, and Wendler (2003), who analyzed the temperature trends of Alaska for slightly earlier time periods. It also is noteworthy that the temperature in Arctic Alaska has continued to rise in the last 25 years, a time during which the mean annual temperature of the rest of Alaska has remained constant or decreased somewhat (Hartmann and Wendler, 2005).

When seasonal temperature trends are considered, substantial warming is evident during winter, while the warming trend is less pronounced in spring and summer. The temperature trend for fall is quite flat, but recent years display above-normal temperatures. This finding is consistent with the observed decrease in sea ice concentrations in coastal regions during this time period (Wendler et al., 2003). Figure 2.1-7 illustrates the decrease in Beaufort Sea ice concentrations between 1970 and 2000.

In Figures 2.1-8 and 2.1-9 the number of days with temperatures below (-18 °C and 34 °C) and above (0 °C and 10 °C) certain thresholds are presented as a time series plot for Barrow from 1949 to 2004. The number of days with a minimum temperature below -18 °C decreased from 170 to 160 days during the 55-year period. More pronounced is the decrease of days with extreme low temperatures (below -34 °C). At the beginning of the time period, there were on average 40 days annually with the minimum temperature below -34 °C. Currently, there are only 22 such days, a reduction close to 50%. This finding is in agreement with the general warming trend that has occurred during the last half century in northern Alaska.

As indicated in Figure 2.1-9, days with a high temperature above 0 °C and 10 °C have increased in frequency of occurrence between 1949 and 2004. Days when the maximum temperature was above freezing (0 °C) increased from 102 to 121 during the 55-year period, while the increase for days with maxima above 10°C increased from 15 to 24 (an increase of about 50%). If this trend continues, vegetation changes may be expected for the North Slope, depending also on the precipitation regime.

Precipitation Trends

A decrease in precipitation of about one-third has been observed in the Arctic for the last half century (Stafford, Wendler, and Curtis, 2000). This decrease was not limited to Alaska, but also was found in most of the Western Arctic (Curtis, Hartmann, and Wendler, 1998). The change is especially pronounced in winter and spring, when the highest temperature increase has been observed. This finding is somewhat surprising, as normally an increase in temperature is associated with an increase in precipitation.

Snowmelt Trends

There has been a trend for earlier snowmelt in the Arctic, as first pointed out by Foster (1989), who analyzed the Barrow data going back to 1940. Dutton and Endres (1991) suggested that the trend was in part due to the rapid development in the village of Barrow, and that the effect was overestimated by Foster. Stone et al. (2002) confirmed Foster’s finding when they showed that from 1940 to present the snowmelt occurs some 8 days earlier on average. This result is not unexpected given the climatological observations, which show a decreasing trend in winter snowfall and higher spring temperatures.

2.1.2 Air Quality

Good air quality exists in the Liberty (SDI) Project area, which is located in the Northern Alaska Intrastate Air Quality Region. The Alaska Department of Environmental Conservation (ADEC) has designated the area as in attainment or unclassifiable for all criteria pollutants, including nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), and lead. The closest existing nonattainment area to the Liberty (SDI) Project area is the Eagle River area of Anchorage, designated nonattainment for PM_{10} and located approximately 1,000 kilometers (km) south of the project area. A portion of the Fairbanks North Star Borough may be designated as nonattainment for very fine particulate matter ($PM_{2.5}$) sometime in 2007 or 2008. Fairbanks is located approximately 625 km south of the project area.

Measurement of ambient concentrations of NO_2, CO, and SO_2 was begun on the SDI on February 1, 2007. Recent ambient pollutant data are available from monitoring stations located on A Pad and the Central Compression Plant (CCP) pad at the nearby Greater Prudhoe Bay (GPB) facility. The data collected in 2005, which are summarized in Table 2.1-8, confirm that the air quality in the area is good and that measured pollutant concentrations are well below any applicable air quality standard.

ADEC has classified the Liberty (SDI) Project area as a Prevention of Significant Deterioration (PSD) Class II area. The nearest PSD Class I area is Denali National Park including the Denali Wilderness but excluding the Denali National Preserve. Denali National Park is located approximately 725 km south of the project area.

2.2 RESERVOIR GEOLOGY

The Liberty Field is located about 5 mi offshore, southeast of Endicott (Figure 3-1). The Tern #3 and Liberty #1 wells establish the presence of producible hydrocarbons within the Kekiktuk Zone 2 reservoir. Two additional wells exist in the Liberty (SDI) Project area (Tern Island #1A and #2A) and provide additional data on the field. A depth-migrated 3-dimensional (3D) seismic survey covers the accumulation and is used to map the reservoir and define the field limits. The well and seismic data support an estimate of 105 MMbbl of recoverable oil.

2.3 GEOMORPHOLOGY

2.3.1 Marine Geology

The Liberty prospect is located at the northern extremity of the Arctic Coastal Plain province. Part of the North Slope physiographic unit, the Arctic Coastal Plain is characterized by a gently sloping tundra-covered plain extending from the foothills of the Brooks Range to the Beaufort Sea. The area is underlain by continuous permafrost, and consists of alluvial and glacial sediments overlying sedimentary bedrock (TAPS Owners, 2001).

Foggy Island Bay is situated between the Sagavanirktok and Shaviovik rivers, and is sheltered by the McClure Islands. The coast can be defined as a tectonically stable trailing-edge type (Inman, 2003). The shoreline is actively retreating, through both wave-induced and thermal erosion processes.

Surficial seafloor sediments found in Foggy Island Bay typically consist of a 2- to 3-m layer of Holocene deposits composed primarily of fine sands and silts (BPXA, 1998). Borings drilled in support of the Liberty (SDI) Project during 1998 indicate that the Holocene sediments are generally lagoonal and deltaic deposits (Duane Miller and Associates, 1998). Coarser sand and gravel are found at higher-wave-energy environments near the shoreline and the barrier islands. Pleistocene deposits comprised of stiff plastic silt and clay are present under the Holocene layer, but also outcrop on the seafloor in some areas (Duane Miller and Associates, 1998). Permafrost was not encountered in the offshore areas during the 1998 soil-boring program. Frozen soils were prevalent, however, near the shoreline and onshore (Duane Miller and Associates, 1998).

A lag deposit of cobbles and boulders known as the “Boulder Patch” is found in Foggy Island Bay. The course material is derived from the Flaxman formation, and is widely believed to have originated from the bedrock of the Canadian Shield (Duane Miller and Associates, 1998). The Boulder Patch is a unique biological community.

2.3.2 Bathymetry

Water depths inside the barrier island chain typically are <30 ft. In general, the sea bottom is characterized by mild slopes and only minor local relief. Widely scattered strudel scours and ice gouges comprise the primary local relief.

Water depths on the east side of the SDI typically range from 2 to 3 m (Bell and Associates, 2007). Shallower water prevails to the south and west.

2.3.3 Coastal Sediment Processes

The nearshore waters of the Alaskan Beaufort Sea typically remain ice-covered for about 9 months of the year. As a result, the total wave energy impacting the coastline tends to be small compared to that which might occur in a more temperate climate. However, waves generated by northeast and northwest storms can produce erosion of the mainland coast, barrier islands, and coastal facilities.

2.3.3.1 Coastal Sedimentation and Erosion

Sedimentation rates in the Liberty (SDI) Project area range from nondetectable (i.e., no recent sediment in the past 50 years) to 0.05 to 0.1 cm/yr (Trefry et al., 2003), and partially support the work by Reimnitz, Graves, and Barnes (1988) that describes the area as net erosional at present. Deposition of fine-grained sediments closer to the mouth of the Sagavanirktok River is expected, but no direct determinations of sedimentation rates have been made nearshore.

Sediment sources to the region include coastal erosion and fluvial material derived from the Sagavanirktok, Kadleroshilik, and Shaviovik rivers. Arcuate-shaped deltas are present at the ocean outlet of each of these rivers. Waves and currents transport the deltaic sediments along the coast and offshore.

Coastal retreat tends to occur at two different rates (Walker, 1983). Storm-induced erosion typically is rapid, and is most pronounced during westerly storms due to the rise in sea level that accompanies such events. More gradual retreat results from the seasonal cycle of thawing and periods of sustained high air temperatures, which induce thermal erosion of ice-rich sediments. These sediments are then removed by normal summer wave conditions.

At many arctic coastal locations, the coastal bluffs thaw during the summer months, creating mud flows which drain onto the beach below. If the thawing is extensive, as might occur during periods of abnormally high temperatures, large-scale slumping or "thermal erosion" can become the dominant cause of bluff recession (Leidersdorf, Gadd, and Vaudrey, 1996). Thermal erosion is most rapid along bluffs that contain monolithic ice lenses ("massive ice") or a high percentage of ice and fine-grained sediments. Such slumping of the thawed bluff material, particularly when gravel and sand are present, may deliver substantial volumes of beach sediment that temporarily protect the bluff face from wave-induced undercutting.

Prior investigators have reported a wide range of bluff retreat rates along the Alaskan Beaufort Sea coast. These findings indicate that erosion rates can vary substantially from location to location, and from year to year at a given location. Bluff retreat estimates along the Alaskan Beaufort Sea coast are summarized in Table 2.3-1, while bluff retreat rates specific to Foggy Island Bay are presented in Table 2.3-2.

Estimated long-term bluff retreat rates along the Alaskan Beaufort Sea coast (Table 2.3-1) range from a modest 0.3 m/yr to over 9 m/yr. Short-term erosion rates can exceed the long-term rates, particularly during periods of frequent coastal storms or sustained high air temperatures. At the Heald Point location, for example, the short-term bluff retreat rate during the 1980s (2.4 to 3.1 m/yr) was found to be twice that of the long-term rate (Leidersdorf, Gadd, and Vaudrey, 1996). The Heald Point site included a section of bluff that contained a 2-m-thick lens of massive ice, further underscoring the importance of thermal erosion in ice-rich bluffs (Leidersdorf, Gadd, and Vaudrey, 1996). Despite witnessing large-scale bluff erosion at many arctic coastal locations, Leffingwell (1919) also emphasized that certain shore areas have remained stable for centuries.

Estimates of bluff erosion rates were developed for four locations in Foggy Island Bay in support of previously considered development strategies for Liberty (Coastal Frontiers, 1997a, 2006). Three of these sites were located on the mainland shoreline, while one was located at Point Brower in the Sagavanirktok River delta (Figure 2.3-1). Bluff recession rates at the three mainland sites were found to be moderate by arctic standards. The maximum short-term rates ranged from 1.6 to 2.7 m/yr, while the long-term recession rates ranged from 0.6 to 1.1 m/yr. The east side of the Pt. Brower site exhibited considerably higher erosion rates than those observed at the mainland sites. The average long-term erosion rate along the east side of the Pt. Brower Site was 2.0 m/yr, while the maximum short-term bluff recession rate was 9.6 m/yr. In contrast, the west side of the Pt. Brower site was relatively stable with an average long-term bluff recession rate of 0.2 m/yr, and a maximum short-term rate of 2.0 m/yr.

2.3.3.2 Barrier Island Processes

The barrier islands that shelter Foggy Island Bay are highly dynamic sedimentary structures that fluctuate in location and shape in response to the environmental forces of waves, wind, currents, and ice. These islands are bounded by dynamic inlets and are subject to sporadic, rapid, and generally westward sediment transport driven by the persistent easterly winds of the region.

Barrier islands in the Beaufort Sea typically are oriented parallel to the mainland coast and are separated from the mainland by lagoons and bays. By virtue of their location, they receive the full impact of coastal storms while providing partial protection for the mainland coast. Arctic barrier islands typically experience dramatic changes in plan form due to phenomena that include elongation, truncation, coalescence, inlet formation, and inlet closure. Wiseman et al. (1973) hypothesized that thermal erosion may play a particularly important role in the formation of some arctic barrier islands. They theorized that the lagoons backing barrier island chains originated through the erosion and coalescing of thaw lakes. This implies that the islands are actually residuals of the original shoreline. The fact that several offshore islands (such as Tigvariak Island, located immediately east of the Liberty site, and Flaxman Island, located farther to the east) have a tundra veneer lends some credence to this hypothesis.

Arctic barrier islands are commonly low in profile, slender in width and arcuate in shape. These characteristics, coupled with the storm surge induced by westerly winds, make them susceptible to wave overwash as well as high alongshore sediment transport rates. Their migratory nature has been well-documented in the past (Wiseman et al., 1973; Cannon and Rawlinson, 1978; Gadd et al., 1982; Miller and Gadd, 1983). Migration rates on the order of several meters per year are common, with the movement typically directed to the west in response to the prevailing easterly storms of the open-water season. However, island movement to the east also has been observed.

2.4 OCEANOGRAPHY

The Liberty prospect is located in Foggy Island Bay, which is part of Stefansson Sound. The Liberty facilities are located on the SDI along the Endicott Causeway (Figure 1-1). Foggy Island Bay is situated between the Sagavanirktok and Shaviovik rivers, and is sheltered by the McClure Islands. Three rivers discharge into Foggy Island Bay: the East Channel of the Sagavanirktok River, the Kadleroshilik River, and the Shaviovik River. The main channel of the Sagavanirktok River discharges directly east of the Endicott Causeway, and the western channel discharges directly west of the causeway into Stefansson Sound.

2.4.1 Seasonal Generalities

The Alaskan Beaufort Sea typically is ice-covered for about 9 months of the year. Breakup in Stefansson Sound and Foggy Island Bay occurs from mid-May to mid-June and is initiated by river breakup and the overflow of freshwater onto the landfast ice. Open-water typically occurs by mid- to late July. The initiation of freezeup in the Liberty (SDI) Project area ranges from late September to late October. All of Foggy Island Bay and most of Stefansson Sound become entirely ice-covered within 1 week after freezeup begins. The transition from freezeup to winter ice conditions in Foggy Island Bay and nearshore Stefansson Sound usually occurs in early to mid-November when the ice thickness is at least 30.5 cm.

2.4.2 Circulation

Circulation in Foggy Island Bay and Stefansson Sound is influenced by atmospheric pressure systems, tidal motion, river discharge, sea ice characteristics, and bathymetry. Wind-driven circulation predominates during the open-water season. Major contributors to under-ice circulation during winter months include wind-induced coastal setup, tides, and sea-ice brine rejection.

Winds are predominately from a northeasterly direction, southwesterly winds occurring more infrequently (Moorhead et al., 1992a; Hoefler Consulting Group, 2005). During the open-water season, easterly winds generate currents to the west, while westerly winds move water to the east. Surface currents are greater than bottom currents (Aagaard, 1984). The mean current direction is to the west, owing to the prevalence of easterly winds.

Cross-shore circulation also occurs during both easterly and westerly wind events. This phenomenon is known as Ekman transport. Coriolis forces deflect surface waters offshore during easterly wind events. Modest upwelling occurs as bottom water moves onshore in response to offshore movement of surface water. Conversely, westerly winds promote onshore movement of surface waters accompanied by a modest offshore movement of bottom water known as downwelling. In both cases, the transport of bottom water (upwelling or downwelling) only partially compensates for the surface water transport. The net result is decreased water levels during easterly wind events and increased water levels during westerly wind events.

Circulation under ice is generally westerly in direction, but is muted compared to open-water conditions (BPXA, 1998). Despite ice cover during the winter, meteorological-driven circulation can occur through wind-stress and coastal setup and setdown (EBASCO, 1990). Weingartner and Okkonen (2001) speculate that wind-forced currents dominate during the winter. Tidal motions also contribute to under-ice circulation (BPXA, 1998). In addition, density-driven currents resulting from brine rejection in sea ice occur during the winter (EBASCO, 1990).

During the spring freshet, the large and sudden discharge of fresh water from rivers can induce under-ice circulation. Weingartner, Okkonen, and Danielson (2005) estimates that the freshwater plume associated with spring river discharge can extend up to 20 km offshore. During May and June 2004, Alkire and Trefry (2006) measured an under-ice plume from the Sagavanirktok River that extended approximately 17 km to the north and 15 km to the west. Following river breakup, North Slope river flow rates are typically low and exert less influence on nearshore circulation during the open-water season.

2.4.3 Currents

As indicated above, wind-driven circulation predominates during the open-water season, with easterly winds generating currents to the west and westerly winds moving water to the east. Winds are predominately from an easterly direction; hence the mean current direction is to the west.

Weingartner, Okkonen, and Danielson (2005) obtained year-round current measurements at four locations in the nearshore Alaskan Beaufort Sea for a period of 3 years between 1999 and 2002. Two stations (McClure and Dinkum) were located near Liberty. The maximum current velocity measured at the McClure and Dinkum stations during the open-water season was 68 and 110 cm/sec, respectively, and more than 50% of the current measurements exceeded 15 cm/sec. Current directions were found to be appreciably correlated with winds. Current velocities for the open-water season presented in the Liberty DPP FEIS (USDOI, MMS, 2002) are in general agreement with the findings of Weingartner, Okkonen, and Danielson (2005).

Open-water current measurements were obtained as part of the Endicott Environmental Monitoring Program on several occasions during the 1980s (LGL Ecological Research Associates Inc. and Northern Technical Services, 1983; Hachmeister et al., 1987; Short et al., 1990; Short et al., 1991; Morehead et al., 1992a; Morehead et al., 1992b; Morehead, Dewey, and Horgan, 1993). During the summer of 1982 (prior to construction of the Endicott facilities), the mean current speeds at four sites in the Sagavanirktok River delta ranged from 12 to 15 cm/sec, with a maximum recorded current speed of 51 cm/sec. Following construction of the causeway, current speeds at sites near the SDI typically ranged from 5 to 15 cm/sec. The maximum recorded current velocities ranged from approximately 25 to 60 cm/sec. These findings are in general agreement with the more recent observations of Weingartner, Okkonen, and Danielson (2005).

Increased current velocities have been documented in the vicinity of the Endicott Causeway breaches (Rummel, Schrader, and Winnick, 1987; Johannessen and Hachmeister, 1987 and 1988; Morehead et al., 1992b; Morehead, Dewey, and Horgan, 1993). Current directions were found to be bi-modal, responding to changes in wind direction and largely perpendicular to the breach orientation. Mean daily current velocities were highly variable. During the summer of 1987, for example, mean daily current speeds for the near-surface waters at the breaches were found to range between 7 and 108 cm/sec. The maximum current speeds at the outer breach ranged from approximately 110 to 250 cm/sec. At the inner breach, the maximum current speeds were found to be slightly lower, ranging from approximately 90 to 150 cm/sec.

Current velocities during the winter are more muted when compared to those observed during the open-water season. Under-ice currents are affected by tides and atmospheric pressure variation rather than by meteorological process (BPXA, 1998). The current direction is westerly/northwesterly 60 to 70% of the time on average (Ban et al., 1999). Under-ice current velocities were collected by Aagaard (1984) at two nearshore Beaufort Sea sites in March and April, 1976. Currents generally were found to be <5 cm/sec. More recently, Weingartner, Okkonen, and Danielson (2005) documented a maximum under-ice current velocity in Foggy Island Bay and Stefansson Sound (McClure and Dinkum stations) of 14 and 20 cm/sec, respectively. Approximately 90% of the current measurements were <10 cm/sec. In contrast to the open-water season, under-ice currents were not well correlated with winds. These findings are in general agreement with the current velocities presented for winter conditions in Liberty DPP FEIS (USDOI, MMS, 2002).

Under-ice currents were measured in Foggy Island Bay and Stefansson Sound by Weingartner, Okkonen, and Danielson (2005) at the time of the spring freshet. Cross-shore current velocities of approximately 10 cm/sec were observed with strong correlation to discharge rates and the associated under-ice plume of the Sagavanirktok River eastern channel. These velocities were much greater than cross-shore directed flow rates observed under the ice during the winter months. During the 2004 spring freshet, Alkire and Trefry (2006) documented an average under-ice current of 7.2 cm/sec, with a mean northwesterly direction. Currents in excess of 10 cm/sec were typically found at plume fronts.

2.4.4 Water Levels

Tides in the Beaufort Sea are semidiurnal in nature, meaning that two high tides and two low tides occur each day. The National Ocean Service (NOS) reports a mean tide range of 16 cm and a diurnal range of 21 cm for the tide station located in Prudhoe Bay (NOS, 2006). The tidal characteristics for this station, which are directly applicable to the conditions at Foggy Island Bay and Stefansson Sound, are shown in Table 2.4-1. Mean lower low water (MLLW) lies 10.3 cm below mean sea level (MSL), while mean higher high water (MHHW) lies 10.6 cm above MSL.

Given the relatively small tide range, water-level fluctuations in the vicinity of the Liberty (SDI) Project area are governed more by meteorological effects than by astronomical tides. As discussed in Section 2.4.2, Coriolis forces deflect surface waters offshore during easterly wind events and onshore during westerly wind events. As a result, westerly wind events produce positive storm surges, while easterly wind events produce negative surges. Since the Prudhoe Bay tide station was established in 1990, the lowest observed water level was 102 cm below MSL on October 9, 2006 (NOS, 2006). The greatest water level measured during the 16-year period of record was 116 cm above MSL on August 11, 2000 (NOS, 2006).

A site-specific hindcast of oceanographic conditions was conducted for the Liberty (SDI) Project in 1997 (OCTI, 1997) using input data from a more generalized deep-water hindcast study of conditions in the Beaufort Sea performed in 1982 (Oceanweather, Inc., 1982). Extreme water levels for westerly storms were predicted for three locations: the original Liberty Island site and two candidate pipeline shore crossings (“East” and “West”). The predicted water levels included three components: storm surge, astronomical tides, and inverted barometer effect. The resulting predictions for each site are given in Table 2.4-2. The 100-year-return-period water level at the original island site is predicted to be 1.89 m above MSL, while for the two shore crossing sites, it is predicted to range between 1.89 and 2.04 m.

More recently, a joint industry project was begun to update the original deepwater hindcast study (Oceanweather, Inc., 1982) referenced above. The updated hindcast, known as “Beaufort Sea Ocean Response Extremes,” or “BORE,” incorporates more than two decades of additional storm events and the possible effects of climate change (Oceanweather, Inc., 2005). A site-specific hindcast of oceanographic conditions in the vicinity of Endicott was conducted using the BORE results (Resio and Coastal Frontiers, 2007). The resulting predictions are given in Table 2.4-2. The 100-year-return-period water level in the vicinity of the SDI is predicted to be 1.66 m above MSL.

2.4.5 Waves

The open-water season in Foggy Island Bay and Stefansson Sound is brief, with sea ice covering the region for about 9 months of the year. During the open-water season, wave heights are limited by the shallow waters adjacent to the coast and the shelter provided by barrier islands. Moreover, the proximity of the arctic pack ice limits the fetch available for wave generation.

Beaufort Sea storms, and hence wave directions, can be classified as either easterly or westerly. Easterly storms typically are of longer duration than westerly storms (Oceanweather, Inc., 1982). As indicated in Section 2.4.4, westerly storms often are accompanied by elevated water levels, while easterly storm may produce lower than normal water levels. Westerly storms tend to be more severe, in part due to the associated storm surge.

Wave measurements were obtained in Stefansson Sound during the summers of 1980, 1981, 1982, and 1983 in support of the Endicott Development (LGL Ecological Research Associates Inc. and Northern Technical Services, 1983; OSI, 1984). In 1980 and 1981, wave heights were less than 0.6 m approximately 90% of the time, with an average wave period <4 sec. The maximum wave height measured was 1.7 m. Small, short-period waves also persisted through most of the summer of 1982, with an average wave height of <0.2 m and an average wave period of <4 sec. Wave heights exceeded 1.0 m on only three occasions, with each event associated with an easterly storm. The largest wave height measured was 1.3 m with an associated period of 3.5 sec. During the summer of 1983, the sea surface was calm (wave heights were <0.1 m) approximately 50% of the time. The greatest wave height measured was 0.6 m on October 6.

Given the scarcity of wave measurements in the Beaufort Sea, extreme wave information must be generated using oceanographic hindcast models. A site-specific hindcast of oceanographic conditions was conducted for the Liberty (SDI) Project in 1997 (OCTI, 1997) using input data from a more generalized deepwater hindcast study of conditions in the Beaufort Sea performed in 1982 (Oceanweather, Inc., 1982). Extreme wave conditions for easterly and westerly storms were predicted for three locations: the original Liberty Island site and two candidate pipeline shore crossings (“East” and “West”). The resulting predictions for westerly and easterly storms are given in Tables 2.4-3 and 2.4-4.

In all cases, the wave heights associated with westerly storms were found to be larger than those with easterly storms. The 100-year westerly wave height at the original island site (located in a water depth of 6.4 m, MSL) was predicted to be 3.7 m with a period of 11.4 sec. At the East Shore Crossing site in a water depth of 0.6 m, the 100-year westerly wave height was predicted to be 1.0 m with a period of 11.4 sec. Slightly smaller wave heights were predicted for the West Shore Crossing site in a water depth of 0.6 m, with a 100-year westerly wave height of 0.9 m and associated period of 11.4 sec.

As indicated in Section 2.4.4, the BORE project was initiated in 2004 as an update to the original deep-water hindcast study (Oceanweather, Inc., 2005). A site-specific hindcast of oceanographic conditions in the vicinity of the SDI was conducted using the BORE results (Resio and Coastal Frontiers, 2007). Predictions of extreme wave conditions for easterly and westerly storms were derived for nine locations around the perimeter of the proposed SDI pad expansion (Figure 2.4-1). The predictions for easterly and westerly storms are given in Tables 2.4-5 and 2.4-6.

The predicted wave heights along the perimeter of the proposed pad expansion vary considerably due to sheltering from the Endicott Causeway and SDI, and the variation in water depths. On the northern side of the pad (Sites 7, 8, and 9), wave heights associated with westerly storms were found to be larger than those with easterly storms. The predicted 100-year westerly wave heights at this location ranged from 2.2 to 2.3 m, with wave periods of 11.8 to 11.9 sec. The east and south sides of the pad expansion (Sites 1 through 6) are sheltered from westerly waves. The predicted 100-year easterly wave heights at these sites ranged from 0.4 to 1.6 m, with wave periods of 11.5 to 11.9 sec.

2.4.6 River Discharge

The Sagavanirktok River, the Kadleroshilik River, and the Shaviovik River discharge into Stefansson Sound. The Sagavanirktok and Shaviovik rivers drain from the foothills of the Brooks Range, with drainage areas of approximately 11,000 and 4,400 km^2, respectively (USDOI, MMS, 2002). The Kadleroshilik River is confined to the coastal plain, draining an area of approximately 1,700 km^2 (USDOI, MMS, 2002).

The average annual flow rate is approximately 78 m^3/sec in the Sagavanirktok River, 23 m^3/sec in the Shaviovik River, and 9 m^3/sec in the Shaviovik River (BPXA, 1998). River flow during the winter months is minimal to nil (TAPS, 2001). The peak flow rates typically occur at the time of spring breakup or during the summer months in response to thunderstorms in the Brooks Range. The maximum mean monthly discharge for the Sagavanirktok River (164 m^3/sec) occurs in June (Figure 2.4-2). The average daily discharge measured in the Sagavanirktok River from 1983 to 2006 is shown in Figure 2.4-3. The maximum flow rate during the period of record, 935 m^3/sec, occurred in August 2002.

Rivers are the primary source of fresh water entering nearshore Stefansson Sound. River water temperatures in the summer (10 to 17 °C) are higher than the nearshore water temperature, and typically remain warmer until September (USDOI, MMS, 2002). At certain times of the year, river discharge can affect nearshore circulation.

In the spring, before the sea ice starts to deteriorate, melting snow swells the upland river channels. The bottomfast ice offshore of the river deltas forms a dam, which causes the flood waters to pour out over the top of the sea ice during late May or early June. As breakup progresses, river water also flows below the sea ice. The average date that the Sagavanirktok River begins to overflood the sea ice in Stefansson Sound and western Foggy Island Bay is May 20, with a standard deviation of 9.6 days, based on a 26-year period from 1973 through 1999, excluding 1991 (Coastal Frontiers, 1999b). During this period the Kadleroshilik and Shaviovik also flood the sea ice along the southern and southeastern shoreline of Foggy Island Bay. As breakup progresses, river water also flows below the sea ice.

The overflood water, which can exceed a depth of 1 m, can spread as far as 6 km offshore into Foggy Island Bay. Historical river overflood limits in Foggy Island Bay and nearshore Stefansson Sound, shown in Figure 2.4-4, display inter-annual variability (D.F. Dickins and Associates, 1999; Coastal Frontiers, 2000, 2003a). In the floating landfast ice zone (typically in water depths greater than 2 m), the overflood waters drain through holes and discontinuities in the ice sheet caused by tidal cracks, thermal cracks, stress cracks, and seal breathing holes. Drainage in the bottomfast ice zone (typically in water depths <2 m) is limited until the ice sheet loosens and rises to the surface.

If the overflow rate is high, powerful strudel jets can develop at the drain sites and create large scour depressions in the seafloor. Drainage, and hence seafloor scouring, tends to be more severe in the floating landfast ice zone and less pronounced in the bottomfast ice zone. In both cases, however, strudel drainage can provide a pathway to transport an oil spill below the ice sheet.

The locations of individual drainage features in Foggy Island Bay were mapped on five occasions between 1997 and 2003 (Coastal Frontiers, 1998, 1999a, 2000, and 2003a). An attempt was made to record all drainage features off the East Channel of the Sagavanirktok River during each of the 5 years. The average number of drains found off the Sagavanirktok River was 51. The greatest number of drains observed was 141 (mapped in 1997), while the fewest number was 10 (mapped in 1998). Comprehensive mapping of drainage features attributable to the Kadleroshilik River overflood was performed only in 1997 and 1998. Nine features were found in 1997, while 64 drains were mapped in 1998. In 1997, 30 drains were mapped off the western portion of the Shaviovik River overflood.

River water also flows under the sea ice. Sea Ice is discussed above in Section 2.4.3.

2.4.6.1 Ice Seasons

Sea ice covers the Foggy Island Bay and nearshore Stefansson Sound for a little more than 9 months of each year. The average length of the ice season is 288 ± 10 days, with a median freeze-up date of October 4 and a median breakup date of July 4. First open-water usually occurs in the 6-m water depth range by July 19. The average length of the gross open-water season is 77 days. The dates are based on a combination of on-site observations from 1980 through 1996 (Vaudrey, 1981a-1986a; Vaudrey, 1988a-1992; Coastal Frontiers, 1997b; satellite imagery from 1972 through 1996 (National Ice Center, 1997); and ice charts acquired from 1953 through 1975 (Cox, 1976).

Freezeup

Freezeup is defined as the first time in the fall when nilas or young ice (10 to 15 cm thick) covers 100% of the sea surface at a specific site or over a particular region. The initiation of freeze-up ranges from the third week in September to the last week in October with a median date of October 4. An undisturbed ice sheet can typically grow to 30 cm thick within the first 3 to 4 weeks after freezeup occurs.

All of Foggy Island Bay and most of Stefansson Sound become entirely ice-covered within 1 week after freezeup begins. However, the young first-year ice (10 to 30 cm thick) remains susceptible to movement and deformation by storm winds in October. These events are not unusual in the middle of Foggy Island Bay. A total of five ice pileup events created by freezeup ice movements affected Tern Island during the month of October from 1982 through 1984.

First-year ridging (60 to 90 cm high) and rafting may occur during these early freezeup ice movement events. However, 80% of the time (i.e., 8 out of 10 years) the first-year sheet ice in Foggy Island Bay remains relatively flat (surface ice features <60 cm high) throughout the year. Flat ice is not always an indicator that no ice movement has occurred. For example, young ice can be completely removed from an area during a storm. When new ice is formed, it may remain intact and quite smooth, giving no indication that appreciable ice movement had occurred earlier.

Once the sheet ice thickness reaches 30 cm, the ice cover becomes relatively stable, confined by the shoreline of Foggy Island Bay to the south, the McClure Island chain to the north, Tigvariak Island to the east, and the Endicott Development to the west. During seven freezeup studies conducted from 1979 through 1985 (OSI, 1979; Vaudrey, 1981a-1986a), no freezeup ice movement in Foggy Island Bay was observed or measured after November 1. The sheet ice can be considered part of the landfast ice zone after mid-November.

Winter

The sea ice regime of the Alaskan Beaufort Sea is usually depicted by a schematic cross-section, which divides the ice into three distinct zones (fast ice, shear or stamukhi zone, and pack ice). While simplistic, this schematic may have some validity in describing the ice that lies to the north of the barrier islands, but it is totally irrelevant to Stefansson Sound and Foggy Island Bay, which are located south of the barrier islands.

The first-year sheet ice constitutes the only appreciable ice feature in Stefansson Sound during the winter. It attains an average maximum ice thickness of 1.8 to 2.1 m by the end of May, growing roughly 30 cm per month from October through March. As the landfast ice sheet continues to grow throughout the winter, the ice becomes bottomfast when it contacts the seafloor in areas where the water depth is less than about 2 m. The sediments beneath the bottomfast ice become ice-bonded as the freezing front penetrates the seafloor.

During the winter, rapid changes in temperature may produce thermally-induced shrinkage cracks in the floating landfast ice, usually propagating from sources of stress concentration, such as manmade gravel islands (including the SDI), or promontories along the coast (e.g., Point Brower). In addition, a working tidal crack can be expected at the perimeter of the floating fast ice along the shoreline and around any grounded ice feature. Other than these minor cracking events, the first-year sheet ice in Stefansson Sound and Foggy Island Bay remains virtually motionless throughout the winter — with measured monthly ice movement rates ranging from 0 and 200 cm/month based on data compiled by OSI (1976; 1978a,b; 1980) and Vaudrey (1996).

Breakup

The transition from winter to breakup season begins in late April or early May, when the daylight hours are lengthening and air temperatures are on the increase. By early to mid-May, the ice sheet has lost sufficient bearing capacity that ice roads can no longer support over-ice operations.

Before the sea ice starts to show apparent signs of deterioration, melting snow in early May helps swell the upland river channels. The bottomfast ice in the shallow water offshore of the river deltas forms a dam, which causes the flood waters of the Sagavanirktok, Kadleroshilik, and Shaviovik rivers to pour out over the top of the sea ice during late May or early June. Typically by mid- to late June, about 2 to 3 weeks after the flooding has ceased, most of the landfast ice within the overflood zone will have melted in place from a combination of the fresh, relatively warm, water and the increased heat absorption by the dirty ice.

Warm air temperatures initiate meltpool formation on the top of the landfast ice sheet, especially where the surface is contaminated with dirt. In late May or early June, meltpools usually cover less than 10% of the landfast ice area beyond the overflood limits. Just before breakup in late June, the number of meltpools increases dramatically, covering approximately 40 to 50% of the sheet-ice surface.

Breakup is defined as the time when the ice concentration goes from 10 tenths to 9 tenths or less. The breakup mechanism for sheet ice is related to lines of weakness that develop along a series of meltpools or old thermal or stress cracks in concert with in-situ sheet-ice deterioration. Melting of the landfast ice reduces confinement, and wind stress may cause breakup along a line of meltpools or along existing cracks. During late June or early July, any 20-kt wind that begins to blow probably will initiate breakup of the floating landfast ice in Foggy Island Bay. The median breakup date is July 4.

Summer

The area in and around Stefansson Sound usually becomes open water by the third week in July, about 2 to 3 weeks after the initial breakup. Open water is defined as 1 tenth or less ice concentration. There is almost a 50% chance of an ice invasion which is greater than 1 tenth ice concentration, shortly after the appearance of the first open-water. Each invasion usually has a duration of about 1 week. Fewer than 10% of these invasions will contain small multiyear ice fragments.

Vaudrey (1997) computed summer season ice statistics for three ice concentration levels from a 44-year data base (1953-96). In severe summers, there is an 18% chance of having 2 to 3 ice invasions of greater than 1 tenth ice concentration. Higher ice concentrations of 3 tenths and 5 tenths are possible, but not likely. There is a 23% chance of having one invasion of 3 tenths ice concentration and a 9% chance of having one invasion of 5 tenths ice concentration. However, the chances of having more than one invasion of 3 tenths or 5 tenths ice concentration is virtually zero in Foggy Island Bay. There are typically 77 days between first open-water and freezeup, but the total number of days of open water is dependent on the number and duration of summer ice invasions.

2.4.6.2 Ice Features

First-Year Ice Sheet

The predominant ice feature in Stefansson Sound and Foggy Island Bay is first-year sheet ice that remains landfast throughout the winter, typically from early November through June. During the winter, the landfast sheet ice grows relatively undisturbed. Sheet-ice thickness is predicted empirically as a function of air temperature using the method of Bilello (1960). Table 2.4-7 presents the average predicted monthly landfast ice-sheet thickness, along with the 10-year minimum and 100-year maximum ice thickness (Vaudrey, 1997).

The sheet-ice growth rate is generally about 30 cm per month between November and April, and the landfast sheet ice attains an average thickness of 1.8 m by April 1. Growth after April 1 slows due to warming air temperatures, but the landfast ice may add another 15 cm of thickness by the end of May. The 100-year maximum undeformed first-year ice thickness is 2.29 m. Auger-hole ice-thickness measurements made in Stefansson Sound during freezeup in 1980 through 1982, midwinter in 1978 and 1984, and early June in 1984 through 1986 differed from the predicted ice thicknesses by only 3 to 5 cm (Vaudrey, 1988a).

Ice Rideup and Pileup

Ice rideup occurs when the ice sheet is driven by a storm wind relatively intact up a beach, coastal pad or manmade island. If the advance of the ice is halted by the slope or by a vertical obstruction, such as a sheet pile wall or tundra bluff, the sheet ice breaks up into individual blocks which form an ice pileup at or near the waterline. Several factors influence the susceptibility of a given location to ice rideup, pileup, and possible encroachment or override. Motion of the sheet ice is initiated by wind stress acting on the ice surface, but the single most important factor in initiating a ride-up or pile-up event is the loss of confinement of the sheet ice. Reversal of the wind direction is the usual cause of confinement loss, due to the presence of cracks or small leads in the nearshore ice.

The most common event is a combination of ice rideup and ice pileup, which occurs when the ice sheet rides up the slope some distance until increasing frictional resistance causes the ice to rubble and form a pileup. If the ice pileup grows to a sufficient height that its peak is above the work surface elevation of a coastal pad or manmade island, ice blocks at the top of the pile can tumble down onto the work surface. Such an event occurred at BPXA's Endeavor Island (3.5-m water depth), which is located adjacent to the Endicott MPI, in October 1982 (Vaudrey, 1983b) when a 30- to 40-kt southwesterly storm (with an estimated return period of 20 years) created an ice pile-up high enough (7.5 m) to permit 20-cm-thick ice blocks to encroach 3 to 5 m onto the work surface of the island.

The coastline, barrier islands, and manmade islands in the Alaskan Beaufort Sea are subject to ice movement against them during both freezeup (early October through late November) and breakup (late June through early July). However, the risk of ice rideup and encroachment at the proposed SDI pad expansion during breakup is considered to be inconsequential due to: (1) rotting ice from the river overflood and (2) higher frictional resistance of the slope protection at the shoreline of the SDI (which cause the sheet ice floes to break up into small blocks and start to form a rubble pile).

The data base for determining the susceptibility of the proposed Liberty pad expansion at the SDI to ice rideup and pileup consists of a combination of 8 years (1978 through 1985) of personal observations by Kovacs (1983 and 1984) and Vaudrey (1981; 1982a,b; 1983a,b; 1984a,b; 1985a,b; and 1986a,b); 4 years (1949, 1955, 1976, and 1977) of aerial photography analysis by Harper and Owens (1981); and a literature review of historical accounts by Kovacs and Sodhi (1980 and 1988).

Frequent ice ride-up and ice pile-up events have occurred at manmade gravel islands located near the SDI. Tern Island, which is located 15 km east of the SDI, experienced ice ride-up or ice pile-up events during each of four successive freezeup seasons (1982 through 1985) and during three of four breakup seasons (1982 through 1984) after construction. One such event is shown in Figure 2.4-5. A similar experience of frequency and intensity of ice rideup and pileup was observed at the Duck III manmade gravel island (located about 3 km east of the SDI) during the freeze-up and breakup seasons of 1982 through 1985. As an example, on October 15-17, 1984, a 15- to 20-kt westerly storm drove 15-cm-thick ice past Duck, creating a 5- to 6-m-high pileup on the western side of the island (Figure 2.4-6).

A recently completed study for the proposed Liberty pad expansion at the SDI estimated a 100-year ice-pile-up height of approximately 13 m (Vaudrey, 2007). For the six slope protection alternatives considered, the predicted ice encroachment distances ranged from 4.3 to 13.7 m.

Rafted Ice, Ridges and Rubble Piles

Because the sheet ice becomes relatively stable within 4 weeks after freezeup in early October, deformed first-year ice features, such as rafted ice, ridges, and rubble piles, are present in limited extent in Stefansson Sound and Foggy Island Bay.

Rafted ice is an ice sheet consisting of two or more sheet thicknesses caused by overriding. Very thin ice may grow, under light pressure, in a pattern of finger rafting to produce ice floes composed of as many as 10 layers, each 5 to 10 cm thick. Rafted ice rarely occurs in Foggy Island Bay and nearshore Stefansson Sound after the ice thickness reaches 30 cm.

Small (60- to 90-cm-high) first-year ridges may develop infrequently across Foggy Island Bay during early freezeup ice movement. A ridge, which is a linear ice feature, forms as a result of buckling when two ice floes collide. Very little, if any, ridge building occurs after the ice becomes landfast sometime in November.

Rubble piles, which are grounded ice features of areal, rather than linear, extent, are composed of ice broken into blocks of different shapes. Rubble piles rarely occur in the protected bays and lagoons inside the barrier island chain, unless they form as part of an ice pileup event against the shoreline, a barrier island, or a manmade gravel island. As with rafting and ridging, rubble piles typically occur only during a 4-week period after freezeup, when the ice sheet is thin and susceptible to movement, and during breakup in late June or early July. Three rubble piles were observed inside the barrier island chain between 1978 and 1985. The features had similar dimensions: 300 to 450 m long, 50 to 100 m wide, with an above-water height of 7 to 10 m (Vaudrey, 1980; Vaudrey, 1983a; Vaudrey, 1984a).

Multiyear Ice

Multiyear ice is sea ice that has survived at least one melt season. Multiyear ice invasions of the nearshore Beaufort Sea occurred on several occasions in the early 1980s prior to and during freeze-up, but no multiyear ice has ever been observed floating around in Foggy Island Bay. A handful of multiyear ice fragments 15 to 30 m in diameter have been observed in the lagoons during 2 of the 7 years (1979-1985) in which freeze-up studies were conducted. These fragments were grounded on shoals at entrances between barrier islands, such as the Newport Entrance north of Tigvariak Island. In consequence, multiyear ice fragments do not represent a hazard to the proposed Liberty pad expansion at the SDI.

2.4.6.3 Ice Movement

All ice motion is dominated by winds. During breakup and early freezeup, when the ice is more confined, the ice movement rate is about 2 to 3% of the wind speed. When ice floes move in relatively open water, the ice movement rates are roughly 4 to 5% of the sustained wind speed. Ice movement in Stefansson Sound is generally in a west-northwest or east-southeast direction, following the “bow-tie” pattern of prevailing easterly or westerly storm winds (Climatic Atlas, 1988).

Movement rates of freeze-up, breakup, and summer ice have been computed from ARGOS satellite-positioning buoys (Colony, 1979; Cornett and Kowalchuk, 1985; St. Martin, 1987; Thorndike and Cheung, 1977a and 1977b; Vaudrey, 1987; Vaudrey, 1989a) and from ice floe monitoring (Tekmarine, Polar Alpine Inc., and OCTI, 1985). Table 2.4-8 presents cumulative frequency distributions of ice drift speed during freeze-up and breakup based on daily ice-movement rates computed from ARGOS-buoy records collected in the eastern Beaufort Sea between 1979 and 1987 and from three site-specific ARGOS GPS stations deployed between Northstar and West Dock during the 1996 breakup season (Vaudrey and Dickins, 1996). The speeds depicted in Table 2.4-8 are daily averages for long-term ice movements, but short-term ice drift speeds, averaged over a period of 2 to 6 hours, can be dramatically higher. Extreme values for ice movement rates are in the range of 2.5 to 3.0 kt.

Movement of the landfast ice sheet occurs during the winter. Oceanographic Services, Inc. (OSI, 1976; 1978a,b; 1980) performed 4 consecutive years (1975-76 through 1978-79) of ice movement measurements using wireline stations. Four of these stations were located in Stefansson Sound. The ice-movement rates for the 20-year and 100-year return periods are 3.5 m/hr and 5.8 m/hr, respectively, based on a statistical analysis (Miller, 1996; Vaudrey, 1997) of the maximum hourly ice-movement rates recorded during each measurement year. The net ice movement by month for January through April for 3 years of ice measurements by Oceanographic Services, Inc. is summarized in Table 2.4-9. Although the 100-year ice movement rate is predicted to be 5.8 m/hr, more than 99% of the time the ice movement rate was less than 30 cm/hr.

Vaudrey (1996) reported similar ice movements measured in the winter of 1995-96 at a single wireline station located in 6.4 m of water in Stefansson Sound, 6 km south of Reindeer Island and 24 km west-northwest of the SDI. The maximum ice movement rate was 95 cm/hr based on 10-minute data and 21 cm/hr based on hourly data. The net movement was 134 cm for January, 73 cm for February, and 9 cm for March and April, resulting in an average ice movement rate of 56 cm/month over the 4-month period.

2.4.6.4 Sea Ice Changes

Satellite imagery obtained between 1979 and 2006 suggests that the areal extent of sea ice during summer and winter months has declined throughout most of the Arctic Ocean. The analysis of long-term data sets indicates substantial reductions in both the extent (area of ocean covered by ice) and thickness of the arctic sea-ice cover during the past 20 to 40 years, with record minimum summer extent in 2002 and again in 2005, and extreme minima in summer 2003, 2004 and 2006 (Stroeve et al., 2005; NASA, 2005; Comiso, 2006a, Stroeve, 2007).

In September 2002, summer sea ice in the Arctic reached a record minimum during summer, 4% lower than any previous September since 1978 and 14% lower than the 1978-2000 mean (Serreze et al., 2003). Three years of low ice extent followed 2002 Taking these 3 years into account, the September ice-extent trend for 1979 to 2004 declined by -7.7% per decade (Stroeve et al., 2005); from 1979 to 2005 declined by -9.8% per decade (Comiso, 2006a); and from 1979 to 2006 delined by -9.81% per decade (Stroeve et al., 2007).

The analysis of 2005 and 2006 arctic winter sea ice shows record low ice extent and area (Comiso, 2006b). The reported values are approximately 6% lower than average for each year (Comiso, 2006b). Stroeve et al. (2007) report a -1.8 and a -2.9% per decade trend for the periods 1953-2006 and 1979-2006, respectively. In contrast, evidence for reduced sea ice thickness during this period developed from upward-looking sonar is inconclusive (Serreze, Holland, and Stroeve, 2007).

Wendler et al. (2003) observed a decrease in sea ice concentrations in coastal regions of the North Slope between 1972 and 1994 (Figure 2.1-7). This finding correlates with an air temperature increase of approximately 1.1 °C during the same period. Sea ice concentrations were found to decline in all months except January. The decline was most pronounced in July and August, with changes on the order of 20% over the 23-year period. Declines during winter months were more modest, at about 3% over the period of record.

Using satellite imagery, Mahoney et al. (2006) identified the possibility of a reduced duration of landfast ice presence along the Arctic Coast of Alaska during the last three decades. Earlier onsets of thawing temperatures in the spring and later incursions of pack ice in the fall are contributors to this trend. Breakup along the Beaufort Sea coast in recent years (1996-2004) was estimated to begin 21 days earlier than in the 1970s, while the formation date of landfast ice during the same period was found to have changed little since the 1970's (Mahoney, Eicken, and Shapiro, 2007). Ice-free conditions were found to occur approximately one month earlier along the Beaufort Sea coast (Eicken et al., 2006). Similarly, Dickins and Oasis (2006) identified a trend of longer open-water seasons during the past decade when compared to the duration of ice-free conditions documented between 1950 and 1984.

The implications of the reduced extent of sea ice for regional oceanography include a longer open-water season and greater areas of open-water available for wave generation. Extended open-water seasons will result in more total wave energy reaching the coast, which in turn could increase shoreline erosion rates. Notwithstanding the trend towards diminished ice cover in the Beaufort Sea, there is no clear evidence that the severity of the wave climate has increased. Oceanweather, Inc. (2005) speculates that the wave-generating potential of the predominantly easterly and westerly storms is not critically affected by the northerly migration of the ice edge.

2.5 MARINE WATER QUALITY

Marine water quality is measured by the physical and chemical characteristics of the water. Seawater contains naturally occurring constituents derived from atmospheric, terrestrial, and freshwater environments, as well as those derived from human activities (pollution). Due to limited industrial activity, most contaminants in the Beaufort Sea and on the North Slope occur in low levels.

Industrial activities are the primary source of pollutants entering the marine environment. These contaminants may be classified as either physical, chemical, or biological. Suspended solids are the principal physical pollutant. Chemical pollutants include both organic (e.g., crude and refined oil) and inorganic substances (e.g., trace metals). Waterborne viruses, protozoa, or bacteria, and excessive biological growth can be characterized as biological pollution.

2.5.1 Salinity and Temperature

Temperature and salinity in the Beaufort Sea are summarized in the Liberty DPP FEIS (USDOI, MMS, 2002). Freshwater discharge from the Sagavanirktok River influences the temperature and salinity of Foggy Island Bay. The impact is greatest near the time of the spring freshet, when river flow rates typically are highest. The freshwater initially creates a brackish nearshore zone with salinities of 10 to 15 parts per thousand (ppt). As mixing commences, salinities increase to 15 to 25 ppt with water temperatures ranging from 0 to 9 °C. The nearshore waters become relatively well-mixed as the open-water season progresses, with salinities greater than 25 ppt and temperatures decreasing to 0 to 2 °C. During the winter, under-ice water temperatures ranging from -2 to 0 °C have been recorded in Foggy Island Bay, while measured salinities have ranged from 21 to 30 ppt during the winter.

Numerous measurements of water temperature and salinity in Foggy Island Bay and the Sagavanirktok River delta were obtained on several occasions during the 1980s as part of the

Endicott Environmental Monitoring Program (LGL Ecological Research Associates Inc. and Northern Technical Services, 1983; Hachmeister et al., 1987; Short et al., 1990; Short et al., 1991; Morehead et al., 1992a; Morehead et al., 1992b; Morehead, Dewey, and Horgan, 1993). Water temperature and salinity near the SDI are highly variable during the open-water season due to the proximity of the Sagavanirktok River and circulation of nearshore water masses. Water temperatures in the Sagavanirktok River tend to fluctuate with air temperatures. During the 1982 monitoring program, for example, the river water temperatures varied from 17 °C in July to 2 °C in September. It is not uncommon for water temperatures near the SDI to vary from 10 °C to 0 °C during the summer. Similarly, salinities in the region may vary from 0 ppt (fresh river water) to 26 ppt (consistent with shelf bottom water).

2.5.2 Dissolved Oxygen

Dissolved-oxygen levels in the Beaufort Sea are summarized in the Liberty DPP FEIS (USDOI, MMS, 2002). Like many cold climate waters, dissolved-oxygen levels in the Beaufort Sea typically are near saturation. Dissolved-oxygen levels during the open-water period are reported to range between 8 and 12 milligrams per liter (mg/l), while under-ice dissolved-oxygen concentrations during the winter are reported to range between 7.6 and 13.2 mg/l. However, areas with limited circulation can turn anoxic before spring breakup. Biological oxygen demand in Foggy Island Bay is reported to be <1 mg/l.

2.5.3 Turbidity

Satellite imagery and data for total suspended solids (TSS) show that turbid waters are generally confined to water depths <5 to 8 m inside the barrier islands (USDOI, MMS, 2002). Turbidity is caused by the presence of fine-grained particles in the water column. These particles are derived from river runoff, coastal erosion and resuspension of seafloor sediments by waves and currents.

During the open-water period of July to September, concentrations of TSS vary in response to water depth, wind conditions and the presence of sea ice. In Foggy Island Bay, concentrations of TSS are typically in the range of 5 to 15 mg/l during July and August, with occasional values greater than 30 mg/l as shown in Tables 2.5-1 and 2.5-2 (Rummel, Schrader, and Winnick, 1987; Dunton et al. 2005). During the 1982 open-water season, a TSS concentration of 400 mg/l was recorded in the nearshore waters of the Sagavanirktok River delta (LGL Ecological Research Associates Inc. and Northern Technical Services, 1983).

Dunton et al. (2005) made extensive measurements of TSS in Foggy Island Bay during 2001 and 2002. Maximum values for TSS (20 to 25 mg/l during summer 2001) were found in shallow water along the Endicott Causeway (Figure 2.5-1). Concentrations of TSS were generally less than 10 mg/l near the originally proposed Liberty Island location (Figure 2.5-1 and Trefry et al., 2004a). Dunton et al. (2005) showed that light attenuation increased directly with increasing concentrations of TSS and that new growth of kelp in the Boulder Patch was indirectly related to levels of TSS during the summer.

As summarized in Table 2.5-3, concentrations of TSS during the open-water period are well correlated to winds and storm events. For example, the maximum values for TSS observed during summer 1999 (Table 2.5-3) were found immediately following a 5-day storm with greater than (>) 25-kt winds. However, during summer 1999, Foggy Island Bay was not sampled until well after the storm subsided, and thus the 1999 data show a smaller maximum value than reported for the overall coastal Beaufort Sea (Table 2.5-1).

During the ice-covered period, concentrations of TSS are believed to be very low. Trefry et al. (2004a) reported background levels of TSS in Foggy Island Bay of 0.1 to 0.6 mg/l under ice during April 2000 with a similar range of TSS under ice across the study area for the Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA) study area during 2001 and 2002 prior to the onset of spring runoff. Weingartner and Okkonen (2001) and Weingartner, Okkonen, and Danielson (2005) deployed year-round moorings inside the barrier islands, including one in Foggy Island Bay from 1999 to 2002. Transmissivity (T) at the moorings was greater than 80% and relatively uniform under ice from February to May. Lower values for transmissivity (i.e., higher TSS) were observed under ice from November to February, indicating that there may be late fall or early winter events that promote some sediment resuspension under ice. This finding is consistent with a previous study which reported TSS levels of 2.5 to 76.5 mg/l under ice along the pipeline route for the then-proposed Liberty Project (Montgomery Watson, 1997 and 1998).

During spring runoff in late-May to mid-June, a large pulse of suspended sediment is discharged into Foggy Island Bay from the Sagavanirktok River. Rember and Trefry (2004) found maximum levels of TSS of 400 to 600 mg/l in the Sagavanirktok River for several days during the spring event in 2001 (Figure 2.5-2). Maximum values for TSS in the Sagavanirktok River during the spring floods of 2002 and 2004 were 300 to 350 mg/l due to lower river flow and, in 2002, a period of cooling and refreezing during the spring meltwater event. Concentrations of TSS from 63 to 314 mg/l were reported during breakup for the Sagavanirktok River from 1971 to 1976 by the U.S. Army Corps of Engineers (Envirosphere Company, 1993). During July through September, concentrations of TSS in the Sagavanirktok River range from 0.2 to 30 mg/l (Rummel, Schrader, and Winnick, 1987; Trefry et al., 2004a). Values for TSS at the higher end of this summer range are directly linked to rain storms.

Spring runoff from the Sagavanirktok River enters Foggy Island Bay as a 0.5- to 2-m-thick layer under the ice with concentrations of TSS that range from 5 to 50 mg/l (Trefry et al., 2006). Alkire and Trefry (2006) traced the flow of river water under ice to the barrier islands during the spring floods of 2004, and Trefry et al. (2006) showed the distribution of TSS in the Sagavanirktok River plume under the ice.

2.5.4 Hydrogen Ion Concentration (pH)/Acidity/Alkalinity

A description of the acidity/alkalinity of Beaufort Sea waters is provided in the Liberty DPP FEIS (USDOI, MMS, 2002). Typical pH values for seawater range from 7.8 to 8.2, while freshwater pH values generally range from 6.0 to 7.0. During the open-water season, pH values in the central part of the Beaufort Sea are reported to range from 7.8 to 8.2. Under-ice pH values during the winter are reported to range between 6.8 and 8.1.

2.5.5 Trace Metals

Trace metals can be useful indicators of industrial impacts because metals are sometimes enriched in the raw and finished materials used in modern industry. Bottom sediments are the ultimate sink, or depository, for trace metals released into the marine environment, and thus many environmental assessments of metals in the environment begin with sediment studies.

Previous studies of trace metals in sediments from the coastal Beaufort Sea have generally shown that metal concentrations are highly variable, but at natural levels with minimal localized inputs from development (Sweeney and Naidu 1989; Snyder-Conn et al., 1990; Crecelius et al., 1991; Naidu et al., 1997, 2001; Valette-Silver et al., 1999). Snyder-Conn et al. (1990) identified elevated levels of Ba, Cr, Pb and Zn in areas adjacent to one or more disposal sites for drilling effluent. Crecelius et al. (1991) found elevated levels of Ba at a few sites in western Harrison Bay and Cr near the mouth of the Canning River, with no other indications of metal contamination.

The MMS ANIMIDA (1999-2003) and Continuation of ANIMIDA Programs (2004-2007) were specifically designed to investigate the distribution of 16 trace metals (Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Tl, V and Zn) near the Liberty Prospect, the Northstar area and in the coastal Beaufort Sea from Harrison Bay to Camden Bay. Considerable variability was found in the concentrations of all metals as well as total organic carbon (TOC) in surface and subsurface sediments from the study area, including Foggy Island Bay (Table 2.5-4).

Concentrations of selected trace metals in sediments from a given depositional environment commonly follow a strong linear trend versus Al. As a result, the observed variability of trace metal concentrations often can be resolved by normalizing metal values with Al. A range of natural metal/Al ratios has been developed for all 16 metals listed above. Natural levels are defined as concentrations within the prediction interval or at <10% above the upper prediction interval (e.g., Cu, Pb, Hg and Ba in Figure 2.5-3). Trefry et al. (2003) reported that only 8 of 1,222 metal concentrations from the broad study area were elevated above natural levels. One of the eight anomalies was for Ba in sediment from Foggy Island Bay near the Liberty Prospect, and five anomalies were found in sediment in the Northstar area.

The historical record of metals in sediments from the coastal Beaufort Sea also was determined during the ANIMIDA Program. Concentrations of trace metals were determined for 104 samples from six cores, including one in Foggy Island Bay (Trefry et al., 2003). Some variability in concentrations of metals was observed in each core, mainly due to variations in the amounts of fine-grained sediment. Overall, concentrations of Ag, Ba, Be, Co, Cr, Cu, Hg, Ni, Pb, Sb, Tl, V and Zn in these cores were not impacted by anthropogenic inputs or diagenesis and show long-term (many decades) deposition of uncontaminated sediments.

More than 50 samples of suspended sediment from the Sagavanirktok River have been collected and analyzed for trace metals since 2000 (Rember and Trefry, 2004; Trefry et al., 2004b). All data for metals in suspended sediment from the river plot within the prediction intervals for natural sediment (e.g., Figure 2.5-3). In general, concentrations of trace metals in suspended sediment from the Sagavanirktok River are higher than in coastal sediments because the suspended particles are clay-rich and do not contain the metal-poor quartz sand and carbonate shell material found in bottom sediments from the Foggy Island Bay.

Sediment quality criteria have been established for several trace metals to help assess possible adverse effects to biota from elevated levels of metals in sediments. Long et al. (1995) introduced an effects range-low (ERL) that is defined as the concentration of a substance that affects 10% of the test organisms and an effects range-median (ERM) that is defined as the concentration of a substance in the sediment that results in an adverse biological effect in about 50% of the test organisms.

Six (Ag, As, Cd, Hg, Pb and Zn) of the 17 metals investigated during this study have been assigned reasonable ERL and ERM concentrations by Long et al. (1995), and these values are listed in Table 2.5-4. None of the concentrations of the these metals in the coastal Beaufort Sea sediments, including Foggy Island Bay, exceeded their respective values for the ERM (Table 2.5-4). Therefore, adverse biological effects as the result of trace metals are not expected to be a frequent occurrence at any site in the study area. Furthermore, no concentrations of Ag, Cd or Pb from this study exceeded the respective values for the ERL (Table 2.5-4), indicating that adverse biological effects from these four metals would be rare. One sediment sample (of 192 total) collected near West Dock contained Hg and Zn at levels that were slightly greater than the ERL (Table 2.5-4). Overall, sediments sampled in Foggy Island Bay and the coastal Beaufort Sea were not contaminated with metals and would rarely cause adverse effects to benthic organisms.

Concentrations of dissolved metals in Foggy Island Bay and throughout the coastal Beaufort Sea are similar to or less than the world average values in coastal and marine areas (Table 2.5-5). With respect to dissolved trace metals, the area seems pristine. Concentrations of dissolved metals in the incoming water of the Sagavanirktok River also are low relative to typical river water (Table 2.5-5), most notably for As, Cr and Hg. These data provide no indication of contamination from dissolved metals in Foggy Island Bay.

Trace metals in marine systems may be assimilated into the food chain and lead to adverse effects to the marine biota and ultimately to humans. In the ANIMIDA/cANIMIDA programs, concentrations of trace metals were determined for clams, amphipods and some fish collected in 1999, 2000 and 2002 (Brown et al., 2004, 2006). For Ba, Cd, Cu, Pb, V and Zn, samples had been previously collected and analyzed in 1986 and 1989 (Boehm et al., 1990).

Mean concentrations of Ba, Cu, Pb, V and Zn in clams (*Astarte* sp.) sampled during 1986, 1989, 1999 and 2000 were relatively uniform (see Figure 2.5-4 for Cu, Pb and Zn). Such uniformity is encouraging because body burdens for metals can be used as a long-term indicator of metal availability. This uniformity also suggests that no detectable shifts in metal levels in *Astarte* have occurred between 1986 and 2000. Some variability in concentrations among years was observed (e.g., Hg in Figure 2.5-4). However, these shifts are sometimes related to the amount of sediment, albeit small, in some samples. In addition, the small number of pools of samples limits the statistical power of the data. No evidence for metal contamination has been found for clams, amphipods or fish (Brown et al., 2004, 2006).

2.5.6 Hydrocarbons

As previously described in the Liberty DPP FEIS (USDOI, MMS, 2002), concentrations of aliphatic and aromatic hydrocarbons in sediments from the coastal Beaufort Sea are high relative to other undeveloped Outer Continental Shelf sediments. However, the hydrocarbons in the study area are mainly derived from natural outcrops of coal and shale and from natural petroleum seeps on land that are drained into rivers and into the coastal Beaufort Sea.

Recent data on organic parameters for surficial sediments from Foggy Island Bay are summarized in Figure 2.5-5, and show total polynuclear aromatic hydrocarbons (PAH), total petroleum hydrocarbons (TPHC), and total steranes and triterpanes (total S/T). Sediments in Foggy Island Bay and along the coastal Beaufort Sea contain a mixture of primarily terrestrial biogenic hydrocarbons and lower levels of petroleum hydrocarbons. This assemblage is clearly dominated by plant wax normal (i.e., straight-chain) alkanes in the n-C27 through n-C33 carbon range (Brown et al., 2004).

The PAH distributions for most of the surficial sediments (Brown et al., 2004) show that the PAHs are primarily of a combined fossil-fuel origin (i.e., petroleum and coal) with a biogenic component (perylene), and lesser contributions of pyrogenic or combustion-related compounds (e.g., 4-, 5-, and 6-ring PAHs). The petrogenic PAHs account for approximately 90% of the Total

PAH less perylene throughout the study area. Perylene, a naturally occurring PAH, was abundant in surficial sediments, often the most abundant single PAH compound in the overall PAH distribution.

Concentrations of hydrocarbons in the sediments in Foggy Island Bay are generally within the observed historical range for these parameters in the overall study area (Brown et al., 2004). Background concentrations of total PAHs (a sum of 2- to 6-ringed parent and alkylated PAHs) in recent Alaskan surficial sediment studies range from <10 to 1,000 ppb. Typically, PAH profiles indicate levels of a fossil fuel-type signature, which appears to be sourced in organics shales brought to the sediments from river runoff and coastal peat. At one location in Foggy Island Bay (station L08), concentrations of total PHC were about 2.5 times greater than background levels, and the source of the PHC was from unknown diesel input. Based on the PAH compositional results (i.e., petrogenic PAHs vs. pyrogenic PAHs), no appreciable changes in PAH composition were observed on an annual basis at Northstar due to construction and production activities.

The PAH data were correlated with silt+clay in Figure 2.5-6 to show that concentrations of these organic substances are directly related to the abundance of higher surface area, silts and clays. Collectively, concentrations of PAH normalized to silt+clay show little evidence of localized inputs of North Slope-related petroleum hydrocarbons to the sediments in the vicinity of the Liberty Prospect, Northstar, or the coastal Beaufort Sea.

Values for the ERL and ERM have been developed for 13 individual PAH compounds and three classes of PAH (low- and high-molecular-weight PAH, and total PAH) by Long et al. (1995). A comparison of the total PAH from all ANIMIDA and cANIMIDA sediments from 1999, 2000, 2002 and 2004 (Figure 2.5-7) shows that none of the total PAH concentrations determined for Foggy Island Bay and throughout the coastal Beaufort Sea exceeded the ERL. The mean total PAH values from each study region were generally an order of magnitude lower than the ERL. Similarly, the individual PAH concentrations did not exceed the ERL for the individual 13 PAH, which could be compared directly. In summary, based on sediment quality criteria, the concentrations of PAH found in the study area sediments are not likely to pose an ecological risk to marine organisms in the area.

Data from 1999, 2000, 2002 and 2004 for total polynuclear aromatic hydrocarbons, total petroleum hydrocarbons, and steranes/triterpanes (S/T) in clams (*Astarte* and *Cyrtodaria*) and amphipods (*Anonyx*) indicate that hydrocarbons in the sediment system are not readily bioavailable, as these species exhibit little ability to bioaccumulate saturated and aromatic hydrocarbons from sediment or from the overlying water column (Brown et al., 2004, 2006). Concentrations of PAH are very low (e.g., Figure 2.5-8 from 2000), showing consistent concentrations of contaminants over time in the study area.

2.6 FRESH WATER ENVIRONMENT

2.6.1 Sagavanirktok River

Onshore access and portions of the Liberty (SDI) Project lie entirely within the Sagavanirktok River delta. The Sagavanirktok River is 180 mi long and has a drainage area of 5,750 mi^2. About half of the basin area occurs in the Brooks Range, one-third within the Foothills physiographic province, and the remainder in the Arctic Coastal Plain. The river is bordered by the Franklin Bluffs to the east and the Kuparuk and Putuligayuk river basins to the west. A summary of hydrologic data for the Sagavanirktok River is provided in Table 2.6-1.

The Sagavanirktok is braided in the lower half of the river. About 25 mi upstream of its mouth, the river bifurcates into the West and East Channels, each consisting of a number of braided subchannels ranging from 200 to 1,200 ft wide within floodplains ranging from 1,000 to 7,000 ft wide. The East Channel, identified as the Main Channel on U.S. Geological Survey (USGS) maps, generally carries about equal flows to the West Channel. Thaw-lake terrain between the East and West channels indicates that the river has not occupied the intervening area for the past 10,000 years, since the early Holocene (SAIC, 1993a).

Channel patterns in the lower Sagavanirktok and its distributaries are formed primarily during summer high-flow events, which cause bank erosion and scour, and bear heavy sediment loads. Although overbank flows occur nearly every year during breakup, frozen ground conditions result in only minor changes to the channel and floodplain during the spring flooding (USDOI, BLM, 2002).

2.6.1.1 Hydrology

North Slope rivers are classified based on the physiographic province of their headwaters (Walker, 1973). Major rivers, including the Sagavanirktok River, have headwaters in the Brooks Range, while smaller rivers and streams originate in the Arctic Foothills or on the Arctic Coastal Plain. The Brooks Range consists of rugged east-west trending mountains that rise from the foothills to elevations above 8,000 ft. In the Sagavanirktok River, the initial snowmelt from the upper basin flows over the frozen river surface and ponds behind snowdrifts and icings. As breakup progresses, small snowdrifts thaw or are overtopped, and the accumulated meltwater is released downstream until it ponds behind larger snowdrifts. The storage and release process results in a peaked hydrograph, often followed by a rapid recession.

Flows are minimal in the Sagavanirktok during winter. Streamflow begins in May or early June during spring breakup flooding. Flows continue throughout the summer and decrease or stop shortly after freeze-up in early October. The mountains of the Brooks Range trap moisture and can receive significant rainfall (Hodel, 1986), resulting in occasional rainfall-induced floods that may exceed the spring breakup flood. Average, minimum and maximum daily flows measured in the Sagavanirktok River near TAPS Pump Station 3 are shown in Figure 2.6-1.

Long-term hydrologic data for North Slope streams are sparse. Drainages near the project area for which long-term discharge data are available include the Kuparuk, Sagavanirktok and Putuligayuk rivers. Because the data are limited, statistical procedures have been applied by the USGS to the limited data to correlate peak streamflow to the physical and climatic basin characteristics (Curran, Meyer, and Tasker, 2003). For North Slope streams, the resulting equations for estimating peak streamflows are based solely on the area of the drainage basin. Watershed models, which are often used to predict river floods based on precipitation input and basin geometry, do not adequately simulate North Slope breakup floods.

2.6.1.2 Flood Frequency and Stage

Continuous water-level measurements and associated river flows have been recorded for the Sagavanirktok from 1971 to 1978, and from 1983 to present at USGS Gauge Stations 15910000 and 15908000. The present gauge site, which is about 90 mi upstream of the delta near TAPS Pump Station 3, measures flow from about 35% of the Sagavanirktok River basin. Breakup and peak flow measurements have also been performed at the Endicott Road bridge site at the West Channel during most years from 1970 to present (Earl and Wright, 1980; McDonald, 1981, 1983, 1984, 1988, 1990a, 1990b; Bell and Associates, 1993, 1995, 1997-2004). Separate flood-frequency analyses have been performed for the Sagavanirktok River Bridge (Earl and Wright, 1980; McDonald, 1984; PND, 2003) and for the upstream gauging stations near Pump Station 3 (Jones and Fahl, 1994; Curran, Meyer, and Tasker, 2003).

Although rainfall floods on the North Slope are typically smaller than the annual breakup event, the Sagavanirktok has been noted as an exception. The largest floods measured in the Sagavanirktok at Pump Station 3 occurred during rainfall events. However, this station gauges flow only from the southern third of the drainage basin, consisting of mountainous terrain characterized by increased precipitation (Kane and Carlson, 1973). In contrast to the upper gauging station, annual hydrographs at the Sagavanirktok River Bridge show behavior typical of other North Slope streams, with annual peak flows during spring breakup. In addition to larger flows, breakup floods produce higher river stages in the coastal plain than rainfall floods because parts of the channel and floodplain are occluded by snow and ice. Twenty-two years of breakup stage and discharge data have been recorded at the West Channel bridge (Table 2.6-2).

Discharge data collected from both the West and East channels of the Sagavanirktok in 1982 and from 1985 to 1990 (Gallaway and Britch, 1983; Envirosphere, 1987, 1990, 1991; SAIC, 1991, 1993a, 1993b) are particularly useful for evaluating the proportion of flow carried by the West and East channels. The peak flow in the West Channel has ranged from about 35 to 75% of the total river flow between 1982 and 1990, and averages 50% (PND, 2006a). Figure 2.6-2 shows the flow distribution in the Sagavanirktok River delta, while Figure 2.6-3 and Table 2.6-3 present breakup flood magnitudes and frequencies at the Sagavanirktok West Channel Bridge.

2.6.1.3 Erosion and Sedimentation

The Sagavanirktok River has a substantial delta, indicating a general magnitude of sediment transport in this river. Sediment transport in North Slope streams is relatively low compared to streams in more southern latitudes due to the limited open-water flow season, the occurrence of high breakup flows while the river bed and banks are still frozen, permafrost, and subsequent low summer flows (Childers and Jones, 1975; Lewellen, 1972). The majority of sediment transport occurs during annual breakup flooding and rare high-volume rainfall floods, as evidenced by gravel bed material in the larger rivers. The Sagavanirktok River is degradational for most of its length, and is only aggradational for the last 15 mi.

2.6.1.4 Ice Conditions

Icings are large bodies of ice that form when water from a river or spring seeps onto the surface during winter. Because water is stored in the icings, downstream streamflow is initially reduced (Sloan, Zenone, and Mayo, 1976). Channel ice in the Sagavanirktok River can develop thicknesses greater than the 2 m typically observed on tundra ponds (BPXA 2001) as a result of groundwater springs or winter overflow building layer upon layer of ice (Carey, 1973; Hodel, 1986). The ability of the Sagavanirktok and other large rivers to carry this thick ice downstream during breakup flooding is limited, however, by the river depth.

Ice jams at the head of the Sagavanirktok River delta during breakup can divert discharge from one channel to the other (Chezhian, 2004). Channel ice at the Sagavanirktok West Channel Bridge has been the subject of an annual ice-cutting program, depending on ice conditions, since the early 1980s, and appears to have prevented major ice jams from occurring at the West

Channel bridge. The total duration of significant ice movement in a given river reach is no more than a few days (Walker, 1973; PND, 2005).

2.6.2 Lakes

Thaw lakes dominate the landscape of the coastal plain, originating as small ponds in low-centered ice-wedge polygons (Sellman et al., 1975). The ponds coalesce to form lakes, which develop a northwest-southeast orientation over time due to wave action from winds prevailing out of the northeast. Lake recharge results from snowmelt and rainfall within the lake basin and spring breakup flooding and overbank flows from nearby streams. Lakes subject to stream overflows during breakup flooding may be replenished annually. Other lakes may have residence times as long as 25 years (USDOI, BLM, 2003). Summer evaporation measured in lakes near Prudhoe Bay averaged about 5 inches (Mendez, Hinzman, and Kane, 1998).

Lakes are a readily available fresh water source in the project area (Sloan, 1987). Shallow lakes less than 6 ft deep freeze to the bottom during most winters. Lake depth is a primary factor in winter water supply for this reason, and lakes are classified accordingly as shallow or deep. Shallow lakes that freeze completely in the winter are directly underlain by permafrost. Deep lakes, which do not freeze to the bottom, are underlain by a thaw depression in the permafrost table that generally does not exceed 20 ft (Sellman et al., 1975). Shallow lakes begin to freeze in September and become ice free by late June, up to a month earlier than most deep lakes (Hobbie, 1984).

Deep lakes, along with gravel mine sites and river channels, are potential sources for fresh water supply for ice road construction in the project area. Several lakes along the Endicott Road and Badami Pipeline alignment have been tapped for ice road water sources, primarily for Badami. In addition, manmade reservoirs in the Sagavanirktok River delta (Duck Island Mine Site), Shaviovik River delta (Shaviovik Reservoir) and lower East Badami Creek (Badami Reservoir) have been used for water supply.

2.6.3 Surface Water Quality

Rivers in the project vicinity have been sampled by the U.S. Geological Survey (Feulner, Childers, and Norman, 1971; Kemnitz et al., 1993) and as part of the Endicott Monitoring Program (Envirosphere Company, 1987). Most fresh waters in the project area are pristine, soft, dilute calcium-bicarbonate waters. Near the coast, sodium chloride (salt) concentrations predominate over bicarbonate concentrations (USDOI, BLM, 1998, 1978; Prentki et al., 1980). Water chemistry in lakes and ponds in the project area is highly variable and dependent on the distance from the Beaufort Sea, frequency of flooding, and whether the lakes and ponds are tapped (connected to river channels most of the year) or perched (isolated from rivers channels most of the year).

The arctic freeze/thaw cycle plays a controlling role in water quality. In winter, surface waters less than 6 ft deep will freeze solid (Hobbie, 1984). In such waters, major ions and other “impurities” are excluded from downward-freezing ice in autumn and forced into the underlying sediment. Most of the ions remain trapped in the sediment after melt-out the following spring, giving these waters a very low dissolved-matter concentration. During the summer, dissolved matter concentrations slowly increase as ice in the bottom sediment melts and the sediments compress (Miller, Prentki, and Barsdate, 1980). Waters deeper than about 6 ft remain unfrozen. In these waters, ions and impurities are excluded from downward-freezing ice and forced into the deeper water column or underlying sediment, with a proportionate increase in concentrations of dissolved materials. As a result, distinct off-flavor and saline taste affect the potability of water from lakes and river pools by late winter.

Water temperatures in the Sagavanirktok River exhibit a seasonal pattern of general warming in June and July followed by cooling during August through mid-September (SAIC, 1994). Monthly average temperatures for a 6-year period (1985-1990) were 46 to 55°F in June, 50 to 56 °F in July, 44 to 53 °F in August, and 36 to 44 °F in September. Based on 14 years of data, the mean date when the Sagavanirktok Delta is frozen in (used as a milestone to indicate the Sagavanirktok River was also frozen in) is October 12, ranging from October 1 to October 25 (SAIC, 1994).

2.6.3.1 Turbidity

Turbidity is a measure of water clarity and varies seasonally in the project area in relation to sediment transport by the major rivers during flooding. Rivers originating in the foothills or Brooks Range have steeper gradients and carry higher suspended-sediment loads, resulting in higher turbidity than smaller streams originating within the Arctic Coastal Plain. Nearly the entire annual sediment load in rivers is carried between May and October, with approximately 70% flowing to the river deltas during breakup in May and June, when suspended-sediment concentrations can reach above 500 mg/l (ARCO, 1997; USDOI, BLM, 1978). Later in summer, suspended-sediment concentrations decrease significantly (USDOI, BLM, 1998). Total suspended solids in the Sagavanirktok River have been measured between 0.2 and 30.0 mg/l in summer, with turbidities ranging from 0.4 to 24.0 NTU (nephelometric turbidity units).

2.6.3.2 Alkalinity and pH

Alkalinity is a measure of the acid-buffering capacity of water. Freshwaters in the arctic tundra are only weakly buffered (USDOI, BLM, 1998, 1978; Prentki et al., 1980; Hershey et al., 1995; O’Brien et al., 1995). In lakes and ponds, alkalinities during snowmelt are about twofold lower than midsummer alkalinities, which are on the order of 20 mg/l as calcium carbonate ($CaCO_3$). Alkalinities in coastal streams are higher, ranging from about 15 to 80 mg/l as $CaCO_3$ in summer, with higher values at lower flow rates. Winter alkalinities in unfrozen pools beneath the ice are on the order of 150 to 200 mg/l as $CaCO_3$.

The pH is a measure of water acidity and alkalinity. A pH of 7 indicates a neutral balance of acid and base, between 5.0 and 6.5 indicates slightly acidic water, and below 4.5 indicates acidic water. A pH between 6.5 and 8.5 is considered necessary to protect aquatic wildlife (ADEC, 2002), and is normal for most surface waters. Rainwater has a pH of 5.5 due to carbon dioxide in the atmosphere. Plants and aquatic life tend to buffer the pH of surface waters and keep the pH in the range of 6.5 to 8.5.

In shallow lakes and ponds, pH values are often depressed to below 7.0 due to snowmelt runoff. After snowmelt, their pH values usually increase to between pH 7.0 and 7.5 (Prentki et al., 1980; O’Brien et al., 1995). The initial low pH is due to acidity of snow on the North Slope, which has a median pH of 4.9 (Sloan, 1987). This low pH, which is below the pH 5.5 expected for uncontaminated precipitation, is thought to be a result of sulfate fallout from arctic air masses industrially contaminated from pollution sources in Eurasia (USDOI, BLM and MMS, 1998). In tundra brown-water streams (so-called because of the color caused by tannins) and some foothill streams, pH values can be <6.0, with acidity attributable to naturally occurring organic acids

(Hershey et al., 1995; Milner, Idrons, and Oswood, 1995; Everett, Kane, and Hinzman, 1996). In streams and rivers, pH values are higher, seasonally ranging between 6.5 and 8.5 (USDOI, BLM, 1978; Kogl, 1971).

2.6.3.3 Salinity

Salinity of coastal waters in the summer varies in the range of 20 to 6 ppt, dropping rapidly to fresh water as the river channels in the deltas are approached. Average salinity measurements are typically highest in river channels (12.5 ppt), intermediate in tapped lakes (7.2 ppt), and lowest in perched lakes (1.0 ppt) (Schell, 1975). The differences in salinity correspond with varying concentrations of dissolved minerals.

As the flows from the major rivers decrease in early fall and storm surges associated with westerly winds occur, fresh water left in the delta channels from the summer flow is gradually replaced by seawater (Schell, Kinney, and Billington, 1971). The denser saltwater flows inward along the channel bottom with accompanying outflow of fresh water on the surface. The principal result of the saltwater intrusion is to create isolated marine environments in separate channels. The extent of marine water intrusion up the river deltas depends on surge height and river flow. Storm surges, which can exceed 10 ft on the Beaufort Sea coast, are more important in the water exchange process during the summer than lunar tides, which average less than 1 ft in the project area (Norton and Weller, 1984; Selkregg et al., 1975). Lunar tides are dominant in winter, however, when ice cover restricts storm surges.

2.6.3.4 Oxygen

North Slope streams are typically near saturation with dissolved oxygen during the summer due to aeration of the flowing waters. Summer concentrations of dissolved oxygen in clear-water streams and lakes in the project area range from 8 to 12 mg/l (Kogl, 1971). Brown-water streams, ponds and lakes generally have lower dissolved-oxygen concentrations. Oxygen saturation values in ponds during the summer months generally fall below 100%, although a range between 60 and 120% has been observed (Prentki et al., 1980). Oxygen values can be much lower—<10% saturation—in vegetated shorelines or in water pooled on wet tundra (USDOI, BLM, 1998). In these locations, chemical processes in the underlying sediment deplete oxygen from the water as rapidly as the water can take up oxygen from the air.

During the winter, large streams and deeper coastal-plain lakes may become supersaturated with oxygen when dissolved oxygen is excluded from ice as it forms, and the exclusion adds more oxygen than underwater respiration by benthic organisms removes (USDOI, BLM, 1978; Prentki et al., 1980; O’Brien et al., 1995). Late winter measurements of oxygen in unfrozen pools beneath ice cover in smaller rivers indicate significant residual oxygen (9 mg/l) and 70 to 99% saturation (USDOI, BLM, 1998). Larger rivers with deep channels also maintain adequate (for fish use) to supersaturated winter-oxygen concentrations (USGS, 2003). Decreasing oxygen concentrations are more likely in ponds during the winter because aeration and photosynthesis by aquatic vegetation, which both increase dissolved oxygen concentrations, do not occur under the inhibiting effects of ice cover and darkness.

2.6.3.5 Organic Nutrients

Nitrogen and phosphorus are the primary nutrients required for algae productivity and availability of food for fish. Low nitrogen concentration is often the limiting factor in phytoplankton productivity in coastal marine water, while low phosphate concentration is the limiting factor in fresh water in the rivers. Streams have relatively high summer concentrations of nutrients until the water reaches the Beaufort Sea, where phytoplankton consume most of the nitrate. Nitrogen concentrations are generally higher in the spring than in the fall because freezing concentrates nutrients in the waterbodies. Nutrient levels in lakes and ponds are much lower than in the major rivers. Samples taken in 1971 had nitrate and nitrite concentrations that were almost undetectable in lake and pond water (Alexander, Culon, and Chang, 1975). Phosphate concentrations were also much lower in lakes and ponds than in the large rivers. Another source of organic nutrients is regeneration of ammonia through the conversion of dissolved organic nitrogen by heterotrophs under the winter ice (Schell, 1975). Phosphate concentrations in freshwater bodies are generally very low.

2.6.3.6 Hydrocarbons

The peat that underlies the North Slope carries substantial hydrocarbon content. This content is evidenced by natural sheens that occur in ponds or flooded footprints in the tundra, foam on the downwind shoreline of lakes on windy days, and elevated hydrocarbon levels in sediments with peat. These phenomena are naturally occurring and are not the result of industrial activities.

Pond waters away from development in the Prudhoe Bay area contain 0.1 to 0.2 ppb total aromatic hydrocarbons, similar to concentrations in pristine marine waters (Woodward et al., 1988). Hydrocarbons derived from the various sources are detectable as elevated levels of saturated and PAH in Colville River sediment and in Harrison Bay sediment (Boehm et al., 1987a). Additional pyrogenic PAH compounds are present in tundra soils and form a depositional record of atmospheric fallout from tundra fires. Concentrations of indicator hydrocarbons from these multiple sources are high and chemically similar to those found in petroleum, thus making it difficult to detect or distinguish anthropogenic contamination from natural background due to fires. Similarly, high levels of hydrocarbons found in other major North Slope rivers have been attributed to natural sources (Boehm et al., 1987a; Yunker and MacDonald, 1995).

2.6.3.7 Trace Metals

Lake and stream waters on the North Slope are generally low in trace metals compared to most temperate-zone fresh waters (Prentki et al., 1980). However, naturally occurring copper, zinc, cadmium, and lead have commonly been found at concentrations above the criteria established to protect aquatic life from toxic effects (ADEC, 2002; USGS, 2003). These metals come from soils in the undeveloped watersheds. The variations in water quality are part of the natural environment for fish and wildlife in the project area and do not result from manmade disturbances (U.S. Army Corps of Engineers, 1998). In measurements made in ponds near Barrow in 1971-72, dissolved copper concentrations were on the order of 1 ppb, dissolved lead 0.7 ppb, and dissolved zinc 5 ppb.

2.6.3.8 Potability

Potable water is fresh water that is free from micro-organisms, parasites, and any other substances at a concentration sufficient to present a potential danger to human health. Surface water is the primary source of potable water on the North Slope. Treatment according to State of Alaska Drinking Water Regulations (18 AAC 80) is required for any potable drinking water system. Secondary standards provide specific parameters that define allowable contaminant concentrations. Additionally, water must have a generally agreeable taste and odor to be considered potable.

Surface waters in the project area generally do not meet potable water standards without treatment. Ponds and local streams are often brown-colored from dissolved organic matter and iron (USDOI, BLM, 1998), and fecal coliform often exceeds Alaska standards. Fecal contamination from avian, caribou and lemming populations is the primary source of water quality reduction below drinking water standards in the project area (USDOI, BLM, 1998; Ewing, 1997; Gersper et al., 1980; ADEC, 2003), and cold water temperatures prolong the viability of fecal coliform. Thus, some smaller waterbodies in the project area may exceed State of Alaska standards for fecal coliform for drinking water or water recreation due to local wildlife abundance (there is no State standard applicable to growth and propagation of natural aquatic life or wildlife). Larger lakes and rivers with higher water volumes tend to be less contaminated with fecal coliform.

2.6.4 Groundwater

The availability of groundwater is limited in the project area by impermeable permafrost, which is almost continuous throughout the North Slope and extends to depths of 2,000 ft or greater in the Prudhoe Bay area (Sloan, 1987; Lachenbruch et al., 1988). Groundwater occurs in thawed zones above, within and beneath the base of this permafrost. Water occurring within the 1- to 4-ft-thick seasonal thaw zone (active layer) is directly connected to and part of the surface water resource.

2.6.4.1 Shallow Groundwater

Shallow groundwater is present in localized unfrozen layers, or *taliks*, within the permafrost beneath deep rivers and lakes. Large rivers and lakes deeper than about 6 ft do not freeze to the bottom in winter and transfer heat downward, allowing a layer of unfrozen sediments to develop (Sloan, 1987). These unfrozen zones beneath and connected to surface waterbodies are called “open” taliks and are recharged from surface snowmelt and precipitation. Recoverable quantities of groundwater may be present where the thaw zone occurs in high-permeability gravel or sand sediments. Such shallow groundwater is likely to be present in the project vicinity beneath areas of the Sagavanirktok River and deep, large lakes.

Groundwater is also found in confined “closed” taliks within the permafrost. These formations can result from groundwater flow, or when lakes fill in with sediment, reducing the heat input and allowing the surface to freeze over and encase the unfrozen zone. The volume of groundwater that can be recovered from closed taliks is limited because they are cut off from recharge sources. Dissolved salts within the groundwater prevent freezing, but also make the water potentially harmful to surface vegetation and unsuitable for drinking without treatment (USDOI, BLM, 2003; Williams, 1970).

2.6.4.2 Deep Groundwater

Wells drilled in the Prudhoe Bay area of the North Slope indicate that the base of permafrost is approximately 2,000 ft deep (Lachenbruch et al., 1988). Deep groundwater beneath the permafrost (subpermafrost water) is recharged slowly from areas to the south in the Arctic Foothills and the Brooks Range by infiltration of meltwater (Nelson and Munter, 1990).

Subpermafrost groundwater from wells drilled near Barrow and Prudhoe Bay have encountered highly mineralized groundwater (Sloan, 1987; Kharaka and Carothers, 1988). Based on this data, it is likely that subpermafrost groundwater beneath the project area will be brackish or saline, and not suitable for human consumption or surface use (Williams and Van Everingdon, 1973).

2.7 BENTHIC AND BOULDER PATCH COMMUNITIES

2.7.1 Plankton Communities

Primary production in the Beaufort Sea is considerably lower than other oceans of the world. In Stefansson Sound, annual production is typically 5 to 20 grams (g) of carbon per square meter (Schell et al., 1982). Although phytoplankton abundance is greatest in nearshore waters <5 m in depth, per-unit-area production is actually higher offshore where waters are less turbid and there is greater penetration of sunlight. Phytoplankton abundance is highest in late July and early August when sunlight is the strongest. Because of the low primary production, zooplankton communities are characterized by low diversity and low biomass (Cooney, 1988). More than 100 species of zooplankton have been reported in the Alaskan Beaufort Sea, with copepods being, by far, the most dominant taxon (Horner, 1981; Richardson, 1986).

2.7.2 Benthic Communities

The marine benthic community in Prudhoe Bay in areas outside of the Boulder Patch is characterized by an infauna assemblage of polychaete worms, tiny mollusks, and benthic amphipods (Feder and Schamel, 1976; Broad et al., 1979; WCC, 1979; Griffiths and Dillinger, 1981; Feder and Jewett, 1982; Carey, Scott and Walters, 1984). A review of arctic invertebrate literature indicates that many of these nearshore benthic marine invertebrates are circumpolar (Carey et al., 1974). Stable infaunal communities occur seaward of the 1.8-m isobath. This is approximately the maximum depth to which landfast sea ice forms in 1 year. Lack of water in the areas shoreward of 1.8 m, plus the scouring effect of the ice during breakup, prevents establishment of permanent communities. Most stations within the 1.8-m contour are comprised of sediments dominated by fine sand, while the sediments deeper than 1.8 m contained more silt.

The nearshore Arctic Coast, including Prudhoe Bay, was explored using grabs and trawls as part of the National Oceanic and Atmospheric Administration (NOAA) Outer Continental Shelf Environmental Assessment Program (OCSEAP) (Broad et al., 1978, 1979, 1981). Broad et al. (1979) reported mean biomass values at three Prudhoe Bay sites as 4.93, 27.6, and 34.08 g/m^2. Polychaete worms and small mollusks were the predominant infaunal organisms. Dominant epifaunal organisms included the isopod *Saduria entomon* and *S. sabini*, nemerteans, and benthic amphipods. Mollusks consisted of 75 to 80% of total biomass, and polychaetes, 10 to 15%. *Portlandica arctica* and *Macoma* spp. were the most abundant bivalves.

From August 1974 until present, benthos in Prudhoe Bay has been sampled and monitored as various docks, causeways, and production islands have been constructed in the area. In the summers of 1974 and 1975 sampling occurred in the west side of Prudhoe Bay in the West Dock vicinity (Feder and Schamel, 1976; Feder et al., 1976; Feder, Shaw, and Naidu, 1976). A total of 38 invertebrate species in eight phyla were collected, with polychaetes and amphipods being the dominant groups. Extensive sampling covering much of Prudhoe Bay occurred in August, 1978, in connection with the Waterflood Project (ARCO Oil and Gas Co.), when a total of 6,430 individuals representing 91 taxa were collected (WCC, 1979). The ten most abundant species, primarily polychaete worms and amphipod crustaceans, accounted for 75% of the specimens collected. Distribution of the species was patchy; only ten taxa occurred in 20% or more of the samples. The seven most abundant and widespread animals were *Pontoporeia affinis* and *Onisimus glacialis* (amphipods), *Ampharete vega*, *Scolecolepides arctius*, *Pygospio elegans*, *Prionospio cirrifera*, and *Chaetozone setosa* (polychaetes) and *Saduria entomon* (isopod). During additional Waterflood Project sampling in July 1981, 6,378 individuals were obtained in 86 taxa (Feder and Jewett, 1982). The five most abundant species were the polychaetes *Prionospio cirrifera*, *Tharyx* sp., *Ampharete vega*, *Pygospio elegans*, and *Chaetozone setosa* which accounted for 73% of the total number of individuals recorded.

Dominant motile invertebrates that live near the seafloor include amphipods, mysids, copepods, and other swimming crustaceans. They are food for some fishes, birds, and marine mammals. Other invertebrates, such as bivalves, snails, crabs, and shrimp, are food for some marine mammals such as whales and bearded and ringed seals (Frost and Lowry, 1984).

2.7.3 Boulder Patch Communities

The Stefansson Sound Boulder Patch, located 20 km northeast of Prudhoe Bay in the Alaskan Beaufort Sea (Figures 2.7-1 and 2.7-1a), supports the only known kelp bed on the Alaskan Arctic Coast that is characterized by abundant red and brown algae and a diverse assortment of invertebrate life attached to a collection of boulders, cobbles, and pebbles (Dunton, Reimnitz and Schonberg, 1982). The estimated area of Boulder Patch with >25% rock cover is 35.7 km^2 and 10 to 25% rock cover is 32.9 km^2 (Gallaway, Martin and Dunton, 1999). This area of hard substrate was discovered in Stefansson Sound, Alaska, by marine geologists during the summers of 1971 and 1972. It lay unexplored until the summer of 1978 when joint geological and biological investigations revealed it was clearly the richest and most diverse biological community yet discovered in the Alaskan Beaufort Sea (Reimnitz and Ross, 1979; Dunton, 1979; Dunton and Schonberg, 1981; Dunton, Reimnitz and Schonberg, 1982; Toimil and England, 1982; Toimil and Dunton, 1983; Busdosh et al., 1985). The Boulder Patch kelp community is a unique feature on the northern Alaskan shelf, which is blanketed predominantly by silty sands and mud (Barnes and Reimnitz, 1974) with an infaunal assemblage dominated by polychaete worms, small mollusks and crustaceans (Feder and Schamel, 1976; Broad et al., 1978; WCC, 1979; Griffiths and Dillinger, 1981; Feder and Jewett, 1982). Although gravel makes up the substrate around the bases of the barrier islands (Beehler et al., 1979a, 1979b), the surface sediment covering most of Prudhoe Bay and adjacent coastal shelf areas is composed of 21% fine silt, 16% silt, 20% very fine sand, and 28% fine sand (Chin et al., 1979).

2.7.3.1 Arctic Kelp

The arctic kelp *Laminaria solidungula* is a predominant member of the Boulder Patch kelp bed community and serves as both food and shelter for a diverse assemblage of marine invertebrate fauna (Dunton, Martin and Mueller, 1992). The growth and productivity of *L. solidungula* is related to its underwater light environment, which varies considerably on both spatial and temporal scales. Continuous measurement of the amount of photosynthetically active radiation (PAR) reaching the plants was examined in August 1984 and continuously from August 1986 to August 1991. Maximum daytime levels of PAR showed large seasonal differences, ranging from 0 to 15 µmol photons per m^2 per sec during the ice-covered period to between 0 and 250 µmol photons per m^2 per sec during the open-water season (Dunton et al., 1992). Periods of decreased water transparency during the summer and large patches of turbid ice in winter were the major causes of low or undetectable levels of PAR. The lowest annual quantum budget for *L. solidungula* ranges from 45 to 50 mol per m^2 per yr, which represents only about 0.2% of total surface PAR. Although *L. solidungula* possesses a very low light requirement for net photosynthetic carbon production, data indicate that this species is living at its physiological limits in the Beaufort Sea Boulder Patch.

Polar marine plants have a variety of adaptive responses that help compensate for lower irradiances at high latitudes. For example, the endemic arctic kelp *Laminaria solidungula* completes over 90% of its annual linear growth during the dark 9-month ice-covered winter period (Dunton and Schell, 1986). Kelp use carbon reserves accumulated during the previous summer when waters are predominantly free of ice and light is available (Chapman and Lindley, 1980; Hooper, 1984; Dunton, 1985; Henley and Dunton, 1995; Dunton and Schell, 1986). Photosynthetic production during the open-water period is usually sufficient to compensate for respiratory demands and allow accumulation of carbon storage compounds. Suspended sediments decrease water transparency and may significantly reduce annual kelp productivity (Dunton, 1990; Best et al., 2001).

Growth and production of the endemic arctic kelp *Laminaria solidungula* is regulated primarily by PAR during the open-water period. Variation of underwater PAR caused by changes in water transparency can have significant effects on the annual productivity of this species (Dunton, 1990). *L. solidungula* has been found to thrive at low light levels and is thus well adapted to the Arctic. It has the lowest irradiance saturation level (38 µmol per m^2 per sec) of any member of its genus and is photoinhibited at irradiance levels of 123 µmol per m^2 per sec (Dunton and Jodwalis, 1988). Its compensation level (2.1 µmol per m^2 per sec) is well below the levels of 5 to 9 µmol per m^2 per sec for other congeneric species (Dunton and Schonberg, 1990). *L. solidungula* benefits from light increases up to 38 µmol per m^2 per sec, but no beneficial effect occurs above this level. However, the plants benefit fully from any increases in light received during the winter-spring period because ambient light levels are usually well below the saturation level (Dunton and Jodwalis, 1988).

In low-light environments, plant production is more a function of exposure to saturating levels of PAR than to the total amount of photons received over the course of a growing season. In 1988, annual quantum budgets for *L. solidungula* varied from 45 to 50 mol per m^2 per sec, near the annual minimum light requirement reported in other studies for the lower limit of *Laminaria* spp. However, the time the plants were exposed to saturating levels of PAR in 1988 was considerably less than in other years. This was correlated with significant reductions in thallus tissue density and carbon content during the summer open-water period in 1988. Percentage of dry to wet weight (tissue density) dropped from about 16 to 10%, and carbon content, from 35 to 28%. The drop in both indices indicated that 1988 summer open-water PAR was insufficient for maintaining maximum photosynthetic carbon fixation. The decreased storage of carbohydrate reserves, which are used for tissue expansion during the dark ice-covered period, resulted in significantly reduced linear growth in all plants the following year (1989). Under saturating irradiances, young and adult plants exhibited similar rates of carbon fixation on an area basis, but under light limitation, fixation rates were highest in adult plants for all tissues. Continuous measurement of in-situ quantum irradiance made in summer showed the maximum PAR can be less than 12 µmol per m^2 per sec for several days when high wind velocities increase water turbulence and decrease water transparency (Dunton and Jodwalis, 1988).

Continuous measurements of photon flux fluence rate (PFFR) made during the ice-covered spring months, when the sun’s duration above the horizon is increasing toward 24 hours a day, reveals a transmittance ranging between 0.001 to 0.6% of surface PFFR. This is well below the lower light limit of kelp growth (0.5 to 1.0%) suggested by Lüning and Dring (1979), Lüning (1981) and Hiscock (1986), and corresponds to an average maximum of about 1 µmol per m^2 per sec, which is nearly seven times lower than reported for the same period by Chapman and Lindley (1980) in the Canadian High Arctic. The great variation in PFFR beneath the ice canopy among years and among sites is directly related to density of sediment inclusions within the ice, supporting the diving observations noted by Dunton, Reimnitz, and Schonberg (1982), Dunton (1984), and Reimnitz and Kempema (1987) on the large-scale heterogeneity of turbid ice in Stefansson Sound. The absence of any consistent pattern of under-ice PAR among years and between sites in Stefansson Sound reflects the random occurrence of this phenomenon on both temporal and spatial scales, one that has broad implications with respect to the productivity in *Laminaria solidungula* (Dunton and Schell, 1986).

There are few quantitative estimates of kelp biomass in the Boulder Patch. In areas of >25% rock cover, Dunton, Reimnitz and Schonberg (1982) recorded a biomass of 262 g per m^2 compared to 67 g per m^2 in areas of 10 to 25% rock cover. Accurate estimates of kelp biomass are critical, since these values are used in models to predict changes in areal net production in response to changes in water column transparency. Measurements of annual production in arctic kelp based on in situ measurements of blade production are 6 to 10 $g/m^2/yr$ carbon (Dunton and Schell, 1986). Linear kelp growth from 1997 through 2004 was measured at seven sites within the Boulder Patch (Aumack, 2003; Dunton, unpublished data). These growth data are comparable to previous studies (Dunton, 1990; Martin and Gallaway, 1994). Annual *Laminaria solidungula* elongation displayed spatial and temporal variability (Figure 2.7-3). The substantial decrease at all sites except Dive Site (DS)-11 in kelp blade elongation in 2000 reflects reduced water transparency during summer 1999, especially near the shoreline. High light attenuation from elevated TSS levels was most likely the result of a series of major storm events that occurred in August and October 1999 (Weingartner and Okkonen, 2001). Consistently high blade elongation rates recorded in *L. solidungula* plants collected from DS-11 reflect both the offshore location of this site relative to other sites and its higher percentage of rock cover (Martin and Gallaway, 1994). Linear growth over 8 years at the seven sites ranged from 16 cm (nearshore site L-2) to 28 cm (offshore site DS-11), with an overall mean of 20 cm. The summers of 2001 and 2002 were the highest light years as reflected in the greatest blade elongation during the following winter (an average of 33 and 28 cm, respectively). An extremely low amount of growth was measured following the stormy summer of 2003 (mean elongation, 6 cm) (Dunton, unpublished data). Dunton’s unpublished data from almost 4 decades of annual kelp growth measurements indicate that summers with very low amounts of growth have occurred frequently during the past decade.

The contribution by kelp to overall coastal productivity is therefore considerable and can account to 50 to 75% of the total productivity of the system (Dunton, Reimnitz and Schonberg, 1982). This energy is passed on to other trophic levels either directly through herbivory or indirectly through bacterial transformation of particulate detritus. Direct evidence for the incorporation of kelp carbon into nearshore arctic is documented by Dunton and Schell (1986, 1987). Distinct seasonal changes in the stable carbon isotope ($\delta\ ^{13}C$) values of several animals indicated a diet shift to an increased dependence on kelp carbon during the dark winter period when phytoplankton were absent. For example, up to 50% of the body carbon of mysid crustaceans, which are key prey species for birds, fishes, and marine mammals, was composed of carbon derived from kelp detritus during the ice-covered period. The $\delta\ ^{13}C$ values of macro-algal herbivores (snails and chitons) reflected their algal food preference, while the majority of species appear to eat a combination of algae and phytoplankton. The selective suspension-feeding bryozoans and hydrozoans reflected a phytoplankton-based diet.

2.7.3.2 Boulder Patch Epifauna

The number of species, numerical abundance and total biomass of the epilithic faunal assemblage of the Boulder Patch is significantly greater than reported from any area along the Alaskan Arctic Coast and represents nearly every major marine taxonomic phylum (Dunton and Schonberg, 1979, 1980, 1981; Dunton, 1979; Dunton, Reimnitz and Schonberg, 1982; Dunton, 1984; Dunton, Martin and Gallaway, 1985; Martin and Gallaway, 1994, Gallaway and Martin, 1987; Gallaway, Martin and Dunton, 1988; LGL Ecological Research Associates, Inc. and Dunton, 1989, 1990, 1991, 1992; Martin and Gallaway, 1994; Dunton and Schonberg, 2000). Nearly all boulder and cobble surfaces are covered by algae and epilithic invertebrates. Many organisms found in the Boulder Patch are previously unreported from the Alaskan Beaufort Sea because they require hard substrate for attachment. About 158 epilithic taxa were collected with an average abundance of 18,441 organisms per m^2 and average biomass of 283 g/m^2 (Table 2.7-1). The wet-weight biomass of the epilithic community is dominated by red and brown macroscopic algae (59% of total), with invertebrates and fishes constituting about 41% of the total biomass.

The most conspicuous member of the community is the kelp *Laminaria solidungula*, although less common kelp species also occur. Beneath this kelp overstory are several species of red algae (*Phycodrys rubens*, *Phyllophora truncata*, *Neodilsea integra*, *Odonthalia dentata*, *Rhodomela confervoides* and the encrusting algae *Lithothamnium*). The predominant faunal groups by weight (Figure 2.7-2) are fishes (9%), porifera (9%), mollusks (7%), bryozoans (5%), cnidarians (4%), and polychaetes (3%) (Dunton and Schonberg, 2000). Sponges and soft corals are the most conspicuous invertebrates due to their large size, abundance, and striking shapes and colors. Two sponges (*Choanites lutkenii* and *Phakellia cribrosa*) and a pink soft coral (*Gersemia rubiformis*) are widespread throughout the Boulder Patch. The chiton *Amicula vestita* constitutes the greatest percentage of molluskan biomass and is one of the few species that grazes directly on the kelp. Clams, mussels, snails, chitons, bryozoans, hydroids, tubicolous polychaetes, sea stars, sea anemones, and sea squirts are common on the rocks or attached to other biota. Interspersed between the rocks were lyre and hermit crabs. Several species of bottom-dwelling fishes are present in the Boulder Patch that include the fourhorn sculpin, great sculpin, snailfish, prickleback, eelpout, arctic flounder. Arctic cod and motile crustaceans (mysids, amphipods, and isopods) are common in the water column adjacent to the Boulder Patch community (Dunton, Reimnitz and Schonberg, 1982).

2.7.3.3 Boulder Patch Infauna

The sediments between boulders and cobbles within the Boulder Patch support a richer infaunal community than sediments from areas outside the kelp beds in Stefansson Sound. These differences in infaunal abundance and biomass between the Boulder Patch and peripheral sediment areas reflect the contribution of algal carbon to the benthic system. Benthos from samples taken between rocks in a densely populated area (site DS-11) included 140 taxa with mean density estimates of 4,830 per square meter and biomass estimates of 30 g/m^2 (Dunton and Schonberg, 2000). Benthos in bottom grab samples from the western fringes of the Boulder

Patch exhibited abundances of 3,800 individuals per square meter and biomass estimates of 46 g/m^2 (Toimil and Dunton, 1983).

Measurements of $\delta\ ^{13}C$ also demonstrated the contribution of algal carbon to the community in the Boulder Patch. Measurements of $\delta\ ^{13}C$ were used to assess the importance of kelp carbon versus phytoplankton carbon to resident fauna in the Boulder Patch (Dunton and Schell, 1987). Individuals of the same species were collected from three types of areas: center of kelp bed (site DS-11), fringe, and outside Boulder Patch. In nearly all cases, the $\delta\ ^{13}C$ values at the kelp DS-11 were 1.5% heavier than the same animals collected at the fringe or outside the kelp community, which supports the hypothesis that many organisms assimilate carbon derived from kelp. Other studies have also documented the importance of benthic macroalgae and algal epiphytes as carbon sources for consumers (Fry, 1984; Kitting, Fry and Morgan, 1984). Approximately 98% of the carbon produced annually in the Boulder Patch comes from kelp and phytoplankton. Dunton (1984) estimates that benthic microalgae contribute about 2% of the annual carbon produced in the Boulder Patch. It also demonstrates that although most kelp carbon is channeled through the detrital food web, its abundance and high nutritional value ensure its relatively efficient transfer throughout the benthic community.

2.7.3.4 Boulder Colonization

Recolonization studies of benthic boulders and cobbles addressed how quickly the benthic community would recover from disturbance. The results of recolonization studies show that development of an epilithic assemblage of organisms is a slow process in the Arctic. Fourteen $0.05\text{-}m^2$ plots of rock at DS-11 were denuded with paint scrapers at 3-month intervals beginning in August 1978 and ending in May 1979. After 3 years, at least 50% of the substratum remained bare on all plots, but most were more than 75% bare (Dunton, Reimnitz and Schonberg, 1982). The recolonization that occurred was by encrusting coralline algae, a foliose red alga, hydroids, and tiny tube-dwelling polychaetes. The factors influencing establishment of epilithic community on the denuded boulders in the Arctic are similar to those identified as important in the establishment and development of communities in temperate regions by Dayton (1971), Dunton (1977), and Osman (1977). They include the stability of the substratum; temporal variability in the composition and abundance of larvae and spores; biological interactions such as predation, herbivory, and competition; and the growth rates of species that settle. In the Boulder Patch, most of the colonizing organisms first appeared in the early winter months. This may be due to the lack of sediment covering the plots at that time. The sediment cover was substantial on the denuded plots during summer and fall, and if small organisms existed, they could not be seen.

Colonization of bare boulders placed at sites in the Boulder Patch in August 1984 also occurred slowly. Colonization in 1986 and 1987 was described as negligible (Martin et al., 1988), although there was early episodic colonization dominated by the polychaete *Spirorbis* sp. In 1990, 6 years after deployment, a boulder placed at site DS-11 had five colonizing species. Two taxa that were evident in the 1989 photograph of this boulder were not seen in 1990, possibly due to heavy siltation of the rock. Finally, a more recent recolonization experiment which began in summer 2002 revealed nearly identical results compared to previous studies (Brenda Konar, University of Alaska, Fairbanks, pers. comm.). It is likely that the naturally occurring periodic inundation by sediment in the Boulder Patch adversely affects the process of recolonization by effectively blocking larvae or spores from reaching the rock surface, or by smothering epilithic biota with a stature <1 or 2 millimeters (mm) (Dunton, Reimnitz and Schonberg, 1982). The availability of primary substratum for recolonization is thus substantially limited during periods of sedimentation.

2.7.3.5 Sedimentation

Although the Sagavanirktok River delta discharges about 6 mi southwest of the Boulder Patch, the boulders do not appear to have been buried over time by riverine sediments. Currents are predominantly wind-driven during the open-water period, when easterly winds dominate. Therefore, the net drift is westward during the summer, moving riverine sediments away from the Boulder Patch (Barnes, Reimnitz and McDowell, 1977; Matthews, 1981). Peak discharge occurs in June following river breakup, but very little sediment accumulates within the sound during this period (Reimnitz and Ross, 1979). The rivers discharging into Stefansson Sound supply only sand-size and finer materials into the water column (Dunton and Schonberg, 2000). Some of the sandy materials have accumulated in an alongshore berm just offshore of the causeway. Sedimentation traps showed that silt constituted the highest percentage (58.5%) of the suspended material collected between May and August, 1981. Clay (38.3%) and sand (3.2%) constituted the remaining fractions (Dunton, Reimnitz and Schonberg, 1982). The percentage of organic matter of the sediment was 8.4%.

In the Boulder Patch, sedimentation is potentially greatest during late summer and early fall when 1 to 5 mm of sediment accumulate on the seafloor and coat the biota (Dunton, Reimnitz and Schonberg, 1982). The changes in water transparency, particularly the very poor conditions, are predominantly products of storms and associated shifts in wind-induced currents. Benthic sediments are lifted from the Boulder Patch and resuspended during severe storms, preventing burial of the rich biological community. The sediments remain suspended for long periods and settle slowly following freezeup in October (Dunton, Reimnitz and Schonberg, 1982). Other studies (Dunton, 1984; Dunton and Schell, 1986) have demonstrated that low winter levels of PAR are related to high sediment concentrations in the ice canopy. These sediments are almost entirely incorporated into the ice canopy during freeze-up in October (Reimnitz and Dunton, 1979; Barnes and Fox, 1982; Dunton, Reimnitz and Schonberg, 1982). Due to the inclusion of fine sediments and particulates into the ice canopy, light transmission into the water column can be completely blocked even during periods of 24-hour daylight which occur in spring. The spring bloom of ice microalgae, which is common in most arctic coastal areas (Alexander, 1974; Hsiao, 1980), does not occur under turbid ice. Turbid ice also blocks light from reaching much of the benthic macroalgal community except during open-water season. The distribution of turbid ice is widespread in the vicinity of the Boulder Patch.

Niedoroda and Colonell (1991) described sediment transport patterns in Stefansson Sound based upon sediment, oceanographic, and meteorological data from 1986. During west winds (~30% of the time), they found that sediment from the nearshore was moved eastward and offshore. Greatest deposition occurred on the upper shoreface, particularly at depths between 2 and 4 m. During east winds (~60% of the time), sediment transport was to the west. Overall, these findings suggest that the event-scale patterns of erosion and deposition in Stefansson Sound are dominantly in the cross-shore direction out to depths of 2 to 4 m. There is a substantial westward net transport of sediments as a result of the greater frequency of east winds.

Water depths in Stefansson Sound do not exceed 10 m and range from 3 to 9 m within the Boulder Patch, but this shallow benthic environment is largely protected by the offshore islands and shoals from gouging by deep-draft ice. The circulation dynamics vary seasonally and in response to the formation and disappearance of the landfast ice. The winter ice field within

Stefansson Sound is landfast, with minimal movement from mid-October through June (Weingartner and Okkonen, 2001). Currents are very weak (<2 cm/sec to undetectable) from mid-October through June, the period of total ice cover (Matthews, 1981). Sedimentation decreases though the winter, with <1.25 mm accumulated on the seafloor between mid-November and late February. Little or no sedimentation was documented between February and May, when maximum water visibility (>20 m) was observed. Freezeup is usually complete by mid-October, with ice reaching a maximum thickness of 2 m by early May. Breakup of most landfast ice in Stefansson Sound occurs before mid-July, although it can occur as early as late June. Breakup is usually followed by a rapid increase in light levels, which remain elevated throughout most of July and August. Winds and currents are strongly correlated during the open-water season, when current speeds typically exceed 10 cm/sec (Weingartner and Okkonen, 2001).

2.7.3.6 Total Suspended Solids

Growth and productivity of kelp within the Stefansson Sound Boulder Patch community are regulated primarily by photosynthetically active radiation (PAR) availability during the summer open-water period. During the 2001-2002 summer periods, the inherent optical properties (IOPs) of Stefansson Sound waters were measured in conjunction with suspended sediment concentrations for input into a radiative transfer equation (RTE) (Aumack, 2003). Highest total suspended solid (TSS) levels were in nearshore areas during both summers and were coincident with increased light attenuations. Lower TSS concentrations and attenuations were measured offshore. Data input to the RTE provided a TSS-concentration-specific attenuation coefficient to be used in conjunction with a productivity model. Using this technique, researchers estimated daily and annual kelp productivities throughout the Boulder Patch. Results suggest that light availability during the summer open-water period is heavily influenced by suspended sediment concentrations in the water column and that higher kelp productivities occur offshore, a result of lower sediment concentrations.

PAR availability in the summer open-water period is not constant and is largely a function of water transparency, measured by the amount of total suspended solids in the local area (Henley and Dunton, 1995). TSS are particles in the water column that diminish subsurface irradiance. These particles include clay, silt, sand, decaying vegetation and animals, or any inanimate particulate matter (Kirk, 1983). TSS originates from erosion, industrial or natural discharge, run-off, dredging, and flocculations. As these suspended particulates move through the water column, they reflect and absorb sunlight, thereby reducing light availability for macroalgal photosynthesis and biomass production. Ultimately, reduced kelp production means less food and habitat for organisms dependent on the kelp forest.

TSS interpolations throughout Stefansson Sound reflect higher water turbidity characteristic of eroding coastlines. TSS measurement along the SDI and Endicott Island shorelines were often three to four times higher (23.0 to 24.2 mg/l) than those at more seaward locations. Values of TSS in the Boulder Patch ranged from 4.2 to 14.3 mg/l (mean 6.8 mg/l), and offshore areas near Narwhal Island measured 2.6 to 2.8 mg/l (Aumack, 2003). Results show a strong relationship between water column TSS and light attenuation at all measured wavelengths. High attenuation coefficients and consequent low light penetration were found near the SDI and Endicott Island. Low attenuation, or high light penetration, corresponds directly to low TSS levels in northern and eastern Stefansson Sound. Offshore waters, typically associated with lower TSS values, had higher light penetration through the water column. The majority of the Boulder Patch, including areas with dense kelp population (>25% rock cover), is found predominantly in offshore waters where attenuation measurement were consistently <3.6/m (Aumack, 2003).

Coastal regions receiving high river discharge or shallow waters with unconsolidated sediments often have high b:a ratios (>30), a direct result of increased TSS. Absorption (a) occurs when photons are absorbed throughout the water column by colored dissolved organic matter (CDOM), biological organisms, suspended sediment, and the water itself (Kirk, 1983; Van Duin et al., 2001). Scattering (b) does not remove any photons but increases the effective path length traveled by a photon, thereby increasing the probability of the photon being absorbed (Kirk, 1983; Van Duin et al., 2001). High ratios of scattering coefficient to absorption coefficient (b:a) are typically associated with areas of increased turbidity (Kirk, 1994). Coastal regions receiving high river discharge or shallow waters with unconsolidated sediments often have high b:a ratios (>30), a direct result of increased TSS, which is typically correlated with photon scattering rather than absorption (Kirk, 1994). Connections between PAR, TSS, and kelp production have been quantified using a production model which is based on a clear-sky irradiance model designed by Gregg and Carder (1990). An RTE and concentrations-specific attenuation coefficients were inserted into the model using data collected in 2001 and 2002. The RTE, *Laminaria solidungula* production vs. irradiance calculations, and annual/hourly TSS and irradiance insertions combined the work of several different parties and can be made available (Dunton, pers. comm.). However, the accuracy of the model requires application of real in-situ (terrestrial and underwater) light data and better estimates of kelp biomass under different concentrations of rock cover.

Spatial and temporal TSS variations alter the number of hours kelp are exposed to levels of saturating irradiance (H_{sat}). The number of hours saturating irradiance has been reached for *Laminaria solidungula* in the Boulder Patch has ranged from as low as 39 hours to as high as 171 hours in a single summer (Dunton, 1990). The highest TSS levels (23.0 to 24.2 mg/l) occurred in nearshore areas during summer 2001 and were coincident with increased light attenuation (11.4 to 14.0/m) (Aumack, 2003). Results clearly demonstrate that suspended sediment concentrations have varying but substantial effects on light availability and subsequent kelp production during the summer open-water period. Increasing average TSS concentrations from 1 to 10 mg/l within ranges measured in situ decreased annual production by an order of magnitude.

2.7.3.7 Supplemental Information

The information above from the EIA overlooks some information on the kelp recovery time after disturbance, the nearshore distribution of marginal kelp, and the results of some recent MMS-funded research. The recovery time after disturbance is important to MMS assessments, because the MMS significance criteria are based partly on the rates of recovery. The EIA submitted as a component of the 2007 Liberty DPP summarizes information on the rate of blade growth for Boulder Patch kelp (Section 2.7.3.1) and, specifically, Section 2.7.3.4 includes information on kelp colonization of boulders. The kelp recolonization rates also are summarized in the Liberty DPP FEIS (USDOI, MMS, 2002:Section IV.A.5.b). The summary explains that recolonization would occur very slowly over a period of about a decade. Effects that would persist for more than 3 decades (3 generations or recolonization periods) would be classified as significant.

The distribution of the Stefansson Sound Boulder Patch kelp community is illustrated in Figure 2.7-1. The figure is a widely accepted one, illustrating the distribution of boulders and cobbles on which the kelp grows. The figure distinguishes the distribution of areas with more than 25% boulders and cobbles from those with 10-25% boulders and cobbles. The figure and the text do not explain that a small amount of kelp grows in nearshore areas in which the concentration of boulders and cobbles is <10%. An example of those nearshore areas with <10% boulders and cobbles is shown in Figure III.C-1 of the Liberty DPP FEIS (USDOI, MMS, 2002).

A recent MMS-funded study examined the recovery and recolonization rates of organisms in the Boulder Patch kelp community (Konar, 2006). The study specifically examined the effect of predators (grazers) on the recovery rate. It concluded that the recovery rate was slightly faster in the absence of predators.

Another study summarized the long-term monitoring at some research sites in the Stefansson Sound Boulder Patch kelp community (Dunton, Funk, and Iken, 2005). The biological diversity at some sites, such as DS-11, have been measured regularly since 1984 (Dunton, 2005), and annual kelp growth rates have been measured since 1977 (Dunton, unpublished).

Two other studies examined the epontic organisms that grow on the bottom surface of the ice (Gradinger and Bluhm, 2005; Bluhm, 2005). These studies examined the effect of suspended sediments (disturbance) on the epontic organisms.

2.8 FISH

A total of 28 species of fish have been identified in the freshwater and coastal marine habitats of the central Alaskan Beaufort Sea (Table 2.8-1). Detailed biological and ecological background descriptions of these species are provided in USDOI, MMS (2002) and USDOI, BLM (2005). USDOI, MMS (2002) describes Beaufort Sea fish as either freshwater, marine, or migratory.

- **Migratory Fishes:** Migratory fishes can be further segregated into anadromous and amphidromous species. Anadromous fishes are hatched and initially reared in freshwater river systems before migrating to sea where they spend most of their lives before returning to their natal streams as adults to spawn (Myers, 1949; Craig, 1989). Arctic cisco are considered anadromous because, although they overwinter in major river systems, non-spawners are believed to remain in brackish water deltas and do not move far upriver into strictly freshwater habitats (Morrow, 1980). Amphidromous fishes cycle annually between freshwater and coastal marine environments (Myers, 1949; Craig, 1989). They spawn and overwinter in rivers and streams but migrate out into coastal waters for several months each summer to feed. The utility of amphidromy is that it allows fish to take advantage of the more plentiful food resources present in arctic coastal waters during summer.
- **Freshwater Fishes:** Freshwater species largely remain within river, stream, and lake systems year round, although they may venture out during summer into coastal areas where waters are brackish.
- **Marine Fishes:** Marine fishes spend their entire lives at sea, although some species may migrate into nearshore coastal waters during summer.

The following descriptions of key fish species found in the proposed development area are extensions of descriptions found in USDOI, MMS (2002).

2.8.1 Freshwater Fishes

Freshwater species may be found in coastal waters during summer in areas of low salinity but typically occur in low numbers (Fechhelm et al., 2005). Greater concentrations of fish would be found in rivers and streams proximal to the development area; however, most species are dispersed widely across the drainage systems of the North Slope. That proportion of any freshwater population falling within the Liberty (SDI) Project area would constitute a minor fraction of the overall stock.

2.8.2 Marine Fishes

Of the marine species that occupy nearshore Beaufort Sea waters during summer, most occur sporadically and typically in very low numbers (Fechhelm et al., 2005). The exceptions are arctic cod, arctic flounder, and fourhorn sculpin. Fourhorn sculpin and arctic flounder are demersal species that have circumpolar nearshore distributions in brackish and moderately saline nearshore waters (Scott and Crossman, 1973; Morrow, 1980). Neither species is found far offshore (Morrow, 1980). Both species migrate into brackish coastal habitats during summer to feed, and may travel considerable distances up rivers. Fourhorn sculpin have been reported as far as 144 km upstream in the Meade River (Morrow, 1980). A background synopsis of arctic cod may be found in USDOI, MMS (2002).

2.8.3 Migratory Fishes

2.8.3.1 Anadromous Fishes

The most abundant anadromous species found in the Liberty (SDI) Project area is the arctic cisco. Despite anecdotal accounts that there may be small spawning runs of arctic cisco in Alaska (USDOI, MMS, 2002), none have been documented. Beaufort Sea arctic cisco are believed to originate from spawning grounds in the Mackenzie River system of Canada (Gallaway et al., 1983). Newly hatched fish are transported westward by wind-driven coastal currents and take up residence in the Sagavanirktok and Colville rivers (Fechhelm et al., 2005). Beginning at about age 5, fish enter the Colville River subsistence fishery (Moulton and Seavey, 2004). Arctic cisco remain associated with the Colville River until the onset of sexual maturity beginning at about age 7, at which time they are believed to migrate back to the Mackenzie River to spawn (Gallaway et al., 1983). The coastal dispersal corridor for young arctic cisco initially moving from Canada to the Sagavanirktok and Colville rivers passes through the Liberty (SDI) Project area. Adults migrating back to the Mackenzie River to spawn likewise would pass through the area.

Arctic cisco appear to be truly anadromous in that, except for spawning, they may spend most of their life in brackish to marine waters, including during the winter (Scott and Crossman, 1973; Morrow, 1980). In Alaska, adult arctic cisco overwinter in the lower reaches of the Colville River where salinities are brackish (Moulton and Seavey, 2004). During summer they migrate along the coast to feed and are one of the most abundant species found in the coastal waters of Prudhoe Bay and vicinity (Fechhelm et al., 2005). The Liberty (SDI) Project area lies well within the coastal foraging range of the Alaskan arctic cisco population.

2.8.3.2 Amphidromous Species

The Sagavanirktok River is believed to support one of the larger Dolly Varden populations in Arctic Alaska (Yoshihara, 1972). Amphidromous Dolly Varden also spawn in many of the “mountain streams” between the Sagavanirktok and Mackenzie rivers (Craig, 1989). Amphidromous Dolly Varden migrate considerable distances along the coast during the summer, and the extensive alongshore and open-water migrations reported for this species suggest they may be more tolerant of marine conditions than other arctic amphidromous species. Dolly

Varden have been taken as far as 15 km offshore in the Alaskan Beaufort Sea (Thorsteinson, Jarvala, and Hale, 1990), and dietary evidence has led to speculation that Dolly Varden feed offshore among ice floes in mid- and late summer (Fechhelm, 1999). The Sagavanirktok population is characterized by a large out migration soon after breakup and a return migration in late August and September (Fechhelm et al., 2005). The Sagavanirktok River delta is, therefore, the principal migratory pathway for this stock to and from foraging and overwintering grounds.

Amphidromous least cisco in the Alaskan Beaufort Sea occur in “tundra” rivers that lie west of and include the Colville River (Craig, 1989). There are no known spawning populations associated with the Sagavanirktok River or the “mountain” rivers that lie along the 600 km of coastline between the Mackenzie and Colville rivers (Craig, 1984). Least cisco are one of the principal species targeted in the fall Colville River subsistence fishery (Moulton and Seavey, 2004). Amphidromous least cisco from the Colville River disperse long distances along the coast during summer and are one of the most abundant species found in the Prudhoe Bay area (Fechhelm et al., 2005). Adults can disperse as far east as Brownlow Point (Griffiths et al., 2002). The Liberty (SDI) Project area is well within the summer feeding dispersal range of this species.

The Sagavanirktok River harbors a disjunct spawning population of broad whitefish (Gallaway et al., 1997; Patton et al., 1997). Juveniles appear to be intolerant of high salinities and typically remain in close proximity to the Sagavanirktok River delta (Fechhelm et al., 1992). Adults undergo more extensive coastal migrations (Morris, 2000) and during summer may disperse as far east as Brownlow Point (Griffiths et al., 2002). Because of the restricted range of juvenile fish, the Sagavanirktok Delta can be considered the primary nursery area for the stock. For adult fish, the Liberty (SDI) Project area lies well within their summer foraging range.

Humpback whitefish spawn and overwinter in the Colville River but not in the Sagavanirktok River (Fechhelm, 1999). Like broad whitefish, humpback whitefish are intolerant of high salinity conditions and remain in brackish nearshore waters and river deltas during summer. Prior to the 1996 installation of a 200-ft breach in the West Dock Causeway, few humpback whitefish were caught in coastal waters east of the structure. Since its installation, adult humpback whitefish are much more abundant in the Sagavanirktok Delta and probably range short distances east of the delta’s eastern edge (Fechhelm et al., 2005). Small humpback whitefish are rare in Prudhoe Bay, suggesting that the Liberty (SDI) Project area is well outside their Colville River foraging range.

2.8.4 Essential Fish Habitat

A background discussion of the Magnuson-Stevens Fishery Conservation and Management Act of 1996 (MSA) and Essential Fish Habitat (EFH) is provided in USDOI, MMS (2002) and USDOI, BLM (2005). Pursuant to NOAA, NMFS (2005), the *Preliminary Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska*, it is the current position of the National Marine Fisheries Service (NMFS) that pink salmon and chum salmon are the only two species of fish found in the Beaufort Sea that are amenable to EFH regulation and consideration (John Kurland, Director, NMFS Habitat Conservation Division, Juneau, pers. commun.; Lawrence Peltz, NMFS Habitat Conservation Division, Anchorage, pers. commun.; and Jeff Childs, formerly with MMS, pers. commun.). The MSA defines EFH as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” [MSA §3(10)]. EFH pertains to habitat “required to support a sustainable fishery and the managed species’ contribution to a healthy ecosystem.” A healthy ecosystem is defined as an “ecosystem where ecological productive capacity is maintained, diversity of the flora and fauna is preserved, and the ecosystem retains the ability to regulate itself. Such an ecosystem should be similar to comparable, undisturbed ecosystems with regard to standing crop, productivity, nutrient dynamics, trophic structure, species richness, stability, resilience, contamination levels, and the frequency of diseased organisms" (50 CFR Part 600).

Pacific salmon fisheries in Alaska are managed under a combination of domestic and international regulations and treaties (NOAA, NMFS, 2004). Salmon fisheries are managed by ADF&G within State waters, where most of Alaska's commercial fishing occurs. Commercial fishing within the Exclusive Economic Zone (EEZ) is limited to Southeast Alaska and to three historic commercial net fisheries: in Cook Inlet, near the mouth of the Copper River, and near False Pass. Federal management at these locations is deferred to the Alaska Department of Fish and Game (ADF&G). Federal management of salmon stocks is largely directed by fishery management plans designed to limit the bycatch of salmon in non-salmon-directed fisheries within the North Pacific EEZ (NOAA, NMFS 2004).

Presently, there appear to be small spawning runs of pink and chum salmon in the Colville River, possibly in some Beaufort Sea rivers to the west, and in rivers along the Chukchi Sea. There is no evidence of successful spawning stocks associated with the Sagavanirktok River or Alaskan watersheds to the east of the Liberty (SDI) Project area. However, the ADF&G Fish Distribution Database and Anadromous Waters Catalogue does indicate that adult pink and chum salmon previously have been documented in the Sagavanirktok and Canning rivers, while adult pink salmon have been noted in the Staines and West Canning rivers. A successful run of chum salmon is established in the Mackenzie River in Canada.

The Colville River chum and pink salmon stocks occupy the extreme northern range of the species' spawning distribution in Alaska. Current theory holds that, upon emergence into coastal waters, the salmon that are spawned in the Colville River and rivers west migrate to the warmer waters of the Bering Sea and do not return to the Beaufort Sea until time of spawning (Craig and Haldorson, 1986). The few adults that have been caught in the Liberty (SDI) Project area occur in late summer and are either adult spawners returning to the Colville River or possibly straying salmon whose eventual reproductive success is questionable.

The coastal waters in and around the Liberty (SDI) Project area consistently have been treated by MMS as if they were EFH for chum and pink salmon, despite these species marginal presence in the Alaskan Beaufort Sea. Based on available data, EFH for the Liberty (SDI) Project area would include all waters of the Colville River and Delta, and the nearshore marine waters stretching from Foggy Island Bay and Stefansson Sound westward along the coastline to the Bering Sea and into the North Pacific Ocean. There are no federally managed commercial salmon fisheries in the Beaufort or Chukchi seas. The entire Arctic EEZ is closed to commercial salmon fishing under the salmon Fishery Management Program. The low numbers of pink and chum salmon that regularly migrate from the Beaufort Sea to the Bering Sea likely constitute a minor component of the commercial fisheries there. There are no federally managed fisheries for other species within the Beaufort and Chukchi seas.

In recent years, concern has been expressed that arctic warming could allow southern stocks of Pacific salmon from the Bering Sea to expand northward into arctic waters, where they might establish spawning populations (Babaluk et al., 2000; Stephenson, 2006). Such an expansion would depend on a number of physical and biological factors, the relevance and importance of which are highly problematic and speculative. Even if such a future expansion does take place, it is more than likely to occur beyond or toward the end of the production life of the Liberty (SDI) Project.

2.9 MARINE MAMMALS

The Liberty DPP FEIS, Lease Sale 202 EA, Lease Sale 193 EIS (USDOI, MMS, 2002; 2006b; 2007b) and BPXA (1998) describe seals and polar bears in the U.S. Arctic Ocean, and these descriptions are summarized and incorporated herein by reference. The Liberty (SDI) Project could affect ringed and bearded seals and polar bears, which are common in the area. Other species that are uncommon in the project area include beluga whales and walruses. Bowhead whales and polar bears are addressed under endangered species (Section 2.13).

2.9.1 Ringed Seals

Widely distributed throughout the Arctic, ringed seal is the most abundant seal species in the Beaufort Sea. Aerial surveys have been conduced in May and June as ringed seals become visible when they haul out on sea ice. Satellite-linked time-depth recorders have been used to evaluate the time spent basking on sea ice. Bengtson et al. (2005) reported that ringed seal density in the eastern Chukchi Sea ranged from 1.62 to 1.91 seals/km^2 based on surveys conducted in 1999 and 2000. These density estimates were made using a correction factor to allow for seals that were not hauled out and thus not visible during the surveys. Ringed seal density was greater in nearshore fast and pack ice than in offshore pack ice. Frost et al. (2004) reported ringed seal densities ranging from 0.81 to 1.17 seals/km^2 in the Beaufort Sea during surveys conducted from 1996 to 1999. Moulton et al. (2005) reported slightly lower ringed seals densities ranging from 0.39 to 0.83 seals/km^2 in the central Beaufort Sea during surveys near the Northstar project form 1997 to 2001. Ringed seal densities during aerial surveys can be affected by a number of factors including water depth, location of ice edges, time of day, weather conditions (i.e., cloud cover, temperature, wind conditions), and survey date (Frost et al., 2004; Kelly et al., 2005). Seal densities reflect changes in the ecosystem's overall productivity in different areas (Stirling and Oritsland, 1995). There is some evidence from recent surveys that ringed seal numbers in the central Beaufort Sea may be reduced compared to those reported in the early 1980s (Moulton et al., 2002). Moulton et al. (2002) suggested that ringed seals in the central Beaufort Sea may prefer areas with intermediate water depth around 10 to 20 m and that few seals occur in areas with water depths <3 m.

Ringed seals probably are a polygamous species. When sexually mature, they establish territories during the fall and maintain them during the pupping season. Pups are born in late March and April in lairs that seals excavate in snowdrifts and pressure ridges. During the breeding and pupping season, adults on shorefast ice (floating fast-ice zone) usually move less than individuals in other habitats; they depend on a relatively small number of holes and cracks in the ice for breathing and foraging. During nursing (4-6 weeks), pups usually stay in the birth lair. This species is a major resource that subsistence hunters harvest in Alaska, and a prey source for polar bears.

2.9.2 Bearded Seals

Bearded seals are found throughout the Arctic and usually prefer areas of less stable or broken sea ice, where breakup occurs early (Cleator and Stirling, 1990). Early estimates of the Bering-Chukchi Sea bearded seal population range from 250,000 to 300,000 animals (Popov, 1976 and Burns, 1981 in Angliss and Outlaw, 2005). During aerial surveys in the eastern Chukchi Sea in 1999 and 2000, Bengtson et al. (2005) reported bearded seals density estimates ranging from 0.07 to 0.14 seals/km^2. These estimates were not corrected for seals that were undetectable during the surveys, and it was not possible to calculate a population estimate for the Bering-Chukchi Sea population. Estimates on the abundance of bearded seals in the Beaufort Sea and in Alaskan waters currently are unavailable, although bearded seals are reported annually during aerial surveys for other marine mammals (Treacy, 2002a, 2000b). Consequently, there is no current reliable population estimate for the Alaskan bearded-seal stock. Bearded seals stay on moving ice habitat in the Beaufort Sea. Their densities in the western Beaufort Sea and in the Liberty (SDI) Project area are highest during summer and lowest during winter. Their most important habitat in winter and spring is active ice or offshore leads.

Pupping takes place on top of the ice from late March through May mainly in the Bering and Chukchi seas, although some pupping takes place in the Beaufort Sea. Bearded seals do not form herds but sometimes form loose groups. Bearded seals are a secondary subsistence food for Barrow residents and provide a relatively low percentage of the total subsistence diet (Braund, 1993).

2.9.3 Walruses

The North Pacific walrus population was estimated at about 201,000 animals in 1990 (Gilbert et al., 1992), comprising about 80% of the world population. In general, most of this population is associated with the moving pack ice year-round. Walruses spend the winter in the Bering Sea; the majority of the population summers within certain areas of the Chukchi Sea, including the westernmost part of the Beaufort Sea. Although a few walruses may move east throughout the Alaskan portion of the Beaufort Sea to Canadian waters during the open-water season, the majority of the Pacific population occurs west of 155° W. longitude north and west of Barrow, with the highest seasonal abundance along the pack-ice front.

Nearly all the adult females with dependent young migrate into the Chukchi Sea during the summer, while a substantial number of adult males remain in the Bering Sea. Spring migration usually begins in April, and most of the walruses move north through the Bering Strait by late June. Females with calves comprise most of the early spring migrants. During the summer, two large arctic areas are occupied—from the Bering Strait west to Wrangell Island and along the northwest coast of Alaska from about Point Hope to north of Point Barrow. With the southern advance of the pack ice in the Chukchi Sea during the fall (October-December), most of the walrus population migrates south of the Bering Strait. Solitary animals occasionally may overwinter in the Chukchi Sea and in the western Beaufort Sea. Walruses are uncommon in the Liberty (SDI) Project area.

2.9.4 Beluga Whales

The beluga whale, a subarctic and arctic species, is a summer seasonal visitor throughout offshore habitats of the Alaskan Beaufort Sea. Based on a correction factor of 2 to account for bias related to animals that may be underwater and unavailable to count during surveys, the most recent estimate for the Beaufort Sea beluga stock is 39,258 animals (Angliss and Outlaw, 2005). Most of this population migrates from the Bering Sea into the Beaufort Sea in April or May; however, some whales may pass Point Barrow as early as late March and as late as July. The spring-migration routes through ice leads are similar to those of the bowhead whale. A major portion of the Beaufort Sea population concentrates in the Mackenzie River estuary during July and August. The eastern Chukchi Sea beluga stock currently is estimated to be at a minimum of about 3,710 whales (Angliss and Lodge, 2004). In the Arctic, belugas feed primarily on arctic and saffron cod, whitefish, char, and benthic invertebrates (Hazard, 1988).

Fall migration through the western Beaufort Sea occurs in September or October. Although small numbers of whales have been observed migrating along the coast, surveys of fall distribution strongly indicate that most belugas migrate offshore along the pack-ice front (Frost, Lowry, and Burns, 1986; Treacy, 1988-1998). Beluga whales are an important subsistence resource of Inuit Natives in Canada and also are important locally to Iñupiat Natives in Alaska. The mean annual harvest of beluga whales by Alaska Natives in the Beaufort Sea was 53 whales between 1999 and 2003 (Angliss and Outlaw, 2005 and references therein). The mean annual take of Beaufort Sea beluga whales in Canadian waters was 99 whales during the same time period. The Beaufort Sea beluga-whale stock is not considered to be “depleted” under the Marine Mammal Protection Act, or “threatened” or “endangered” under the Endangered Species Act.

2.9.5 Underwater Acoustics

Measurements of underwater ambient noise and sound transmission loss were made at the Liberty prospect during summer 1997 (Greene, 1998), and winter measurements were made during exploratory drilling at Liberty in winter 1997 (Greene, 1997). (Note that sounds were recorded at the proposed Liberty Island location and the currently proposed Liberty SDI location.) The results are summarized here. Comparisons are presented with similar measurements made near the Northstar prospect in 1996-1997 and at the Seal Island (Davis, Greene, and McLaren, 1985) and Sandpiper (Johnson et al., 1986) prospects in the 1980s.

2.9.5.1 Ambient Noise

Ambient noise was measured in 30-second segments every 15 minutes from August 1 to September 13, 1997 at two seafloor recorders 570 m apart. Ambient noise varied with average hourly wind speed measured from a barge that was usually located within 55 km (30 n. mi.) of Liberty. The correlation coefficients between the wind speed and the broadband (20 to 5000 Hz) ambient noise level were r = 0.831 based on the northwest recorder and r = 0.746 for the southeast recorder. For wind speeds of 0, 10, 20 and 30 kt, typical overall ambient noise levels in the 20 to 5000 Hz band were 85, 94, 104 and 114 dB re 1 µPa, respectively. The overall median levels approximated the levels expected for Sea States 0 to 2, based on the standard Knudsen fiducials extended to low frequency. The 5th percentile levels were below those expected for Sea State 0 at all frequencies below 3150 Hz, and the 95th percentile levels varied between those expected for Sea States 2 and 6. For the data from both recorders taken together, the median 20 to 5000 Hz band level for the 44 days was 97 dB re 1 µPa, or 9 dB above the corresponding level for Knudsen’s Sea State 0. The 5th and 95th percentile levels were 78 and 110 dB re 1 µPa, respectively. The levels were consistent with other ambient noise measurements made in similar locations at similar times of the year.

These summer measurements complemented winter measurements made during February 1996. The measured ambient levels in winter (Greene, 1997) were generally lower than those measured in summer.

To study the short-term variability of the ambient noise in relation to longer term averages, 10 segments were selected from the seafloor recorder data. These segments were selected from times of low, high, and moderate noise levels. In 9 of the 10 cases, the 0.25-second averages were less than the 30-second average for over half the time. The one exception was the minimum noise case when the median 0.25-second average equaled the 30-second average. This indicates that if an animal is capable of recognizing sounds during short periods (on the order of 1/4-second in duration), it probably could hear a sound that is slightly weaker than the average (long-term) noise level. It could do so during periods when the ambient noise level is lower than average. This result is consistent with similar observations made northeast of Pt. Barrow during May (Greene, Hanna, and Richardson, unpubl.).

The frequency distribution of ambient noise was studied by observing the distribution of 1/3-octave band levels. When the ambient noise is predominantly attributable to wind and waves, the 1/3-octave band levels decrease at about 2 dB/octave with increasing frequency. However, the results from the Liberty seafloor recorders showed median levels decreasing with increasing frequency from 20 to 50 Hz but increasing with frequency from 50 to 1000 Hz. It is likely that sources other than wind and waves (such as distant vessels) contributed to the general ambient noise at Liberty.

2.9.5.2 Sound Transmissions

Acoustic transmission loss was measured on July 31, 1997, using as sources a four-element sleeve gun array and a minisparker. Both were tethered to a tug anchored at Liberty. Received sounds were recorded quantitatively at distances up to 8.1 km southeast and 10.1 km north of Liberty. Acoustic transmission loss was determined from those recordings.

For both sources, the broadband spreading losses were close to spherical, i.e., -20 log (R), over distances to 350 m. At greater ranges, the sounds from the array of sleeve guns diminished generally according to -25 log (R) while the minisparker sound diminished at approximately -10 log (R), corresponding to cylindrical spreading. This difference is attributed to the sleeve-gun array being a relatively low frequency source (63 to 800 Hz) compared to the minisparker (315 to 3150 Hz). Besides these logarithmic spreading losses, there was an additional linear loss of about -0.0020 dB/m for the sleeve gun array and -0.0033 dB/m for the minisparker. The higher linear loss rate for the minisparker corresponds to higher absorption and scattering losses at higher frequencies.

Propagation loss rates varied with frequency. There were some consistent trends in the relationships between frequency and loss rates; however, there were also some patterns that were not explained by a simple physical model.

The results of this study can be used to predict the received levels vs. distance of sounds from industrial sound sources that will operate at Liberty during construction and operation of oil production facilities. Those received levels can be compared to the expected range of ambient noise levels, thereby determining distances beyond which the industrial sounds will probably be masked.

2.9.5.3 Comparisons with Related Ambient Noise

There have been numerous other measurements of ambient noise in different parts of the Beaufort Sea during various times of year. Simultaneously with the 1997 Liberty prospect study, a 6-day series of measurements was obtained offshore of the barrier islands 60 km northwest of Liberty in water 25 m deep (Greene, Norman, and Hanna, 1998), offshore from Northstar. The 5th percentile and 95th percentile levels were generally higher offshore from Northstar. At frequencies below 125 Hz, median levels offshore were generally lower than those at Liberty. Conversely, above 125 Hz, the offshore medians tended to be higher than those at Liberty. The shallower water at Liberty (6.4 vs. 25 m) is important in limiting low frequencies and therefore resulting in less ambient sound at low frequencies.

The median levels at Liberty were between the idealized spectra for Sea States 0 and 2, while the Northstar medians at frequencies <100 Hz were below those expected for Sea State 0.

Ambient noise in the Northstar area (25 km northwest of Prudhoe Bay) in a water depth of 12 m was also studied in fall 1984. Ambient noise was received by three hydrophones on the bottom near Seal Island, at the site that became Northstar (Davis, Greene, and McLaren, 1985). The median and 95th percentile levels from Seal Island show that the ambient noise was high-pass filtered at about 60 Hz by the shallow water channel. Components of ambient noise below about 63 Hz were weak. At a water depth of 12 m, 60 Hz is the frequency for which the water depth is equal to one-half wavelength. At higher frequencies, the negative slope of the spectrum levels with increasing frequency parallels the nominal sea-state spectra. The medians are at levels corresponding to about Sea State 1.

Ambient noise was also studied offshore of the barrier islands during 8 days in fall 1985. Ambient noise was recorded via a single bottom hydrophone 450 m from Sandpiper Island (Johnson et al., 1986) at a water depth of 15 m. Sandpiper Island is about 16 km from Northstar and 66 km northwest of Liberty. During the recording period, no storms with winds about 20 knots occurred at Sandpiper, but the 5th percentile levels were notably higher than those in the shallower water at Liberty. A drill rig on Sandpiper was in cold standby—a generator was running for camp power.

Ambient noise was also studied northeast of Pt. Barrow in May during 4 years: 1989-91 and 1994. Sounds were recorded from sonobuoys and from hydrophones deployed over the edges of ice floes (Greene, Hanna, and Richardson, unpublished). Ice cover varied from 75 to 100%. The median levels measured at the Pt. Barrow and Liberty sites tend to agree across a range of frequencies despite the wide variety of water depths and the high percentage of ice cover northeast of Pt. Barrow in spring compared to the shallow open water at Liberty.

In comparison with the other data, the natural background noise at the Liberty site was relatively low in winter and high in summer.

The proposed SDI expansion is located in and adjacent to water depths of 1 to 10 m to maximum depths of 6 to 10 m between the SDI and the barrier islands. Ambient noise is expected to be similar to or less than the original Liberty site, due to the shallow water depth and underwater topography forming a shallow valley (6 to 10 m) between the SDI and the shallow (<3-6 m) inlets between the barrier islands.

2.10 MARINE AND COASTAL BIRDS

About 70 species of birds may occur in the Liberty (SDI) Project area (USDOI, MMS, 2002). Nearly all species are migratory, inhabiting Arctic Slope or Beaufort Sea habitats from May to September. Major groups that are common in this area during all or part of this period include loons/ waterfowl, shorebirds, seabirds, and passerines. Raptors and owls are less common.

Shorebirds and passerines are the most abundant species groups in the Liberty area. Loons, waterfowl and seabirds commonly use nearshore coastal waters (20-m depths or less) during spring and fall migrations, during broodrearing, and for molting (Fischer and Larned, 2004). River deltas, tundra habitats and coastal lakes and ponds are used by all bird species during summer. Birds that may overwinter in the onshore development area include raptors, owls, ptarmigan and the common raven.

The spectacled eider, Steller's eider, Kittlitz's murrelet, and the yellow-billed loon are discussed in Threatened and Endangered Species (Section 2.13.1 Birds).

2.10.1 Annual Cycle

2.10.1.1 Spring Migration

Waterfowl migrate eastward across northern Alaska along a broad front over land and sea during mid-May to mid-June. Exposed habitats, mainly in river deltas, attract some birds early during migration. The availability of open water leads offshore (mainly within 10 km of barrier islands) largely determines seaduck migration routes and timing. Between 250,000 and 1,000,000 long-tailed ducks nesting in western arctic North America migrate through the Beaufort Sea region each spring (Dickson and Gilchrist, 2002; Robertson and Savard, 2002), along with king eiders, common eiders and many other Arctic nesting species. Many migrants follow offshore lead systems and would not cross the coastal area where the Liberty development will be located.

Loons and eiders gather in spring runoff water in river deltas during late May and early June until local nesting areas are free of snow, and gather in river channels near nesting habitat until open water develops around the margin of lakes and ponds used for nesting. Most shorebirds are first noted dispersed across tundra breeding areas as soon as snow-free areas appear. Gulls and some ducks may arrive during late April in the Point Brower area of the Sagavanirktok River delta (USDOI, MMS, 2002). Migratory raptors and owls generally depart wintering areas in March to early April and arrive on the Arctic Coastal Plain in late April to early May. Migrant Lapland longspur and snow buntings arrive as snow-free areas become available, probably during May in most years.

Like many shorebirds, buff-breasted sandpipers leave wintering grounds in early February to mid-March and begin to migrate north (Lanctot and Laredo, 1994). Most shorebirds arrive on arctic breeding grounds during late May or early June.

2.10.1.2 Nesting and Broodrearing Periods

Lesser snow geese and brant nest on Howe and Duck islands in the Sagavanirktok River Delta and common eiders, glaucous gulls and arctic terns nest on nearshore delta islands and barrier islands in the Liberty (SDI) Project area (see Maps 6 and 7 in USDOI, MMS, 2002). Loons, tundra swans, greater white-fronted geese, Canada geese, and other waterfowl nest, forage, rear their broods, and molt in wetland habitats in the river deltas and across the onshore portion of the proposed Liberty (SDI) Project area (see Maps 6 and 7 of USDOI, MMS, 2002). Important broodrearing areas for snow geese and brant from early July to Late August are salt marsh and coastal sedge habitats throughout Foggy Island Bay, including the eastern Sagavanirktok River Delta, Kadleroshilik River delta, and Shaviovik River delta (Johnson, 2000a; Johnson, 1998). In the area between Prudhoe Bay and the Badami development, nest densities for several species (including Pacific loon, Canada goose, black-bellied plover, pectoral sandpiper, dunlin, stilt sandpiper, and red phalarope) reach their highest levels in coastal habitats surrounding the lower Kadleroshilik River (TERA, 1995).

The most abundant shorebirds were semipalmated sandpiper, pectoral sandpiper, dunlin, red phalarope and red-necked phalarope (TERA, 1995). The highest shorebird nesting densities generally occur in areas of mixed wet and dry habitats, whereas birds often move to wetter areas for brood rearing.

Nesting areas at the Endicott Causeway are mid-way between the Prudhoe and the Kadleroshilik River areas sampled by TERA (1995). Nest density for all birds combined was 60-70 nests/km^2.

2.10.1.3 Post-Nesting Period

From mid-July to early September, long-tailed ducks (and lesser numbers of eiders and scoters) aggregate in coastal lagoons to feed and molt before migrating westward in the fall. Many waterfowl depart the coastal areas by the middle or end of August, but some loons and tundra swans may be found in remaining open-water areas through September, long-tailed ducks through October, and some king and common eiders remain into early November (Johnson and Herter, 1989).

Among phalaropes and some sandpipers, the non-incubating members of pairs leave nesting areas on the tundra (early July), soon after the eggs are laid, and concentrate in coastal habitats. The other parent and fledged young follow in several weeks. In mid-August, juveniles form large flocks on coastal and barrier island beaches, foraging intensively on outer beaches, lagoon shorelines, and mudflats. Shorebirds move widely on a daily basis during staging, and residency time within a staging are may range from 10 to 25 days (Powell, Taylor, and Lanctot, 2005). Most shorebirds have departed the area by mid-September. Large flocks of glaucous gulls and black-legged kittiwakes migrating from nesting areas in the Canadian arctic also pass through the Liberty (SDI) Project area during September. By mid to late September most seabirds have left the Arctic Coastal Plain, although some juvenile and adult gulls may remain at landfills through November. In late August to mid September, arctic peregrine falcons and gyrfalcons forage in coastal areas, often preying on juvenile shorebirds. Passerines tend to flock following breeding, and some migrants may remain in the Liberty (SDI) Project area into September.

2.10.2 Habitats

2.10.2.1 Offshore Marine Waters

Eiders migrated westward through offshore waters from early July to November (Johnson and Herter, 1989). Bird densities generally are low in offshore areas, with long-tailed ducks less than or equal to (≤)11 birds/km^2 seaward of the barrier islands east of Foggy Island Bay, and ≤3 birds/km^2 farther offshore (Fischer and Larned, 2004). During aerial surveys in 1999-2001, common eiders, king eiders, and long-tailed ducks dominated in late June and king eiders were most abundant offshore (Fischer and Larned, 2004). By late August, king eiders still were numerous, but long-tailed ducks also occurred in large numbers, mainly <50 km of the coast.

2.10.2.2 Nearshore Marine Waters

In the Liberty area, shallow waters in Foggy Island Bay and salt marsh habitat along the Sagavanirktok, Kadleroshilik, and Shaviovik river deltas provide the most protected areas for molting, feeding and brood-rearing geese. Shallow lagoons provide important feeding and staging habitat, particularly for post-breeding molting long-tailed ducks, eiders, and scoters (Truett and Johnson, 2000). Simpson Lagoon-Gwydyr Bay in the west, and Leffingwell Lagoon in the east, support tens of thousands of postbreeding long-tailed ducks (Fischer and Larned, 2004). Pacific loons primarily use shallow water close to shore, but may occur up to 60 km from shore (Fischer and Larned, 2004). Red-throated loons have been observed more than 50 km from shore, primarily use nearshore waters (Fischer and Larned, 2004). In the Alaskan Beaufort Sea shallow nearshore waters, Pacific loons were most abundant from Cape Halkett to Prudhoe Bay and red-throated loons were most abundant between Oliktok Point and Brownlow Point (Fischer and Larned, 2004).

2.10.2.3 Barrier Islands

These sparsely vegetated gravel islands provide nesting habitat for common eiders, glaucous gulls, and arctic terns. Barrier islands provide nesting habitat for common eiders, especially islands with accumulated driftwood and free of predators (Johnson, 2000b). Cross Island, Pole Island, and Lion Point (gravel spit northwest of Tigvariak Island) have been especially important islands for nesting common eiders (Johnson, 2000b). Very high densities of molting/feeding long-tailed ducks occur along the leeward (south) sides of barrier islands, particularly in the Jones-Return Island group, and the Stockton-Maguire-Flaxman island group (Fischer and Larned, 2004). Notable numbers of molting common and king eiders also aggregate near Flaxman, Pole, and Belvedere islands (Fischer and Larned, 2004). High densities of staging shorebirds may use the inner shores of barrier islands (Powell, Taylor, and Lanctot, 2005). The occurrence of many species on barrier and other islands in particular has been noted by Native residents (USDOI, MMS, 2002).

2.10.2.4 Tundra

Shorebirds are likely to be found in any type of tundra (Troy, 2000). The most numerous shorebird species in the Liberty (SDI) Project area prefer wet tundra habitats (sandpipers, phalaropes) or nest on or near well-drained gravelly areas (plovers). Tundra habitats available to shorebirds include dry, moist and wet tundra, flooded tundra, sparsely vegetated areas, ponds, and lakes. In general, the highest nest densities tend to occur in drier areas (moist or wet tundra) and in areas with extensive micro-relief (polygon rims, strangmoor). Seabirds such as arctic terns, Sabine’s gulls and glaucous gulls nest individually or in small colonies in tundra habitats often associated with large thaw lake basins, especially those with complex lake shorelines and small islands. Short-eared owl and snowy owl nest on tundra across the Arctic Coastal Plain, but the number of the breeding birds probably reflects the abundance of their primary microtine food (lemmings) (Pitelka, Tomich, and Treichel, 1955). The northern harrier, also a ground nesting species, is a fairly common visitant on the Arctic Coastal Plain (Johnson and Herter, 1989) and may occasionally nest there (Burgess et al., 2003).

2.10.2.5 Other Habitats

Saltmarsh and sedge habitats in river deltas in the outer Sagavanirktok, Kadleroshilik, and Shaviovik deltas are heavily used by molting geese, especially snow geese and brant from the Sagavanirktok Delta, and local and molt migrant white-fronted and Canada geese (Johnson, 2003; Johnson, 2000a). River deltas in the Liberty (SDI) Project area (outer Sagavanirktok and Shaviovik), particularly the outer mudflats, are heavily used by shorebirds (Andres, as cited in Nickles et al., 1987); this probably also is true of the Kadleroshilik. Vegetated river bars are used by many tundra-nesting species including black-bellied plover, American golden plover, ruddy turnstone, rock ptarmigan, and Lapland longspur (USDOI, MMS, 2002).

Buff-breasted sandpipers use drier habitat than most other shorebirds and depend on drier sloping areas or polygonal-featured tundra for nesting (Lanctot and Laredo, 1994). The number of adults counted on breeding grounds varies dramatically year to year. Nest densities at Milne

Point ranged from 0.3 to 1.3 nests/km^2 and at Prudhoe Bay ranged from 0.5 to 1.0 nests/km^2, and post-season densities were 0.0 to 2.4 birds/km^2 (Gotthardt and Lanctot, 2002).

Male buff-breasted sandpipers have been observed occupying a lek (where males were observed giving "wing flash" territorial displays) on a riverine island in the lower Kadleroshilik River (USDOI MMS, 2002).

Gyrfalcons, peregrine falcons, golden eagles, and rough-legged hawks may forage on the Arctic Coastal Plain during summer. Peregrine falcons and rough-legged hawks have also bred near the coast using artificial substrates/structures for nesting (Ritchie, 1991; Ritchie, Schick, and Shook, 2003). Ravens nest on towers and buildings.

2.10.2.6 Abundance

Red-throated and Pacific loons were most abundant offshore areas around the Liberty (SDI) Project area during July and August 1999-2000 (Fischer, Tiplady, and Larned, 2002), but these numbers were typically low. Relative densities for red-throated and Pacific loons in the Liberty (SDI) Project area were <0.01 to 0.21 loons/km^2 based on breeding pair surveys from 1998 to 2001 (Mallek, Platte, and Stehn, 2002).

Broodrearing snow geese concentrate in the Sagavanirktok, Kadleroshilik, and Shaviovik river deltas (Johnson, 2000a). Some of the broodrearing areas are at the site of the proposed Duck Creek mine site (see Map 6 in USDOI, MMS, 2002). Broodrearing areas for brant in the Liberty (SDI) Project area were primarily east and west of the Endicott Causeway (see Map 7 in USDOI, MMS, 2002).

Post-breeding long-tailed ducks were most abundant in offshore area around the Liberty (SDI) Project site in late July through August 1999-2000 (Fischer, Tiplady, and Larned, 2002). Large flocks of molting long-tailed ducks concentrated on the leeward sides of barrier islands ~20 km from the South Drilling Island (Fischer, Tiplady, and Larned, 2002). The barrier islands were an important broodrearing and molting area for common eiders and lesser numbers of king eiders and scoters (Fischer and Larned, 2004; USDOI, MMS, 2002:Map 7).

Glaucous gulls are the most abundant seabird in the Liberty (SDI) Project area (Fischer and Larned, 2004; Fischer, Tiplady, and Larned, 2002). Densities of glaucous gulls in offshore Alaskan Beaufort Sea marine waters were higher in areas with low ice cover and ranged from 0.04 to 0.08 gulls/km^2 within the 10-20-m contours (barrier islands to 30 km from shore) and from 0.01 to 0.08 gulls/km^2 beyond the 20-m depth contour (beyond 30 km from shore) (Fischer and Larned, 2004).

Historically buff-breasted sandpipers were common in North America. The small total North American population of 15,000 individuals and an apparently declining population trend have raised concerns about this species. The status of the buff-breasted sandpiper population was reviewed by Gotthard and Lanctot (2002), which resulted in their being listed as "highly imperiled" in 2004 (USDOI, FWS, 2004). Northern Alaska breeding grounds support 20% of the 25,000 worldwide population and 50% of the Western Hemisphere breeding population of buff-breasted sandpipers.

2.10.3 Population Status

Arctic Coastal Plain breeding pair surveys indicate that Pacific loons have remained stable at a population index of about 29,000 individuals and red-throated loons have increased by about

3.3 % per year from 1985 to a population index of 5,142 in 2006 (Mallek, Platte, and Stehn, 2007).

Population trends for most waterfowl species have remained unchanged since 1986 or 1992; notable exceptions are long-tailed duck, which has significantly declined, and tundra swan and arctic tern, which have significantly increased (Mallek, Platte, and Stehn, 2006). Both Fischer and Larned (2004) and Johnson et al. (2005) also documented significant declines in long-tailed duck density in nearshore molting areas in the central Alaskan Beaufort Sea. Long-tailed duck populations in northwestern Canada have also declined (Dickson and Gilchrist, 2002; Robertson and Savard, 2002).

The snow goose colony on Howe Island in the Sagavanirktok River Delta area, west of Liberty, increased steadily through the early 1990s, but declined markedly due to egg predation by grizzly bears and foxes during 1994-2003 (Johnson and Noel, 2005). A sharp increase in the number of nesting snow geese and brant was noted on Howe Island in 2004 and this snow goose colony has continued to increase (Rodrigues, McKendrick, and Reiser, 2006) after food-conditioned grizzly bears from nearby industrial areas were destroyed (Johnson and Noel, 2005).

Mallek, Platte, and Stehn (2006) conducted breeding pair surveys across the Arctic Coastal Plain 1982-2006. Glaucous gulls appeared to be slowly increasing to a population index of about 19,000 in 2006. Increases in the population index for Sabine’s gulls reached a population index of 16,531 in 2006. Similarly, arctic terns appear to be increasing to a population index of 24,329 in 2006. Jaegers, however, despite the highest population index on record in 2006, have a slight decreasing population trend (1986-2006).

Dunlin regularly occur in the project area and are listed as “Species of High Concern” in the Alaska Shorebird Conservation Plan (USDOI, FWS, 2004). Troy (2000) reported that dunlin were exhibiting a persistent directed declining trend in abundance in the Prudhoe Bay area 1981-1992.

2.11 TERRESTRIAL MAMMALS

Among the terrestrial mammals that occur in the Liberty area, the caribou, muskoxen, grizzly bear, and arctic fox are the species that could be affected by development. Mammals likely to occur in the project area are listed in Table 2.11-1.

2.11.1 Caribou

The Central Arctic Caribou Herd ranges within the project area. Its summer range extends from Fish Creek, just west of the Colville River, east to the Katakturuk River and from the Beaufort Sea coast inland south approximately 48 km (Figure 2.11-1; Lenart, 2005a; Arthur and Del Vecchio, 2004). Central Arctic Herd caribou winter in the northern and southern foothills and mountains of the Brooks Range (Lenart, 2005a). Some caribou of the Porcupine Caribou Herd may occur on the coastal plain near the Liberty (SDI) Project during summer, but few calve there or use the area after calving (Griffith et al., 2002). Calving by the Central Arctic Herd occurs in early June, usually within 30 kilometers of the Beaufort Sea coast. There are two calving groups, based on the locations of the calving-concentration areas. One calving area is east of, and one west of the Sagavanirktok River (Arthur and Del Vecchio, 2004; Lenart, 2005a; Cronin et al., 1997). The Liberty (SDI) Project is near the eastern calving and postcalving ranges of the Central Arctic herd. Mid-June calving densities in the area bounded by the Beaufort Sea coast south to 69° 54.5’ N.latitude between the Sagavanirktok River and Bullen Point ranged from 0.62 caribou/km^2 to 2.38 caribou/km^2 during 2000 to 2003 with most caribou 5 km or more from the coast in the 1,487 km^2 survey area (Figure 2.11-2; Noel and Cunningham, 2003; Jensen, Noel, and Ballard, 2003; Jensen and Noel, 2002; Noel and Olson, 2001).

Caribou calving in the eastern area may occur within the Liberty (SDI) Project area during late June, July and August (Arthur and Del Vecchio, 2004; Lenart, 2005a). Caribou densities between the Sagavanirktok River and Bullen Point south to 70° N.latitude ranged from 0.01 caribou/km^2 to 8.43 caribou/km^2 during 2000 to 2003 within the 1,043 km^2 survey area (Noel and Cunningham, 2003; Jensen, Noel, and Ballard, 2003; Jensen and Noel, 2002; Noel and Olson, 2001). The most consistent pattern of caribou distribution within this area during July was use of riparian and coastal insect-relief habitats, typically sandbars, spits, river deltas, gravel river bars, and some barrier islands, by large groups (mean group size 50 to 500) of caribou (Figure 2.11-2; Noel and Cunningham, 2003).

The Central Arctic Herd increased from 5,000 animals in the 1970s to 13,000 in the early 1980s to 23,000 in the early1990s and then declined to 18,000 in the mid 1990s. The decline in the mid 1990s has been attributed to decreased productivity related to changes in calving distribution and increased energy expenditure during the insect season for cows in the eastern portion of the calving range caused by oil field infrastructure (Cameron et al., 2005). However, other factors may be responsible for the changes in herd numbers (e.g., winter mortality, emigration/immigration, Cronin et al., 1997; Cronin, Whitlaw, and Ballard, 2000). The Central Arctic Herd was last estimated at 31,857 caribou in July 2002, a 17% increase from the July 2000 estimate of 27,128 and a 61% increase from the July 1997 estimate of 19,730 caribou (Lenart, 2005a). This increase has been attributed to high parturition rates, high early summer calf survival and low adult mortality (Lenart, 2005a).

Wolves, grizzly bears, and golden eagles prey on caribou, although predation during calving and post-calving may be low for the Central Arctic Herd (Murphy and Lawhead, 2000). Winter mortality may have been higher in the 1990s, because more Central Arctic Herd caribou wintered south of the Brooks Range where wolves may be more abundant and snowfall is heavier (Lenart, 2005a). Harvest and hunting pressure on the Central Arctic Herd increased in the early 1990s due to hunting restrictions on interior Alaska herds and increased access to the Central Arctic Herd with opening of the Dalton Highway to public traffic. Total reported harvest has increased from an average of about 331 in the 1990s to about 470 in the 2000s, with an estimated harvest (reported and unreported) of 813 to 863 in 2004 to 2005 (Lenart, 2005a).

2.11.2 Muskoxen

Muskoxen were extirpated from northern Alaska by the late 1800s (Allen, 1912; Lent, 1998). From 1969 to 1970, 64 muskoxen from Greenland were reintroduced to northeastern Alaska, mostly in the Arctic National Wildlife Refuge (ANWR) but some also near the Kavik River (Jingfors and Klein, 1982). Since that time, the population has expanded its range east into Canada, west into the National Petroleum Reserve-Alaska (NPR-A), and south to areas near the Yukon River (Lenart, 2005b). The Alaskan North Slope population increased in size until the mid 1990s, appeared to stabilize around 550 animals until 2000, and then declined to about 195 by 2005 (Lenart, 2005b). The recent decline in total numbers can be attributed to a localized decline in the ANWR, as aerial counts in 1990 documented 332 and 122 muskoxen in the ANWR and between the Canning and Colville Rivers, respectively, and then 9 and 186 muskoxen in the same respective areas in 2005 (Lenart, 2005b). While emigration from the ANWR may have caused some of the decline in that area, reduced net productivity and recruitment were also evident (Reynolds, Wilson, and Klein, 2002; Lenart, 2005b). Predation by bears or variability in weather that affects forage availability may have been responsible for reduced survival of young and adults (Reynolds, Wilson, and Klein, 2002; Reynolds, Shideler, and Reynolds, 2002).

Muskoxen occur on the Arctic Coastal Plain year-round and use habitats along river corridors, floodplains, foothills, and bluffs in all seasons (Reynolds, Wilson, and Klein, 2002). Muskoxen usually produce single calves and overall have low reproductive potential relative to most ungulate species (Lent, 1988). Most females sampled from northeastern Alaska first bred successfully at 3 years of age, experienced reproductive pauses between calves of 2 or 3 years, and stopped calving by 15 years of age (Reynolds, 2001); these numbers may indicate less production than average for the species (Klein, 2000). Calves are usually born from April through June (Lent, 1988).

Muskoxen eat sedges, forbs, and willow leaves in summer and primarily sedges in winter (Klein, 2000). Spatial habitat models may be used to identify local areas likely to be selected seasonally by muskoxen such as wetter low-lying areas in summer and drier more rugged areas in winter (Lent, 1988; Danks and Klein, 2002). During summer, muskoxen form relatively small groups and travel more widely than during winter when groups tend to be larger and more sedentary (Reynolds, Wilson, and Klein, 2002; Lenart, 2005b). Lenart (2005b) noted a female that moved about 100 miles in a 2-month period during spring, traveling with a larger group for at least half that distance. Aerial surveys have documented relatively small groups near the coast between the Sagavanirktok River and the Badami Unit during spring and summer. Groups of muskoxen were located near the coast next to the Sagavanirktok, Kadleroshilik, Shaviovik, and Kavik Rivers and also on Tigvariak Island (Figure 2.11-3). Group sizes ranged from 1 to 18, with a total of 98 muskoxen observed, though many individuals were likely recounted among surveys. The greatest number of muskoxen documented during a single survey period was 28 individuals among 3 groups on June 1-14, 2002. Calves were present in 1 of these groups near the Kadleroshilik River (Jensen, Noel, and Ballard, 2003).

Grizzly bears kill calf and adult muskoxen, and may become more efficient with experience (Reynolds, Shideler, and Reynolds, 2002). Muskoxen have been legally hunted east of the Canning River since 1982 and between the Canning and Colville Rivers since 1990 (Lenart, 2005b). Subsistence hunting was preferentially allowed until 1998 when registration and drawings hunts were initiated (Lenart, 2005b). The annual harvest has been <4% of the population size and has primarily targeted bulls (Lenart, 2005b).

2.11.3 Grizzly Bears

Alaskan grizzly bears range north to the Beaufort Sea coast, but the coastal plain is considered marginal bear habitat due to severe climate, short growing season, and limited food resources (Shideler and Hechtel, 2000). Grizzly bears have low reproductive potential compared to other North American terrestrial mammals (Pasitschniak-Arts and Messier, 2000). Shideler and Hechtel (2000) reported lower cub mortality for bears feeding on anthropogenic food sources in North Slope oil fields relative to those feeding on natural food sources alone, but higher postweaning human kills may have compensated for greater initial net production. The population trend of grizzly bears between the Colville and Canning rivers is probably stable (Shideler and Hechtel, 2000; Stephenson, 2003). Densities of grizzly bears tend to be lower on the coastal plain (0.5 to 2 bears/1,000 km^2) than in the foothills of the Brooks Range (10 to 30 bears/1,000 km^2; Carroll, 1995), but densities in the oil fields were relatively high with about 60 to 70 resident bears or 4 per 1,000 km^2 (Shideler and Hechtel, 2000).

Because of permafrost, grizzly bear den sites on the coastal plain are generally restricted to well-drained habitats such as pingos, stream banks, hillsides, and sand dunes where insulating snow cover tends to accumulate in the southwestern lee of prevailing winds. Dens are typically used only once (Shideler and Hechtel, 2000). In the North Slope region, bears enter dens between late September and early November and exit between March and May (Shideler and Hechtel, 2000). Cubs are born sightless and helpless in the den during mid-winter (Pasitschniak-Arts, and Messier, 2000). Bears may select well-drained riparian habitats for vegetative forage in spring; wetter herbaceous meadows, riparian habitats, and ground squirrel mounds in summer; and inland areas with berries during the fall (Shideler and Hechtel, 2000). Grizzly bears frequently prey on ground squirrels, and also on bird eggs and nestlings, rodents, fox pups, caribou calves, adult and calf muskoxen, and marine mammal carcasses. Anthropogenic food sources may also be used when available (BPXA, 1998). The average annual home range for 5 radio-collared adult females was about 3,000 km^2; they may travel up to 50 km per day (Shideler and Hechtel, 1995, 2000). Combined field and genetic studies show that bears move across the North Slope, with considerable gene flow among bears in the western Brooks Range, the Prudhoe Bay region, and ANWR (Cronin et al., 2005).

Spring and summer aerial surveys of the coastal area between the Sagavanirktok River and the Badami Unit from 1998 to 2003 documented the presence of grizzly bears (Figure 2.11-3). Spring and summer surveys of the same area in 2001 and 2002 documented 19 bears among 10 groups. Juveniles were present in at least 2 groups (Jensen and Noel, 2002; Jensen, Noel, and Ballard, 2003). Most of the 10 groups were near riparian corridors such as the Shaviovik, Kavik, and Kadleroshilik rivers and were at least 10 km from the coast. The greatest number of bears observed during a single survey period was 5 bears among 3 groups on June 13-14, 2002 (Jensen, Noel, and Ballard, 2003).

Human hunting is the primary source of mortality of adult grizzly bears (Pasitschniak-Arts and Messier, 2000). Wolves and wolverines can kill bear cubs but are not present in appreciable numbers on the Arctic Coastal Plain (Shideler and Hechtel, 2000). Adult male bears may also kill cubs (Ballard et al., 1993). The Alaska Department of Fish and Game manages a sustainable annual harvest of about 5% of the North Slope bear population between the Colville and Canning rivers (Stephenson, 2003). Most bears are taken during the fall by resident hunters. The annual harvest consists mostly of males and has averaged 13.5 bears per year from 1989 to 2002 (Stephenson, 2003). A relatively large number of bears was taken in defense of life or property in 2001, perhaps as a result of reduced anthropogenic food availability in the oil fields (Shideler and Hechtel, 2000; Stephenson, 2003).

2.11.4 Arctic Foxes

Arctic foxes are typically found north of the foothills on Alaska’s North Slope (Burgess, 2000). Reproductive potential of the arctic fox is highest among carnivores but influenced by availability and variability of food resources that include rodents, nesting birds and eggs, marine mammal carcasses, and seal pups (Smith, 1976; Quinlan and Lehnhausen, 1982; Tannerfeldt and Angerbjorn, 1998; Anthony, Barten, and Seiser, 2000). Fox populations may cycle in response to prey populations such as lemmings, but anthropogenic or marine resources may buffer against such oscillations (Burgess, 2000; Roth, 2003). Periodic rabies epizootics may also affect arctic fox populations (Ballard et al., 2001; Mork and Prestrud, 2004). Foxes often cache food, may readily switch between prey sources, and are capable of removing over 1,000 eggs per fox per year from nesting bird colonies (Stickney, 1991; Samelius and Alisauskus, 2000).

Arctic foxes may move onto the Beaufort Sea ice in winter to scavenge from polar bear kills, but stable anthropogenic food sources may reduce seasonal movements (Eberhardt, Garrott, and Hanson, 1983b). Similarly, natal den densities were higher within the oil fields near Prudhoe Bay (1/15.2 km^2) than on adjacent undeveloped tundra (1/28.1 km^2; Ballard et al., 2000). Undeveloped areas east of Prudhoe Bay have even lower den densities (Burgess, 2000). Arctic fox dens tend to be fixed features on the landscape and are often located in pingos and low ridges, and next to streams in well-drained sandy soils where snow accumulation is minimal (Chesemore, 1967; Burgess, 2000). Foxes may also den in culverts and road embankments, and underneath buildings (Eberhardt, Garrott, and Hanson, 1983a; Ballard et al., 2000). Many dens are not used in a given year, and the proportion used appears to rely on availability of local food resources (Chesemore, 1967; Eberhardt, Garrott, and Hanson, 1983a).

Spring and summer aerial surveys of the coastal area adjacent to the Liberty (SDI) Project between the Sagavanirktok River and the Badami Unit in 2001 and 2002 documented the presence of arctic foxes and active dens (Figure 2.11-3; Jensen and Noel, 2002; Jensen, Noel, and Ballard, 2003). Locations of foxes were distributed widely both north to south and east to west across the study area. Dens were also distributed widely across the study area, but two were within 1 km of the Badami pipeline west of the Kadleroshilik River. The greatest number of foxes observed during a single survey period was six individuals (4 at dens) on June 17, 2001 (Jensen and Noel, 2002).

Predators of foxes near the project area are mainly brown bears and golden eagles that primarily take pups (Garrott and Eberhardt, 1982; Burgess, 2000). Harvest data for arctic foxes are not available for northeastern Alaska, but indications from trapper reports are that foxes remain common, and trapping pressure has decreased since the late 1980s due to low fur prices (Stephenson, 2001).

2.12 VEGETATION AND WETLANDS

The proposed Liberty (SDI) development will occur by expanding the existing Endicott SDI located on the Endicott Causeway to support ultra extended reach drilling. No terrestrial vegetation will be directly affected by the expansion of SDI. Support for the expansion of SDI will include the development of a gravel mine source located along the Endicott road, approximately 7.5 mi northeast of the Deadhorse Airport. The proposed mine site is adjacent to the existing Duck Island Mine Site. Refer to the Gravel Mine Site and Rehabilitation Plan found at Appendix I of this EA.

The coastal plain in the development area is a vast expanse of wetlands dominated by permafrost landscape features; patterned, polygonized ground and wind-driven thaw-lake complexes. Topographic relief is subtle, giving rise to broadly meandering streams and expansive braided river systems. The gravel mine source and associated ice road route is located on the east side of the western most channel of the Sagavanirktok River delta.

The braided channel system of the Sagavanirktok forms an extensive delta region that supports diverse plant communities. Calcareous sediments transported from the Brooks Range have a regional influence on soil conditions (Walker and Everett, 1991). In contrast to the acidic soils found across much of Alaska's North Slope, loess deposits from the Sagavanirktok River are evident in the slightly alkali soil pH in this region. This gradient is also manifest at the species level within plant communities of the area (Walker, 1985).

The location of the mine and ice road can be generally described as a complex of wet and moist sedge meadow communities dominated by *Carex aquatilis* and *Eriophorum angustifolium*. *Arctophila fulva* is often present in wetter areas and shallow flooded habitats. Drier habitats support species of *Dryas*, other forbs and grasses, as well as several species of *Salix*. Seasonal flooding and sloughs are common and give rise to barren or sparsely vegetated habitats.

To precisely define and quantify vegetative communities, land cover mapping of the mine area and potential ice road routes occurred in August 2007. To remain consistent with existing land cover maps in the Prudhoe Bay region, the area was mapped using Walker's vegetation and land cover classification scheme. Walker's approach involves categorizing sites with respect to site moisture regime and dominant plant growth forms (and landform type when plant cover is very sparse or nonexistent). The complete vegetation and land cover survey is located in this EA as Appendix H.

2.13 THREATENED AND ENDANGERED SPECIES

The Endangered Species Act (ESA) of 1973 defines an endangered species as any species that is in danger of extinction throughout all or a significant portion of its range, and a threatened species as any species that is likely to become endangered within the foreseeable future. The bowhead whale (endangered), the Steller's eider (threatened), the spectacled eider (threatened), and the Kittlitz's murrelet (a candidate species) may occur in the general area of the Liberty (SDI) Project (USDOI, MMS, 2002). The MMS conducted Section 7 consultations on these species with the NMFS and FWS for the proposed Liberty (SDI) Project. The consultations are provided at Appendices C and D of this EA.

Two other species (the yellow-billed loon and the polar bear) are addressed in this section as they are being evaluated for listing under the ESA and could be listed while the Liberty (SDI) Project is operational.

2.13.1 Birds

2.13.1.1 Spectacled Eider

The spectacled eider is a seaduck that nests in arctic Russia and western and northern Alaska, and winters in the Bering Sea. The Alaska breeding population has declined markedly especially on the Yukon-Kuskokwim Delta (Stehn et al., 1993) leading to listing under the Endangered Species Act as threatened throughout its range (58 FR 27474). Subsequent research has revealed the species to be widespread on the North Slope (Larned, Stehn, and Platte, 2005).

An estimated 6,731 spectacled eiders seasonally occupy the Arctic Coastal Plain (Larned, Stehn, and Platte, 2006). This value is an index unadjusted for eiders undoubtedly present but undetected. Abundance of spectacled eiders decreases from west to east across the Arctic Coastal Plain. Most high-density areas are west of Harrison Bay, and relatively few pairs are found east of the Shaviovik River. The Liberty (SDI) Project is located near the eastern limit of the North Slope spectacled eider range where spectacled eiders breed in low densities (Larned, Stehn, and Platte, 2005).

Spectacled eiders return from wintering grounds in the Bering Sea to the Arctic Coastal Plain in late May or early June and can be found in the Liberty (SDI) Project area during that entire time. Routes traveled during their spring migration are not well-known, but the North Slope segment may be overland (TERA, 1999). Some spectacled eiders trapped in June near Deadhorse continued on to the Kadleroshilik River, supporting an overland migration for this portion of the route (Troy, 2003).

Spectacled eiders are dispersed nesters (Petersen, Grand, and Dau, 2000). Breeding-pair surveys indicate spectacled eiders may be present across most of the Liberty (SDI) Project area (Larned, Stehn, and Platte, 2005). Nesting has been confirmed at many sites in the Prudhoe Bay oil field (TERA, 1993, 1997) and in the vicinity of the Kadleroshilik and Shaviovik rivers (USDOI, MMS, 2002). Few spectacled eiders are found in the area east of the Shaviovik River (Larned, Stehn, and Platte, 2005; TERA, 2002), but nesting may occur at least as far east as the Okpilak River in ANWR.

Larned et al. (2006) reported on spectacled eider surveys conducted when males and females are on the breeding grounds. Males depart the breeding grounds for coastal areas when the clutch is complete and the hen begins nest incubation. Relative nesting density of spectacled eiders is variable. Larned, Stehn, and Platte (2005) reported an estimated nesting density of 0.61 nesting eiders/km^2 around the proposed gravel pit site. Nesting density appeared lower in 2006 (Larned, Stehn, and Platte, 2006).

Migrant and staging spectacled eiders may occur in offshore waters from late June to September. Postbreeding males depart tundra-nesting areas and may move to nearshore marine habitats during mid- to late June, at the onset of incubation. Females leave from late June through mid-September, depending on their breeding success—failed breeders depart earliest. Shipboard surveys (August to mid-September, Divoky, 1984) and aerial surveys (mid July to early September, Fischer, Tiplady, and Larned, 2002) detected many eiders but no spectacled eiders within the Liberty area. Results from satellite tracking suggest that relatively few postbreeding male spectacled eiders use the Beaufort Sea, and the few that do use it are restricted to the limited ice-free areas such as river deltas (Troy, 2003).

Female spectacled eiders were found to make extensive use of the Beaufort Sea post-breeding, with the highest use area near Smith Bay. The second most important area in the Beaufort Sea for female spectacled eiders was near the Stockton Islands offshore of the eastern end of the Liberty (SDI) Project area (Troy, 2003). Telemetry data from a relatively small number of female spectacled eiders indicated use of marine habitats offshore of the Liberty (SDI) Project area. Given the relatively small proportion of the North Slope population of spectacled eiders breeding east of the Sagavanirktok River, however, it is unlikely that more than 100 spectacled eiders occur in marine waters around the Liberty (SDI) Project area at any one time.

After leaving the coastal plain, spectacled eiders molt in a few locations in arctic and eastern Russia or Ledyard Bay in northwestern Alaska before continuing on to staging areas near St. Lawrence Island and wintering areas in the central Bering Sea (Petersen, Larned, and Douglas, 1999).

2.13.1.2 Steller's Eider

The Alaska breeding population of Steller's eider was listed as threatened in 1997 (59 FR 35896), because of substantial decreases in population and nesting range (Quakenbush et al., 2002). Although historical data suggest that Steller's eiders formerly occurred across much of the Alaska Arctic Coastal Plain, including in the Liberty area, there have been no recent (post-1970) sightings between the Sagavanirktok River and the Alaska–Canada border (Quakenbush et al., 2002) and the species is considered a casual (i.e., not annual) visitant in the Liberty area.

Although there are numerous recent sightings of this species in the Prudhoe Bay area, and a record of a flight-capable brood near Prudhoe Bay in 1993 (Quakenbush et al., 2002), there are no unequivocal records of nesting east of Prudhoe Bay (e.g., Rodrigues, 2002; TERA, 2002; Ritchie, Schick, and Shook, 2003). Aerial surveys for eiders on the Arctic Coastal Plain indicate a wide distribution, but with only a few sightings between the Colville and Sagavanirktok rivers (Quakenbush et al., 2002) and none east of the Sagavanirktok River (W. Larned, FWS, pers. commun.; Larned, Stehn, and Platte, 2005). The extent of offshore use by Steller's eiders is poorly known (USDOI, MMS, 2002). A dark-plumaged Steller's eider observed near Northstar in early October 2004 (R. Day, ABR, pers. commun.) may be the only offshore record in this part of the Beaufort Sea.

2.13.1.3 Kittlitz's Murrelet

The Kittlitz's murrelet (*Brachyramphus brevirostris*) is a small alcid seabird found in discontinuous populations in both the east and west North Pacific Ocean and adjacent Arctic waters. Major population centers are Prince William Sound and Glacier Bay. Presence in the Beaufort Sea has not been confirmed, but it is possible they occur there in small numbers (USDOI, FWS, 2006b).

Kittlitz's murrelets are typically associated with glacially influenced inlets (Day, Kuletz, and Nigro, 1999; USDOI, FWS, 2004) on most parts of their range where they prefer waters within about 200 m of shore. There are no glacial inlets along the Chukchi or Beaufort sea coastlines. Divoky (1987) found Kittlitz's murrelets had pelagic distribution from approximately 21 km to 213 km offshore, with the farthest distance offshore found during the 24 August-22 September survey period.

Spring migration for Kittlitz's murrelets in the nearby Chukchi Sea is unknown, but it could be assumed they follow the retreating ice front in spring. Kittlitz's murrelets may follow offshore leads north to take advantage of the abundant under ice plankton blooms and the large biomass of forage species associated with those blooms. Kittlitz's murrelets seen along the Chukchi Sea coast in summer probably move south with the advancing ice front. Postbreeding distribution is poorly understood, but is likely farther offshore than prebreeding season. Winter distribution is poorly understood, but is probably pelagic in the Bering Sea.

The average age of first breeding for marbled murrelets is also not known, but based on other alcids of similar size, it is assumed to be between 2 and 5 years, with 3 years as a likely average (DeSanto and Nelson, 1995; Beissinger and Nur, 1997; Boulanger et al., 1999). Little is known about the reproductive strategy of the Kittlitz's murrelet because nesting sites are difficult to find (Day et al., 1999). Birds appear to be paired upon arrival to the breeding grounds. Egg-laying ranges from mid-May to mid-June depending on the population and range. One egg per clutch with one clutch per year is speculated. Both parents incubate and feed their young. Fledging in northern populations is generally during August.

Nests have been found at the distal end of the Delong Mountains south near Cape Thompson (USDOI, FWS, 2004). The Center for Biological Diversity (CBD) believes the species nests as far north as Cape Beaufort between Cape Lisburne and Point Lay (CBD, 2001).

The diet of the Chukchi summer residents is unknown, but Kittlitz's murrelets along the Chukchi coast during summer may be feeding on Arctic cod (*Boreogadus saida*), Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), or euphausiids that are relatively abundant in some localities. Similar to other small seabirds, Kittlitz's murrelets may be living close to their bioenergetic threshold most of the year and must forage with regularity to survive.

Recent population estimates for more southern populations are available (USDOI, FWS, 2004), but estimates for the nearby Chukchi Sea population are dated. The Center for Biological

Diversity estimates the Kittlitz's murrelet population along the Chukchi Sea coastline (including Wrangel Island) was 450 in 1993 and 171 in 2000 (CBD, 2001). The number of murrelets using the Liberty (SDI) Project area is unknown, but would be expected to be very small, if they occur there at all.

2.13.1.4 Other Species That May be listed under ESA Within the Life of the Project

The yellow-billed loon (*Gavia adamsii*) occurs in the Liberty (SDI) Project area. This species was petitioned for listing under the ESA on March 30, 2004 (CBD, 2004). Since that time, a status assessment and Conservation Agreement have been developed (Earnst, 2004; USDOI, FWS, 2006a). The draft 90-Day Finding on the petition was expected to be published in the *Federal Register* (*FR*) in early June 2007 (USDOI, FWS, 2007). The yellow-billed loon is included in this section because of the high potential that it will receive protection under the ESA during the life of the Liberty (SDI) Project.

Yellow-billed Loon

The total world-wide population of yellow-billed loons is estimated at 16,000 individuals, of which the northern Alaska breeding grounds support on average 3,369 individuals, including <1,000 nesting pairs/year. No declining trend was apparent in the number of yellow-billed loons estimated from breeding-bird surveys on the Arctic Coastal Plain, but survey variability was high and the power to detect trends was low (Earnst, 2004).

Yellow-billed loons first arrive in northern Alaska during the last 10 days of May. Individuals and small groups gather in open river channels, and larger flocks gather in marine bays until sufficient open water develops around the margin of lakes and ponds used for nesting. Loons generally nest and lay eggs during mid- to late June, with hatch in mid- to late July and young can fly by mid- to late September (Earnst, 2004).

Most yellow-billed loons nest between the Meade and Colville rivers on the Alaskan Arctic Coastal Plain, although they may also breed sparsely east of the Colville River to the Canning River (Earnst, 2004). Relative density of yellow-billed loons in the Liberty (SDI) Project area was <0.01 loons/km^2 based on breeding-pair surveys during July 1998-2001 (Mallek, Platte, and Stehn, 2002). Yellow-billed loons require nesting and broodrearing lakes that are large enough to allow takeoff from open water, form an ice-free moat around shore in early spring that protects nests from wind-blown ice and allow adults to take off, support a substantial population of small fish, have a section of gently sloping shoreline for nesting and brooding, and have sheltered areas where young chicks can rest and hide (Earnst, 2004).

Adult yellow-billed loons with territories near the coast as well as nonbreeding individuals may travel to marine waters to forage (Earnst, 2004). In the shallow nearshore waters of the Alaskan Beaufort Sea, yellow-billed loons were most abundant in Harrison Bay during July (Fischer and Larned, 2004).

Adults leave their territories during late August to mid September and successful breeders leave soon after their chicks can fly. Yellow-billed loons sometimes remain in open rivers until forced out by ice in late September to early October. Adults may migrate separately from offspring, and may migrate following leads in the pack ice far from shore in the Chukchi Sea and Beaufort Sea. Yellow-billed loons reach wintering sites off the coast of Japan, North Korea, and the Yellow Sea between North Korea and China where they remain by the end of November (Earnst, 2004).

2.13.2 Mammals

2.13.2.1 Bowhead Whale

The bowhead whale was listed as endangered on June 2, 1970. The Bering-Chukchi-Beaufort Seas bowhead whale also is classified as a strategic stock, because it is listed as endangered under the ESA and also is designated as depleted under the Marine Mammal Protection Act (MMPA). No critical habitat has been designated for the species, although the National Marine Fisheries Service (now NOAA Fisheries) recently received a petition to designate critical habitat for bowhead whales.

The Western Arctic stock of bowhead whales was estimated to be 8,000 individuals in 1993 with a range between 6,900 and 9,200 individuals with a 95% confidence interval (Zeh, George, and Suydam, 1995; Hill and DeMaster, 1999). Zeh, Raftery, and Schaffner (1995) subsequently revised this population estimate by incorporating acoustic data that were not available when the earlier estimate was developed. The revised estimate of the population was between 7,200 and 9,400 individuals in 1993, with 8,200 as the best population estimate, and the estimate recognized by the International Whaling Commission. This revised population estimate also was the population estimate used by NOAA Fisheries in their stock assessments (Hill and DeMaster, 1999; Angliss, Lopez, and DeMaster, 2001). An alternative method produced an estimate of 7,800 individuals with a 95% confidence interval of 6,800 to 8,900 individuals. Zeh, Raftery, and Schaffner (1995) estimated that the Western Arctic stock increased at a rate of 3.2% per year from 1978 to 1993. Recently George et al. (2004) reported that the Western Arctic bowhead population numbered approximately 10,470 animals in 2000. The minimum population estimate calculated by Angliss and Lodge (2004) for the Western Arctic bowhead stock is 8,886 whales. Angliss and Outlaw (2007) indicate the most recent minimum population estimate to be 9,472 bowhead whales, using the 2001 abundance estimate. The increase in the estimated population size is most likely due to a combination of improved data and better censusing techniques, along with an actual increase in the population. The historic population before commercial whaling was estimated at 10,400 to 23,000 whales in 1848, compared to an estimate of between 1,000 and 3,000 animals in 1914 near the end of the commercial-whaling period (Woody and Botkin, 1993).

Information on many aspects of bowhead-whale natural history is discussed in the Liberty DPP FEIS (USDOI, MMS, 2002). Topics discussed include wintering areas and habitats, spring and fall migration routes, tagging studies that describe bowhead movements and speed, effects of oceanographic conditions on bowhead migration, results of aerial survey data collected in the Liberty (SDI) Project area, traditional knowledge of bowhead movements, and aging techniques. The Liberty DPP FEIS points out that little is known about natural mortality in the Bering, Chukchi, and Beaufort seas, or about age at sexual maturity or mating behavior and timing.

The Liberty DPP FEIS also contains a lengthy discussion of bowhead feeding behavior and prey availability. Based on contents of stomach samples, some level of feeding occurs during spring migration and the area west of Barrow may be an important feeding area in some years. Bowhead feeding has also been reported in the eastern Beaufort Sea and the Amundsen Gulf region in Canada during the summer and in the Beaufort Sea during fall migration, but the importance of these areas in the annual activity budgets of bowheads is not known. A study by Richardson (1987) concluded that food consumed in the eastern Beaufort Sea did not contribute significantly to the overall bowhead whale population’s annual energy needs, although the area may be important to some individual whales in some years. The amount of feeding that occurs in the Beaufort Sea during fall migration appears to vary from year to year.

More recently, Lee et al. (2005) studied stable isotope in bowhead baleen and suggested that the Western Arctic population of bowhead whales acquires the bulk of its annual food intake from the Bering-Chukchi system, where the whales spend much of the fall plus the winter and early spring. The data indicate that bowheads acquire only a minority of their annual diet from the eastern and central Beaufort Sea where they spend the summer. However, subadults apparently feed in the central and eastern Beaufort Sea more frequently than adults. Lee et al. (2005) indicate that their conclusions are based on some uncertainties and that additional sampling would be valuable in refining the present estimates and the overall understanding of seasonal feeding by bowheads.

Near Kaktovik in the fall, bowheads apparently feed primarily on copepods and to a lesser extent on euphausiids (Lowry and Sheffield, 2002). However, in the western Beaufort Sea near Barrow fall bowhead whale diet was dominated by euphausiids. Stomach samples of 14 whales taken in spring at Barrow contained almost entirely euphausiids and 6 had nearly all copepods (Lowry and Sheffield, 2002). Significantly more copepods were reported in spring versus fall bowhead-stomach samples.

Bowhead whales migrate parallel to the north coast of Alaska during fall. Fall migration typically begins out of the Canadian Beaufort Sea in late August and early September (Schick and Urban, 2000) and continues through the Alaskan Beaufort Sea throughout October. A peak in the number of whales transiting through the Beaufort Sea typically occurs in the middle of September. Inupiat whalers from Kaktovik and Nuiqsut (based from Cross Island) each harvested 4 bowhead whales near the middle of September 2006 (Pausanna, 2006).

During the westward autumn migration bowhead whales are generally seaward of the barrier islands with annual variability in the mean distance offshore (Treacy, 2002a). The mean distance of migrating bowheads from shore in the Beaufort Sea west of Prudhoe Bay in 2000 (17.7 km) was less than for any single year (1982-2000) and much less than the cumulative mean (35.4 km; Treacy, 2002a). Blackwell et al. (2004) also reported interannual variability in the proximity of migrating bowheads to shore in the southern portion of the bowhead migration corridor near Prudhoe Bay. The migration corridor tended to be closer to shore in 2003 than the previous 2 years. Bowheads appear to migrate farther offshore during heavy-ice years and nearer shore during years of light sea-ice (Treacy, 2002b; Monnett and Treacy, 2005).

2.13.2.2 Polar Bears

Denning female polar bears could be impacted by noise from the SDI expansion. Polar bears sometimes choose terrestrial den sites near the coast, along lakeshores, on riverbanks, and in other areas with unique topographical features (Durner, Amstrup, and Ambrosius, 2001; Durner, Ambrosius, and Fischbach, 2003). Durner, Amstrup, and Ambrosius (2001) identified large areas along the coast and adjacent areas along the Sagavanirktok River near the SDI that are suitable for terrestrial maternal-den sites. Additionally, the proportion of maternal dens in terrestrial versus pack-ice habitats appears to be increasing in recent years. Fischbach, Amstrup, and Douglas (2007) reported that the proportion of dens on pack ice declined from 62% during 1985 to 1994 to 37% during 1998 to 2004. Changes in ice quantity and quality related to climate change could result in increased numbers of terrestrial maternal-den sites near the Liberty (SDI) Project in future years (Fischbach, Amstrup, and Douglas, 2007).

Note: This section was originally prepared by a contractor for BPXA. Much of the text was taken directly from the 2002 Liberty FEIS. This section updates information generated since the 2002 Liberty FEIS and provides site-specific information for the current Liberty (SDI) Project.

The MMS has revised this section to a limited extent for accuracy, clarity, completeness, and consistency with other MMS NEPA documents.

On February 16, 2005, the CBD petitioned the FWS to list the polar bear as a threatened species under the ESA because of melting of their sea ice habitat (CBD, 2005). In June 2005, the IUCN/SSG (World Conservation Union/Species Survival Commission) Polar Bear Specialist Group (PBSG) concluded that the IUCN Red List classification of the polar bear should be upgraded from Least Concern to Vulnerable, based on the likelihood of an overall decline in the size of the total world polar bear population by more than 30% within the next 35 to 50 years. The principal reason for this projected decline is “climatic warming and its consequent negative effects on the sea ice habitat of polar bears” (IUCN/SSG, Polar Bear Specialist Group, 2005). On February 7, 2006, the 90-day finding by the FWS determined that the CBD petition contained sufficient information indicating that listing polar bears as threatened may be warranted. The FWS conducted a 12-month status review of the species to determine whether listing was warranted and concluded the status review with a positive finding. On January 7, 2007, the FWS proposed to list the polar bear as a threatened species under the ESA.

Per the FWS *Federal Register* notice dated January 9, 2007, entitled *Endangered and Threatened Wildlife .... Proposed Rule To List the Polar Bear (Ursus maritimus) as Threatened Throughout Its Range* ... the following statment regarding oil and gas activities is quoted:

> Historically, oil and gas activities have resulted in little direct mortality to polar bears, and that mortality which has occurred, has been associated with human bear interactions as opposed to a spill event. However, oil and gas activities are increasing as development continues to expand throughout the United States Arctic and internationally, including in polar bear terrestrial and marine habitats. The greatest concern for future oil and gas development is the effect of an oil spill or discharges in the marine environment impacting polar bears or their habitat.

Polar bear seasonal distribution and local abundance vary widely in the Alaskan Beaufort Sea. Sea ice and food are the two most important natural influences on polar bear distribution. Polar bear use of coastal areas during the fall open-water period has increased in recent years (Kochnev et al., 2003; Schliebe et al., 2005). Nearshore densities of polar bears can be two to five times greater in autumn than in summer (Durner and Amstrup, 2000). For example, aerial surveys flown in September and October from 2000 to 2005 have revealed that 53% of the bears observed along the coast have been females with cubs, and that 73% of all bears observed were within a 30-km radius of the village of Kaktovik, on the edge of the ANWR (Schliebe et al., 2005). Congregations of more than 60 polar bears and as many as 12 brown bears have been observed feeding on whale carcasses near Kaktovik in recent years during the fall open-water period (Miller, Schliebe, and Proffitt, 2006). These observed changes in polar bear distribution have been correlated with the distance to the pack ice at that time of year. The farther from shore the leading edge of the pack ice is, the more bears are observed onshore in fall (Kochnev et al., 2003; Ovsyanikov, 2003; Schliebe et al., 2005; Kochnev, In prep.).

Drifting pack ice off the coast of the Alaskan Beaufort Sea probably supports more polar bears than either shorefast ice or polar pack ice, probably because young seals are abundant in this habitat. Durner et al. (2004) studied polar bear use of sea-ice habitats and reported that female polar bears preferred areas with relatively shallow water and high ice concentration. Polar bears sometimes concentrate along Alaska’s coast when pack ice drifts close to the shoreline, at bowhead whale-carcass locations such as Cross and Barter islands (Kalxdorff et al. 2002), and when shorefast ice forms early in the fall. During fall and winter, polar bears occur along the Beaufort Sea coast and on barrier islands. Kalxdorff et al. (2002) reported 97 polar bear sightings during four aerial surveys along the mainland coast and barrier islands between Harrison Bay and Kaktovik during fall 2001. Moulton and Williams (2003) reported 46 sightings of polar bears during spring aerial surveys while monitoring marine mammals for BPXA's Northstar development in 2002. Most of the sightings were located near and north of Cross Island, and no sightings were reported in the Liberty area. Polar bears are mobile and bears from the Chukchi and northern Beaufort seas often occur in the southern Beaufort Sea (Amstrup, McDonald, and Durner 2004).

Pregnant and lactating females with newborn cubs are the only polar bears that occupy winter dens for extended periods. Durner, Amstrup, and Fischback (2003) reported that dens in northern Alaska were constructed in ice and snow and usually consist of a simple chamber with a single entrance/egress tunnel, although multiple chambers and tunnels were reported at some dens. Dens were located on or associated with pronounced landscape features such as coastal and river banks, lake shores and an abandoned oil field gravel pad. Durner, Amstrup, and Ambrosius (2001, 2006) mapped the locations of suitable polar bear denning habitat on the Alaskan Arctic Coastal Plain including the Liberty (SDI) Project area.

In addition to being protected by the MMPA and proposed to be listed under the ESA, polar bears and their habitats are covered further by the International Agreement on the Conservation of Polar Bears. This 1976 agreement among Canada, Denmark, Norway, the Union of Soviet Socialist Republics, and the United States addresses protection of "habitat components such as denning and feeding sites and migration patterns." A bilateral agreement between the United States and Russia to conserve polar bears in the Chukchi/Bering seas also was signed in October 2000.

In 1988, the Inuvialuit Game Council from Canada and the North Slope Borough from Alaska implemented the Polar Bear Management Agreement for the Southern Beaufort Sea, a voluntary agreement that limited the total harvest from the SBS population to within sustainable levels (Brower et al., 2002).

2.14 CULTURAL RESOURCES

Cultural resources in and/or near the Liberty (SDI) Project area may include sites and materials of prehistoric Native American (e.g., habitation sites, lithic scatters, and isolated finds), historic European and Euro-American, and historic Iñupiat origin (e.g., traditional cabin and subsistence sites, campsites, burial grounds, and other traditional land-use areas, landscapes, symbols, and place names).

Sources for information about cultural resources include:

- The Alaska Heritage Resources Survey (AHRS) maintained by the Alaska Department of Natural Resources, Office of History and Archaeology (ADNR, OHA, 2005);
- The Traditional Land Use Inventory (TLUI) maintained by the North Slope Borough (NSB, 2003); and
- Reports associated with oil and gas exploration and development. In particular, the Liberty Project Environmental Report (LGL, WCC, and Applied Sociocultural Research, 1998) and the Liberty DPP FEIS (USDOI, MMS 2002) provided relevant information.

The TLUI is a list of important cultural sites and subsistence use areas, with the core information being the traditional knowledge and accounts of elders applied to the land use history and patterns of individual communities including the village of Nuiqsut (e.g., NSB, 1976, 1978; Hoffman, Libbey, and Spearman, 1988; Brown, 1979; Ito-Adler and Hall, 1986; and IAI, 1990a); Kaktovik (e.g., Jacobson, No date; Jacobson and Wentworth, 1982; Pedersen, Coffing, and Thompson, 1985; and IAI, 1990b); and overviews of cultural resources in the Beaufort Sea region (e.g., NSB, 1977, 1980, 1981, No date.; Nielson, 1977; Hall, 1981; Libbey, 1981; Okakok, 1981; Pedersen, No date, 1995; Galginaitis et al., 1984; Pedersen and Coffing, 1984; Coffing and Pedersen, 1985; IAI, 1985, 1990a). Research pertaining to cultural resources in the Beaufort Sea region is included in lease sale EIS's (e.g., USDOI, BLM, 1979, 1982; USDOI, MMS, 1984, 1987, 1990a, 1990b, 1996a, 1990b, 1997); development EIS's (e.g., USDOI, BLM, 2004a, 2004b, 2005; USDOI, MMS, 2002; U.S. Army Corps of Engineers and ERT, 1984); and focused survey reports conducted as part of the permitting process for individual wells and other exploratory/development projects including the Liberty Development Project (e.g., Lobdell, 1980, 1985, 1986, 1990, 1991, 1993, 1995, 1996, 1998a, 1998b, 1998c; Lobdell and Lobdell, 1999, 2000a, 2000b; WCC, 1981; Duane Miller and Associates, 1997; Watson Company, 1999; Reanier, 2000, 2002, 2003). Lobdell (1998a, 1998b) conducted cultural resources surveys for the Liberty Project area in 1997 and 1998. No previously unknown or unrecorded cultural resources were identified during these surveys, and while no cultural resources were within the project footprint originally proposed, two historic sites were located within 1 mi of originally proposed project components.

The area of potential effect of the alternatives originally considered in the Liberty DPP FEIS included an area that encompassed a manmade gravel island located in Foggy Island Bay with full production facilities, subsea pipeline, the area around the landfall of this pipeline from the production facility, and the tie-in of this pipeline with the Badami Sales Oil Pipeline. The Liberty (SDI) Project now includes an expansion of the existing Endicott Satellite Drilling Island for the well pad and existing infrastructure. Two alternatives (well pads located at Pt. Brower and near the Kadleroshilik River and using Endicott and Badami, respectively, as processing hosts) are onshore developments that take advantage of existing infrastructure. These onshore alternatives do not expand the potentially affected area.

Section 4.2.1 contains details on the permitting process that will be followed to assure the avoidance or mitigation of cultural resources, including in the new gravel mine site planned for the project.

2.14.1 Prehistoric Resources

BPXA contracted with Reanier & Associates, Inc. to conduct an archaeological and cultural resources reconnaissance survey of the current Liberty (SDI) Project that included onshore gravel source sites and the expanded SDI footprint. The survey was completed in August 2007, and no new cultural resources were discovered. There are no previously known sites within the proposed Liberty (SDI) Project area.

2.14.2 Historic Resources

The MMS, after consulting the State of Alaska AHRS database, has identified no cultural and archaeological sites offshore, nearshore, or onshore within the proposed Liberty (SDI) Project area.

2.15 SOCIOECONOMICS

2.15.1 Economy

The discussion of economics addresses the affected environment in a national, State, and local (particularly Alaska North Slope) context. This section incorporates by reference the relevant material on economics contained in the original Liberty Project Environmental Report (LGL, WCC, and Applied Sociocultural Research, 1998), Liberty DPP FEIS (USDOI, MMS, 2002), other North Slope EIS's completed since 2002, including the Alpine Satellite Development Plan (USDOI, BLM, 2004a); the Northwest National Petroleum Reserve-Alaska Final Amended Integrated Activity Plan (USDOI, BLM, 2004b); the Northeast National Petroleum Reserve-Alaska Final Amended Integrated Activity Plan (USDOI, BLM, 2005); the Proposed OCS Lease Sales 193 (USDOI, MMS, 2006a), 195 (USDOI, MMS, 2004), and 202 (USDOI, MMS, 2006b; see also USDOI, MMS, 2003); the TAPS Right-of-Way Renewal (USDOI, BLM, 2002); and the National Research Council (NRC) study of the cumulative effects of oil and gas activities on Alaska's North Slope (NRC, 2003).

The description of the affected environment from an economic perspective can be summarized simply as follows: domestic crude oil production is critically important at the national, State, and local (North Slope Borough) levels.

2.15.1.1 National Level

As recently as the end of World War II, the United States was self-sufficient in crude oil. Since then, the rate of increase of U.S. crude oil consumption greatly outpaced that for domestic production and the U.S. has become a net importer. Current projections (EIA, 2005) indicate that U.S. dependence on foreign oil producers will grow to 70% of U.S. demand by 2025. Additional imports adversely affect the balance of trade, exacerbate domestic inflation, reduce the gross domestic product, and increase reliance on imports from countries that are unstable and/or unfriendly to the United States.

2.15.1.2 State Level

Petroleum contributes substantially to gross state product, employment (and high-paying employment), and revenues. For example, the combination of petroleum taxes and royalties since production began on the North Slope annually contributed between 60 and 90% of total State unrestricted fund revenues. Since the Liberty FEIS was completed in 2002, these revenues from the North Slope have approximately tripled from approximately $1 billion to $2.8 billion (Alaska Department of Revenue, Revenue Sources Book, 2006).

Petroleum also is important to the State economy, because it is the funding source for Alaska's largest financial asset—the Alaska Permanent Fund. The Permanent Fund was established in 1978 to be a savings account to hold a share of the royalties (petroleum production owned by the State of Alaska) received by the State. The rationale for its establishment was that the fund would grow over time as production declined, and the earnings of the fund eventually would substitute for oil production as a source of revenues to help support necessary public spending on education and other public programs. Since the fund's inception, the Alaska constitution has required that 25% of royalties be deposited into the fund. In addition, annual deposits to offset the erosion of the value of the fund due to inflation have been made since the early 1980s, and on occasion, special deposits have also been added to the principal, which cannot by law be spent. The fund is invested in a diverse portfolio of stocks, bonds, and real estate, and has grown in value to nearly $33 billion as of the end of June 2006 (http://www.apfc.org/theapfc/faq.cfm).

2.15.1.3 Local Level

The Liberty FEIS provides data on the contribution of taxes on petroleum facilities to the North Slope Borough. According to the 2005 NSB Annual Financial Report, nearly $200 million of the $315 million total NSB revenues came from property taxes, almost exclusively on oil industry facilities. This same report (page iii) stated:

> Since 1968, oil and gas exploration and development on Alaska's North Slope has become the principal industry in the Borough and the employer of the bulk of the Borough's workforce. The other service providers, including the government sector, exist primarily due to the presence of the oil and gas industry (NSB, http://www.north.slope.org/nsb/default.htm).

The NSB communities have also been affected by growth in the capacity of State government to provide services to local communities as a result of the petroleum revenues flowing to the State although recent developments, such as the suspension of State revenue sharing with local communities, have created difficulties in funding infrastructure in many smaller villages. Enhancement of the quality of primary and secondary education is the most obvious example of service improvement, but others such as health care, transportation infrastructure, and public safety have also benefited. These services produce additional jobs and income for local residents. Petroleum revenues have also allowed the State to keep the tax burden on Alaskan households low, and along with the Permanent Fund Dividend, have substantially increased the discretionary income of all Alaskan households, supporting a large number of jobs in this and other regions of the State. As noted by MMS (USDOI, MMS, 2002): "Social services have increased dramatically since 1970, with increased Borough budgets and grants acquired early on by the Iñupiat Community of the Arctic Slope, and later by the Arctic Slope Native Association and other borough nonprofits."

Revenues from the oil industry have been important to the success of Native corporations, such as the Arctic Slope Regional Corporation. This success, in turn, provides jobs for Alaskan Natives and dividends for shareholders, although local hire in the oil patch remains low. In 1992, Natives employed at Prudhoe Bay comprised less than 1% of the 6,000 North Slope oil industry workers. This pattern is confirmed by 1998 data showing only 10 NSB Inupiat residents as employed in the oil industry (see, e.g., USDOI, MMS, 2003; NRC, 2003).

In short, all levels of government stand to gain economically from increased domestic crude oil production and other measures (e.g., conservation initiatives and the development of alternative energy sources) to reduce dependence on imported oil. Higher crude-oil prices adversely affect the national government, but benefit Alaska. Development of the Liberty (SDI) Project will not solve the Nation's energy problem, but is fully consistent with the National Energy Strategy. Liberty is one of the projects included in the State's projections of future oil production and revenues. Quantitative estimates of the economic impacts associated with development of the Liberty (SDI) Project are provided in the discussions of the economic impacts of the proposed action and no-action alternative.

2.15.2 Sociocultural Systems

"Sociocultural systems" as used in the Liberty FEIS (USDOI, MMS, 2002) encompass: "…the social organization and cultural values of a society." Included under this rubric, the FEIS provided a profile of the sociocultural systems that characterize the North Slope communities of Barrow, Nuiqsut, and Kaktovik—communities that might be impacted by this development. The quantitative data included in this section were based largely on the results of the 1990 Census. Results of the 2000 Census are now available and several EIS's incorporate these data, including the Alpine Satellite Development Plan (USDOI, BLM, 2004a); the Northwest National Petroleum Reserve-Alaska Final Amended Integrated Activity Plan (USDOI, BLM, 2004b); the Northeast National Petroleum Reserve-Alaska Final Amended Integrated Activity Plan (USDOI, BLM, 2005); the Proposed OCS Lease Sales 193, 195, and 202 (USDOI, MMS, 2006a, 2004, 2006b; see also USDOI, MMS, 2003); the TAPS Right-of-Way Renewal (USDOI, BLM, 2002); and the NRC study of the cumulative effects of oil and gas activities on Alaska's North Slope (NRC, 2003). Another useful report published since the Liberty FEIS was written by Northern Economics, Inc. (2006). All are incorporated by reference.

2.15.2.1 Demographics

Although new Census data are available, these data do not materially alter the findings and conclusions presented in the Liberty FEIS. Selected demographic information in summary form includes:

- The NSB is the largest borough in Alaska, accounting for 15% of the area of the State. Were the NSB a State, it would rank 12th in area (at 89,000 mi^2 in area, this borough is slightly larger than the State of Minnesota). The borough includes eight villages: Anaktuvuk Pass, Atqasuk, Barrow, Kaktovik, Nuiqsut, Point Hope, Point Lay, and Wainwright.
- Table 2.15-1 provides additional demographic information on the NSB communities including year incorporated, land and water area, population (in total and by gender), median age, median 1999 household income, percentage of families below the poverty level, selected housing characteristics, available health services, schools, transportation and communications, and alcohol restrictions. The Census of 2000 counted 7,367 persons as residents of the NSB, for an average population density of approximately 1 person/12.1 mi^2.
- Ethnically, more than 70% of the NSB population is all or partially Iñupiat. The NSB accounts for approximately 4.6% of the Alaska Native population of the State (Goldsmith et al., 2004). As shown in Table 2.15-1, there are substantial ethnicity differences among the NSB villages; Barrow's population is approximately 64% Iñupiat, whereas this percentage is consistently higher in the seven smaller villages. As noted in USDOI, MMS (2002), the ethnicity of Barrow has changed in recent years: "In 1970 the Iñupiat population of Barrow represented 91% of the total population…. By 1990, Iñupiat representation had dropped to 63.9%." For comparison, the percentages of American Indian and Alaskan Native persons in Alaska and the total U.S. are 15.6% and 0.9%, respectively (http://quickfacts.census.gov/qfd/states/02000.html).
- For the most part, communities in the NSB have younger populations than the U.S. as a whole. For example, according to 2000 Census estimates, the median ages of residents of Barrow, Kaktovik, and Nuiqsut were 28.8, 32.1, and 23.8 years of age, respectively.

Median ages of all Alaskan residents and all U.S. residents were 32.4 and 35.3 years of age, respectively (USDOC, Bureau of the Census, 2001). Goldsmith et al. (2004) show that Alaska Natives are a young population compared with other Alaskans and other Americans.

- Median household incomes for Barrow, Kaktovik, and Nuiqsut were $67,097, $55,625, and $48,036, respectively, reflecting enhanced earning opportunities in Barrow compared to the other two communities. Corresponding figures for Alaska and the United States were $51,571 and $41,449, respectively (http://quickfacts.census.gov/qfs/states/02000.html). These figures need to be interpreted with care, however, as costs of living are higher in the NSB than in the major cities of Alaska or the other states (see e.g., Goldsmith et al., 2004).
- Table 2.15-1 provides 2000 Census data on the percentage of housing units lacking complete plumbing facilities, kitchen facilities, and telephone service for the NSB communities. These percentages are greater than corresponding percentages for the rest of the United States, which reflects the remoteness of the region and the cost and logistical difficulties of providing certain services in the Arctic.

2.15.2.2 Social Organization and Cultural Values

The Liberty FEIS (USDOI, MMS, 2002) provides an in-depth discussion of the nature of Iñupiat life. Key points are discussed below.

Kinship is the foundation for social organization in Iñupiat communities and plays an important role in all aspects of Iñupiat life. Iñupiat households were historically comprised of large extended families and were part of a larger community kinship unit. An Iñupiat household on the North Slope may contain a single individual or group of individuals who are related by marriage or ancestry. Iñupiat households generally depend on the regular involvement of extended family members in providing economic support. Iñupiat social organization includes not only household and family kinship ties, but a larger social network of friends and kin. These networks are linked through overlapping memberships and are involved in the organization of formal and informal subsistence groups. Iñupiat social networks determine how subsistence resources are harvested, distributed, and consumed. Sharing is a regular and expected part of maintaining strong kinship bonds, and a generous person is regarded with esteem in the community.

Traditional Iñupiat cultural values focus on a close relationship to the land, natural resources, the supernatural, and the community, its needs, and its support of individuals. Historically and traditionally, survival in the Arctic centered on the pursuit of subsistence resources and the knowledge needed to find, harvest, process, store, and distribute the harvest. Iñupiat culture depends on the intergenerational transmission of traditional knowledge and beliefs about subsistence resources including observations of game behavior, how to use those observations to successfully locate and harvest game, and how hunters and their families should behave to ensure successful future harvests. Despite recent economic, technological, and social changes in the region, subsistence remains an essential and vital part of Iñupiat life and provides the basis for cultural values and social organization. The process of obtaining, refining, and passing on subsistence skill is inextricably linked to the Iñupiat culture, which is based on interdependent family groups and a tradition of sharing harvested resources. The majority of North Slope residents self-identify as subsistence hunters and harvesters, and they continue to participate in subsistence activities throughout the year.

Subsistence activities play an important role in defining Iñupiat cultural values such as social organization, cooperation and sharing, and the formation of kinship ties (USDOI, MMS, 2002). Cultural values are exemplified by bowhead whale hunting, which has been a central part of Iñupiat culture for at least 1,000 to 1,500 years. Bowhead whale hunting remains the center of Iñupiat spiritual and emotional life; it embodies the values of sharing, association, leadership, kinship, arctic survival, and hunting prowess; and it is at the core of Iñupiat cultural identity. The whale hunt encompasses key Iñupiat values and provides the basis for social organization in many Iñupiat communities (Galginaitis and Funk, 2004). Individual organization of whaling crews is often an indicator of a larger organizational pattern within the Iñupiat community and often defines social ties and leadership roles (USDOI, MMS, 2002). The whale hunt is a village-wide cooperative event. In addition to the boat crews who participate in yearly whale hunts, most people in the villages are involved in other aspects of support, such as butchering and processing (Richardson and Thomson, 2002). Structured sharing of subsistence resources is evident both within and among communities, forming kinship bonds and social networks between individuals and villages. These relationships are essential to maintaining cultural values and social structure. Disruptions to individual harvest success could potentially affect the Iñupiat system of sharing, a process which is vital to the social structure of Iñupiat communities (USDOI, BLM, 2005).

While Iñupiat lands are important for the harvest areas and resources they provide, they also hold a deeper meaning to the residents of the North Slope communities. Traditionally, areas were named for the extended family groups that inhabited them, and eventually, the Iñupiat divided the area into people of the land (Nunamiut) and people of the coast (Taermiut) (Spencer, 1976 as cited in USDOI, BLM, 2005). For example, some of the people who resettled Nuiqsut identified themselves as Kuukpikmuit, or “people of the Colville River Delta.” Maintaining a connection to this land is a priority for residents in these Iñupiat communities.

2.15.2.3 Institutional Organization of the Communities

The Liberty FEIS (USDOI, MMS, 2002) provides information on organizations operating in or around the North Slope Borough. Key points include:

- The majority of community services in North Slope communities are provided by the NSB, which is also the largest employer of North Slope residents and provides local services such as public safety, public utilities, fire protection, and some public health services. NSB revenues, primarily from oil industry taxation, fund these services. (See the section on economics.)
- The Arctic Slope Regional Corporation, which was formed under the Alaska Native Claims Settlement Act, runs a number of subsidiary corporations on the North Slope and throughout Alaska. Most communities also house local governments that provide varying degrees of services to North Slope villages. These include village corporations, Traditional Village Councils, Indian Reorganization Act (IRA) Councils, and city government. Village corporations are important entities for the local economy (e.g., Ukpeagvik Iñupiat Corporation in Barrow, Kuukpik Corporation in Nuiqsut and Kaktovik Iñupiat Corporation in Kaktovik). The role of Native Corporations is discussed at length in a recent report prepared for MMS (Northern Economics, Inc., 2006).
- Nongovernmental organizations include the Alaska Eskimo Whaling Commission, the Iñupiat Community of the Arctic Slope, and the Kuukpikmiut Subsistence Oversight

Panel, Inc. These organizations, particularly the former, have recently become more active and visible in regional governance (USDOI, MMS, 2002).

2.15.2.4 Other Ongoing Sociocultural Issues

The Liberty FEIS (USDOI, MMS, 2002) notes that current sociocultural systems are undergoing change and strain. This conclusion is shared in more recent EIS's. Previous EIS's discussed issues pertaining to changes in employment, increased income, decreased Iñupiaq fluency, and increased crime and substance abuse rates (e.g., USDOI, MMS, 1987, 1990a, 1996, 1998; USDOI, BLM, 1998). Despite relative economic well-being, North Slope residents have come under increased stresses on social well-being as well as cultural integrity and cohesion (USDOI, MMS, 2002; USDOI, BLM, 2004a,b, 2005).

2.15.3 Subsistence and Area Use Patterns

Subsistence is a key element of the Iñupiat lifestyle. The ideology, tradition, and practice of subsistence resource harvest, use, and sharing are crucial underpinnings of Iñupiat society today. The associated systems of rules and practices constitute a body of knowledge that underlies Iñupiat peoples' behavior and defines who they are as a people. Subsistence activities are a key determinant of Iñupiat conceptions of the universe and their role in it. While many Iñupiat people participate in the wage economy, use modern equipment and tools, and wear imported clothing, these new items are incorporated, used, and conceived of in intrinsically Iñupiat ways integral to their culture.

Information on subsistence was summarized in the original Liberty Development Project Environmental Report (LGL, WCC, and Applied Sociocultural Research, 1998) and the Liberty FEIS (USDOI, MMS, 2002). Subsistence has been extensively discussed in more recent EIS's and EA's, including the Alpine Satellite Development Plan (USDOI, BLM, 2004a); the NE NPR-A Final Amended Integrated Activity Plan (USDOI, BLM, 2005), the Proposed OCS Lease Sales 193, 195, and 202 (USDOI, MMS, 2006a, 2004, 2006b; see also USDOI, MMS 2003); the TAPS Right-of-Way Renewal (USDOI, BLM, 2002); and the NRC study of the cumulative effects of oil and gas activities on Alaska's North Slope (NRC, 2003). The material in these publications is incorporated by reference. Key content is summarized below.

2.15.3.1 Subsistence Areas

The Liberty FEIS (USDOI, MMS, 2002) provides a short description of the subsistence areas for Nuiqsut, Kaktovik, and Barrow. These are summarized in the map shown in Figure 2.15-1. (Figure 2.15-2 provides more detail for Nuiqsut.) The Liberty reservoir (also shown in this figure) is near the Nuiqsut and Kaktovik subsistence areas, which are discussed below.

Nuiqsut

Nuiqsut hunters harvest resources over an expansive area of the North Slope. Nuiqsut's subsistence marine-resource harvest area includes the Beaufort Sea from Cape Halkett in the west to Flaxman Island in the east, and up to 30 mi offshore (Figure 2.15-1). Cross Island is the center of Nuiqsut's subsistence bowhead-whale hunting.

Nuiqsut whalers have accompanied Kaktovik whalers when conditions near Cross Island have been extremely unfavorable for whaling (heavy ice). Before oil development at Prudhoe Bay, the onshore area from the Colville River delta in the west were historically important to the

Iñupiat for subsistence harvests of caribou, waterfowl, furbearers, fish and polar bears. More recently, safety and security concerns in certain developed areas, including Prudhoe Bay, have placed access limits on Iñupiat subsistence users. Access policies vary among oil field units (see e.g., U.S. Army Corps of Engineers, 1997).

Kaktovik

Kaktovik is located on Barter Island on the northern edge of the Arctic National Wildlife Refuge. Kaktovik subsistence users use an area of up to 11,400 mi^2 extending along the coast from Demarcation Point to Foggy Island, including the offshore barrier islands, and to the foothills and low passes of the Brooks Range via several river drainages (Pederson, 1990) (Figure 2.15-1). Summer resource harvests tend to take place along the coast and barrier islands, while winter harvests tend to take place inland along river courses such as the Hulahula, Shaviovok, and Sadlerochit rivers (Pederson, 1990).

Barrow

As with other communities adjacent to the planning area, Barrow residents enjoy a diverse subsistence resource base that includes both marine and terrestrial animals (Alaska Dept. of Community and Economic Development [ADCED], 2005). Barrow harvesters' lifetime subsistence-harvest area as documented in Pederson (1979) can be seen in Figure 2.15-1.

2.15.3.2 Cultural Importance of Subsistence

Subsistence is part of a rural economic system, often termed a mixed, subsistence-market economy, wherein families invest their resources in small-scale, efficient technologies to harvest wild foods (Alaska Department of Fish and Game [ADF&G], 2000). Subsistence resource harvests provide a reliable economic base for domestic family units who have invested in equipment and transportation to conduct these important activities. Subsistence resource harvests support extended families and others through redistribution to elders, coworkers, and other channels. These activities also support collective harvest activities associated with participation in whaling crews, and the cycle of public events based on whaling traditions (Bodenhorn, 2003). In practice, wage employment is a means to support subsistence activities, although the two are mutually interdependent.

Subsistence meets the self-limiting needs of families and small communities, not primarily on commercial market production. Participants in this mixed economy in rural Alaska augment their subsistence production by cash employment. Cash wages provide the means to purchase the equipment, supplies, and fuel used in subsistence activities.

Subsistence activities, particularly bowhead whale hunting, continue to be the basis for Iñupiat culture, values, and tradition (Bodenhorn, 2003). The Iñupiat maintain connections to their traditionally used lands and resources through elder-directed, multigenerational use and re-use of camps, cabins, and areas of importance. The Iñupiat continue to base their social calendar on solitary and cooperative hunting of seasonally available subsistence resources. Subsistence users continue to share their resources through kin-based networks over an even greater area than in the historic period, transporting subsistence foods to relatives in urban Alaska and beyond (Stephen R. Braund & Associates and Institute of Social & Economic Research [SRB&A and ISER], 1993). Elders are valued for their knowledge and insight, and are cared for and respected by their communities. Iñupiat celebrations and festivals are still important local and regional events and some celebrations, previously suppressed or abandoned, are being organized and held again (SRB&A and ISER, 1993). More recent recurring events, including basketball tournaments and the World Eskimo Indian Olympics, function to maintain and enhance contacts between communities and regions.

2.15.3.3 Annual Cycle of Harvest Activities

Each of the NSB villages has a broadly similar annual cycle of harvest activities. Those for Barrow, Kaktovik, and Nuiqsut are given in NRC (2003).

2.15.3.4 Subsistence-Harvest Seasons and Harvest Success Profile

Two major subsistence-resource categories occur on the North Slope: the coastal/marine and the terrestrial/aquatic (USDOI, MMS, 2002). In the coastal/marine group, the food resources harvested are whales, seals, walrus, waterfowl, and fish, while in the terrestrial/aquatic group, the resources sought are caribou, freshwater fish, moose, Dall sheep, grizzly bear, edible roots and berries, and furbearers. Each of the NSB villages has a characteristic subsistence harvest pattern, although there is substantial year-to-year variability. Although subsistence harvests differ from community to community, the resource combination of caribou, bowhead whales, and fish was identified as the primary grouping of resources harvested (USDOI, MMS, 2002).

Specific data on subsistence harvests for Barrow, Kaktovik, and Nuiqsut have been published (Brower and Opie, 1997; USDOI, BLM, 2004a, 2005; USDOI, MMS, 2002, 2003, 2004, 2006a, 2006b; U.S. Army Corps of Engineers, 1999) and are incorporated by reference. Because Nuiqsut is the closest village to the proposed Liberty Development Project and might be expected to experience greater effects, more detailed data are provided for this community below.

A diverse seasonal abundance of terrestrial mammals, fish, birds, and other resources is available in the Nuiqsut area, where traditional subsistence activities revolved around caribou, marine mammals, and fish, with moose, waterfowl, and furbearers as important supplementary resources. The Colville River is the largest river system on the North Slope and supports the largest overwintering areas for whitefish (Craig, 1987). Nuiqsut is geographically remote from its whaling camp on Cross Island, necessitating a long trip through the barrier islands to West Dock and then due north to whaling camp (Brown, 1979).

The seasonal availability of many important subsistence resources controls the timing of subsistence harvest activities (Table 2.15-2).

The ADF&G collected subsistence harvest data for Nuiqsut in 1985 and 1993, selecting 1993 as the most representative year for subsistence harvest data (Tables 2.15-3 and 2.15-4) (ADF&G, 2001). Estimates of Nuiqsut's total annual subsistence harvests in recent years were 160,035 pounds in 1985, 150,196 pounds in 1992, and 267,818 pounds in 1993 (Table 2.15-3). The 1993 harvest of 742 pounds per capita of wild resources represents approximately 2 pounds per day per person in the community. In 1985, fish and land mammals accounted for 86% of Nuiqsut's total subsistence harvest, and marine mammals contributed 8%. In 1993, fish, land mammals, and marine mammals accounted for approximately one-third each (Table 2.15-3). The importance of subsistence to Nuiqsut residents is shown in high participation rates for 1993 in households that use (100%), harvest (90%), try to harvest (94%), and share (98%) subsistence resources (Table 2.15-4).

Nuiqsut landed no bowheads in 1985 or 1994. The community harvested two bowheads in 1992 and three in 1993. In years when bowhead whale, fish, and terrestrial mammal subsistence harvests are successful, such as 1992 and 1993, each of these resources may provide nearly one-third of the subsistence resource harvest (Tables 2.15-3 and 2.15-4 and Figures 2.15-3 and 2.15-4) (Fuller and George, 1999). In 1992, bowhead whales (32%), caribou (22%), and fish (25%) comprised 79% of Nuiqsut's annual subsistence harvest. In 1993, bowhead whales (29%), whitefish (29%), and caribou (31%) comprised 88% of Nuiqsut's annual subsistence harvest in terms of edible pounds (Table 2.15-4 and Figure 2.15-4) (Fuller and George, 1999).

Bowhead Whales

Since completion of the Liberty FEIS (USDOI, MMS, 2002) additional information on bowhead whale harvests and effort has been developed for Nuiqsut. This new information is summarized below.

Even though Nuiqsut is not located on the coast (it is approximately 16 to 17 mi inland and 18 to 33 mi via the river, depending on which channel is taken to the Beaufort Sea), bowhead whales are a major subsistence resource for this community. Bowhead whaling is usually undertaken between late August and early October from Cross Island, with the exact timing depending on ice and weather conditions. Variable ice conditions may extend the season to 2 months or contract it to <2 weeks. Nuiqsut whalers use aluminum or fiberglass boats, 18 to 24 ft long, with outboard motors to hunt bowheads in open water in the fall, unlike spring whaling in Barrow where the hunt is staged from the edge of ice leads using skin boats. Nuiqsut residents report that they harvest bowhead whales most frequently within 10 mi of Cross Island, but hunters often travel much farther from the island.

Historically, the entire coastal area from Nuiqsut east to Flaxman Island and the Canning River delta has been used for whaling, but whaling to the west of Cross Island has not been as productive as hunting closer to the island, and whaling too far to the east requires long tows of the whales back to Cross Island for butchering, creating the potential for meat spoilage (Impact Assessment, Inc.[IAI], 1990a). The recent Nuiqsut subsistence bowhead whale (aġviq) hunting area is depicted in Figure 2.15-5. The general Nuiqsut harvest area for bowhead whales is located off the coast between the Kuparuk and Canning rivers.

Whalers currently travel to Cross Island to conduct fall bowhead whaling. They have also used Pingok and Narwhal islands as bases and may still have structures on Narwhal Island. Cross Island has cabins for the crews to stay in and equipment for hauling up and butchering the whales. Nuiqsut hunters typically travel out either the Nigliq or the main Colville channel of the Colville River delta (depending on water levels) and travel along the coast inside or just outside the barrier islands. Depending on conditions, whalers usually stop at West Dock for coffee before heading due north for Cross Island. In the past, work groups may start fishing and hunting other species to support the whalers after setting up camp (USDOI, BLM, 2004a), but in the last several years most of the whalers' energy has been directed towards whaling (Galginaitis and Funk, 2003a, 2003b, 2004, Galginaitis, 2005a, 2005b). A successful whale harvest may contribute up to a third of Nuiqsut's entire subsistence harvest by weight for all resources. The meat and muktuk are shared with other rural Alaskan communities and cities, contributing a valued identity food to Iñupiat who reside away from the North Slope.

A summary of whale harvest by Nuiqsut crews is presented in Table 2.15-5. Nuiqsut whalers attribute at least part of their relative lack of success in the 1970s and 1980s to interference from oil and gas exploration, as well as poor weather and ice conditions in some years, and a difficult logistical situation. These factors are also evident in the 3 years with the greatest incidence of "struck and lost" whales (1989-1991 or 1992). Once Cross Island was established as a logistical center for Nuiqsut whaling and Nuiqsut whalers gained experience there, harvest success became more regular. Cross Island is a low, sandy barrier island with a raised area built from gravel for past oil and gas exploratory drilling. Cross Island is about 3 mi long and 450 ft wide, and is constantly changing due to erosion and redeposition.

Summary characteristics for the 2001-2004 whaling seasons are presented in Table 2.15-6 (Galginaitis and Funk 2003a,b, 2004, 2005; Galginaitis 2005b). Additional information is provided in the Lease Sale 202 EA (USDOI, MMS, 2006b).

Figure 2.15-5 displays Global Positioning System (GPS) tracks for most scouting activity for Nuiqsut whalers for 2001, 2002, and 2003 by year. The density of the tracks indicates that boats typically (but not always) tend to stay close to each other. This reflects the cooperation that Nuiqsut whalers generally display. The similarities from one whaling season to the next in terms of number of crews and boats, length of season, days of scouting, and harvest are fairly high.

Caribou and Caribou Use Areas

Because oil development is associated with onshore pipelines, roads, and production facilities, it is important to consider terrestrial as well as marine subsistence resources. Nuiqsut hunters harvest several large land mammals, including caribou and moose. Caribou may be the most preferred land mammal in Nuiqsut's diet, and during periods of high availability, they provide a source of fresh meat throughout the year. Subsistence caribou harvest data are shown in Table 2.15-4 (ADF&G, 2001; Brower and Hepa, 1998). In 1985, Nuiqsut hunters harvested an estimated 513 caribou, providing approximately 60,000 edible pounds of meat or 38% of the total subsistence harvest (ADF&G, 2001). Fuller and George (1999) estimated that 278 caribou were harvested in 1992. A 1993 ADF&G subsistence study estimated a harvest of 672 caribou, providing approximately 82,000 edible pounds of meat or 31% of the total subsistence harvest (ADF&G, 2001). In 1993, 74% of Nuiqsut's households harvested caribou, 98% used caribou, 79% shared caribou with other households, and 79% received caribou shares (ADF&G, 2001).

A subsistence harvest survey covering the period from July 1994 to June 1995 reported that 258 caribou were harvested by Nuiqsut hunters, or 58% of the total subsistence harvest in edible pounds (Brower and Hepa, 1998) (Table 2.15-4). Brower and Hepa (1998) note that this was a relatively low number of caribou harvested compared to reported harvests for earlier years, and that no bowheads were taken that year. Subsistence harvest data are variable and it is difficult to pinpoint "assignable causes" given this variability. Explanations offered by local hunters for the decreased harvest were: (1) the need to travel longer distances to harvest caribou than in the past, (2) the increasing numbers of musk ox that hunters believe keep caribou away from traditional hunting areas, (3) restricted access to traditional subsistence hunting areas due to oil exploration and development in these areas, and (4) disruption of caribou migration into traditional Nuiqsut harvest areas (Brower and Opie, 1997; Brower and Hepa, 1998).

Geographic and seasonal variation in caribou harvests are depicted in the recent Alpine Satellite Development Plan (ASDP) EIS (USDOI, BLM, 2004a), which illustrates the intensity of harvest effort for caribou for numerous locations used by Iñupiat subsistence hunters. Harvest areas are often associated with TLUI sites, cabins, camps, and Native allotments that often have harvest locations for other species nearby. These harvest locations may be used in winter (October through May), summer (defined as the open water period, including June through September), or both, and they may be accessed by foot, boat, all-terrain vehicle and snowmachine.

Fish and Fish Use Areas

Nuiqsut has the largest documented subsistence fish harvest on the Beaufort Sea coast (Moulton, 1997; Moulton, Field and Brotherton, 1986). Fish provide the most edible pounds per capita of any subsistence resource harvested by Nuiqsut (Table 2.15-3). Fish, a traditional staple of both coastal and terrestrial Iñupiat, may vary in numbers seasonally and from year to year, but normally provide a substantive contribution to subsistence resource harvests. Subsistence harvests of fish are not subject to seasonal limitations under federal fisheries management, and no permit is required for rural harvesters.

Nuiqsut resource users have a long history of subsistence fishing in the Colville River and its tributaries from the Colville River delta to the confluence with the Ninuluk Creek, the Nigliq Channel, and nearby Fish and Judy creeks and the innumerable lakes in the region. Nuiqsut fishermen also use coastal areas east to the Kuparuk River and fish around several barrier islands, including Thetis and Cross islands. Families set nets near Nuiqsut in the Nigliq Channel when time, transportation needs, or funds do not permit longer trips from town, particularly during the school and work year.

Figures 2.15-6 and 2.15-7, derived from Moulton (2002), show the highly variable nature of the subsistence fish harvest in the Colville River delta and Nigliq areas. Fishing effort ranged by area from 19 to 1,407 net-days, although there is no clear correspondence between the harvest and harvest effort, because low efforts brought more fish as in 1993, while high efforts as in 2002 resulted in few fish harvested even considering the reduced number of sites sampled. As shown in the Moulton data, the arctic cisco harvest at the five monitored set-net harvest sites in that study range from a 1993 peak of nearly 47,000 to a 1988 low of approximately 6,100, nearly one-eighth the number of the peak. This variability demonstrates the importance of having alternative species and harvest strategies available should poor fish harvests coincide with reduced terrestrial or marine mammal harvests.

Seals and Seal Use Areas

Seals are hunted nearly year-round (Table 2.15-2), but the majority of the seal harvest occurs during the open-water season. In the spring, seals may be hunted once the landfast ice goes out. Present day sealing is most commonly done at the mouth of the Colville River when it begins flooding after ice breakup in June. Seal meat is eaten, but the dietary importance of seals comes primarily from seal oil, which is served with almost every meal that includes subsistence foods. Seal oil is also used as a preservative for meats, greens, and berries. Seal meat and oil are traded to residents of Anaktuvuk Pass for dried caribou and other products. Seal skins are important in the manufacture of clothing and, because of their beauty, spotted seal skins often are preferred for making boots, slippers, mitts, and parka trim. In practice, however, ringed seal skins are used more often in the making of clothing because the harvest of this species is more abundant. Seal skins are used for handicrafts and other articles, are bartered, or are sold (USDOI, BLM, 2004a).

Ringed (natchiq), spotted (qasigiaq), and bearded (ugruk) seals are important subsistence resources for Nuiqsut hunters. In April and May, hunters ride out to Harrison Bay on snow machines and look for breathing holes, cracks in the ice and open water where seals might surface to breathe. By the second week in June, open waters on the Colville River and much of Harrison Bay allow hunters to take boats out on a route locally called “around the world,” following the Nigliq Channel to Harrison Bay, west to Atigaru Point, then along the ice edge out as far as 28 miles, then to Thetis Island (Amauliqtuq), east to Oliktok Point, then back south through the main channel of the Colville River.

Polar Bears

The harvest of polar bears (nanuq) by Nuiqsut hunters begins in mid-September and extends into late winter. Polar bear meat is sometimes eaten, although only limited harvest data are available. The NE NPR-A Final Amended IAP/EIS (USDOI, BLM, 2004b) notes: "Nuiqsut residents have indicated that polar bears are not an important subsistence resource for the community and if taken would be an incidental harvest."

Beluga Whales

Nuiqsut residents indicate that beluga whales are not important to the subsistence cycle of the community, although some sources have mentioned beluga whales being taken incidentally during the bowhead harvest (USDOI, BLM, 1998).

Walrus: ADF&G subsistence survey data indicate that two walrus were harvested in the 1985/1986 harvest season, but no new walrus data for the community have been gathered since then (ADF&G, 2001). Walrus are probably taken incidentally during seal hunting (NSB, 1998). During the 2004 whaling season, walrus were seen (and heard) on Cross Island for the first time in anyone's memory.

Moose and Moose Use Areas

Moose (tuttuvak) are normally harvested by boat in August upriver from Nuiqsut on the Colville, Chandler and Itkillik rivers, but the timing of harvest varies depending on hunting seasonal regulations. Local residents have indicated that the weather is not suited for moose hunting in September due to winds and fall whaling occupies much of the community during the month of September.

Harvest data for moose are indicated in Table 2.15-4. In 1985, hunters reported a harvest of 13 moose (ADF&G, 2001). In 1993, nine moose were reported harvested by surveyed subsistence households (ADF&G, 2001, Brower and Hepa, 1998). A subsistence-harvest survey conducted by the NSB DWM for the period from July 1994 to June 1995 reported five moose harvested or 5% of the total edible pounds harvested that season (Brower and Hepa, 1998).

Moose are hunted from the Colville River Delta area upstream to Ninuluk Creek, up the drainages of the Itkillik River and Fish and Judy creeks, and up some side streams off the Colville River. One hunter mentioned going almost to the Killik River confluence looking for moose, while several others reported Fish and Judy creeks, the Chandler and Anaktuvuk river confluences, several side streams and channels of the Colville River and the Itkillik River area as prime moose hunting areas (USDOI, BLM, 2004a). Although relatively small numbers of moose are harvested, they are a valued component of the subsistence harvest in Nuiqsut, and hunters spend considerable effort in their pursuit. Moose offer a large amount of meat per animal harvested because of their relatively large size compared to other terrestrial mammal subsistence resources. Moose, when harvested, are very commonly shared with the rest of the community at large.

Waterfowl and Waterfowl Use Areas

The most important species of waterfowl for Nuiqsut hunters are the Canada and white-fronted goose and brant; eiders are also harvested.

The only upland bird hunted extensively is the ptarmigan (ADF&G, 2001; Brower and Hepa, 1998). Recent data indicate the subsistence bird harvest provided 5% of the total subsistence harvest (Brower and Hepa, 1998) (Table 2.15-3). Waterfowl hunting occurs mostly in the spring, beginning in May, and continues throughout the summer. In the summer and early fall, such hunting usually occurs as an adjunct to other subsistence activities, such as checking fish nets.

Waterfowl harvested by the Iñupiat of Nuiqsut occupy two habitats in the greater Nuiqsut area. Ducks, geese, and brant molt and nest in the wet tundra to the north of Nuiqsut. Eiders nest on the sandy areas of the Colville River Delta and the barrier islands, molting after their arrival. Both groups of waterfowl raise their young in the area until fall, when they migrate south. Nuiqsut hunters harvest waterfowl in May and June during the migration using snow machines and boats. The hunters harvest the migrating birds from snow blinds built to the south, near Sentinel Hill and Ocean Point or at Fish Creek. Once the river breaks up, hunters look for birds by boat, and start to look for eiders in the delta and in Harrison Bay at the ice edge as summer approaches. Hunters end the waterfowl harvest when the birds are on their nests (USDOI, BLM, 2004a).

The NSB collected waterfowl harvest data for 1994-1995, 2000 and 2001 (Brower and Hepa 1998; USDOI, BLM, 2004a). Goose hunting areas include the Fish and Judy creeks area, the Colville River Delta, the area around Nuiqsut extending to the Fish and Judy creeks area, along the Colville River up to Sentinel Hill, the area around Ocean Point, and along the Itkillik River. As shown in the ASDP EIS (USDOI, BLM, 2004a), more than three-quarters of geese, including white fronted and Canada, were harvested in the Fish and Judy creeks area and the Colville River Delta. Most of the remaining geese were harvested up the Colville River from Ocean Point to Umiraq. Interviewed subsistence users in Nuiqsut related that the harvest sequence for migratory waterfowl proceeds from the south, and that those harvested upriver are the first birds of the season (USDOI, BLM, 2004a).

Furbearers

As discussed in the ASDP EIS, Nuiqsut fur hunters described three species of terrestrial furbearers as being especially important: wolf (amġuq), wolverine (qavvik), and fox (USDOI, BLM, 2004a). Once there is adequate snow in the winter for snowmachine travel, generally by November, hunters begin the pursuit of wolf and wolverine in earnest. The harvest area for furbearers extends from the eastern edge of the Colville River Delta along the coast almost to Admiralty Bay and then south along the Ikpikpuk River to the Colville River and eastward to the Toolik River, north and crossing the Dalton Highway to Franklin Bluffs, and west and north back to the Colville River Delta.

Berries and Plants

Berries (akpik) of numerous varieties are harvested in the Fish and Judy creeks area, and along the Colville, Chandler, Anaktuvuk, and Itkillik rivers. Plants such as masu (Eskimo potato), medicinal plants, and greens are harvested when families are out at camp hunting and fishing in the late summer. Berry picking is still considered a job primarily for women and children, but men pick berries on occasion. Berry varieties include salmonberries (aqpik) and blueberries (asiaq). Berries are primarily harvested in August, when many families are out moose hunting up the creeks and rivers of the area, and often they will pick buckets or large freezer bags full of berries. These are taken home and stored in ice cellars or freezers for later use in agutuq, or Eskimo ice cream, made from whipped seal or other fat, sugar, plants, and berries.

2.15.4 Land Ownership

The majority of land and waters in the project area are owned by either the State (mainland, islands, and within the 3-mi offshore zone) or Federal Government (OCS outside the 3-mi zone). There is private land including three Native allotments and Cross Island, which is owned by the NSB (Figure 2.15-8).

2.15.5 Environmental Justice

Environmental Justice Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (59 *FR* 7629), requires each Federal Agency to make the consideration of environmental justice part of its mission. Section 1-101 states:

> To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions…

Other portions of this order require agencies to develop strategies to address environmental justice (1-103), research, data collection, and analysis (Section 3-3), and, of particular relevance to this analysis, requirements to collect, maintain, and analyze information on the consumption patterns of populations who principally rely on fish and/or wildlife for subsistence (4-401). EIS's drafted after the effective date of this order contain sections on environmental justice.

In particular, Alaska Iñupiat Natives, a recognized minority, are the predominant residents of the North Slope Borough. Therefore, it is important to address whether or not the environmental impacts of the proposed Liberty (SDI) Project will have disproportionately high and adverse impacts on NSB residents.

Executive Order 13175, "Consultation and Coordination with Indian Tribal Governments," requires Federal agencies to consult with tribal governments on Federal matters that significantly or uniquely affect their communities. In January 2001, a USDOI Alaska Regional Government-to-Government policy was signed by all the USDOI Alaska Regional Directors, including the MMS.

The MMS public process for Environmental Justice outreach and for gathering and addressing Environmental Justice concerns and issues is described in detail in the Beaufort Sea multiple-sale FEIS (USDOI, MMS, 2003). Since 1999, all MMS public meetings have been conducted under the auspices of Environmental Justice. Environmental Justice-related concerns are taken back to MMS management and incorporated into environmental studies planning and design, environmental impact evaluation, and the development of mitigating measures.

Outreach meetings for the Liberty (SDI) Project were conducted by BPXA on February 28, 2006, in Barrow with the NSB Planning and Wildlife Management Departments; on June 7, 2006, in Barrow with ICAS; on June 8, 2006, in Barrow with NSB Mayor Edward Itta; and on March 8, 2007, in Barrow with NSB personnel. The MMS attended both the February 28, 2006, and the June 7, 2006, meetings in Barrow. On April 18, 2006, MMS conducted government-to-government consultation with the Native Village of Kaktovik. Attendees at all meetings were generally positive about the onshore approach to the project and in Barrow, concerns were raised about Native allotments and oil spills in the project's vicinity. Issues raised at these meetings include:

- the oil industry's continuing inability to clean up an oil spill in broken ice;
- the need to stage cleanup equipment in local communities to make spill response more timely and to give more local people response training;
- bowhead whale migration may be deflected from noise caused by small vessels;
- the need to expand conflict avoidance agreements to other resources not considered by the Alaska Eskimo Whaling Commission (AEWC), such as fish, bearded seals, walrus, and beluga whales;
- that multiple industrial operations may have a cumulative adverse impact on bowhead whale migration;
- include a cumulative effects analysis that addresses the recommendations of the 2003 NRC Report Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope;
- the effects of toxins and contaminants in the Arctic environment on subsistence foods;

On May 11, 2007 (pursuant to Executive Order 13175) MMS invited Federally Recognized Tribes to hold formal Government-to-Government consultations regarding the current Liberty (SDI) Project. Refer to Appendix G for Government-to-Government consultations.