Environment Canada Environnement Canada

Atlas de sensibilité du littoral de la région

BEAUFORT

Regional Coastal Sensitivity Atlas

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ABSTRACT

Environment Canada and other Federal agencies have important roles in terms of environmental emergency prevention, preparedness, and response. In the face of increasing economic opportunities in Canada's northern regions, the need to improve our state of preparedness for oil spill related emergencies, in particular, is critical. This version of the Beaufort Regional Coastal Sensitivity Atlas is an update of the information provided in the Arctic Environmental Sensitivity Atlas System (AESAS) (2004) and presents an overview of resources that are vulnerable to oil spills. It includes baseline coastal information such as shoreline form, substrate, and vegetation type, which is required for operational prioritization and coordination of on-site spill response activities (i.e., SCAT: Shoreline Cleanup and Assessment Technique), as well as sensitive biological resources and sensitive human use resources. The study area includes the coastal area that extends along the mainland from the Yukon/Alaska border at 141°W east through the Mackenzie Delta to the Northwest Territories/Nunavut border at 120°W. The area also includes the entire coast of Banks Island to the north of the mainland and the East and Middle Channels of the Mackenzie River Delta north of Inuvik.

RESUMÉ

Environnement Canada et d'autres organismes fédéraux ont un rôle important à jouer en termes de prévention, de préparation, et de réponse lors d'urgences environnementales. Face à l'augmentation des possibilités économiques dans les régions nordiques du Canada, la nécessité d'améliorer notre état de préparation aux situations d'urgence liées à des déversements d'hydrocarbures en particulier, est critique. Cette version de l'Atlas de la sensibilité de la région Beaufort est une mise à jour des informations fournies dans l'Atlas de sensibilité environnementale de l'Arctique (AESAS, 2004) et donne un aperçu des ressources qui sont vulnérables aux déversements d'hydrocarbures. L'Atlas comprend des informations côtières de base tels que: le type de rivage, le substrat, et le type de végétation qui est nécessaire pour établir les priorités opérationnelles et la coordination des activités d'intervention lors de déversements (c'est-à-dire TERR, Technique d'Évaluation et de Restauration du Rivage), ainsi que les ressources biologiques sensibles et les ressources socio-économique sensibles. La zone d'étude comprend la zone côtière qui s'étend le long de la partie continentale de la frontière Yukon / Alaska à 141 ° O, à travers le delta du Mackenzie jusqu'à la frontière des Territoires du Nord-Ouest/Nunavut à 120 ° O. La zone comprend également toute la côte de l'île Banks au nord des terres, et les canaux 'East' et 'Middle' du fleuve Mackenzie Delta au nord d'Inuvik.

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Table of Contents

PROJECT BACKGROUND

The primary objective of this Atlas is to provide a synthesis of environmental information relevant to the planning and implementation of oil-spill countermeasures in coastal areas of the Beaufort Sea. This Atlas is intended to be used as a link between the environmental characteristics of the region and the practical considerations of providing an effective response to marine oil spills. The Atlas is not meant to be a comprehensive oil-spill manual.

In 2009 Environment Canada's Landscape Science Division and Environmental Emergencies Division initiated a project focused on providing a priori baseline coastal information for the Canadian Arctic in order to support a range of coastal planning activities, including oil-spill response and clean-up efforts. This project known as 'eSPACE' (emergency Spatial Pre-SCAT for Arctic Coastal Ecosystems; SCAT: Shoreline Cleanup and Assessment Technique) carried out detailed shoreline mapping for the Beaufort region along with various other arctic study areas, and as well, developed shoreline characteristic mapping methods based on satellite imagery including Radarsat-2 data. The shoreline type database included in this Atlas was collected and generated through the eSPACE project.

Coastal sensitivity mapping is an important step in oil-spill preparedness, response, and cleanup efforts, and maps are an essential tool to assist responders during an incident, as they allow priority protection and clean-up sites to be identified and allow responders to plan the best-suited response strategy. In general, sensitive shorelines and ecosystems, protected areas, high biodiversity areas, critical habitats, endangered species, and key natural resources are considered especially sensitive to oil spills because they are of environmental, economic, or cultural importance, at risk of coming in contact with spilled oil, and likely to be affected once oiled (Michel, Christopherson and Whiple, 1994).

Oil spills in the Canadian Arctic present many potential problems for local communities, oil-spill responders, regulatory authorities, and hydrocarbon industrial operators. The Canadian Arctic shoreline spans more than 162,000 km (DFO, 2013a) and makes up almost three quarters (71%) of the total Canadian coastline. The Beaufort coastline alone comprises more than 7,500 km, which is an enormous area to manage and protect. With expanding industrial activity in the area, including oil exploration and development, mineral development, and marine transportation, the potential for spilled oil and other pollutants is increasing significantly. Higher maritime risk is associated with exploration projects in this region in terms of the potential risk of collisions and getting stuck in the ice, even more so with increased traffic from adventurer vessels, research vessels and ships traversing the Northwest Passage (NOAA, 2013). It is also expected that maritime supply traffic, which will navigate through the Mackenzie River Delta and Beaufort Sea, will increase over the next few years. In addition, the harsh climate, lack of services and infrastructure, and high costs make spill response operations a challenge.

This Atlas is intended to be used for planning and implementing oil-spill countermeasures during ice-free conditions in coastal areas of the Beaufort Sea. The area is typically covered in sea ice during eight or nine months of the year and open water season occurs from June through early October (Phillips et al, 2007). There is no opportunity for fresh oil to reach the shoreline from a marine spill while the ocean is frozen, therefore the information in this Atlas is valid during the open water season only.

The Beaufort Coastal Sensitivity Atlas was developed to meet the needs of industry, government and local community groups for a document related to offshore oil field development in the Beaufort Sea (AESAS, 2004). This current version of the Atlas is an update of the information provided in the Arctic Environmental Sensitivity Atlas System (AESAS) which was last released in 2004.

This Atlas presents comprehensive baseline spatial coastal information which is required for informed decision making and integrated coastal and ocean management. The information is presented in a concise, graphic form with important supporting text, in order to satisfy a wide variety of perceived user groups, including government scientists, Canadian Coast Guard and industry response teams, policy directors, regulatory agencies, Beaufort Sea community organizations, and land use planners. The environmental and socio-economic information of the Beaufort's coastal zone can be used for many applications including informing emergency preparedness, habitat management, environmental assessments, and ecosystem conservation. Information contained in the Atlas should be supplemented by local knowledge and real time information in the event of a spill.

The Atlas has been updated with the newest and best available information. In cases where no new data was available, data from the 2004 Atlas and other sources has been used. Note: This Atlas is by no means intended to be an exhaustive biological resource atlas for the region.

Oil-spill cleanup methods are introduced in this Atlas. These are intended for use in the decision process as an aid to the selection of appropriate, practical and feasible oil-spill response strategies and techniques. Each oil spill is unique and should be assessed as such. The oil-spill cleanup section is not a technical manual. Technical experts should be consulted to advise on the application of strategies and techniques for local environmental conditions and for the specific type of oil that is spilled.

FORMATS AND DATA PRESENTATION

This Atlas has been produced in three different formats to maximize accessibility to users in varying situations.

- A large-format hard-copy printed atlas displaying a series of coastal sensitivity maps and general geographic information for the Beaufort region. This product is also available as a digital PDF document.
- An online web-mapping application, which gives users full access to shoreline videography and geo-tagged photos through the internet along with biological data and local traditional knowledge for the region.
- An offline and mobile geospatial digital atlas which is available on a USB stick and allows users to explore the data and create customized maps.

The printed Atlas is a large-format product that provides users with large maps. The digital Atlas contains the same information and has the added capacity to turn information on and off as required.

The printed Atlas is organized in the following manner. The Introduction has been organized to present an overview of the Beaufort region. A series of maps describe the geography, physiography, bathymetry, coastal processes, physical oceanography, and human use in the region. Following this, information on the development of the shoreline classification and the Shoreline Cleanup and Assessment Technique (SCAT) is presented. This section of the Atlas includes information on the coastal zones which are of interest in shoreline cleanup, the collection of video and ground data, and the classification of the shoreline type. The processes used for collecting data and the development of an Environmental Sensitivity Index (ESI) are described, including how the shoreline type classification was converted into the ESI.

Information on available response options used during cleanup and a brief overview of appropriate cleanup techniques for each physical shoreline type are presented along with a description of how oil behaves when it contacts different substrates.

A detailed series of shoreline sensitivity maps which include sensitivity rankings, shoreline species, and resource use (human use) makes up the bulk of the Coastal Atlas. This series of maps presents the Beaufort coast at a mapping scale of 1:100,000; the Mackenzie Delta is displayed at a larger scale (1:50,000) to properly show the detail in this region.

OVERVIEW OF THE REGION

The 2012 Beaufort Regional Coastal Sensitivity Atlas covers the region in the northwestern corner of Canada and is approximately 1,738,700 km^2. It includes both a portion of the Inuvialuit Settlement Region (ISR) and the Beaufort Large Ocean Management Area (LOMA). The coastal area that is covered by the Atlas extends along the mainland from the Yukon/Alaska border at 141°W east through the Mackenzie Delta to the Northwest Territories/Nunavut border at 120°W. The area also includes the entire coast of Banks Island to the north of the mainland and the East and Middle Channels of the Mackenzie River Delta north of Inuvik. The major communities within the study area are Tuktoyaktuk, Aklavik, Inuvik, Paulatuk, and Sachs Harbour.

The Beaufort Sea is the shallow part of the Arctic Ocean which extends from the Canadian Arctic archipelago westward to Alaska, north of the Mackenzie Delta. The area is characterized by permanently and seasonally ice-covered regions. The latter are typically covered in sea ice for eight or nine months of the year and open water season occurs from June through early October (Phillips et al, 2007).

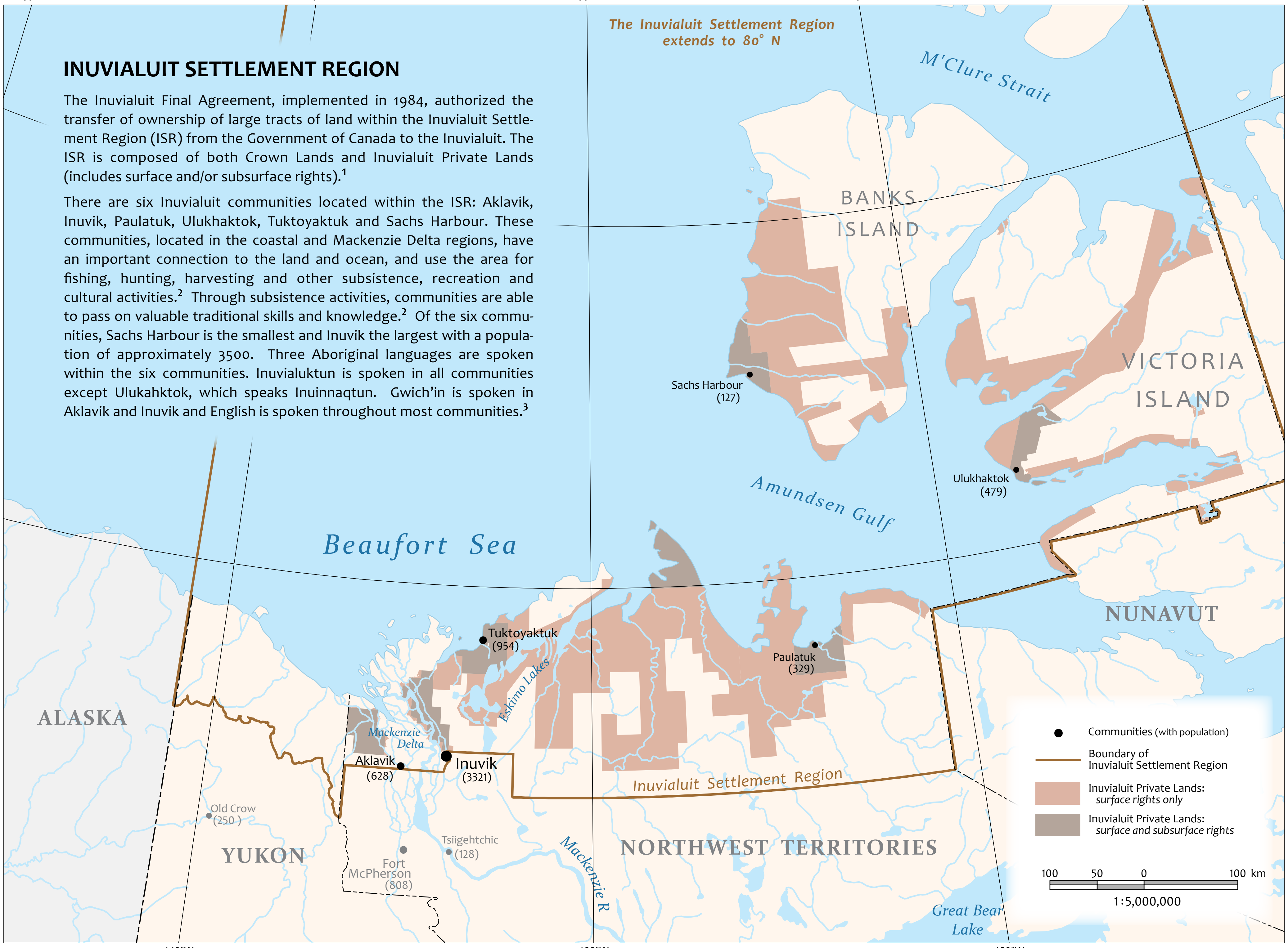
Beaufort and Banks Island coastal types consist mainly of mixed sediment beaches, pebble cobble beaches, sand beaches, tundra cliffs, and bedrock cliffs as well as a variety of sensitive shoreline types including mud tidal flats, low-lying inundated tundra, and peat shorelines. Cliffs along the Beaufort are low (< 60 m), while those around Banks Island reach up to 356 m (CHS, 1994). The Mackenzie Delta channels are relatively flat, with elevations ranging from 1 – 1.5 m. The Mackenzie Channels are primarily composed of mud tidal flats, marsh, swamp, mud/clay banks, vegetated banks, and peat shorelines, which are relatively more sensitive shoreline types (CHS, 1994). Spits, barrier beaches, and barrier islands partially enclosing lagoons account for more than 20% of the total Beaufort coastline (Ruz, Héquette, and Hill, 1991).

The climate of the Beaufort coastal region is dry and cold, conditions typical of an arctic climate (NSIDC, 2013). The sun is above the horizon 24 hours/day during May to mid-July and below the horizon 24 hours/day during December to early January, significantly influencing the amount of solar radiation received (DFO, 2005). The winter season extends from October through June,resulting in short summers. Air temperatures are very dependent on wind, wind direction, and ice cover (Smith, Meikle and Roots, 2004). The presence of clouds, which trap solar radiation close to the surface, can increase air temperatures by an additional 10°C (Overland, 2009). The mean annual temperature is -10 °C (Smith, Meikle and Roots, 2004). Monthly mean temperatures range between -27 °C in January to +14 °C in July (Bonsal and Kochtubajda, 2009). Extreme minimums can reach as low as -56 °C during the winter and extreme highs have reached +32 °C during the summer (Bonsal and Kochtubajda, 2009).

INUVIALUIT SETTLEMENT REGION

The Inuvialuit Final Agreement, implemented in 1984, authorized the transfer of ownership of large tracts of land within the Inuvialuit Settlement Region (ISR) from the Government of Canada to the Inuvialuit. The ISR is composed of both Crown Lands and Inuvialuit Private Lands (includes surface and/or subsurface rights).[1]

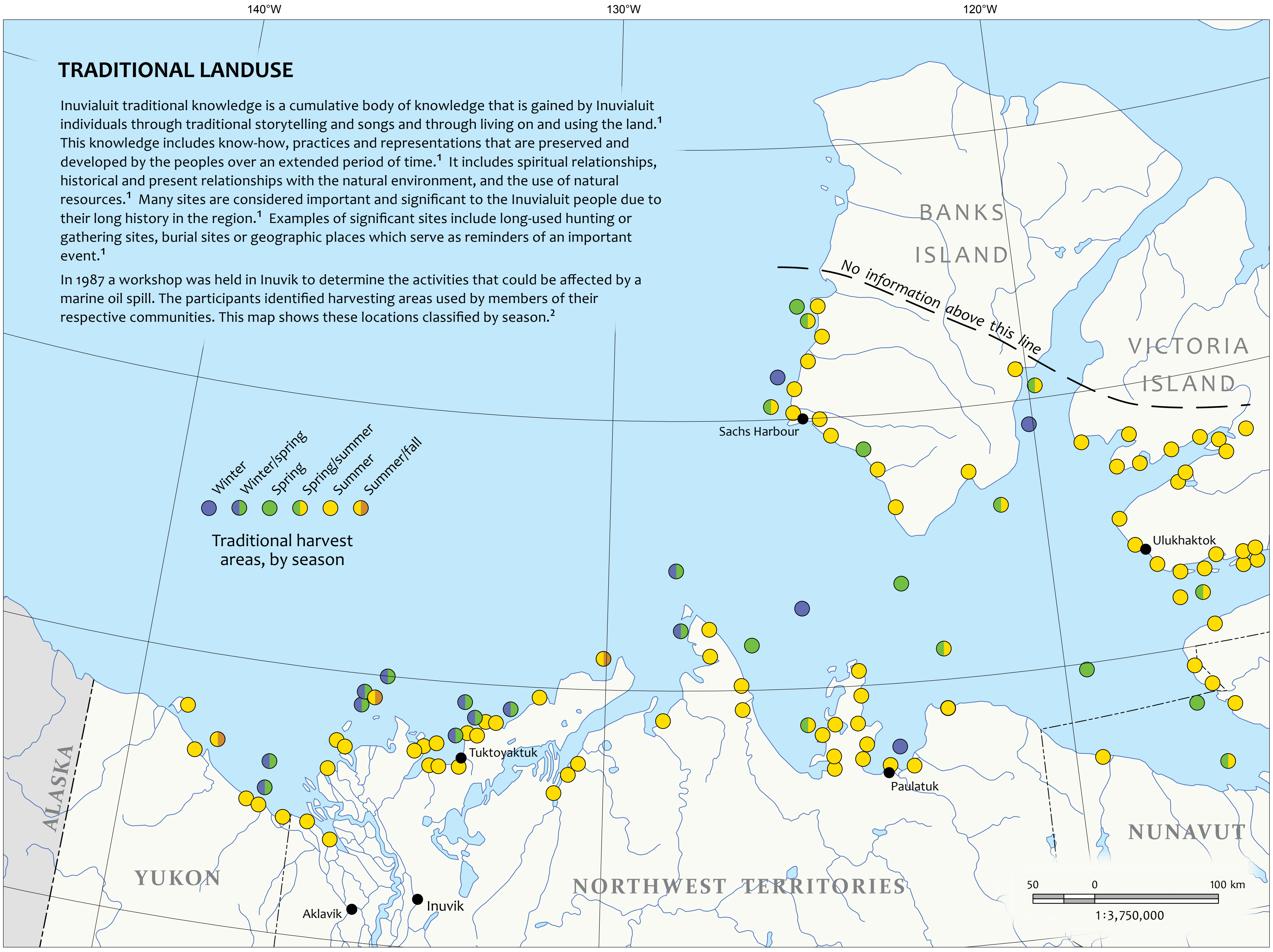
There are six Inuvialuit communities located within the ISR: Aklavik, Inuvik, Paulatuk, Ulukhaktok, Tuktoyaktuk and Sachs Harbour. These communities, located in the coastal and Mackenzie Delta regions, have an important connection to the land and ocean, and use the area for fishing, hunting, harvesting and other subsistence, recreation and cultural activities.[2] Through subsistence activities, communities are able to pass on valuable traditional skills and knowledge.[2] Of the six communities, Sachs Harbour is the smallest and Inuvik the largest with a population of approximately 3500. Three Aboriginal languages are spoken within the six communities. Inuvialuktun is spoken in all communities except Ulukahktok, which speaks Inuinnaqtun. Gwich'in is spoken in Aklavik and Inuvik and English is spoken throughout most communities.[3]



TRADITIONAL LANDUSE

Inuvialuit traditional knowledge is a cumulative body of knowledge that is gained by Inuvialuit individuals through traditional storytelling and songs and through living on and using the land.[1] This knowledge includes know-how, practices and representations that are preserved and developed by the peoples over an extended period of time.[1] It includes spiritual relationships, historical and present relationships with the natural environment, and the use of natural resources.[1] Many sites are considered important and significant to the Inuvialuit people due to their long history in the region.[1] Examples of significant sites include long-used hunting or gathering sites, burial sites or geographic places which serve as reminders of an important event.[1]

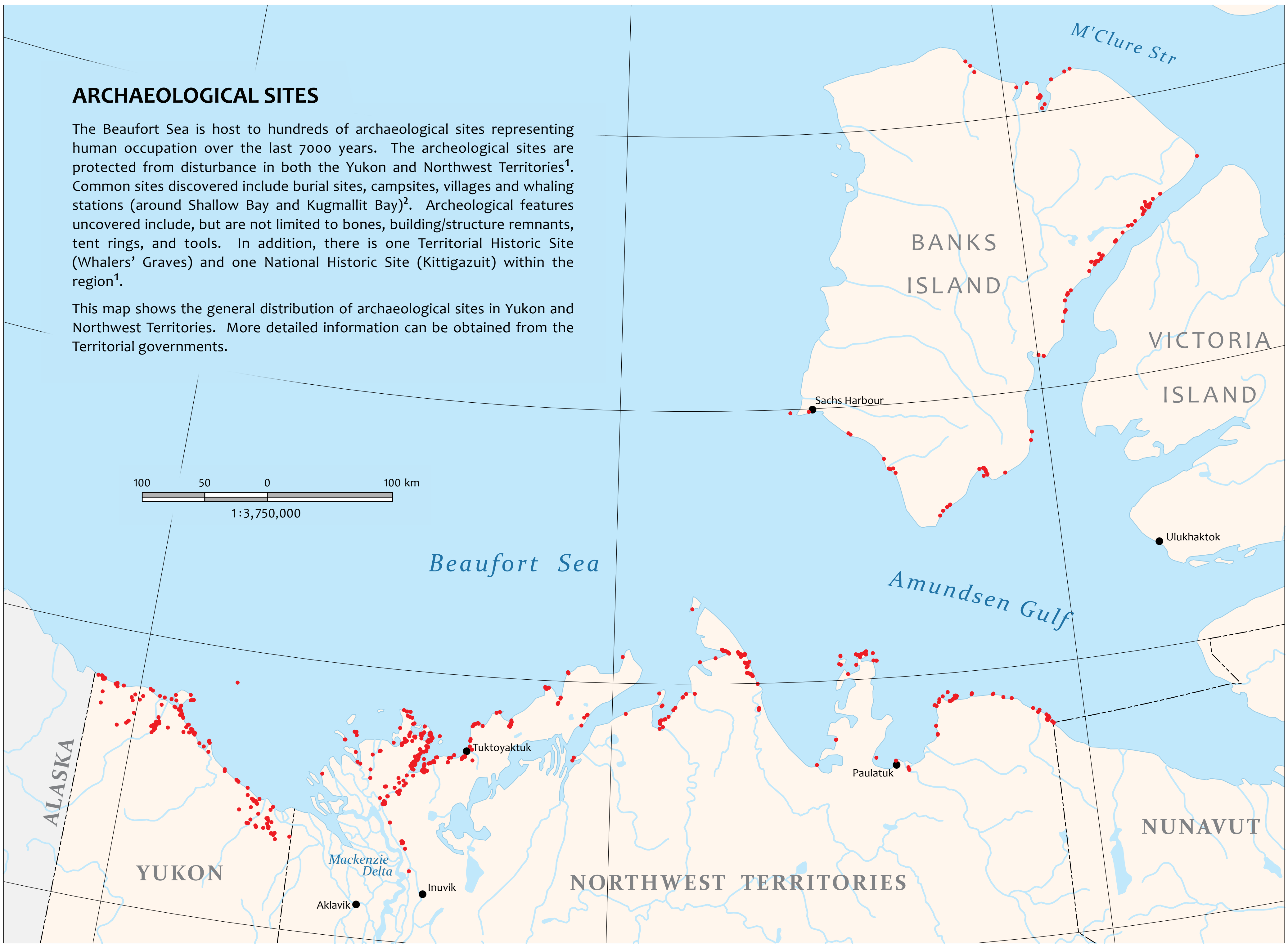
In 1987 a workshop was held in Inuvik to determine the activities that could be affected by a marine oil spill. The participants identified harvesting areas used by members of their respective communities. This map shows these locations classified by season.[2]



ARCHAEOLOGICAL SITES

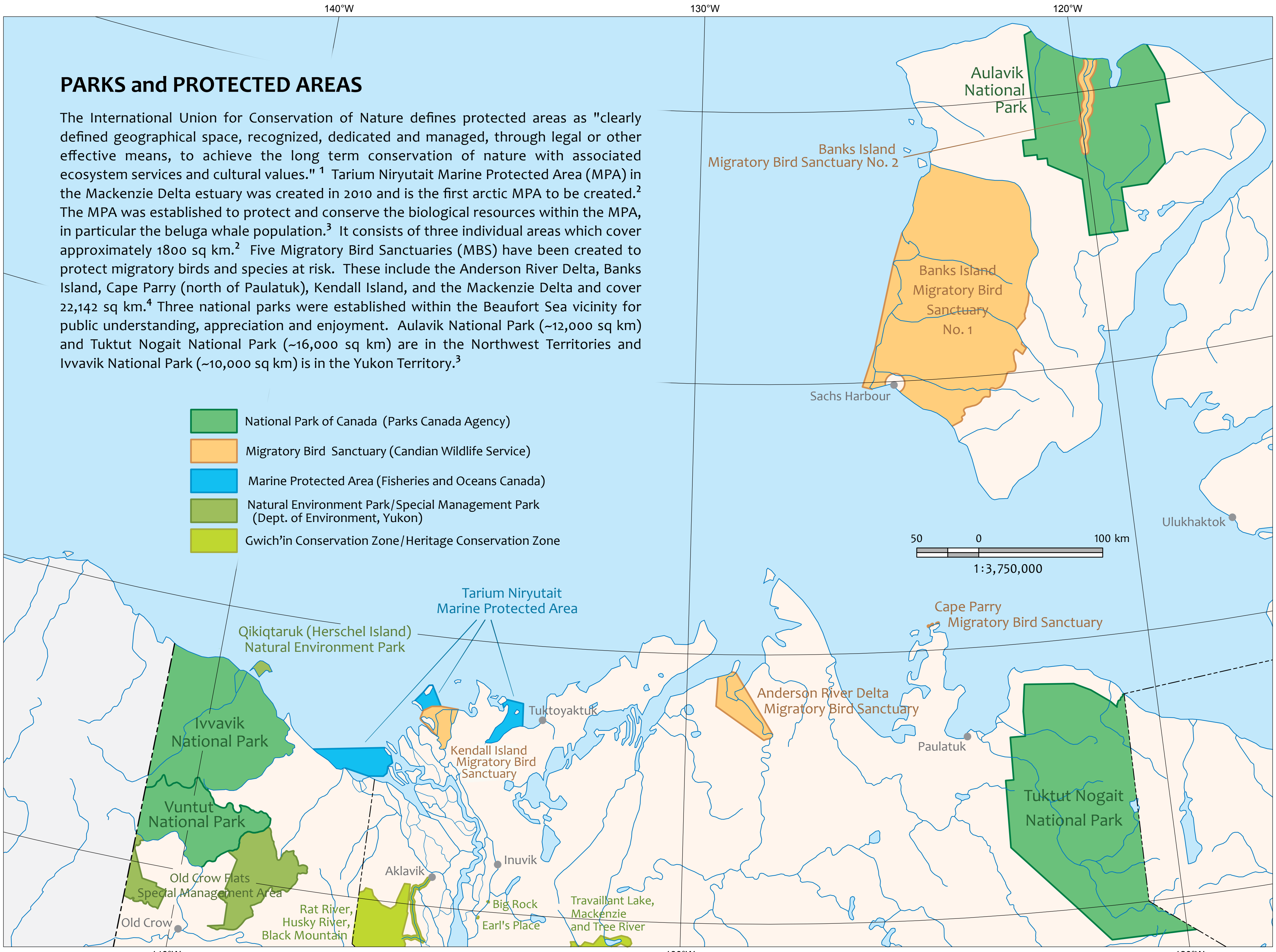
The Beaufort Sea is host to hundreds of archaeological sites representing human occupation over the last 7000 years. The archeological sites are protected from disturbance in both the Yukon and Northwest Territories[1]. Common sites discovered include burial sites, campsites, villages and whaling stations (around Shallow Bay and Kugmallit Bay)[2]. Archeological features uncovered include, but are not limited to bones, building/structure remnants, tent rings, and tools. In addition, there is one Territorial Historic Site (Whalers' Graves) and one National Historic Site (Kittigazuit) within the region[1].

This map shows the general distribution of archaeological sites in Yukon and Northwest Territories. More detailed information can be obtained from the Territorial governments.



PARKS and PROTECTED AREAS

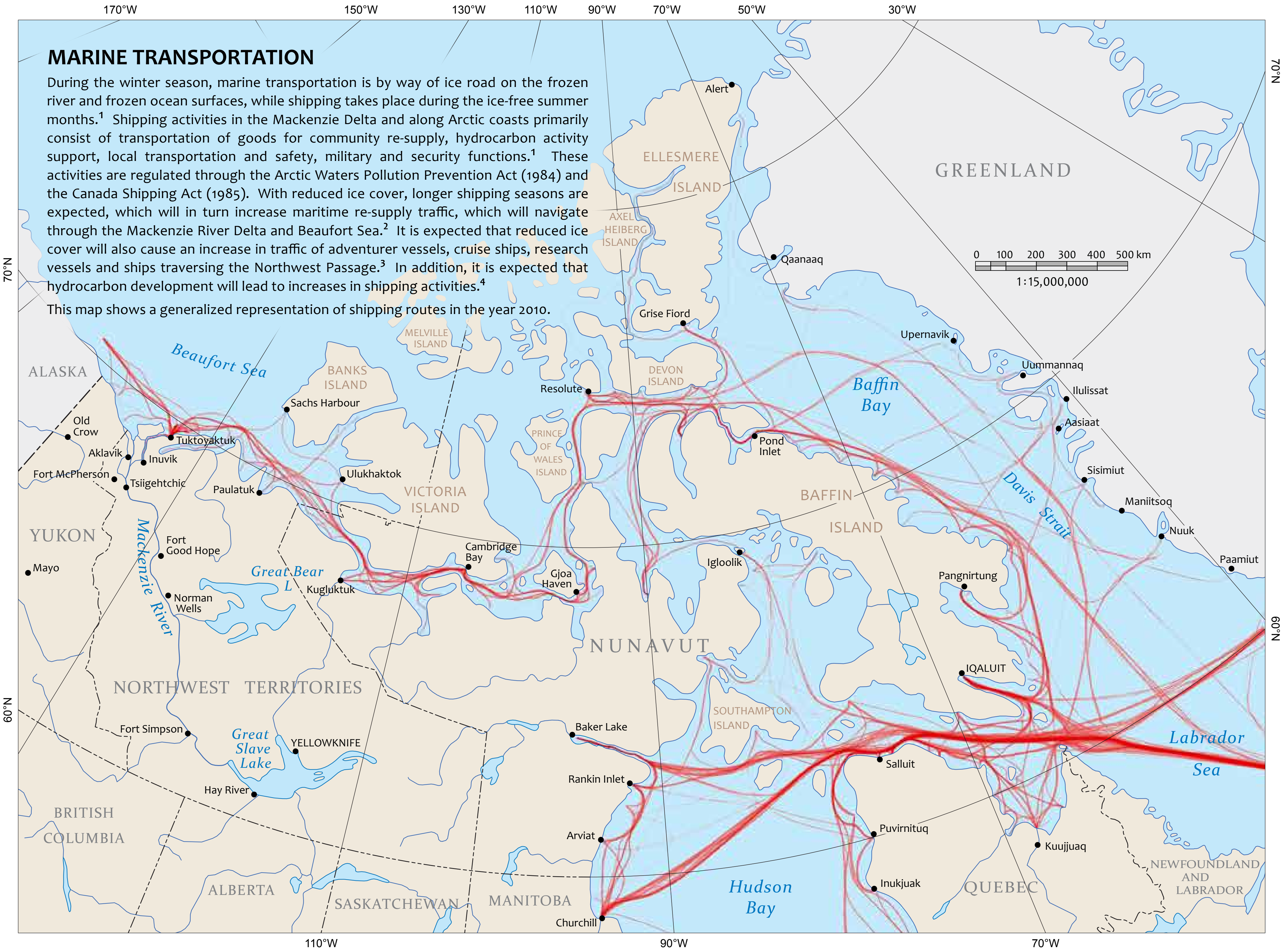
The International Union for Conservation of Nature defines protected areas as "clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values." [1] Tarium Niryutait Marine Protected Area (MPA) in the Mackenzie Delta estuary was created in 2010 and is the first arctic MPA to be created.[2] The MPA was established to protect and conserve the biological resources within the MPA, in particular the beluga whale population.[3] It consists of three individual areas which cover approximately 1800 sq km.[2] Five Migratory Bird Sanctuaries (MBS) have been created to protect migratory birds and species at risk. These include the Anderson River Delta, Banks Island, Cape Parry (north of Paulatuk), Kendall Island, and the Mackenzie Delta and cover 22,142 sq km.[4] Three national parks were established within the Beaufort Sea vicinity for public understanding, appreciation and enjoyment. Aulavik National Park (~12,000 sq km) and Tuktut Nogait National Park (~16,000 sq km) are in the Northwest Territories and Ivvavik National Park (~10,000 sq km) is in the Yukon Territory.[3]



MARINE TRANSPORTATION

During the winter season, marine transportation is by way of ice road on the frozen river and frozen ocean surfaces, while shipping takes place during the ice-free summer months.[1] Shipping activities in the Mackenzie Delta and along Arctic coasts primarily consist of transportation of goods for community re-supply, hydrocarbon activity support, local transportation and safety, military and security functions.[1] These activities are regulated through the Arctic Waters Pollution Prevention Act (1984) and the Canada Shipping Act (1985). With reduced ice cover, longer shipping seasons are expected, which will in turn increase maritime re-supply traffic, which will navigate through the Mackenzie River Delta and Beaufort Sea.[2] It is expected that reduced ice cover will also cause an increase in traffic of adventurer vessels, cruise ships, research vessels and ships traversing the Northwest Passage.[3] In addition, it is expected that hydrocarbon development will lead to increases in shipping activities.[4]

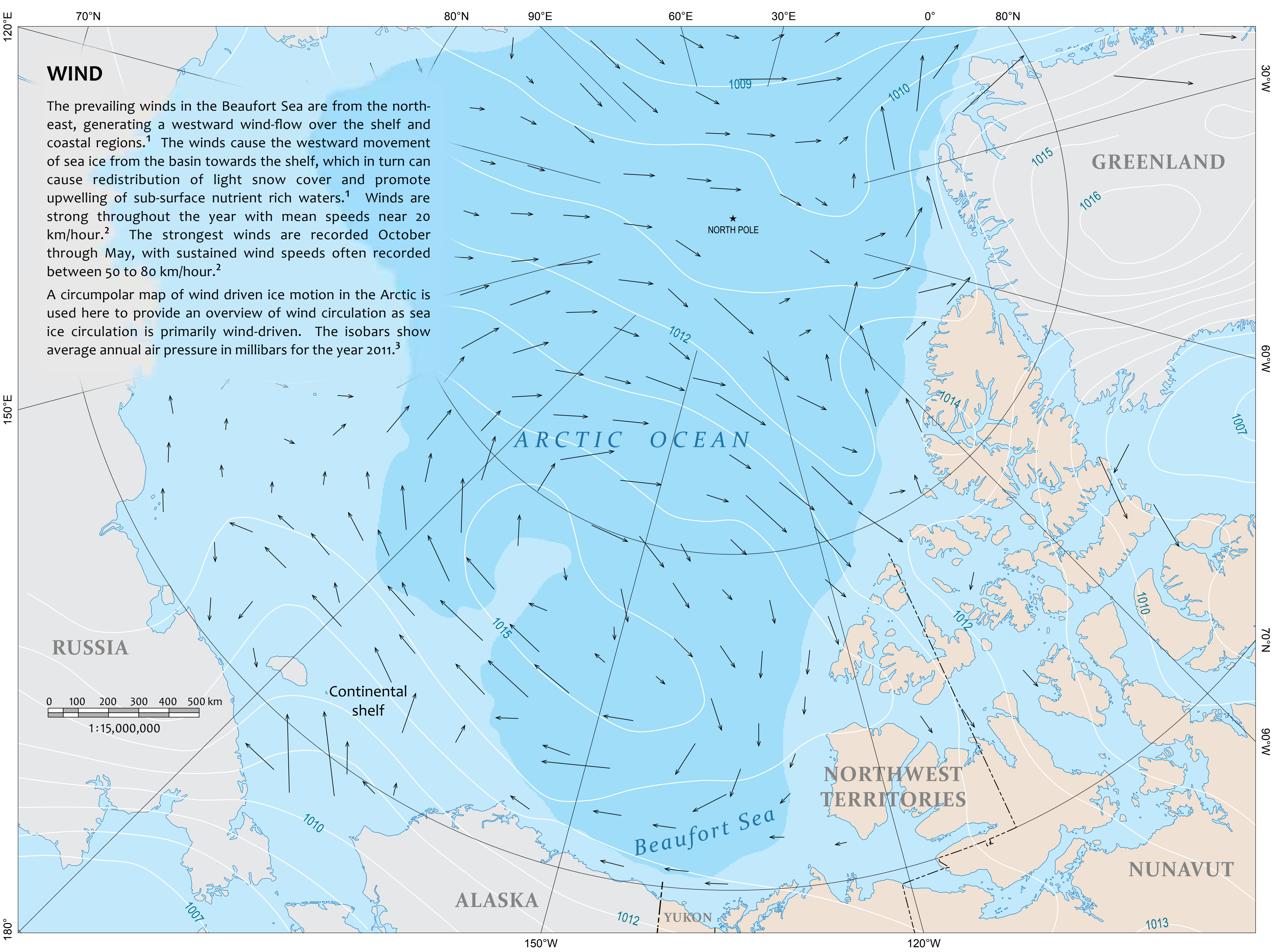
This map shows a generalized representation of shipping routes in the year 2010.



WIND

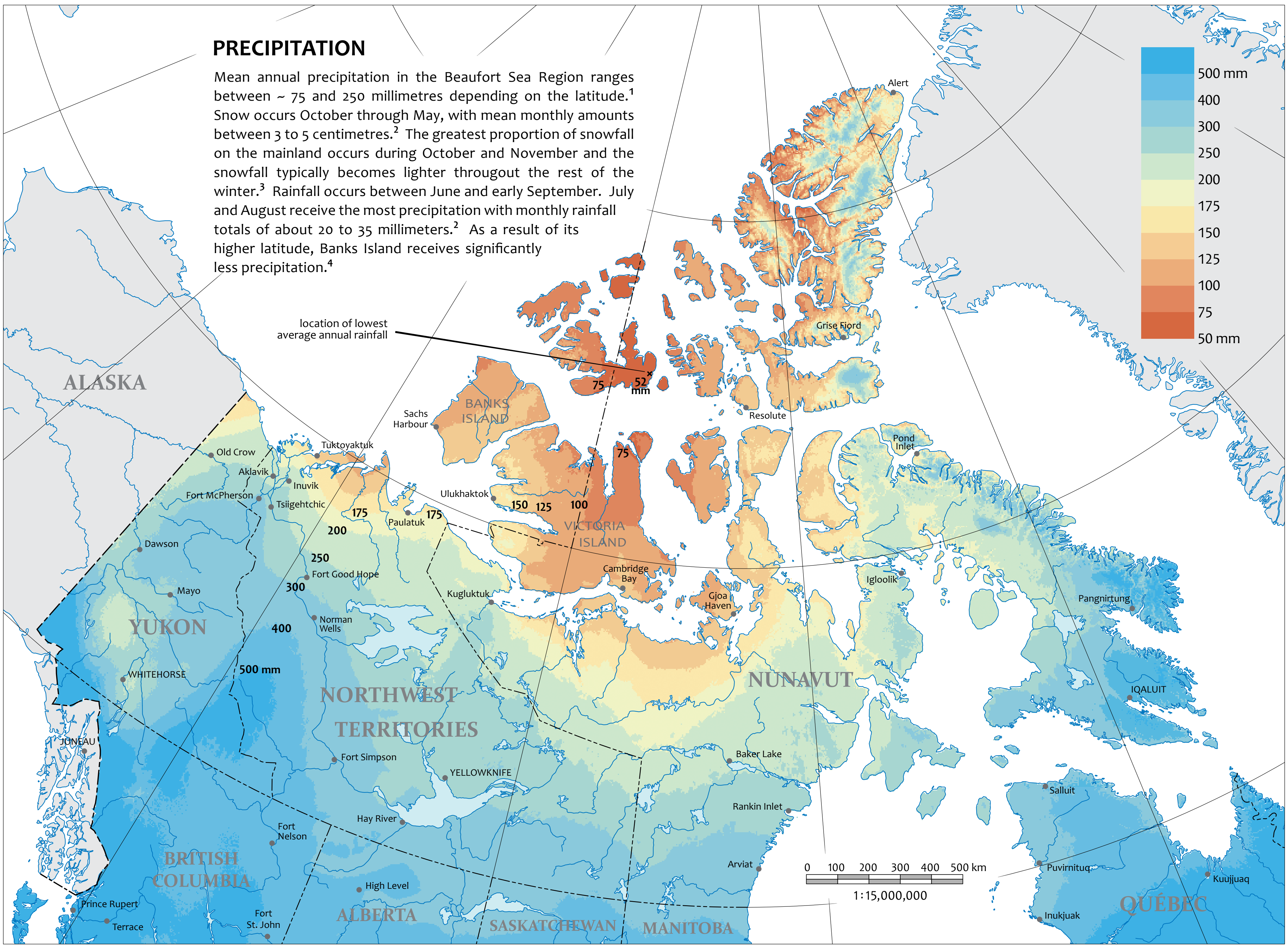
The prevailing winds in the Beaufort Sea are from the north-east, generating a westward wind-flow over the shelf and coastal regions.[1] The winds cause the westward movement of sea ice from the basin towards the shelf, which in turn can cause redistribution of light snow cover and promote upwelling of sub-surface nutrient rich waters.[1] Winds are strong throughout the year with mean speeds near 20 km/hour.[2] The strongest winds are recorded October through May, with sustained wind speeds often recorded between 50 to 80 km/hour.[2]

A circumpolar map of wind driven ice motion in the Arctic is used here to provide an overview of wind circulation as sea ice circulation is primarily wind-driven. The isobars show average annual air pressure in millibars for the year 2011.[3]



PRECIPITATION

Mean annual precipitation in the Beaufort Sea Region ranges between ~ 75 and 250 millimetres depending on the latitude.[1] Snow occurs October through May, with mean monthly amounts between 3 to 5 centimetres.[2] The greatest proportion of snowfall on the mainland occurs during October and November and the snowfall typically becomes lighter througout the rest of the winter.[3] Rainfall occurs between June and early September. July and August receive the most precipitation with monthly rainfall totals of about 20 to 35 millimeters.[2] As a result of its higher latitude, Banks Island receives significantly less precipitation.[4]



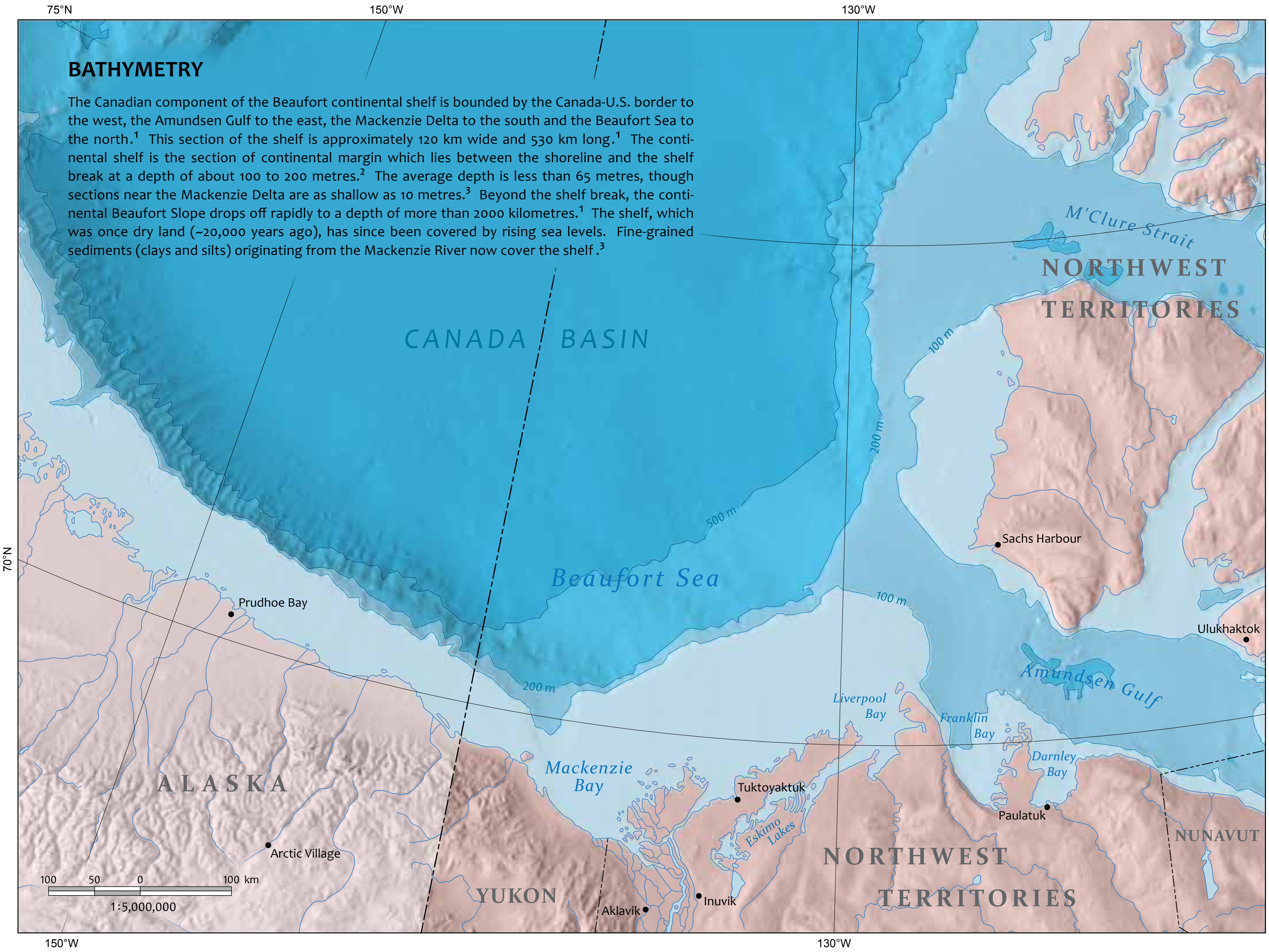
DRAINAGE

The Mackenzie River is the dominant river that drains into the Beaufort Sea. Approximately 300 cubic km of fresh water is discharged annually (~ 10,000 m³/sec) from the Mackenzie River into the Beaufort Sea.[1] With it, about 130,000,000 tonnes of sediment[2] are transported to the Arctic Ocean each year making the Mackenzie River the most sediment-rich river in the Arctic.[3] Most sediments deposited on the shelf are composed of clay or silt, with small amounts of gravel.[2] Freshwater discharge is at its highest in mid-May and June due to the breakup of ice on the river in late April.[2] The shores of the Mackenzie River are commonly flooded in the spring due to obstructions from bottomfast and landfast ice.[3] Freshwater input is lowered during the winter (~ 4000 m³/sec) and accumulates behind an ice dam near the mouth of the river. This causes the formation of Lake Mackenzie, a brackish body of water which floats above underlying marine water.[2]

This map shows the divide between Arctic and Pacific Ocean drainage. White lines delineate Environment Canada's sub-drainage areas.

BATHYMETRY

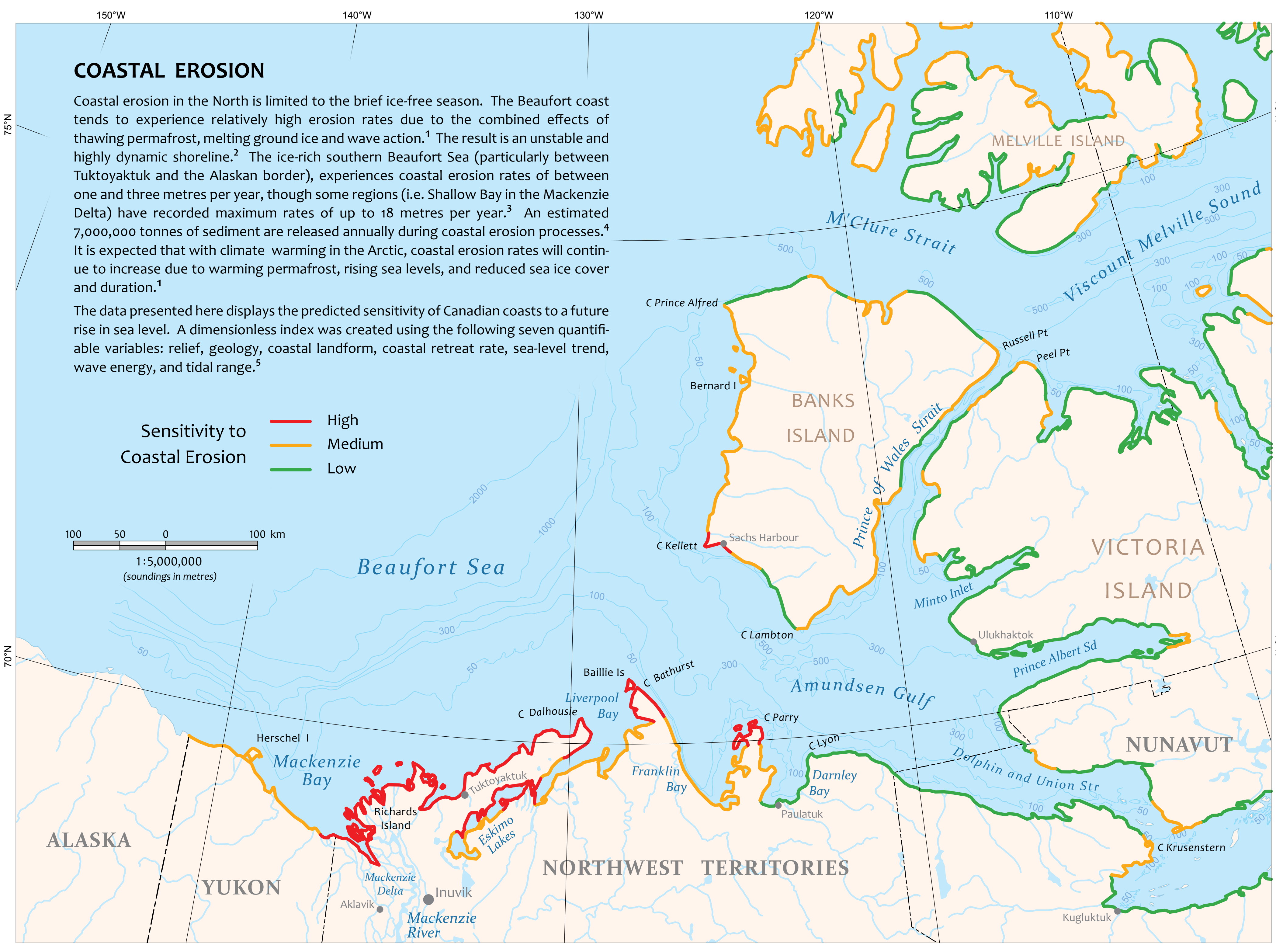
The Canadian component of the Beaufort continental shelf is bounded by the Canada-U.S. border to the west, the Amundsen Gulf to the east, the Mackenzie Delta to the south and the Beaufort Sea to the north.[1] This section of the shelf is approximately 120 km wide and 530 km long.[1] The continental shelf is the section of continental margin which lies between the shoreline and the shelf break at a depth of about 100 to 200 metres.[2] The average depth is less than 65 metres, though sections near the Mackenzie Delta are as shallow as 10 metres.[3] Beyond the shelf break, the continental Beaufort Slope drops off rapidly to a depth of more than 2000 kilometres.[1] The shelf, which was once dry land (~20,000 years ago), has since been covered by rising sea levels. Fine-grained sediments (clays and silts) originating from the Mackenzie River now cover the shelf.[3]

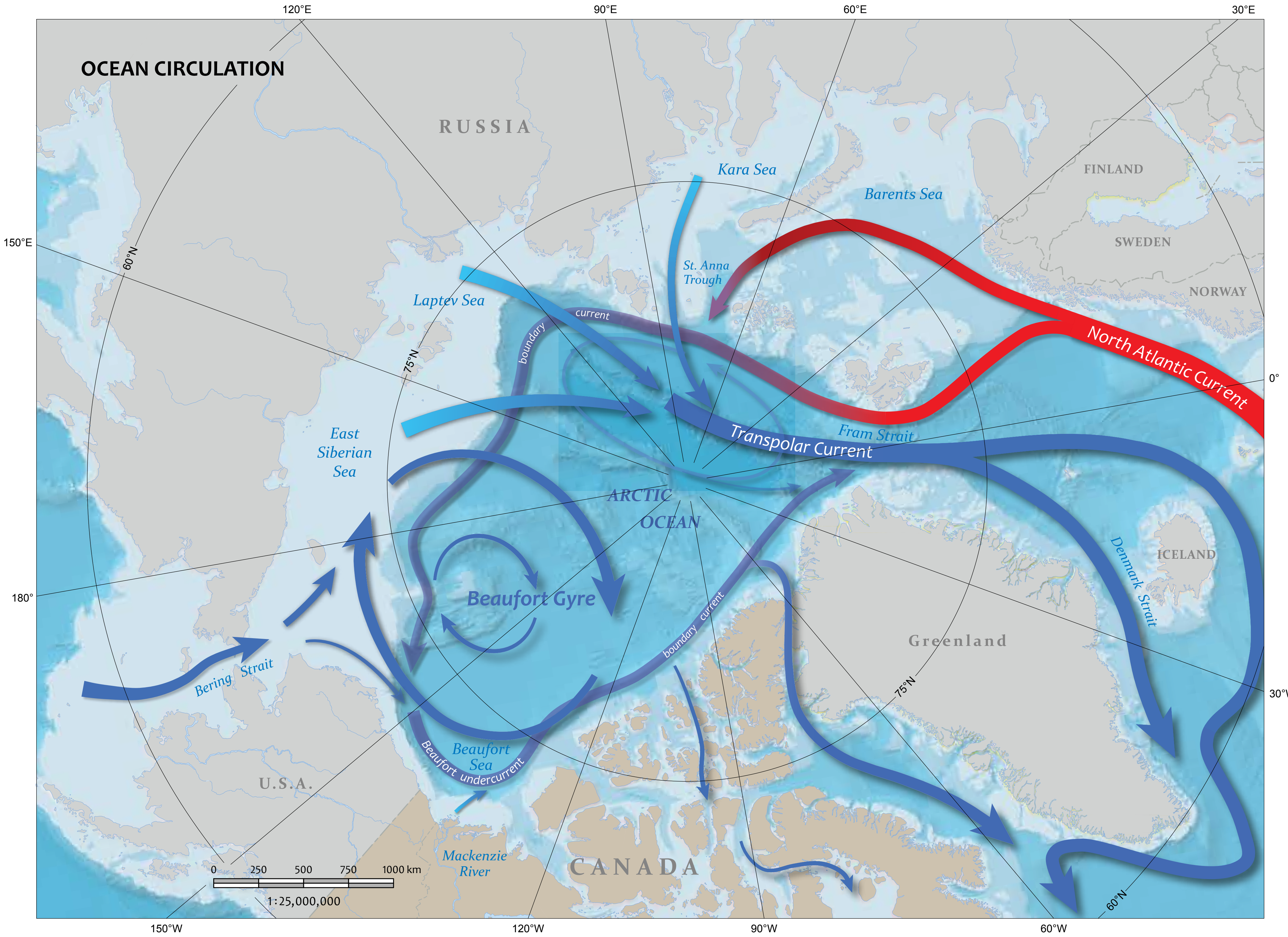


COASTAL EROSION

Coastal erosion in the North is limited to the brief ice-free season. The Beaufort coast tends to experience relatively high erosion rates due to the combined effects of thawing permafrost, melting ground ice and wave action.[1] The result is an unstable and highly dynamic shoreline.[2] The ice-rich southern Beaufort Sea (particularly between Tuktoyaktuk and the Alaskan border), experiences coastal erosion rates of between one and three metres per year, though some regions (i.e. Shallow Bay in the Mackenzie Delta) have recorded maximum rates of up to 18 metres per year.[3] An estimated 7,000,000 tonnes of sediment are released annually during coastal erosion processes.[4] It is expected that with climate warming in the Arctic, coastal erosion rates will continue to increase due to warming permafrost, rising sea levels, and reduced sea ice cover and duration.[1]

The data presented here displays the predicted sensitivity of Canadian coasts to a future rise in sea level. A dimensionless index was created using the following seven quantifiable variables: relief, geology, coastal landform, coastal retreat rate, sea-level trend, wave energy, and tidal range.[5]





Variations in water density in the Arctic Ocean are primarily determined by changes in salinity. Cold and relatively less salty water enters the Arctic Ocean through the narrow Bering Strait between Alaska and Siberia.[1] Once in the Arctic Ocean basin, the water is swept into the Beaufort Gyre which dominates the Beaufort Sea's main circulation.[2] A wind-driven ocean current, it causes the upper 50 m of surface water and sea ice to circulate in a clockwise motion resupplying the shelf with nutrients.[3] These waters are far less salty than water below.[4] The gyre also collects a reservoir of relatively fresh water from inputs from Siberian and Canadian rivers.[1] When winds shift and circular currents weaken, large volumes of fresh water flow from the gyre into the Transpolar Current.[1]

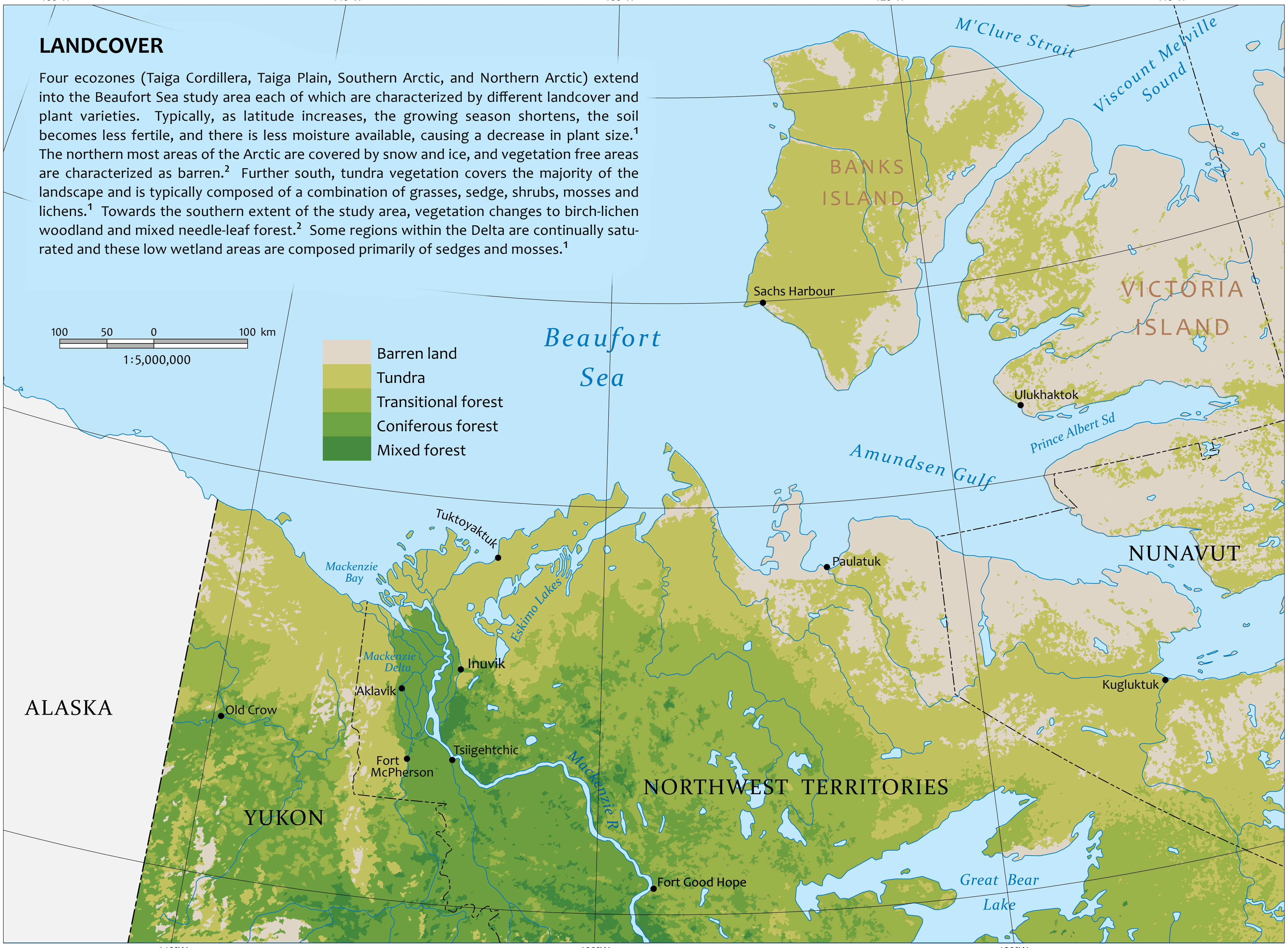
The Transpolar Current transports water and ice from Siberia across the pole and down the east coast of Greenland, where it joins the East Greenland current. A predominant westerly wind and input from Siberian rivers causes Arctic surface water to move eastward into the Atlantic.[4]

The North Atlantic Current provides about 60% of the inflow to the Arctic Ocean bringing warmer and saltier water from the Atlantic Ocean.[4] This water, originating from the Gulf Stream, moves through the Fram Strait into the Arctic. As the water cools, it begins to circulate in a counter-clockwise direction around the perimeter as a boundary current.[1] When this current is located beneath the Beaufort Gyre, it is known as the Beaufort Undercurrent. It moves waters originating from the Atlantic and Pacific Ocean eastward and transports nutrients from offshore areas towards the shelf.[5]

Along the Beaufort mainland, nearshore circulation patterns are significantly more variable and are influenced by wind direction, wind intensity and to some extent the Mackenzie River discharge during the ice free season. During the winter, water mass densities related to salinity gradients, influence flows when ice cover prevents the effects of the wind.[2] Tidal ranges in the Beaufort Sea are less than 0.5 metres[6], and negligible along the Channels of the outer Delta.

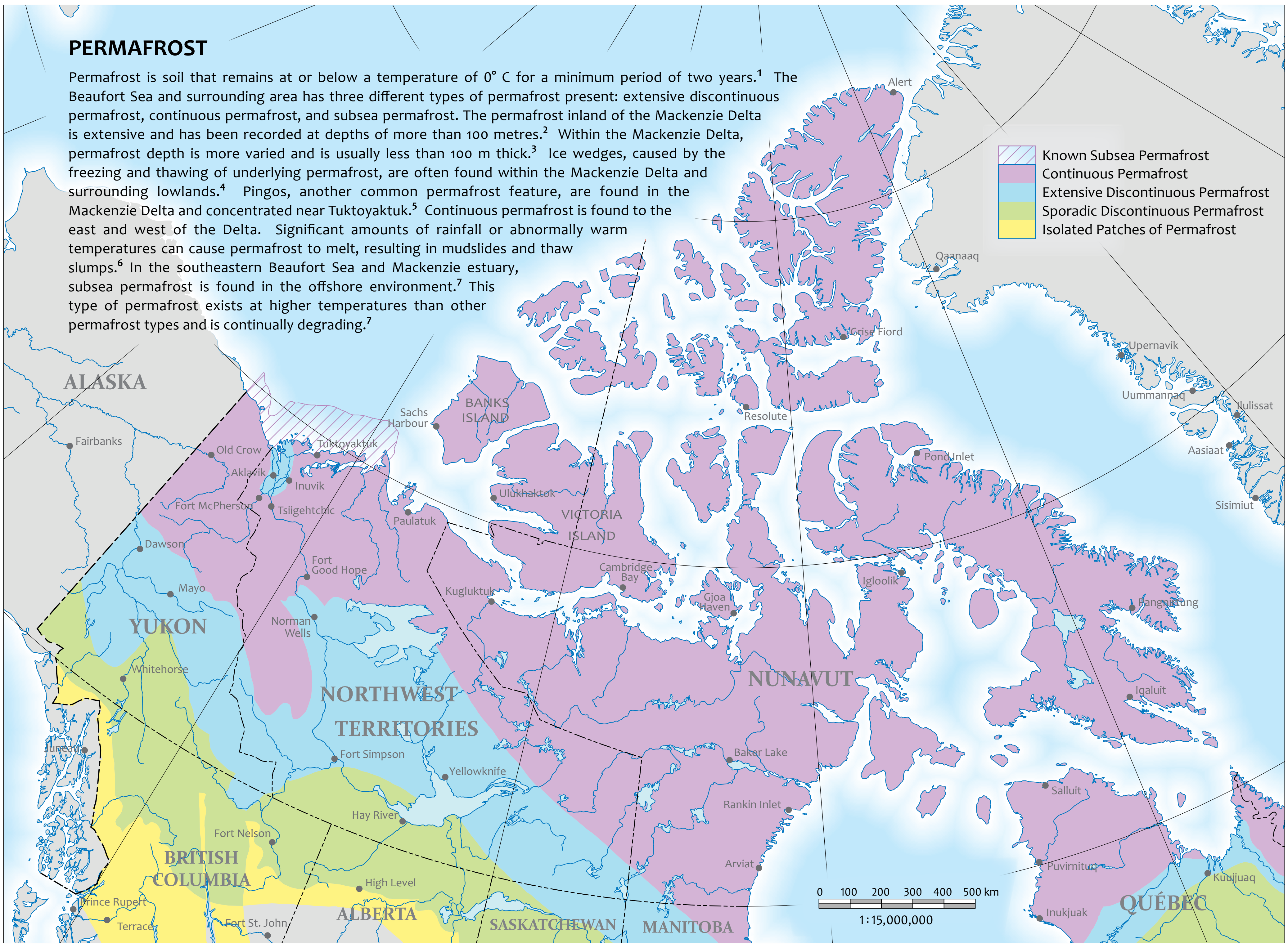
LANDCOVER

Four ecozones (Taiga Cordillera, Taiga Plain, Southern Arctic, and Northern Arctic) extend into the Beaufort Sea study area each of which are characterized by different landcover and plant varieties. Typically, as latitude increases, the growing season shortens, the soil becomes less fertile, and there is less moisture available, causing a decrease in plant size.[1] The northern most areas of the Arctic are covered by snow and ice, and vegetation free areas are characterized as barren.[2] Further south, tundra vegetation covers the majority of the landscape and is typically composed of a combination of grasses, sedge, shrubs, mosses and lichens.[1] Towards the southern extent of the study area, vegetation changes to birch-lichen woodland and mixed needle-leaf forest.[2] Some regions within the Delta are continually saturated and these low wetland areas are composed primarily of sedges and mosses.[1]



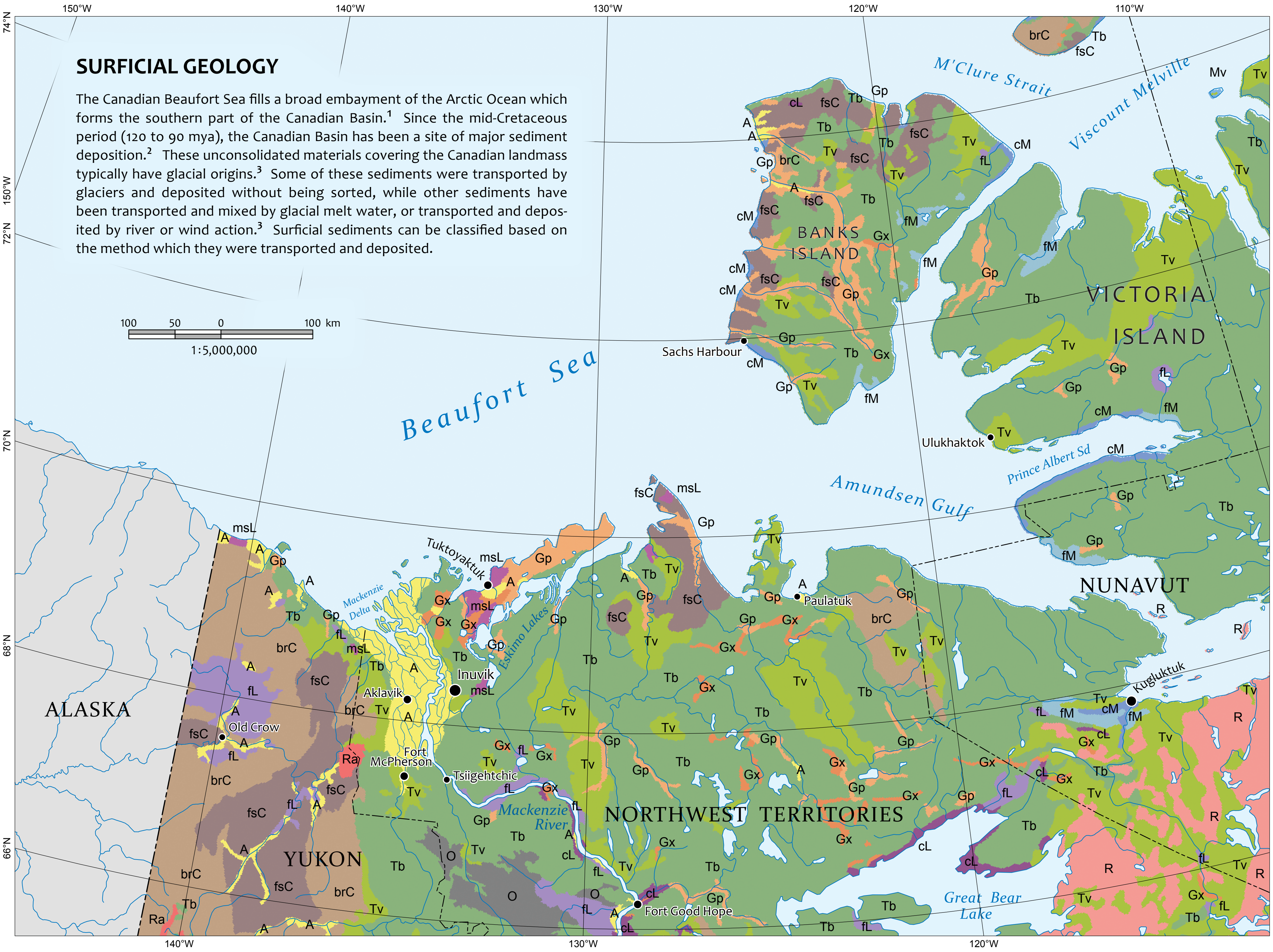
PERMAFROST

Permafrost is soil that remains at or below a temperature of 0° C for a minimum period of two years.[1] The Beaufort Sea and surrounding area has three different types of permafrost present: extensive discontinuous permafrost, continuous permafrost, and subsea permafrost. The permafrost inland of the Mackenzie Delta is extensive and has been recorded at depths of more than 100 metres.[2] Within the Mackenzie Delta, permafrost depth is more varied and is usually less than 100 m thick.[3] Ice wedges, caused by the freezing and thawing of underlying permafrost, are often found within the Mackenzie Delta and surrounding lowlands.[4] Pingos, another common permafrost feature, are found in the Mackenzie Delta and concentrated near Tuktoyaktuk.[5] Continuous permafrost is found to the east and west of the Delta. Significant amounts of rainfall or abnormally warm temperatures can cause permafrost to melt, resulting in mudslides and thaw slumps.[6] In the southeastern Beaufort Sea and Mackenzie estuary, subsea permafrost is found in the offshore environment.[7] This type of permafrost exists at higher temperatures than other permafrost types and is continually degrading.[7]



SURFICIAL GEOLOGY

The Canadian Beaufort Sea fills a broad embayment of the Arctic Ocean which forms the southern part of the Canadian Basin.[1] Since the mid-Cretaceous period (120 to 90 mya), the Canadian Basin has been a site of major sediment deposition.[2] These unconsolidated materials covering the Canadian landmass typically have glacial origins.[3] Some of these sediments were transported by glaciers and deposited without being sorted, while other sediments have been transported and mixed by glacial melt water, or transported and deposited by river or wind action.[3] Surficial sediments can be classified based on the method which they were transported and deposited.



A	**Alluvial deposits**: *stratified silt, sand, clay, and gravel; floodplain, delta, and fan deposits; in places overlies and includes glacio-fluvial deposits*

Lacustrine deposits: sediments deposited in lakes under nonglacial conditions and remaining at or below present lake level

msL	**Lacustrine mud and sand** **Lacustrine mud**: *fluid silty clay and clayey silt; deposited as quiet water sediments.* **Lacustrine sand**: *sand and locally gravel; deposited as sheet sands; lags, and beaches*
O	**Organic deposits**: *peat, muck and minor inorganic sediments; large bog, fen, and swamp areas where organic fill masks underlying surficial materials; generally >2 m thick*

Colluvial deposits: colluvial and residual materials deposited as veneers and blankets of debris through downslope movement and in-place disintegration of bedrock; includes areas of rock outcrop

brL	**Colluvial blocks and rubble** **Colluvial blocks**: *blocks, and rubble with sand and silt; derived from carbonate and consolidated fins clastic sedimentary rock substrate.* **Colluvial rubble**: *rubble and silt; derived from carbonate and consolidated fine clastic sedimentary rock substrate*
fsL	**Colluvial fines and sands** **Colluvial fines**: *silt, clay and fine sand; derived from weakly consolidated shale and siltstone substrate.* **Colluvial sands**: *sand and gravel; derived from poorly lithified sandstone and conglomerate substrate*

Glaciolacustrine and lacustrine deposits: sediments deposited in a glacial lake during deglaciation and subsequent lake drainage

fL	**Fine grained**: *silt, and clay, locally containing stones; deposited as quiet water sediment*
cL	**Coarse grained**: *sand, silt, and gravel; deposited as deltas, sheet sands, and lag deposits*

Glaciomarine and marine deposits: sediments deposited from meltwater and floating ice, in marine waters, during deglaciation and subsequent regression

fM	**Fine grained**: *dominantly silt and clay, locally containing stones; deposited as quiet water sediments*
cM	**Coarse grained**: *sand, silt, and gravel; deposited as deltas, sheet sands, and lag deposits*

Glaciofluvial deposits: gravel and sand deposited by meltwater streams

Gp	**Plain**: *sand and gravel; deposited as outwash sheets, valley trains, and terrace deposits*
Gx	**Complex**: *sand and gravel and locally diamicton; undifferentiated ice contact stratified drift, and outwash; locally includes till and rock*

Glacial deposits: silty, sandy, and clayey diamicton; formed by the direct action of glacier ice

Tb	**Till Blanket**: *thick and continuous till*
Tv	**Till veneer**: *thin and discontinuous till; may include extensive areas of rock outcrop*

Rock: areas of abundant (>75%) rock outcrop

Ra	**Alpine complexes**: *rock, colluvium, and till; rock and Quaternary deposits complex in an area, characterized by alpine and glacial landforms*
R	**Undivided**: *rock with minor Quaternary deposits*

MAP TEXT AND DATA REFERENCES

INUVIALUIT SETTLEMENT REGION

Text Reference

[1] Aurora Research Institute. 2014. Inuvialuit settlement region. URL: http://nwtresearch.com/licensing-research/scientific-research-license/supporting-information/inuvialuit-settlement-region. (Accessed: February 7, 2014).

2 Beaufort Sea Partnership (BSP). 2009. Integrated Ocean Management Plan (IOMP) for the Beaufort Sea: 2009 and Beyond. 139 p.

[3] Government of the Northwest Territories (GNWT). 2008. Official languages of the Northwest Territories. URL: http://www.ece.gov.nt.ca/files/publications/024-Official_ Languages_ Map-web.pdf. (Accessed: August 14, 2013).

Map Reference

Joint Secretariat. 2001. The Inuvialuit Settlement Region: Inuvialuit private lands. Data Format: shapefile. (URL: http://www.jointsecretariat.ca/images/isr-private_lands_keymap(8x11).jpg).

Joint Secretariat, 2009. The ISR relative to Canada. Data Format: shapefile. (URL: http://www.jointsecretariat.ca/maps.html).

Natural Resources Canada (NRCAN), 2011. CanVec version 9, Toponymy Theme. Data format: shapefile. (URL: ftp://ftp2.cits.rncan.gc.ca/pub/canvec/).

Government of Yukon Socio-Economic Web Portal. 2013. Population Estimates 2013. URL: http://www.sewp. gov.yk.ca/home?tab=region. (Accessed: January 20, 2014).

Northwest Territories Bureau of Statistics. 2012. Population Estimates 2012. URL: http://www.statsnwt.ca/ population/population-estimates/. (Accessed: January 20, 2014).

Nunavut Bureau of Statistics. 2012. Population Estimates 2012. URL: http://www.stats.gov.nu.ca/Publications/Popest/Population/Population%20estimates%20Report,%20July%201,%202012.pdf . (Accessed: January 20, 2014).

TRADITIONAL LANDUSE

Text Reference

[1] Inuvik Community Corporation (ICC). 2006. Inuvialuit settlement region traditional knowledge report. Report Submitted to: Mackenzie Project Environmental Group, Calgary, Alberta. 200 p.

[2] Arctic Environmental Sensitivity Atlas System (AESAS). 2004. Environment Canada, Yellowknife, NT.

Map Reference

Arctic Environmental Sensitivity Atlas System (AESAS). 2004. Sustainable Resource harvesting 1987 .Adapted from Beaufort Operational Maps 1-27 and Amundsen Operational Maps 1-19.

ARCHAEOLOGICAL SITES

Text Reference

[1] Prince of Wales Northern Heritage Centre (PWNHC). 2013. NWT Archaeological Reports. URL: http://www.pwnhc.ca/research/archrep/. (Accessed: Aug 13, 2013).

[2] Fisheries and Oceans Canada (DFO). 2008. Social, cultural and economic overview and assessment report for the Beaufort Sea Large Ocean Management Area. Prepared by: Social, Cultural and Economic Working Group. 132 p.

Map Reference

Prince of Wales Northern Heritage Centre, Government of the Northwest Territories, Education, Culture and Employment; and the Government of Yukon, Archaeology Program; Government of the Yukon, Department of Tourism and Culture. 2013. Archaeological site data. Data format: shapefile.

PARKS AND PROTECTED AREAS

Text Reference

[1] International Union for Conservation of Nature (IUCN). 2008. Hope for a protected planet with protected areas. URL: http://www.iucn.org/about/work/programmes/gpap_home/pas_gpap/. (Accessed: Aug 13, 2013).

[2] Beaufort Sea Partnership (BSP). 2012. Tarium Niryutait Marine Protected Area. URL: http://www.beaufortseapartnership.ca/tnmp_area.html. (Accessed: August 13, 2013).

[3] Fisheries and Oceans Canada (DFO). 2008. Social, cultural and economic overview and assessment report for the Beaufort Sea Large Ocean Management Area. Prepared by: Social, Cultural and Economic Working Group. 132 p.

[4] Environment Canada. 2013. Migratory Bird Sanctuaries. URL: http://www.ec.gc.ca/ap-pa/default.asp?lang=En&n= D1E052D8-1. (Accessed: August 13, 2012).

Map Reference

Environment Canada (EC). 2013. Protected Areas, Canada, 2013. Data format: shapefile.

MARINE TRANSPORTATION

Text Reference

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

[2] Pharand, D. 2007. The Arctic Waters and the Northwest Passage: A Final Revisit, Ocean Development and International Law, Vol. 38, pp. 3-69.

[3] National Oceanic and Atmospheric Administration (NOAA). 2013. Preparing for Oil Spills in the Future Arctic. URL: http://oceanservice.noaa.gov/news/features/jun09/arctic.html. (Accessed May 14, 2013).

[4] Ruffilli, D. 2011. Arctic marine and intermodal infrastructure: Challenges and the government of Canada's response. Publication No. 2011-77-E. Library of Parliament, Ottawa, Canada, pp. 1-8.

Map Reference

Canadian Arctic Shipping Routes for 2010, Transport Canada, Special Projects and Arctic Shipping, 2011, S. Harder (Analyst/Distributor), Marine, Transport Canada, Pacific Region. Data format: shapefile.

WIND

Text Reference

[1] Hopcroft, R., Bluhm, B., and Gradinger, R. 2008. Arctic Ocean Synthesis: Analysis of climate change impacts in the Chukchi and Beaufort Seas with strategies for future research. Institute of Marine Sciences, University of Alaska, Fairbanks.

[2] Smith, C.A.S., Meikle, J.C., and Roots, C.F. (Editors). 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313 p.

[3] National Ocean and Atmosphere Administration (NOAA). 2012. Arctic report card: update for 2012. URL: http://www.arctic.noaa.gov/report12/ArcticReportCard_full_report.pdf (Accessed: December 19, 2013).

Map Reference

National Ocean and Atmosphere Administration (NOAA). 2012. Arctic report card: update for 2012. Adapted from Figure 2.6.

PRECIPITATION

Text Reference

[1] INEGI, NRCan, and USGS. 2010. North American Environmental Atlas - WorldCLIM Precipitation, 1950-2000. Aguascalientes, Mexico; Ottawa, Canada; Reston, USA. Data format: raster. (URL: http://www.cec.org /Page.asp?PageID=924&ContentID=2336).

[2] Smith, C.A.S., Meikle, J.C., and Roots, C.F. (editors). 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313 p.

[3] Canadian Hydrographic Service (CHS). 1994. Sailing directions - Arctic Canada, Vol.1, Fourth Edition. Department of Fisheries and Oceans, Ottawa.

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

Map Reference

INEGI, NRCan, and USGS. 2010. North American Environmental Atlas - WorldCLIM Precipitation, 1950-2000. Aguascalientes, Mexico; Ottawa, Canada; Reston, USA. Data format: raster. (URL: http://www.cec.org/Page.asp?PageID=924&ContentID=2336).

DRAINAGE

Text Reference

[1] Macdonald, R.W., Carmack, E.C., McLaughlin, F.A., Iseki, K., MacDonald, D.M., and O'Brien, M.C. 1989. Composition and modification of water masses in the Mackenzie shelf estuary. J. Geophysical Res. C. Oceans 94: 18057-18070.

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

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

Map Reference

INEGI, NRCan, and USGS. 2010. North American Environmental Atlas - Watersheds (1:10,000,000). Aguascalientes, Mexico; Ottawa, Canada; Reston, USA. Data format: shapefile. (URL: http://www.cec.org/Page.asp?PageID=924&ContentID=2866).

BATHYMETRY

Text Reference

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

[2] United Nations. 2006. The definition of the continental shelf and criteria for the establishment of its outer limits. URL: http://www.un.org/Depts/los/clcs_new/continental_ shelf_description.htm. (Accessed: August 12, 2013).

[3] Dome Petroleum Ltd., Esso Resources Canada Ltd., and Gulf Canada Resources Inc. 1982. Environmental impact statement for hydrocarbon development in the Beaufort Sea-Mackenzie Delta Region. Volume 3A: Beaufort Sea-Delta Setting.

Map Reference

Bathymetry: International Bathymetric Chart of the Arctic Ocean (IBCAO) version 2.2. (URL: www.ibcao.org).

Base map: Atlas of Canada. 2008. North Circumpolar Region, Atlas of Canada Reference Map Series. Ottawa, Ontario, Canada. Data format: PDF, shapefile. (URL: http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/1289e492-d8a0-59d9-ab10-9d7e4ac74e89.html).

COASTAL EROSION

Text Reference

[1] Lantuit, H., and Pollard, W.H. 2008. Fifty years of coastal erosion and retrogressive thaw slump activity on Herschel Island, southern Beaufort Sea, Yukon Territory, Canada. Geomorphology, vol. 95, pp. 84–102.

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

[3] Solomon, S.M. and Forbes, D.L. 1994. Impacts of climate change on the Beaufort Sea coastal zone, p. 1810-1823. In Coastal Zone Canada '94, Cooperation in the Coastal Zone: Conference Proceedings, Sept. 20-23, 1994. Edited by P.G. Wells, P.J. Ricketts, S.M. Heming, J. Dale and G. R. MacMichael. Compiled and edited by: Coastal Zone Canada Association, Dartmouth, NS.

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

[5] Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M-H., and Solomon, S. 1998. Sensitivity of the coast of Canada to sea-level rise, Geological Survey of Canada Bulletin 505, 79 p.+ map. Adapted from Figure: Sensitivity of the coast of Canada to sea-level rise. (URL: http://www.bubbledust.ca/shaw_science_7.html).

Map Reference

Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M-H., and Solomon, S. 1998. Sensitivity of the coast of Canada to sea-level rise; Geological Survey of Canada Bulletin 505, 79 p.+ map. Adapted from Figure: Sensitivity of the coast of Canada to sea-level rise. (URL: http://www.bubbledust.ca/shaw_science_7.html).

OCEAN CIRCULATION

Text Reference

[1] Polar Discovery. 2006. Arctic Ocean Circulation. URL: http://polardiscovery.whoi.edu/arctic/circulation.html. (Accessed: February 10, 2014).

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

[3] Hopcroft, R., Bluhm, B., and Gradinger, R. 2008. Arctic Ocean Synthesis: Analysis of climate change impacts in the Chukchi and Beaufort Seas with strategies for future research. Institute of Marine Sciences, University of Alaska, Fairbanks.

[4] Canada's Aquatic Environments. 2002. Arctic Marine Regions: Currents. URL: http://www.aquatic.uoguelph.ca/oceans/ArticOceanWeb/Currents/frontpagecur.htm. (Accessed: February 10, 2014).

[5] Bringué, M. and Rochon, A. 2012. Late Holocene paleoceanography and climate variability over the Mackenzie Slope (Beaufort Sea, Canadian Arctic). Marine Geology, Vol 291-294, pp.83–96.

[6] Fisheries and Oceans Canada (DFO). 2013b. Tides, Currents and Waterlevels. URL: http://www.tides.gc.ca/eng. (Accessed: May 27, 2013).

Map Reference

Woods Hole Oceanographic Institution, 2006. Polar Discovery - Arctic Ocean Circulation. (URL: http://polardiscovery.whoi.edu/arctic/circulation.html).

Base map: Atlas of Canada, 2008. North Circumpolar Region, Atlas of Canada Reference Map Series. Ottawa, Ontario, Canada. Data format: PDF, shapefile. (URL: http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/1289e492-d8a0-59d9-ab10-9d7e4ac74e89.html).

Bathymetry: International Bathymetric Chart of the Arctic Ocean (IBCAO) version 2.2. (URL: www.ibcao.org).

LANDCOVER

Text Reference

[1] Arctic Canada. 2013. Flora of the Canadian Arctic. URL: http://www.sfu.ca/geog351fall02/gp2/WEBSITE/2_ content_v.html. (Accessed: Nov 5, 2013).

[2] Arctic. 2013. Landscapes and Vegetation Zones. URL: http://arctic.ru/geography-population/landscapes- vegetation. (Accessed: Nov 5, 2013).

Map Reference

Natural Resources Canada (NRCan). 2009. AVHRR Land Cover Data, Canada 1993. Data format: shapefile. (URL: ftp://ftp2.cits.rncan.gc.ca/pub/geott/eo_imagery/landcover/scale/).

PERMAFROST

Text Reference

[1] Washburn, A. L. 1979. Geocryology. London: Edward Arnold, 406 p.

[2] Dyke, L.D., Aylsworth, J.M., Burgess, M.M., Nixon, F.M., and Wright, F. 1997. Permafrost in the Mackenzie Basin, its influence on land-altering processes, and its relationship to climate change. pp. 111-116. In Mackenzie Basin Impact Study: Final Report. Edited by S.J. Cohen. Environmental Adaptation Research Group, Environment Canada.

[3] Solomon. S.M. 2002. Kitigaaryuit coastal stability baseline assessment. In Appendix B, Hart, E.J. 2002. Kitigaaryuit Archaeological Inventory and Mapping Project - 2001. Inuvialuit Social Development Program, Inuvik, NT.

[4] Mackay, J.R. 1989. Ice-wedge cracks, Western Arctic coast. The Canadian Geographer, vol. 33, 4, 4 p.

[5] Mackay, J.R. 1998. Pingo growth and collapse, Tuktoyaktuk Peninsula Area, Western Arctic Coast, Canada: a long-term field study. Géographie physique et Quaternaire, vol. 52, pp. 271-323.

[6] Aylsworth, J.M., and Duk-Rodkin, A. 1997. Landslides and permafrost in the Mackenzie Valley. In Mackenzie basin impact study: final report. Edited by S.J. Cohen. Environmental Adaptation Research Group, Environment Canada. pp. 117-121.

[7] Osterkamp, T.E. 2001. Sub-sea permafrost. In Steele, J. H., S. A. Thorpe, and K. K. Turekian, eds., Encyclopedia of Ocean Sciences. Academic Press, pp. 2902 -2912.

Map Reference

Natural Resources Canada (NRCan). 2009. Canada-Permafrost Layer 1993. Fifth Edition, National Atlas of Canada. Data format: shapefile.

SURFICIAL GEOLOGY

Text Reference

[1] Hill, P.R., Héquette, A., Ruz, M-H., and Jenner, K.A. 1991. Geological investigations of the Canadian Beaufort Sea coast. Geological Survey of Canada open file report 2387. 348 p.

[2] Dietrich, J.R, Dixon, J., and McNeil, D.H. 1985. Sequence analysis and nomenclature of Upper Cretaceous to Holocene strata in the Beaufort-Mackenzie basin. In Current Research, part A, Geological Survey of Canada, Paper 85-1A, pp. 613-628.

[3] Natural Resources Canada (NRCan). 2012. Geology and Geosciences. URL: http://atlas.nrcan.gc.ca/site/english/maps/geology.html#surficialmaterialsandglaciation. (Accessed: September 25, 2013).

Map Reference

Geological Survey of Canada (GSC). 2010. Surficial Materials of Canada 1995. Data format: shapefile.

BASEMAP LAYERS

Map Reference

Canada Centre for Mapping and Earth Observation, NRCan. 2012. Atlas of Canada National Scale Data 1:15,000,000. Ottawa, Canada. Data format: shapefile. (URL: http://geogratis.gc.ca/api/beta/en/nrcan-rncan/ess-sst/-/(urn:iso:series)atlas-of-canada-national-scale-data-115000000).

Canada Centre for Mapping and Earth Observation, NRCan. 2013. Atlas of Canada National Scale Data 1:5,000,000. Ottawa, Canada. Data format: shapefile. (URL: http://geogratis.gc.ca/api/beta/en/nrcan-rncan/ess-sst/-/(urn:iso:series)atlas-of-canada-national-scale-data-15000000).

DEVELOPMENT OF SHORELINE CLASSIFICATION FOR THE BEAUFORT SEA

Baseline coastal information such as shoreline form, substrate and vegetation type, is required for operational prioritization and coordination of on-site spill response activities (i.e., SCAT: Shoreline Cleanup and Assessment Technique). In addition, it provides valuable information for wildlife and ecosystem management.

To produce this dataset, georeferenced high definition videography was collected during the summers of 2010 to 2012 along coastlines within the Beaufort Sea study site. Coastline vectors were split based on homogeneity of the upper intertidal zone (UI) and detailed information describing the upper intertidal (UI), supratidal (SI), and backshore (Bs) zones was extracted from the video and entered into a geospatial database using a customized input form. In total, almost 8,000 km of northern shorelines were mapped, including 22 different shoreline types based on the upper intertidal zone. The shoreline classification information was then used to generate the Environmental Sensitivity Index (ESI) which provided a concise summary of coastal shorelines which are at risk during a spill. The ESI was then incorporated with additional biological and human resource information to create ESI maps which will serve as valuable information for oil-spill response planning should the need arise.

ACROSS-SHORE ZONES

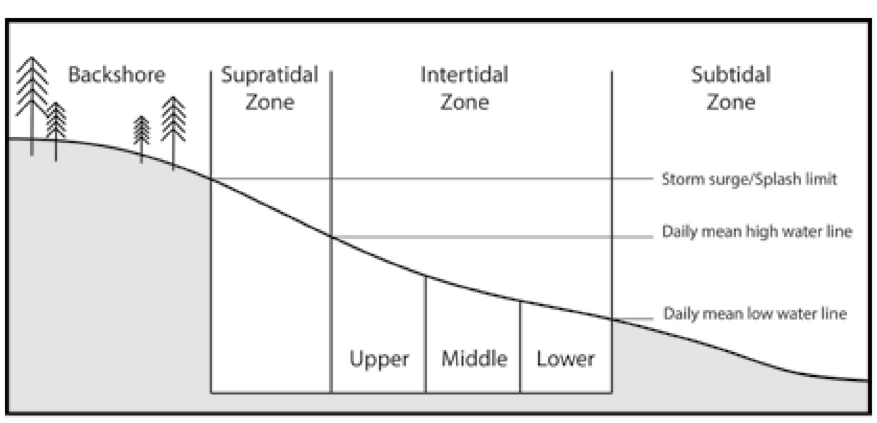
There are four basic zones which are used to characterize the morphology of the shoreline in an onshore to offshore progression:

The **Backshore (Bs)** is the area above the current limit of marine processes, but of interest because it provides cleanup teams with information about access to the oiled shoreline segment (Owens, 2010).

The **Supratidal (SI) zone** is considered the section of the shoreline that would be impacted by storm waves and surge events. There is some potential that oil may reach the SI zone during storm events and is therefore of interest to this project (Owens, 2010).

The **Intertidal Zone** is the physical interface between water and land and is covered by water at high tide. It is further divided into three separate subzones. The Upper Intertidal Zone (UI) is the upper one-third of the intertidal zone, up to the daily mean high water line (Owens, 2010). This zone is of interest to this project because this is the area where the majority of oil would be deposited in the event of a spill and where the clean-up activities would take place. The Mid Intertidal Zone (MI) is the middle one-third of the intertidal zone, and the Lower Intertidal Zone (LI) is the lower one-third of the intertidal zone, down to the daily mean low water line.

The **Subtidal Zone** is the area below the current low water line, and therefore remains submerged most of the time, except during extreme low tides.



SCAT – SHORELINE CLEANUP AND ASSESSMENT TECHNIQUE

In the event of an oil spill, clean-up teams implement the Shoreline Clean-up and Assessment Technique (SCAT), which is a systematic documentation of oiled shorelines using standardized terms and definitions (Owens and Sergy, 2003). Developed to provide accurate information to cleanup teams, it is now an integral part of spill response operations.

To perform an assessment, a SCAT team must evaluate the oiling conditions, factor in shoreline type, and identify sensitive resources, before determining the need for cleanup and recommending remediation methods (NOAA, 2010).

While SCAT is implemented when responding to a new spill, the idea of having a "Pre-SCAT" plan was developed to provide first responders with a priori knowledge of the shoreline types they would encounter before they reach an oiled segment, permitting prioritization of areas for clean-up based on susceptibility to long-term damage as well as significant wildlife or important habitats present (Percy et al., 1997).

COLLECTION OF VIDEO AND GROUND DATA

During the summers of 2010 to 2012, low-altitude helicopter surveys were conducted along the Beaufort Sea coast to capture video of the shoreline characteristics. Flights were performed along the mainland coast, the Mackenzie River channels and around Banks Island. A JVC Pro High Definition GY-HM100U camera recorder was used to collect high-definition videos at an altitude of 300 to 400 feet with a flight speed between 70 and 80 knots. The helicopter was positioned approximately 500 feet offshore in order to ensure a clear view of the upper intertidal zone. Oblique video was collected by angling the video camera at a 45° angle from the helicopter, to maintain a clear view of the shoreline. The videos were geo-tagged using a VMS 300 video mapping system (Red Hen Systems Inc., 2003) combined with a nanoFlash recorder (Convergent Design, 2013).

The video camera was focused primarily on the upper part of the intertidal zone. Integrated audio commentaries provided additional information and included a description of the across-shore zones (i.e. upper intertidal zone (UI), supratidal zone (SI), and the backshore (Bs)) with respect to their geology, geomorphology, and vegetation (Owens and Sergy, 2004).

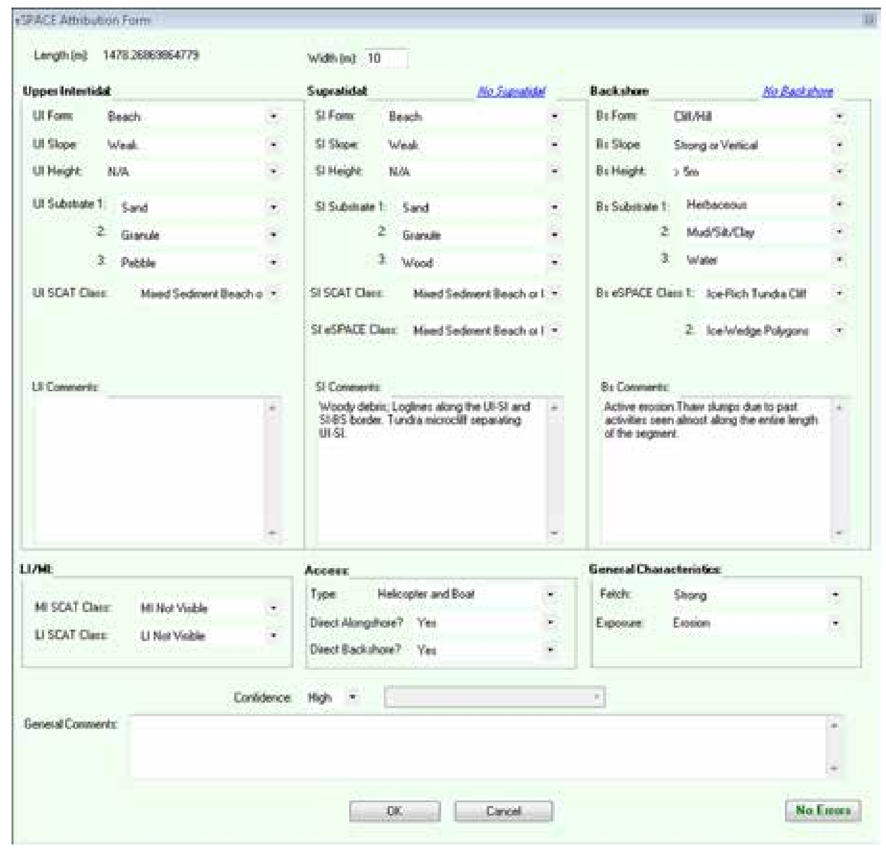
The geo-tagged video that was recorded was post-processed using the GeoVideo (Red Hen Systems Inc, 2004) extension in ArcMap 9.3 (ESRI, 2008). The extension enabled the georeferenced videos to be imported into the ArcMap environment in order to be integrated with other geospatial information. Post-processing converted the geospatial information stored within the video file to a point shapefile representing the helicopter track flown with each point in the shapefile linked to a video frame. Video and audio for any location was then viewable at any point along the flight path and a moving cursor showed the helicopter's location along the path.

SHORELINE INTERPRETATION AND SEGMENTATION

Shoreline segmentation is the process of breaking the continuous shoreline into homogeneous segments based on the type of shoreline present in the upper intertidal zone. The primary goal of segmentation was to characterize and label the upper intertidal zone using the SCAT shoreline types. Owens (2010) developed SCAT classes specifically for the Canadian Arctic. The classes provide a basic description of the character of the shoreline where oil would be deposited and provide insight to cleanup teams regarding oil behaviour and treatment options. Environment Canada currently uses 25 shoreline types as the basis for summarizing SCAT information.

Interpreters viewed the video within ArcMap using the GeoVideo extension. Since the GPS tracklog from the helicopter was offset from the shoreline, an existing shoreline vector (derived from 1:50,000 CanVec product (Hydrology layer v.9; NRCan, 2011)) was used for the actual segmentation. Ancillary data, including SPOT 4/5 orthoimages (20 m ground pixel) (NRCan, 2010) and 1:50,000 Toporama products (NRCan, 2012), are used for positional reference and as basemaps (e.g., to determine the location of segment boundaries based on features visible in both the videography and ancillary data).

The shoreline segmentation consisted of manual interpretation of the oblique videography to split and classify the shoreline vectors. Interpreters divided the vector shoreline into alongshore segments according to observed changes in the upper part of the intertidal zone (UI) as this is the area where the oil would be deposited and where the cleanup activities would take place (Owens and Sergy, 2004). The minimum size of an alongshore segment was 200 m and the maximum was 2 km based on the segment length used during a SCAT survey to provide acceptable resolution and information on the location of the oil, while not generating too much data (Owens and Sergy, 2004). Beyond simply segmenting the vector and assigning a shoreline type, a custom data entry form was created to fully characterize the shoreline based on requirements of Environment Canada's Environmental Emergencies Division. On average, a fully trained interpreter was able to segment 40 km of shoreline per day.



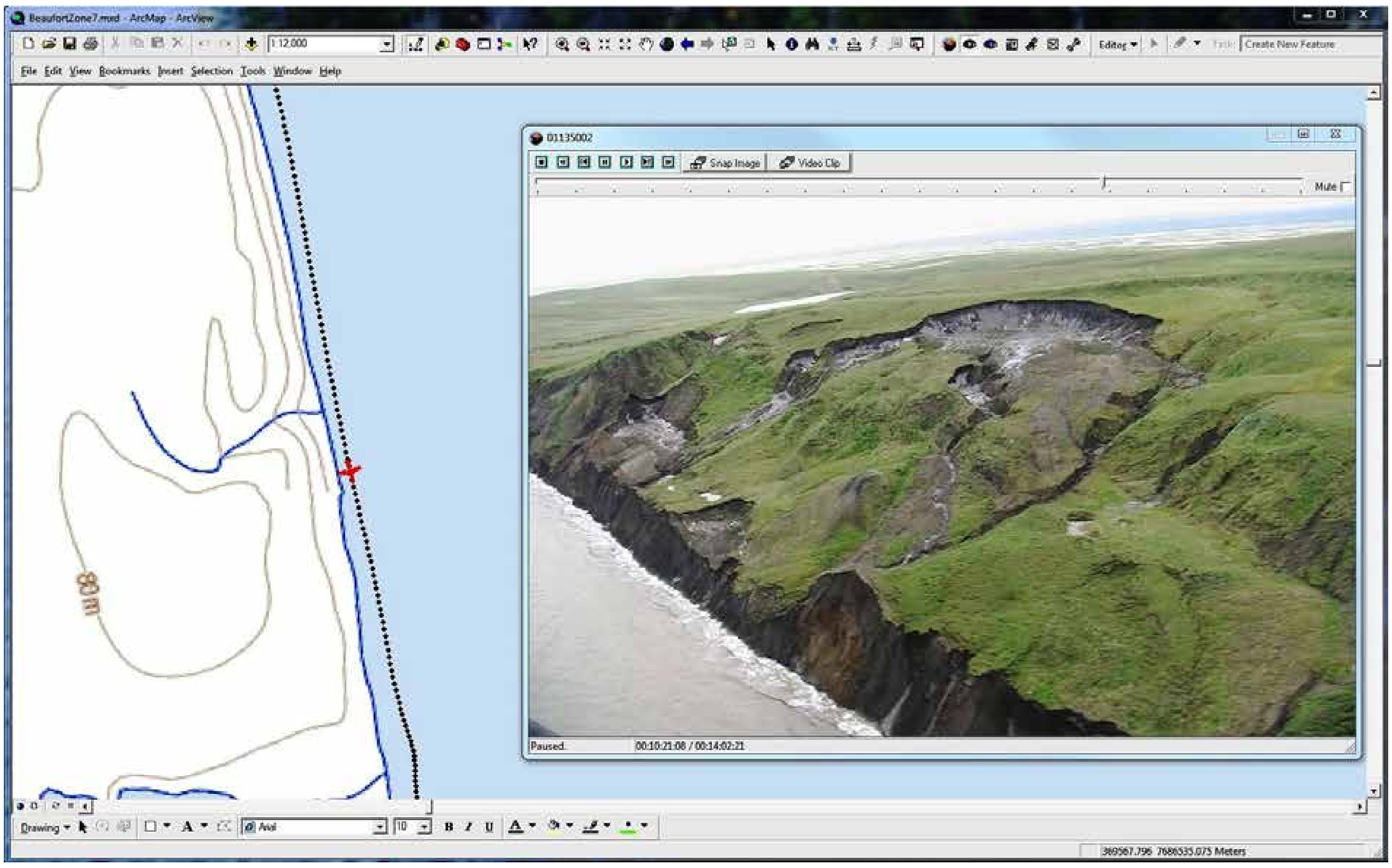
The custom form was preferred to other methods of production due to the ability to standardize data collection and add logic to the production process. The use of drop down menus and pre-programmed rules ensured appropriate classification of the zones. Information on the across-shore zones (i.e. UI, SI, and Bs), such as the substrate types, shoreline height, and slope, as well as accessibility for cleanup teams, was recorded using the form. Attributes were identified using key elements of image interpretation (colour, texture, pattern, association, and vegetation (Lillesand et al., 2004)).

SCAT Classes	**Mapped Shoreline (km)**
Bedrock Cliff/Vertical	195
Bedrock Platform	14
Bedrock Sloping/Ramp	7
Boulder Beach or Bank	21
Driftwood	26
Ice-Poor Tundra Cliff	31
Ice-Rich Tundra Cliff	163
Inundated Low-Lying Tundra	365
Man-Made Permeable	3
Man-Made Solid	<1
Marsh	341
Mixed and Coarse Sediment Tidal Flat	43
Mixed Sediment Beach or Bank	2,604
Mud/Clay Bank	141
Mud Tidal Flat	740
Peat Shoreline	1,155
Pebble/Cobble Beach or Bank	366
Sand Beach or Bank	975
Sand Tidal Flat	526
Sediment Cliff/Dune/Talus	36
Snow/Ice	40
Vegetated Bank	98
Total	**7,889**

See Appendix C for a breakdown by study area.

Many shoreline attributes were not determined exclusively from the videography, rather, satellite imagery and other geospatial datasets were used. The width of a shoreline segment, corresponding to the average (representative of the entire segment) across-shore distance of the SI zone and the entire intertidal zone (UI, MI, LI) combined, was estimated using SPOT imagery, the Toporama product, as well as the videos. Fetch was estimated from the basemaps in the GIS as a function of the segment's perpendicular distance to the nearest offshore obstacle and of the segment's angle of opening (e.g., closed bay vs. peninsula), representing an average exposure.

A measure of interpreter confidence was also recorded in the input form. While the geo-tagged video greatly enhanced the ability to properly establish shoreline boundaries, decisions made about distant or difficult to see segments resulted in segments boundaries with lower confidence. Low confidence in a shoreline segment was assigned when the interpreter hesitated on the limit of the three zones or was not certain of the data entered into the form. The segment was then reviewed by a second interpreter, but may maintain a low confidence classification if a feature remains uncertain.



THE ENVIRONMENTAL SENSITIVITY INDEX (ESI)

The Environmental Sensitivity Index (ESI) is a shoreline classification system that was developed by the National Oceanic and Atmospheric Administration (NOAA) in the mid-1970s to classify the sensitivity of coastal regions to oil spills (CORI and AMR, 2007). The ESI integrates three elements into the index (IPIECA, IMP, and OGP, 2011):

- **Shoreline type:** Defined by grain size and slope and determines the capacity of oil penetration and/or burial on the shore.
- **Exposure to wave and tidal energy**: Determines the natural persistence time of oil on the shoreline.
- **General biological productivity and sensitivity**: Defines other associated sensitive resources.

The ESI uses a ranking system of 1-10 to indicate the relative degree of sensitivity of each class to oil spills, from 1 (least sensitive) to 10 (most sensitive). In addition to the 1 to 10 ranking, each shoreline segment is also assigned to one of 28 shoreline type classes (See table titled 'Specific Shoreline Types Included by Each ESI Ranking', page 24).

ASSIGNING ESI BASED ON SCAT CLASS

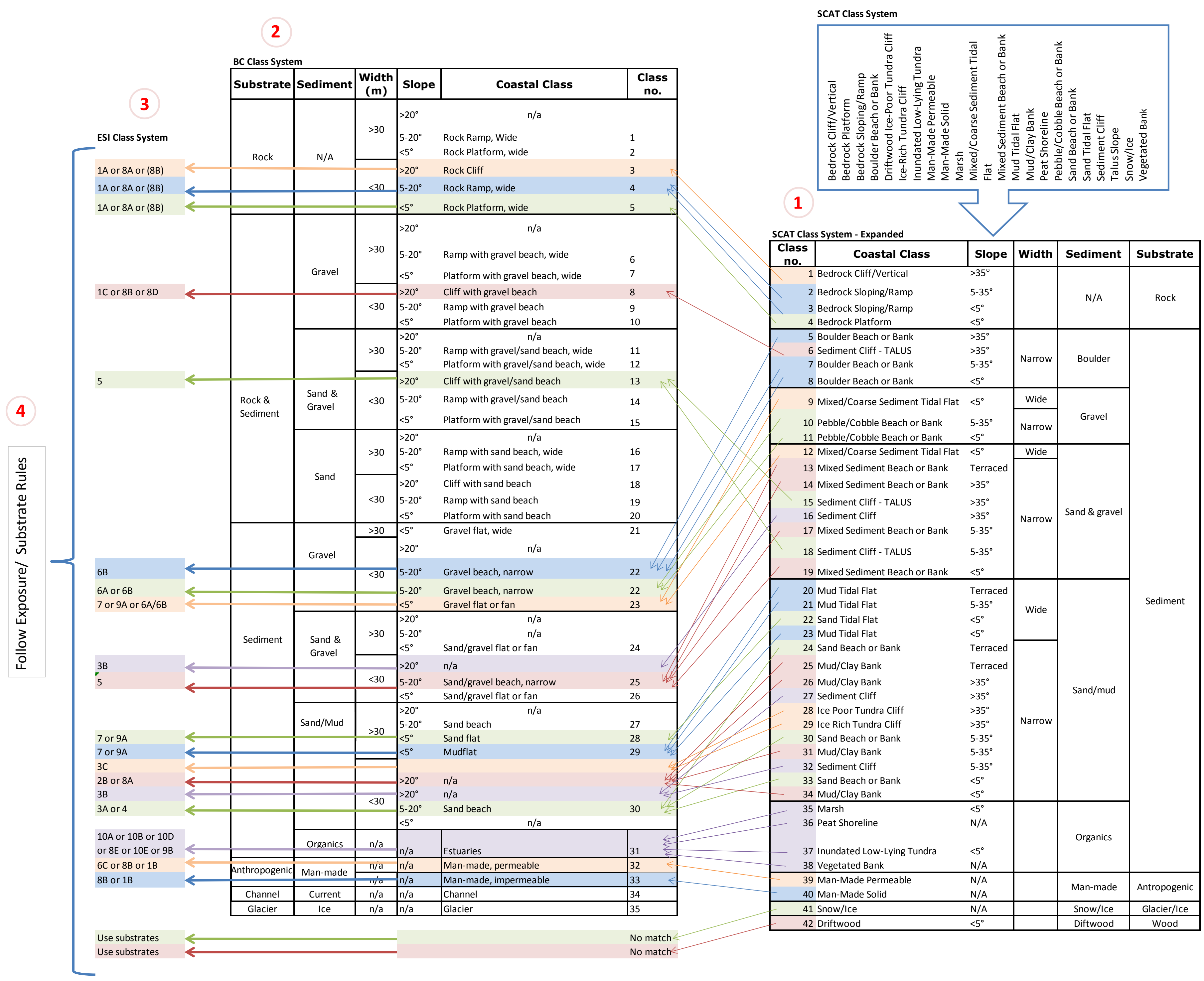
The conversion from SCAT classifications to the ESI was done using the followings steps following Harney et al. (2008).

1. The first step involved expanding the current SCAT shoreline classes. This was done by dividing the shorelines into more descriptive classes based on sediment type, width of the shoreline and slope. For example, the SCAT class 'Bedrock Sloping/Ramp' became "Bedrock Sloping/Ramp – Moderate slope' and 'Bedrock Sloping/Ramp – Flat slope' in the expanded class. This resulted in a set of classes that better matched the British Columbia class system.

2. The next step required the user to match the expanded SCAT classes to their most similar BC class based on sediment type, width of the shoreline and slope (CORI and AMR, 2007).

3. The classes were then converted from the BC Class system to the ESI by following the rule set provided by Harney et al. (2008).

4. Often there were several ESI classes available to choose from at this stage which required the user to select the appropriate class based on the substrate and exposure present as outlined in the ESI rule set.



EXPLANATION OF ESI RANKINGS

The following description of ESI rankings 1-10 were taken from Petersen, J., Michel, J., Zengel, S., White, M., Lord, C. and Plank, C., 2002. Environmental sensitivity index guidelines: Version 3.0. NOAA Technical Memorandum NOS OR&R 11.

Rank of 1: Exposed, Impermeable Vertical Substrates
These shoreline types are exposed to large waves, which tend to keep oil offshore by reflecting waves. The substrate is impermeable so oil remains on the surface where natural processes will quickly remove any oil that does strand within a few weeks. Stranded oil tends to form a band along the high-tide line, above the elevation of the greatest biological value. No cleanup is generally required or recommended.

Rank of 2: Exposed, Impermeable Substrates, Non-Vertical
These shorelines are exposed to high wave energy. They have a flatter intertidal zone, sometimes with small accumulations of sediment at the high-tide line, where oil could persist for several weeks to months. Biological impacts can be immediate and severe, if fresh oil slicks cover tidal pool communities on rocky platforms. However, the oil is usually removed quickly from the platform by wave action. Cleanup is not necessary except for removing oiled debris and oil deposits at the high-tide line, in areas of high recreational use, or to protect a nearshore resource.

Rank of 3: Semi-Permeable Substrate, Low Potential for Oil Penetration and Burial; infauna present but not usually abundant
This shoreline contains compact, fine-grained sand substrates which inhibit oil penetration, minimizing the amount of oiled sediments to be removed. Fine-grained sand beaches generally accrete slowly between storms, reducing the potential for burial of oil by clean sand. On sheltered sand beaches, burial is seldom of concern because of the low wave energy. On exposed beaches, oil may be buried deeply if the oil stranded right after an erosional storm or at the beginning of a seasonal accretionary period. Cleanup on fine-grained sand beaches is simplified by the hard substrate that can support vehicular and foot traffic. Infauna densities vary significantly both spatially and temporally.

Rank of 4: Medium Permeability, Moderate Potential for Oil Penetration and Burial; infauna present but not usually abundant
Coarse-grained sand beaches have potential for higher oil penetration and burial (≥1m). These beaches can undergo very rapid erosional and depositional cycles, with the potential for rapid burial of oil, even after only one tidal cycle. Cleanup is more difficult, as equipment tends to grind oil into the substrate because of the loosely packed sediment. Also, cleanup techniques have to deal with multiple layers of oiled and clean sediments, increasing the amount of sediments to be handled and disposed of. These more mobile sediments usually have low infauna populations, which also vary greatly over time and space.

Rank of 5: Medium-to-High Permeability, High Potential for Oil Penetration and Burial; infauna present but not usually abundant
The gravel-sized component can be composed of bedrock, shell fragments, or coral rubble. Because of higher permeability, oil tends to penetrate deeply into sand and gravel beaches, making it difficult to remove contaminated sediment without causing erosion and sediment disposal problems. These beaches may undergo seasonal variations in wave energy and sediment reworking, so natural removal of deeply penetrated oil may only occur during storms that occur just 1 or 2 times/year. These types of beaches range widely in relative degree of exposure. Biological use is low, because of high sediment mobility and rapid drying during low tide.

Rank of 6: High Permeability, High Potential for Oil Penetration and Burial
Gravel beaches have the highest potential for very deep oil penetration which slows natural removal rates of subsurface oil. The slow replenishment rate of gravel makes removal of oiled sediment highly undesirable, and so cleanup of heavily oiled gravel beaches is particularly difficult. For many gravel beaches, significant wave action occurs only every few years, leading to long-term persistence of subsurface oil. Riprap is a man-made equivalent of this ESI rank, with added problems because it is usually placed at the high-tide line where the highest oil concentrations are found and the riprap boulders are sized so that they are not reworked by storm waves. Flushing can be effective for removing mobile oil, but large amounts of residue can remain after flushing, particularly for heavy oils. Sometimes, the only way to clean riprap completely is to remove and replace it.

Rank of 7: Exposed, Flat, Permeable Substrate; infauna usually abundant
Exposed tidal flats commonly occur with other shoreline types (marsh vegetation), on the landward edge of the flat. Oil does not readily adhere to or penetrate the compact, water-saturated sediments of exposed sand flats. Instead, the oil is pushed across the surface and accumulates at the high-tide line. Even when large slicks spread over the tidal flat at low tide, the tidal currents with the next rising tide pick up the oil and move it alongshore. However, oil can penetrate the tops of sand bars and burrows if they dry out at low tide. Because of the high biological use, impacts can be significant to benthic invertebrates exposed to the water-accommodated fraction or smothered. Cleanup is difficult because of the potential for mixing the oil deeper into the sediment (i.e. foot traffic).

Rank of 8: Sheltered Impermeable Substrate, Hard; epibiota usually abundant
Oil tends to coat rough rock surfaces in sheltered settings, and oil persists long-term because of the low-energy setting. Solid rock surfaces are impermeable to oil, but rocky rubble slopes tend to trap oil beneath a veneer of coarse material. Both types can have large amounts of attached organisms, supporting a rich and diverse community. Cleanup is often required because natural removal rates are slow, but is often difficult and intrusive. Sheltered seawalls and riprap are the man-made equivalents, with similar oil behavior and persistence patterns. Usually, more intrusive cleanup is necessary for aesthetic reasons. In riverine settings, terrestrial vegetation along the river bluff indicates low energy and thus slow natural removal rates.

Rank of 9: Sheltered, Flat, Semi-Permeable Substrate, Soft; infauna usually abundant
The soft substrate and limited access makes sheltered tidal flats almost impossible to clean. Usually, any cleanup efforts mix oil deeper into the sediments, prolonging recovery. Once oil reaches these habitats, natural removal rates are very slow. Biological use is high, making them very sensitive to oil-spill impacts. Low riverine banks are often muddy, soft, and vegetated, making them extremely difficult to clean. Natural removal rates could be very slow, and depend on flooding frequency.

Rank of 10: Vegetated Emergent Wetlands
Marshes, mangroves, and other vegetated wetlands are the most sensitive habitats because of their high biological use and value, difficulty of cleanup, and potential for long-term impacts to many organisms. When present, mangroves are considered a specific habitat type and are not grouped with scrub-shrub vegetation. Many factors influence how oil affects wetlands: oil type, extent of vegetation contamination, degree of sediment contamination, exposure to natural removal processes, time of year of the spill, and species types.

SPECIFIC SHORELINE TYPES INCLUDED BY EACH ESI RANKING

1 Exposed, Impermeable Vertical Substrates	**6 High Permeability, High Potential for Oil Penetration and Burial**
1a Exposed rocky shores (estuarine, lacustrine, and riverine) 1b Exposed, solid, man-made structures (estuarine, lacustrine, and riverine) 1c Exposed rocky cliffs with boulder talus base Exposed, rocky cliffs/Boulder talus base	6a Gravel beaches (estuarine and lacustrine) Gravel bars and gently sloping banks (riverine) Gravel beaches (cobbles and boulders) (estuarine - Southeast Alaska only) Gravel beaches (granules and pebbles) (estuarine – Southeast Alaska only) 6b Riprap (estuarine, lacustrine, and riverine) Gravel beaches (cobbles and boulders) (estuarine – Southeast Alaska only) 6c Riprap (estuarine - Southeast Alaska only)
2 Exposed, Impermeable Substrates, Non-Vertical	**7 Exposed, Flat, Permeable Substrate; infauna usually abundant**
2a Exposed wave-cut platforms in bedrock, mud, or clay (estuarine) Shelving bedrock shores (lacustrine) Rocky shoals; bedrock ledges along rivers (riverine) 2b Exposed scarps and steep slopes in clay (estuarine)	7 Exposed tidal flats (estuarine and lacustrine)
3 Semi-Permeable Substrate, Low Potential for Oil Penetration and Burial; infauna present but not usually abundant	**8 Sheltered Impermeable Substrate, Hard; epibiota usually abundant**
3a Fine- to medium-grained sand beaches (estuarine) 3b Scarps and steep slopes in sand (estuarine) Eroding scarps in unconsolidated sediments (lacustrine) Exposed, eroding river banks in unconsolidated sediments (riverine) 3c Tundra cliffs (estuarine)	8a Sheltered rocky shores and sheltered scarps in bedrock, mud, or clay (estuarine) Sheltered rocky shores (impermeable) and sheltered scarps in bed rock, mud, or clay (estuarine – Southeast Alaska only) Sheltered scarps in bedrock, mud, or clay (lacustrine) 8b Sheltered, solid man-made structures, such as bulkheads (estuarine, lacustrine, and riverine) Sheltered rocky shores (permeable) (estuarine – Southeast Alaska only) 8c Sheltered riprap (estuarine, lacustrine, and riverine) 8d Sheltered rocky rubble shores (estuarine) 8e Peat shorelines (estuarine) 8f Vegetated, steeply-sloping bluffs (riverine)
4 Medium Permeability, Moderate Potential for Oil Penetration and Burial; infauna present but not usually abundant	**9 Sheltered, Flat, Semi-Permeable Substrate, Soft; infauna usually abundant**
4 Coarse-grained sand beaches (estuarine) 4 Sand beaches (lacustrine) 4 Sandy bars and gently sloping banks (riverine)	9a Sheltered tidal flats (estuarine) Sheltered sand/mud flats (lacustrine) 9b Vegetated low banks (estuarine and riverine) Sheltered, vegetated low banks (lacustrine) 9c Hypersaline tidal flats (estuarine)
5 Medium-to-High Permeability, High Potential for Oil Penetration and Burial; infauna present but not usually abundant	**10 Vegetated Emergent Wetlands**
5 Mixed sand and gravel beaches (estuarine and lacustrine) 5 Mixed sand and gravel bars and gently sloping banks (riverine)	10a Salt- and brackish-water marshes (estuarine) 10b Freshwater marshes (estuarine, lacustrine, riverine, and palustrine) 10c Swamps (estuarine, lacustrine, riverine, and palustrine) 10d Scrub-shrub wetlands (estuarine, lacustrine, riverine, and palustrine) Mangroves (in tropical climates) (estuarine) 10e Inundated, low-lying tundra (estuarine)

ESSENTIAL ELEMENTS OF ESI RANKINGS

1 Exposed, Impermeable Vertical Substrates

- Regular exposure to high wave energy or tidal currents.
- Strong wave-reflection patterns are common.
- Substrate is impermeable (usually bedrock or cement) with no potential for subsurface penetration.
- Slope is ≥ 30°, resulting in a narrow intertidal zone.
- By the nature of the high-energy setting, attached organisms are hardy and accustomed to high hydraulic impacts and pressures.

2 Exposed, Impermeable Substrates, Non-Vertical

- Regular exposure to high wave energy or tidal currents.
- Regular strong wave-reflection patterns.
- Slope is ≤30°, resulting in a wider intertidal zone.
- Substrate is impermeable with no potential for subsurface penetration.
- Sediments can accumulate at the base of bedrock cliffs, but are regularly mobilized by storm waves.
- Attached organisms are hardy and used to high hydraulic impacts.

3 Semi-Permeable Substrate, Low Potential for Oil Penetration and Burial; infauna present but not usually abundant

- The substrate is semi-permeable (fine- to medium-grained sand), with oil penetration usually ≤ 10 cm.
- Sediments are well-sorted and compacted (hard).
- On beaches, the slope is very low, ≤ 5°.
- Rate of sediment mobility is low, so potential for rapid burial is low.
- Surface sediments are often reworked by waves and currents.
- There are relatively low densities of infauna.

4 Medium Permeability, Moderate Potential for Oil Penetration and Burial; infauna present but not usually abundant

- The substrate is permeable (coarse-grained sand), with oil penetration up to 25 cm possible.
- The slope is intermediate, between 5° and 15°.
- Rate of sediment mobility is relatively high, with accumulation of up to 20 cm of sediments within a single tidal cycle possible; there is a potential for rapid burial and erosion of oil.
- Sediments are soft, with low trafficability.
- There are relatively low densities of infauna.

5 Medium-to-High Permeability, High Potential for Oil Penetration and Burial; infauna present but not usually abundant

- Medium-to-high permeability (mixed sand; gravel (≥20%)); with penetration ≥ 50 cm.
- Finer-grained sediments (sand to pebbles) are at the high-tide line and coarser sediments (cobbles to boulders) are in the storm berm.
- The slope is intermediate, between 8° and 15°.
- Sediment mobility is very high during storms; potential for rapid burial and erosion of oil.
- Sediments are soft, with low trafficability.
- Infauna and epifauna populations are low.

6 High Permeability, High Potential for Oil Penetration and Burial

- The substrate is highly permeable (gravel-sized sediments), with penetration ≥ 100 cm.
- The slope is intermediate to steep, between 10° and 20°.
- Rapid burial and erosion of shallow oil can occur during storms.
- There is high annual variability in degree of exposure.
- Sediments have lowest trafficability of all beaches.
- Natural replacement rate of sediments is the slowest (of beaches).
- Infauna and epifauna populations are low.

7 Exposed, Flat, Permeable Substrate; infauna usually abundant

- They are flat (≤ 3°) accumulations of sediment.
- Highly permeable, dominated by sand (some silt and gravel).
- Sediments are water-saturated so oil penetration is very limited.
- Exposure to wave or tidal-current energy is evidenced by ripples in sand, scour marks, or presence of sand ridges or bars.
- Width can vary from a few meters to nearly 1 km.
- Sediments are soft, with low trafficability.
- Infauna densities are usually very high.

8 Sheltered Impermeable Substrate, Hard; epibiota usually abundant

- They are sheltered from wave energy or strong tidal currents.
- Substrate is hard (bedrock, man-made materials, or stiff clay).
- The type of bedrock can be highly variable, from smooth, vertical bedrock, to rubble slopes, which vary in permeability to oil.
- Slope is usually steep (≥ 15°), resulting in a narrow intertidal zone.
- There is usually a very high coverage of attached algae and organisms.

9 Sheltered, Flat, Semi-Permeable Substrate, Soft; infauna usually abundant

- Sheltered from exposure to wave energy or strong tidal currents.
- The substrate is flat (≤ 3°) and dominated by mud.
- The sediments are water-saturated, so permeability is very low, except where animal burrows are present.
- Width can vary from a few meters to nearly 1 km.
- Sediments are soft, with low trafficability.
- Infauna densities are usually very high.

10 Vegetated Emergent Wetlands

- The substrate is flat (mud, sand, highly organic and muddy soils).
- Various types of wetland vegetation (herbaceous grasses, woody vegetation) cover the substrate. Floating and submersed aquatic vegetation are treated separately from the ESI classification as biological resources under the habitat.
- The break between salt- and brackish-water marshes and freshwater marshes occurs at the inland extent of 0.5 ppt salinity under average yearly low-flow conditions.
- The difference between scrub-shrub wetlands (<6 m) and swamps (=6 m) is plant height.

SHORELINE TREATMENT

SHORELINE TREATMENT RESPONSE OPTIONS

The objective of treating oiled shorelines is to accelerate natural recovery or remove stranded oil and oiled materials. Removing stranded oil involves a variety of physical, biological and chemical techniques. Biological and chemical methods attempt to alter the oil in order to enhance collection or accelerate natural weather processes.

1. Natural recovery method:

This method allows the shoreline to recover from an oil spill without human intervention. Natural shoreline processes such as waves and sediment re-working allow oil to become naturally weathered and degraded.

Response Option	Description
Natural recovery	The objective of natural recovery is to allow a site to recover without intervention or intrusion.

2. Physical response methods:

- **Washing techniques** – Those that involve using water and attempt to recover the oil for disposal.
- **Removal techniques** – Those that involve actual removal of the oil or oiled materials from the shore zone for disposal.
- **In-situ treatments** – Those that alter the character of the oil or change the location of the oil with respect to the intertidal zone to promote or increase weathering and natural degradation. They do not generate any oiled materials which require transfer and disposal.

Washing Techniques	Description
Flooding	The objective of flooding is to flood a site so that mobile or remobilized oil is lifted and carried downslope to a collection area. Pressure range: <20 psi; Temperature range: ambient water.
Low-pressure, Cold-water	The objective of low-pressure, cold-water washing is to wash or flush oils toward a collection area using normal temperature sea water at low pressure. Pressure range: <50 psi; Temperature range: ambient water.
Low-pressure, Warm/hot-water	The objective of low-pressure, warm/hot-water washing is to wash and flush oils at low pressure, using heated water, toward a collection area. Pressure range: <50 psi; Temperature range: 3-100°C.
High-pressure, Cold-water	The objective of high-pressure, cold-water washing is to wash or flush oils toward a collection area using normal temperatures sea water at high pressure. Pressure range: 50-1000 psi; Temperature range: ambient water.
High-pressure, Hot-water	The objective of high-pressure, hot-water washing is to wash and flush oils at high pressure, using heated water, toward a collection area. Pressure range: 50-1000 psi; Temperature range: 3-100°C.
Steam	The objective of steam cleaning is to remove stains or dislodge thin layers of viscous oil from hard surfaces. . Pressure range: 50-1000 psi; Temperature range: 200°C.
Sand Blasting	The objective of sand blasting is to remove stains or dislodge thin layers of viscous oil from hard surfaces using sand. Pressure range: ~50 psi; Temperature range: n/a.

Source: http://www.noaanews.noaa.gov/stories2011/images/controlledburnuscg.jpg

Removal Techniques	Description
Manual Removal	The objective of manual removal is to remove oil or oiled materials with manual labour and hand tools (rakes, forks, trowels, shovels, buckets, etc.). This method is ideal for small amounts of surface oil.
Vegetation Cutting	The objective of vegetation cutting is to remove oiled stems to prevent remobilization of the oil or contact by animals and birds, or to accelerate the recovery of the plants. This method is ideal where remobilization of oil will affect other resources.
Vacuum Systems	The objective of vacuum systems is to remove oil by suction from areas where it has pooled or collected in sumps. This method is ideal for light to medium, non-volatile, pooled or collected oil.
Mechanical Removal	The objective of mechanical removal is to remove oil and oiled materials using mechanical equipment (elevating scrapers, loaders, backhoes, trucks, graders, bulldozers, etc.). This method is ideal for large volumes of medium, heavy or solid oil.
Sorbents	The objective of sorbents is to place sorbents in a fixed location(s) so that they pick up oil by contact. Ideal for light to heavy, non-solid, non-volatile oils.

In-situ Treatments	Description
In-situ Burning	The objective of in-situ burning is to remove or reduce the amount of oil by burning it onsite. Ideal for large amounts of oil.
Mixing	The objective of mixing is to expose or breakup surface and/or sub-surface oil to accelerate evaporation and other natural degradation processes. Ideal for small amounts of medium to heavy oils, and buried oil.
Sediment Relocation	The objective of sediment relocation is to accelerate natural degradation by moving oil and oiled materials to areas with higher levels of physical wave energy. Ideal for buried oil stranded above the normal limit of wave action.

3. Chemical/Biological methods:

These methods alter the character of the oil or change the location of the oil with respect to the intertidal zone to promote or increase weathering and natural degradation. They do not generate any oiled materials which require transfer and disposal.

Biological / Chemical Techniques	Description
Dispersants	The objective of dispersants is to create fine oil droplets that are dispersed into the adjacent waters where they are then naturally weathered and degraded. Ideal for light to medium oils and fresh oils.
Shoreline Cleaners	The objective of shoreline cleaners is to remove and recover oil using a cleaning agent that lifts the oils from the substrate. Ideal for non-solid oils or as a pretreatment with collection methods.
Bioremediation	The objective of bioremediation is to accelerate natural biodegradation processes by the addition or nutrients (fertilizers containing nitrogen and phosphorus). Ideal for small amounts of residual oil.

Source: http://www.afrc.af.mil

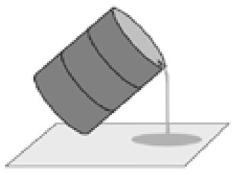
OIL VISCOSITY RANGES

Environment Canada (1998) has grouped oils and crudes into three categories based primarily on viscosity. Depending on the type of oil and the shoreline it is deposited on, different response options are employed.

Viscosity Ranges:

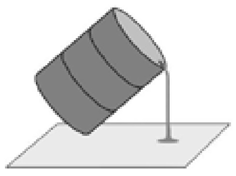
Light - Free flowing (Like water)

- Diesel
- Gasoline
- Heating oil
- Kerosene



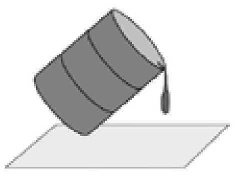
Medium - Slow pouring (Like molasses)

- Bunker A
- Fuel Oil No.4
- Lubricating oils
- Medium crudes



Heavy - Barely flowing (Like tar)

- Bunker B and C
- Fuel Oil No.6
- Weathered crudes
- Bitumen



Source: EPPR, 1998

Source: http://thecabin.net AP Photo/Log Cabin Democrat, Courtney Spradlin

Additional Resources

All oil properties and persistence descriptions are adapted from the following sources. Please refer to these resources for additional information. This is not meant to replace existing manuals and reference documents, nor is it a technical manual. Rather, it provides an overview of shoreline types and techniques available to responders.

- Environment Canada. 1998. Field guide for the protection and cleanup of oiled shorelines, Environment Canada, Atlantic Region, Environmental Emergencies Section, Dartmouth, NS, (2nd edition), pp. 53-94.
- Owens, E.H., and Sergy, G.A. 2004. The Arctic SCAT Manual: A Field Guide to the Documentation of Oiled Shorelines in Arctic Regions, Environment Canada, Edmonton, AB, Canada, 172 pages.
- Emergency Prevention, Preparedness and Response (EPPR). 1998. Field Guide for Oil Spill Response in Arctic Waters 1998. Environment Canada, Yellowknife, NT, Canada, 348 pages.

APPROPRIATE CLEAN-UP STRATEGIES FOR BEAUFORT SHORELINES

In the following section, strategies and techniques are outlined for the 22 shoreline types found in the upper intertidal zone along the Beaufort coast. SCAT classifications are listed for 25 shoreline types, however 3 were not found in this region. This section presents the primary shoreline types found in the Beaufort Sea environs and describes how oil behaves when it comes into contact with each substrate and shoreline type. Appropriate oil-spill response tools and cleanup techniques are recommended for each Arctic shoreline type.

MAN-MADE SOLID

Man-made (anthropogenic) structures composed of impermeable material such as concrete, asphalt, and metal. Common features in the North include structures for moorage (docks, wharfs, and marinas), protected anchorages (breakwaters), or backshore protection (seawalls - often built to protect the shore from erosion by waves, boat wakes, and currents) (Owens, 2010). These shorelines do not have extensive biological communities as plants are scraped off by ice, though some plants and animals can survive in cracks and crevices.

Oil on Man-Made Solid Structures

Predicted Oil Behaviour

- Stranded oil remains on the surface because man-made solid is impermeable.
- Oil reacts to man-made structures in a variety of ways depending on the material and surface texture present: concrete (rough), metal (smooth), and asphalt (rough). Oil is more likely to stick to rougher surfaces.
- Oil will likely be deposited in the upper half of the intertidal zone.
- Oil won't likely be deposited in the lower half of the intertidal zone as the surface is usually wet, and oil won't adhere.

Oil Persistence

- Oil residence on solid man-made structures is relatively short (days to weeks) for light oils. On exposed coasts, oil often does not strand due to wave reflection, though if stranded, oil is quickly washed away by wave action (days to weeks). When oil is splashed above the normal limit of wave action on exposed coasts, it may persist for long amounts of time (days to years).
- Along sheltered coasts, a band of oil is often deposited at or above the high tide line. Along these low energy coasts, heavy or weathered oils can persist for years.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++		
Low-pressure, cold-water	++	++	+
Low-pressure, warm/hot-water		++	+
High-pressure, cold-water			+
High-pressure, hot-water			+
Steam, sand blasting			+
Manual removal		+	+
Sorbents	+	+	
Dispersants		+	
Shoreline cleaners		+	

++ Good
+ Fair (for small amounts of oil only)

MAN-MADE PERMEABLE

Man-made (anthropogenic) structures composed of permeable material such as wood and riprap boulders (Owens, 2010). Common features in the North include rip rap, structures for moorage (docks, wharfs and marinas), protected anchorages (breakwaters), or backshore protection (seawalls) (Owens, 2010).

Source: http://www.kaganandsonllc.com/images/6x12_riprap.jpg

Oil on Man-Made Permeable Structures

Predicted Oil Behaviour

- In each case, an oiled man-made permeable structure would be treated or cleaned in the same manner as a natural shoreline type with equivalent characteristics.
- Dolos, riprap, tires, and timber posts are on the same size order as boulders.
- Gabion mats or baskets would be defined as boulder, cobble, or pebble/cobble, depending on the size of the material used.

Oil Persistence

- On exposed coasts, oil often does not strand due to wave reflection, though if stranded, oil is washed away relatively quickly by wave action (weeks to months). On more sheltered coasts, oil may persist for long amounts of time (months to years).

Preferred Response Options

- Permeable man-made structures are considered in the context of the size of the material used for construction.

Boulder beaches or Riprap Shorelines

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	+
Flooding	++	++	
Low-pressure, cold-water	++	++	+
Manual removal	+	+	++
Sorbents	+	+	+

Pebble-cobble Beaches

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	
Mixing	+	+	
Sediment relocation	+	+	
Bioremediation	+	+	

++ Good
+ Fair (for small amounts of oil only)

BEDROCK

Bedrock shorelines are impermeable outcrops of consolidated native rock (Owens, 2010). Bedrock cliffs are sloped faces >35° and in some areas erosion can create notches, caves, sea-arches, and sea-stacks. Platforms are near horizontal with an overall slope <5° (Owens, 2010). Ramps have an inclined slope in the range of >5° to <35° (Owens, 2010). These shorelines do not have extensive biological communities as plants are scraped off by ice, though some plants and animals can survive in cracks and crevices.

Oil on Bedrock

Predicted Oil Behaviour

- Stranded oil remains on the surface of a bedrock shoreline because bedrock is impermeable.
- Oil may be deposited in the upper half of the intertidal zone as it adheres to the dry bedrock.
- Oil won't likely be deposited in the lower half of the intertidal zone as the bedrock is usually wet, and oil cannot adhere to the surface, but could penetrate crevices or sediment veneers.

Oil Persistence

- Typically, oil does not strand due to high wave action and reflection on exposed coasts. Oil can be splashed above the limit of normal wave action but will often be removed rapidly (days to weeks) by normal wave action.
- Along sheltered, low energy coasts, oil is often deposited in the upper intertidal zone in a strip at the high-water mark. Heavier oils can persist for long amounts of time (years) due to low wave action while light oils will likely wash off in a short time (days to weeks).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low-pressure, cold-water	++	++	+
Low-pressure,warm/hot-water		++	+
High-pressure, cold-water			+
High-pressure, hot-water			+
Manual removal	+	+	+
Vacuum systems	++	++	+
Sorbents	+	+	
Dispersants		+	
Shoreline cleaners		+	

++ Good
+ Fair (for small amounts of oil only)

SAND BEACH OR BANK

A beach composed of sand, for which the grain size diameter is in the range of 0.0625 mm to 2.0mm. Small amounts (<10%) of granules (2 to 4 mm diameter), pebbles, cobbles, boulders, silts, or clay may be present. Sand beaches can be subdivided based on the dominant size of the sand: coarse-sand beaches have larger sand grain size (0.5 to 2 mm diameter) and usually have steeper slopes and poorer bearing capacity; fine-sand beaches (grain size < 0.5 mm) have a flatter slope and are typically more compacted and provide better traction and higher bearing capacity (Owens, 2010). These shorelines have minimal biological communities due to their high-energy environments. Few species of burrowing animals live in this environment.

Oil on Sand Beaches

Predicted Oil Behaviour

- Sand beaches are permeable for some medium and all light oils. Wave action can easily result in mixing, burial or erosion of these lighter stranded oils.
- On a medium- or coarse-grained sand beach, light oils can easily penetrate and mix with ground water. Changing tide levels can refloat and transport lighter oils.
- Medium and heavy oils are unlikely to penetrate more than 25 cm because the water table for sand beach is close to the surface. When wave action occurs, mixing or burial of heavier oils can easily occur due to sand's mobile properties.
- Oil does not stay stranded in the lower intertidal zones as the sand is usually wet due to backwash and ground water. Lighter oils would be refloated up the beach and deposited in the upper intertidal zone.

Oil Persistence

- Along exposed coasts, oil persistence will be short (days to weeks) due to higher wave action. Sheltered coasts generally have longer oil persistence (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	
Mixing	+	+	
Sediment relocation	+	+	

++ Good
+ Fair (for small amounts of oil only)

MIXED SEDIMENT BEACH OR BANK

A beach composed of sand plus any combination (>10%) of granule, pebble, cobble, and/or boulders. The interstitial spaces (voids) between the coarse pebble/cobble fractions are in-filled with sand or granules. This important characteristic distinguishes a mixed sediment beach from a pebble/cobble beach. This beach ranges from fine-mixed (sand, granule and pebble, also called sand/gravel beach) to coarse-mixed, which includes larger cobble material. A mixed sediment beach with boulders is distinguished from a boulder beach by having a proportion of boulders < 25%. Minimal biological resources can survive in the upper intertidal zone and higher-energy environments. Species are more likely to be found in the lower sections of the intertidal zone or in sheltered environments.

Oil on Mixed-Sediment Beaches

Predicted Oil Behaviour

- Lighter oils are able to penetrate a mixed-sediment beach (with medium and coarse-grained sediments) enabling oil to mix with groundwater and/or be transported by the changing tide.
- Medium or heavy oils do not penetrate a mixed-sediment beach as easily as a coarse-sediment beach.
- Oil does not stay stranded in the lower intertidal zones as the sand is usually wet due to wave action and groundwater. Lighter oils would be refloated up the beach and deposited in the upper intertidal zone and above the high-tide swash.

Oil Persistence

- Generally, along exposed coasts, oil persistence will be short (days to weeks) due to higher wave action. Sheltered coasts generally have longer oil persistence (months to years).
- Oil that penetrates below the surface may persist for long amounts of time and may not be physically reworked except during infrequent, high-energy storms.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	
Mixing	+	+	
Sediment relocation	+	+	

++ Good
+ Fair (for small amounts of oil only)

PEBBLE/COBBLE BEACH OR BANK

A beach where the clearly dominant material is pebbles and/or cobbles. Pebbles have a grain-size diameter of 4 to 64 mm; cobbles are in the 64 to 256 mm range. The interstitial spaces between individual pebbles or cobbles are relatively open and not in-filled with finer material. This important characteristic distinguishes a pebble/cobble beach from a mixed sediment beach. Small amounts of sand may be present (≤10%). Granules (2 to 4 mm diameter) usually are included in the pebble category. This beach type includes pebble beach, cobble beach, and pebble/cobble beach. Minimal biological resources can survive in the upper or middle intertidal zone and higher-energy environments. Species are more likely to be found in the lower sections of the intertidal zone or in sheltered environments.

Oil on Pebble-Cobble Beaches

Predicted Oil Behaviour

- Pebble-cobble beaches are permeable to all oils except semi-solid oils. The larger the sediment size, the deeper the oil is able to penetrate.
- Light or non-sticky oils can easily be flushed out of surface sediments due to the large gaps between pebbles and cobbles. Retention of oil is usually low, as oil is naturally flushed away.
- Oil does not usually stay stranded in the lower intertidal zones as the sand is usually wet due to backwash and groundwater. Lighter oils would be refloated up the beach and deposited in the upper intertidal zone.

Oil Persistence

- Oil that penetrates below the surface may persist for long amounts of time and may not be physically reworked except during infrequent, high-energy storms.
- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered (low-energy) shorelines will generally have longer oil residence times (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	+
Low-pressure, cold-water	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	+	++
Sorbents	+	+	+
Mixing	+	+	
Sediment relocation	+	+	
Bioremediation	+	+	

++ Good
+ Fair (for small amounts of oil only)

BOULDER BEACH OR BANK

This shoreline type consists of an unconsolidated accumulation of boulders in the shore zone. Boulders are, by definition, greater than 256 mm in diameter (roughly the size of a basketball). Pebble-cobble material is common in the subsurface of boulder beaches. Boulder beaches frequently give way to mud or sand tidal flats in the lower intertidal zone. A boulder beach is distinguished from a mixed sediment beach with boulders by having a proportion of boulders greater than 25%. This shoreline supports higher amounts of biological communities, due to the stable nature of the shoreline. Plants and animals are common on or between boulders.

Oil on Boulder Beaches

Predicted Oil Behaviour

- Boulder beaches are permeable, and have a stable surface layer.
- The large spaces between the individual boulders allow all types of oil to be carried into the sediments.

Oil Persistence

- Oil persistence is primarily a function of the oil type and wave-energy levels on the beach. Light or non-sticky oils can easily be flushed out of surface sediments due to the large gaps between boulders.
- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered (low-energy) shorelines will generally have longer oil residence times (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	+
Flooding	++	++	
Low-pressure, cold-water	++	++	+
Manual removal	+	+	++
Sorbents	+	+	+

++ Good
+ Fair (for small amounts of oil only)

MUD/CLAY BANK

A mud/clay bank is a river bank composed of mud/clay. This shoreline type is used solely in association with riverine environments (rather than ocean shorelines). The slope can range between a flat (0°) and a cliff (>35°). These shorelines are often backed by wetland vegetation. Typically, biological utilization is lower in areas where stronger are currents present in the riverine environment, but can be high in sheltered areas.

Oil on Mud/Clay Bank (Riverine)

Predicted Oil Behaviour

- Oil penetration is limited on mud/clay banks because the clay substrate is impermeable. Oil will likely not adhere to the substrate if wet or if a vertical clay surface is present.
- A thin band of oil may remain at or above the high water line.

Oil Persistence

- Exposed shorelines will generally have short oil persistence (days to weeks) as oil is removed by wave action.
- Oil may persist in sheltered (low-energy) shorelines where the slope is moderate for longer periods of time (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	++
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal		+	+
Vacuum systems	++	++	
Sorbents	+	+	+

++ Good
+ Fair (for small amounts of oil only)

MUD TIDAL FLAT

Mud flats have a level or low angle sloping surface dominated by very fine sediments – typically silt and clay with a grain size less than 0.0625 mm. They may or may not include organic detritus and/or small amounts of sand. They are usually wide, but can range from a few meters to hundreds of meters (Owens, 2010). Granules, pebbles, cobbles, and boulders may be present as long as they consist of less than 10%. Biological productivity in these habitats is very high as they include many species of plants, bivalves, worms, and other invertebrates. These shorelines are a primary feeding ground for birds.

Oil on Mud Tidal Flats

Predicted Oil Behaviour

- Oil penetration is limited on mud flats because these flats do not fully drain at low tide and many sections remain water-saturated. Some low-viscosity oils may mix with the waters in the sediments.
- Lighter oils may be refloated up the flat by the tide and deposited in the upper intertidal zone or on crests of dry ridges.
- Highly viscous or dense oil may become buried. The oil may penetrate the subsurface through mud cracks or holes of burrowing animals and persist in the subsurface sediments for long periods (years).

Oil Persistence

- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered (low-energy) shorelines will generally have longer oil residence times (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	++
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal			+
Vacuum systems	++	++	
Sorbents	+	+	+

++ Good
+ Fair (for small amounts of oil only)

SAND TIDAL FLAT

Sand flats have a level or low angle sloping surface (<5°) in which the dominant sediment is sand (grain size diameter 0.0625 mm to 2.0mm) (Owens, 2010). Granules, pebbles, cobbles, and boulders may be present as long as they consist of less than 10%. Sand flats are usually wide, but can range from a few meters to hundreds of meters in width and have a very dynamic, mobile, and unstable surface layer. Biological utilization is high in these shorelines as they have high numbers of infauna, provide important bird and insect habitat, and provide foraging areas for fish.

Oil on Sand Tidal Flats

Predicted Oil Behaviour

- Oil penetration is limited on sand flats because these flats do not fully drain at low tide and many sections remain water-saturated. Some low-viscosity oils may mix with the waters in the sediments.
- Lighter oils may be refloated up the flat by the tide and deposited in the upper intertidal zone or on crests of dry sand ridges.
- Highly viscous or dense oil may become buried. The oil may penetrate the subsurface through the holes of burrowing animals and persist in the subsurface sediments for long periods (years).

Oil Persistence

- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered, (low-energy) shorelines will generally have longer oil residence times (months to years). Mixing and sediment relocation are more effective on flats with wave or current action.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	++
Flooding	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal			++
Sorbents	+	+	

++ Good
+ Fair (for small amounts of oil only)

MIXED AND COARSE SEDIMENT TIDAL FLAT

A tidal flat composed of sand or mud, plus any combination of coarse sediments (>10%) such as granules, pebbles, cobbles, and boulders. The shorelines are sometimes referred to as "gravel" flats. This shore type includes both mixed and coarse sediment flats where the distribution of sand (or mud) versus coarse sediments may range greatly. On mixed sediment flats, the coarser pebble/cobble fractions are in-filled with sand or granules. On coarse sediment flats, there is a distinct surface layer of coarse sediment without the sand infill. Minimal biological resources can survive in the upper intertidal zone and higher-energy environments. Species are more likely to be found in the lower sections of the intertidal zone or in sheltered environments.

Oil on Mixed-Sediment Tidal Flat

Predicted Oil Behaviour

- Lighter oils are able to penetrate a mixed-sediment flat (with medium and coarse-grained sediments) enabling oil to mix with ground water and/or be transported by the changing tide.
- Highly viscous or dense oil may become buried. The oil may penetrate the subsurface through the holes of burrowing animals and persist in the subsurface sediments for long periods (years).
- Oil does not stay stranded in the lower intertidal zones as the sand is usually wet due to wave action and groundwater. Lighter oils would be refloated up the flat and deposited in the upper intertidal zone.

Oil Persistence

- Generally, along exposed coasts, oil persistence will be short (days to weeks) due to higher wave action. Sheltered coasts generally have longer oil persistence (months to years).
- Oil that penetrates below the surface may persist for long amounts of time and may not be physically reworked except during infrequent, high-energy storms.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	

++ Good
+ Fair (for small amounts of oil only)

ICE-RICH TUNDRA CLIFF

Ice-rich tundra cliffs are an erosional feature on Arctic coasts primarily composed of a tundra mat, peat, and ice, with relatively little sediment (Owens, 2010) and are generally fronted by sand or gravel beaches. Ice-rich tundra cliffs are uniquely an arctic shoreline type. It is common to see several mass wasting processes on tundra cliffs, such as surface wash, ground ice slumps, debris slides, bloc failure, and thermo-erosional falls. Mudflows from the slump typically flow across the beach (Owens, 2003). Minimal biological resources can survive on the surface of tundra cliffs because of their unstable nature, though the vegetation on the tundra is sensitive to disturbance, and migratory birds use these shorelines during the summer months.

Oil on Ice-Rich Tundra Cliffs

Predicted Oil Behaviour

- Oil that is washed up on exposed ground ice is unlikely to stick and would flow back down onto the beach unless air temperatures are below freezing.
- If there are fragmented or slumped blocks at the base of the cliff, oil may pool in the spaces between the blocks. This is likely to occur at the top of a beach where both oil and peat blocks often accumulate.
- Oil may be splashed on to the top of a low cliff surface where it would be untouched by normal wave action. Sand and gravel may be deposited on the surface during storm wave action. If these substrates become oiled, they would be treated as sand or pebble-cobble depending upon their character.

Oil Persistence

- Oil persistence is usually short due to natural erosion. Oil persistence may be longer if the oil is buried by block falls or incorporated into peat slurries. If oil is on the cliff surface or on slumped tundra blocks, it will likely be reworked and remobilized by wave action.
- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered, low-energy shorelines will generally have longer oil residence times (months to years). Mixing and sediment relocation are more effective on shores with wave action.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	++
Low pressure, cold water	++	++	++
Manual removal		+	+
Mechanical removal		++	++
Sorbents	+	+	
Mixing	+	+	+
Sediment relocation	+	+	+

++ Good
+ Fair (for small amounts of oil only)

ICE-POOR TUNDRA CLIFF

Ice-poor tundra cliffs are unconsolidated sediment cliffs with an overlying surface layer of tundra vegetation and peat, and may have minor interstitial ice in the cliff face (Owens, 2010). These cliffs are generally fronted by narrow gravel or sand beaches. The dominant mass wasting processes for ice-poor tundra cliffs are surface wash and debris slides (Owens, 2003). Minimal biological resources can survive on the surface of tundra cliffs because of their unstable nature, though the vegetation on the tundra is sensitive to disturbance, and migratory birds use these shorelines during the summer months.

Oil on Ice-Poor Tundra Cliffs

Predicted Oil Behaviour

- If there are fragmented or slumped blocks at the base of the cliff, oil may pool in the spaces between the blocks. This is likely to occur at the top of a beach where both oil and peat blocks often accumulate.
- If there is a sand or mixed sediment beach at the base of the cliff, oils may penetrate. If these substrates become oiled, they would be treated as sand or mixed sediment depending upon their character.
- Oil may be splashed on to the top of a low cliff surface where it would be untouched by normal wave action. Sand and gravel may be deposited on the surface during storm wave action. If these substrates become oiled, they would be treated as sand or pebble-cobble depending upon their character.

Oil Persistence

- Oil persistence is usually short due to natural erosion. Oil persistence may be longer if the oil is buried by block falls, incorporated into peat slurries or absorbed into a beach. If oil is on the cliff surface or on slumped tundra blocks, it will likely be reworked and remobilized by wave action.
- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered, (low-energy) shorelines will generally have longer oil residence times (months to years). Mixing and sediment relocation are more effective on shores with wave action.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	++
Low pressure, cold water	++	++	++
Manual removal		+	+
Mechanical removal		++	++
Sorbents	+	+	
Mixing	+	+	+
Sediment relocation	+	+	+

++ Good
+ Fair (for small amounts of oil only)

SEDIMENT CLIFF

Sediment cliffs are cliffs of unconsolidated sediment which may or may not have a surface layer of vegetation (other than tundra) at the top. Sediment/rock fragments can be various sizes and shapes and can range from fine to coarse and angular (Jackson, 1997). This class includes sediment cliffs in the form of talus and dunes as well. Sediment cliffs are distinguished from ice-poor tundra cliffs by the absence of tundra vegetation or peat mat at the top of the cliff. Minimal biological resources can survive on the surface of sediment cliffs because of their unstable natures.

Oil on Sediment Cliff

Predicted Oil Behaviour

- Lighter oils would be refloated up the cliff and deposited in the upper intertidal zone at the high water line.
- Sand is permeable for some medium and all light oils. Sand is generally impermeable for most medium and heavy oils. Burial and natural removal of oil can occur during major slumping or erosional events.
- Light oils can easily penetrate medium and coarse-grained sediments. These sediments are permeable, and usually have an unstable surface layer.
- The large spaces between bigger sediments allow all types of oil to be carried into the sediments.
- See boulder beach for the treatment of oiled boulder talus slope.

Oil Persistence

- On exposed coasts, oil often does not strand due to wave reflection, though if stranded, oil is washed away relatively quickly by wave action (weeks to months). On more sheltered coasts, oil may persist for long amounts of time (months to years).

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low-pressure, cold-water	++	++	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	
Mixing	+	+	
Sediment relocation	+	+	

++ Good
\+ Fair (for small amounts of oil only)

DRIFTWOOD

Driftwood shorelines are dominated (>75% of ground cover) by floating wood and logs that have been deposited on the shore by wave action (Solomon, 2004). Low-lying areas in the Arctic are susceptible to flooding by meteorological tides, or storm surges, and the inland extent of these occasional marine incursions is commonly marked by log or debris lines (Owens, 2010). Minimal biological communities exist on driftwood shorelines, though plants and animals can be found on or between logs.

Oil on Driftwood

Predicted Oil Behaviour

- An oiled driftwood shoreline would be treated or cleaned in the same manner as a shoreline type with equivalent characteristics.
- Driftwood is on the same size order as boulders and creates a similar gap size and thus should be treated as a boulder beach.
- Driftwood is permeable, and has a stable surface layer. Oil will adhere to the dry surface of the driftwood.
- Driftwood frequently overlays sand or mixed sediment beaches.
- The large spaces between the individual pieces of driftwood allow all types of oil to be carried into the sediments.

Oil Persistence

- Oil persistence is primarily a function of the oil type and wave-energy levels on the beach. Light or non-sticky oils can easily be flushed out of surface sediments due to the large gaps between driftwood pieces.
- Exposed (high-energy) shorelines will generally have short oil persistence (days to weeks), and sheltered (low-energy) shorelines will generally have longer oil residence times (months to years).

Preferred Response Options (Same as Boulders)

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	+
Flooding	++	++	
Low-pressure, cold-water	++	++	+
Manual removal	+	+	++
Sorbents	+	+	+

++ Good
+ Fair (for small amounts of oil only)

SNOW AND ICE

A shoreline composed of snow and/or ice that covers the underlying substrate. Semi-permanent snow patches are common along the eastern shore of the high Arctic. They cover the underlying substrate materials and persist in the supratidal zone and sometimes into the upper intertidal zone throughout the summer open water season. Biological communities are not present along these shorelines. Common ice features that form in the shore zone include shore-fast ice, ice floes stranded on a shore, and tundra erosion exposing permafrost and ground ice at the shore.

Oil on Snow and Ice

Predicted Oil Behaviour

- Since snow is permeable, stranded oil will be absorbed into the snow and be partially contained by the snow (natural sorbent). The freeze-thaw process forms ice lenses within the snow which can limit penetration of oil into snow.
- Oil-in-snow content is dependent on oil type and snow character, and is lowest on firm compacted snow surfaces in below-freezing temperatures and highest for fresh snow conditions.
- Oil causes snow to melt. For example, crude oils cause lots of snow to melt but do not spread over a wide surface area. Gasoline causes some melting but has the ability to move quickly in snow and cover a larger area. Light oils are able to move upslope through snow by capillary action.
- The presence of ice in the shore zone helps prevent oil on surface water from making contact with shore substrates.
- Ice is impermeable so stranded oil remains on the surface. Oil will not adhere to the ice surface unless air, water, and oil surface temperatures are below 0°C.
- Where there is broken ice present, without a landfast ice cover, oil may reach the shore and become stranded on the substrate in between the ice pieces.

Oil Persistence

- Oil persistence on ice and snow is highly variable. Oil may freeze onto the ice surfaces and remain stranded until the ice melts. Once the ice and snow melt, the oil may then penetrate into the underlying substrate and may persist for long periods of time, depending on the substrate and exposure.

Preferred Response Options

Snow

Treatment Method	Light	Medium	Heavy
Natural recovery	++	+	
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	+	++	++
Sorbents	+	+	+
In-situ burning	++	++	

Ice

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++		
Low pressure, cold water	++	++	+
Low pressure, warm/hot water		++	++
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal	++	++	++
Sorbents	+	+	
In-situ burning	++	++	++

++ Good
+ Fair (for small amounts of oil only)

MARSH

Periodically or permanently flooded, marshes have no trees or bushes (<25%), and in-season vegetation (>25% local vegetation density) can be seen emerging above the water (Grenier *et al.*, 2007). Coastal marshes are covered at least once a month by salt or brackish water at high tide and support salt-tolerant plants such as grasses, rushes, reeds, and sedges. Marsh types vary significantly in species assemblages, in substrate character, and in size (Owens, 2010). Typically, sediments are composed of organic muds. Marshes can also be characterized by bare patches (ice scour). Marshes are distinguished from swamps by having shallower water and less open water than swamps and are dominated by herbaceous vegetation rather than trees or shrubs. These shorelines are extremely productive for plant and animal life, and provide habitat to many migratory birds.

Oil on Marshes

Predicted Oil Behaviour

- Oil adheres readily to marsh vegetation.
- The fringe of a marsh can be impacted by oil during neap high tides or normal water levels. Oil on the fringe may be washed by subsequent tides and weathered somewhat rapidly, depending on energy levels.
- Higher interior meadow areas can be deposited with oil during periods of spring tides or higher water levels. Oil on the meadow area may weather slowly as it experiences little wave action.
- Light oils may penetrate into marsh sediments through cracks or holes of burrowing animals and persist in the subsurface sediments for long periods (years). Medium and heavy oils will remain on the surface and may smother plants and animals.

Oil Persistence

- Natural recovery rates vary and recovery may take as little as a few years following light oiling but may take decades in extensive, thick deposits of viscous oil.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	+
Flooding	++	++	
Low pressure, cold water	++	++	
Manual removal			+
Vegetation cutting		+	+
Sorbents	+	+	

++ Good
+ Fair (for small amounts of oil only)

PEAT SHORELINE

A shoreline where the dominant substrate is peat - a spongy compressible, fibrous material that forms by the incomplete decomposition of plant materials (Owens, 2010), found in a water-saturated environment, such as a fen or bog. Peat can have a persistently high moisture content (80-90%). As tundra outcrops erode, peat is released and often accumulates in low-energy, sheltered areas. The peat deposits may occur as 1) a mat on a beach which may be wet or dry and are easily eroded and redistributed by wave or current action, or 2) a mobile slurry which may appear like coffee grounds, occurs in the water, often at the edge of the beach or shore, and consists of thick mats of suspended peat (Owens, 2003). This shoreline can also include soil and other organic materials.

Oil on Peat Shoreline

Predicted Oil Behaviour

- Heavy oils do not generally penetrate deeply into a peat mat (even if dry or dewatered). These oils may be buried or become mixed with peat where it is reworked by wave action.
- Light oils will generally penetrate into a peat mat. When this occurs, there may be relatively little recoverable oil on the surface.
- Dry peat can hold large amounts of oil: 1 to 5 kg of oil/kg of dry peat.
- When oils contact a peat slurry, mixing will likely occur. The slurry behaves in a similar manner as loose granular sorbent and is able to partially contain and prevent the oil from spreading.

Oil Persistence

- Stranded oil will have a low residence time due to high erosion rates along these shores.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low pressure, cold water	+	+	+
Manual removal	+	+	+
Vacuum systems	++	++	
Mechanical removal		++	++
Sorbents	+	+	
Mixing		+	
Sediment relocation		+	

++ Good
+ Fair (for small amounts of oil only)

INNUNDATED LOW-LYING TUNDRA

This shoreline type is characterized by very low-lying coastal tundra that is flooded or inundated by marine waters during spring high tides or wind-induced surges (Owens, 2010). These low-lying areas are not normally located within the intertidal zone (Owens, 2003). It is characterized with regular geometric patterns, e.g. a network of vegetated strings and shallow water ponds. Subsidence in some locations has resulted in permanent inundation of coastal tundra. The shore zone is dominated by vegetation which is salt-tolerant. These shorelines are important for animal life, and provide habitat to many migratory birds.




Oil on Inundated Low-Lying Tundra

Predicted Oil Behaviour

- In the summer, inundated low-lying tundra is often water-saturated, restricting oil to surface areas only. Oil may collect on the surface of the water in shoreline indentations (i.e. breached polygons) and may be refloated and carried away by high tides.
- Vegetation is often water-saturated which limits oil penetration.
- Where the tundra surface is covered by peat (see Peat Shoreline), heavy oils do not generally penetrate deeply into a peat mat (even if dry or dewatered). These oils may be buried or become mixed with peat where it is reworked by wave action. Light oils will generally penetrate into a peat mat. When this occurs, there may be relatively little recoverable oil on the surface.
- Lighter oils may be refloated up the flat by the tide and deposited in the upper intertidal zone or on crests of dry sand ridges.
- Other substrates may be present with inundated low-lying tundra. Wave action may push sand, gravel, and driftwood on to the intertidal zone and backshore directly on the vegetation or peat mat. If these substrates become oiled, they would be treated as sand, pebble, cobble or boulder beaches depending upon their character.

Oil Persistence

- Natural recovery rates vary and recovery may take as little as a few years following light oiling but may take decades in extensive, thick deposits of viscous oil.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	
Flooding	++	++	
Low pressure, cold water	++	++	++
Manual removal		+	+
Vacuum systems	++	++	
Sorbents	+	+	

++ Good
+ Fair (for small amounts of oil only)

VEGETATED BANK

Vegetated banks consist of upland vegetated terrain alongside the bed of a river, creek or stream. The vegetation can consist of any type (herbaceous, shrub, and/or tree) with >25% ground cover. This class is used solely in association with riverine environments (rather than ocean shorelines). Occasionally these shorelines are flooded by high water. These shorelines are biologically rich habitats.

Oil on Vegetated Banks

Predicted Oil Behaviour

- When the water level is high, oil readily adheres to vegetation and will coat the surface.
- If the vegetation is thick, it will help restrict oil from penetrating the vegetation. Oiling will be heaviest on the outer fringe of vegetation.
- When the water level is low, there is less impact to the vegetation and oil will only coat a narrow band of sediment at the high water mark. This band may vary with changing tidal levels.

Oil Persistence

- Natural removal rates can be very slow due to low energy environments and dense vegetation.

Preferred Response Options

Treatment Method	Light	Medium	Heavy
Natural recovery	++	++	+
Low pressure, cold water	++	++	
Manual removal			+
Vacuum systems	++	++	++
Sorbents	+	+	
Vegetation cutting		+	+

++ Good
+ Fair (for small amounts of oil only)

SUPRATIDAL AND BACKSHORE TYPES

The Backshore and Supratidal zones are areas that see little to no wave action, resulting in little to no oil reaching these zones. There are no cleanup techniques defined for these zones, but it is still important to characterize them as they define access constraints to the intertidal zone, and can be used as potential staging areas during oil-spill cleanup operations (Owens, 2004). Vegetation found in these zones are typically non-saltwater tolerant species.

FOREST

An upland area in which trees are the dominant land cover type (>25% ground cover). Trees are typically more than 2 meters tall though may be stunted in northern environments due to climate. A forest can contain deciduous, coniferous or mixed vegetation. Coniferous forests occur when coniferous species contribute >75% of the total tree area. Below the tree canopy, underbrush can be present and include herbs, shrubs, and saplings.

HERBACEOUS

An upland area in which herbaceous vegetation is the dominant land cover type (>25% ground cover). A herbaceous plant is one that has leaves and stems which die down at the end of the growing season to the soil level. They have no persistent woody stem above ground and can be annuals or perennials. Grasses and forbes dominate this landscape. Vegetation can vary in height and is typically influenced by the amount of annual rainfall.

ICE-WEDGE POLYGONS

Ice-wedge polygons are one of the most common features in the Arctic. Several wedges connected together create a pattern in the ground called an ice-wedge polygon. (1) Low-centered polygons develop as ice wedges grow, pushing the adjacent ground upward to form a raised rim. When several ice wedges join together, an irregular polygon is created. The raised rim of this polygon tends to trap water, creating a pattern of small wetlands. Low-centred polygons occur where ice wedges are actively growing. (2) A high-centred polygon develops when plant material eventually fills the central wetland area of a low-centred polygon. Instead of pooling in the center of the polygon, water runs off into the bordering troughs (Parks Canada, 2010). (3) Dried out ice-wedge polygons are un-vegetated but patterns are still visible.

NATURAL BARREN SURFACE

Natural barren suface describes an unproductive area of land where plant growth is sparse, stunted or not present (<25% vegetation). Poor growth may occur due to high winds, climate, or infertile soil. Unconsolidated sediment and soil is exposed and visible. This land cover type occurs on upland sites.

SHRUBLAND

An upland area in which the plant community is characterized by vegetation dominated by woody shrub species (>25% ground cover) and often includes grasses and herbs. A shrub is defined as a woody plant with one or multiple stems generally not exceeding 6m tall. Deciduous shrubland occurs when deciduous species contribute >75% of the total tree area (Wulder and Nelson, 2003). Shrubland can occur as mature vegetation and remain stable over time or it can occur as the result of a disturbance, such as fire.

SWAMP

These shorelines are generally composed of stagnant water at high water periods or slowly draining water occupied by shrubs and trees (>25% ground cover). The vegetation cover can be continuous or take the form of groves (Grenier et al., 2007). Both coniferous and deciduous trees, or tall shrub vegetation cover may be present (Warner and Rubec, 1997). They are distinguished from marshes by their greater proportion of open water surface and are dominated by trees or shrubs rather than herbaceous vegetation.

TUNDRA

Tundra is a treeless, level or gently undulating plain characteristic of Arctic and Subarctic regions (Bates and Jackson 1980). Tundra has a spatially varying mix of plant cover composed of dwarf shrubs, grasses, mosses, and lichens (>25% ground cover). It is frequently characterized by ice-wedge polygons that form as water fills then freezes in cracks in the permafrost (Owens, 2003). Tundra is found in a permafrost environment. Tundra that extends to the land/water interface with no discernible UI zone and which does not appear to be inundated low-lying tundra is classified as a peat shoreline.

WATER BODIES

Water bodies include any significant accumulation of water on the surface. These water bodies may be flowing or standing and include all water bodies other than wetlands, such as lakes, rivers, ponds and streams, etc. Man-made water bodies, such as reservoirs, are also included in this land cover class.

GLOSSARY OF TERMS

across-shore zone - the division of an alongshore segment into zones based on tidal elevations (Owens, 2010).

alongshore segment - a relatively homogeneous along-shore section of the shoreline; within a segment, the morphology, sediment texture, major biological assemblages, and dynamic physical processes do not vary in the alongshore direction (Owens, 2010).

backshore - the area above the current limit of marine processes. This coastal zone is not directly impacted by marine processes (Owens, 2010).

beach - a gently sloping zone of unconsolidated material, typically with a slightly concave profile, extending landward from the low-water line to the place where there is a definite change in material or physiographic form (such as a cliff) or to the line of permanent vegetation (usually the effective limit of the highest storm waves); a shore of a body of water, formed and washed by waves or tides, usually covered by sand or gravel (Jackson, 1997).

cliff - sloped face >35° and in some areas erosion can create notches, caves, sea-arches, and sea-stacks (Owens, 2010).

delta - forms at the mouth of a river where it flows into the ocean. Deltas are formed from the deposition and accumulation of the sediments carried by the river as the flow leaves the mouth of the river (confined) into the ocean (open).

dune - hill of sand built by wind or wave transport. Coastal dunes form where constructive waves encourage the accumulation of sand, and where prevailing onshore winds blow this sand inland.

ecosystem - describes the complex of biotic populations, the biophysical (environmental) constraints on the biotic populations, and the ability of the complex to function as an ecological unit (Osterkamp, 2008).

epifauna - animals living on the surface of the seabed or a riverbed, or attached to submerged objects or aquatic animals or plants.

ESI – Environmental Sensitivity Index. A shoreline classification system used to classify the sensitivity of coastal regions to oil spills (CORI and AMR, 2007).

eSPACE – Emergency Spatial Pre-SCAT for Arctic Coastal Ecosystems. A project which was initiated to provide baseline coastal mapping in order to support a range of coastal planning activities, including oil spill response and clean-up efforts.

fetch - the combination of fetch length (the length of open water over which a given wind has blown) with wind speed and direction determines the size and power of the waves produced. The longer the open water available for the wind to drag along the water, the more potential energy the wave will have. When combined with strong winds blowing in the same direction, a large fetch can produce destructive waves.

flat (tidal) - an extensive, nearly horizontal, barren or sparsely vegetated tract of land that is alternately covered and uncovered by the tide, and consists of unconsolidated sediment (mostly clays, silts and/or sands and organic materials) (Jackson, 1997).

flat/lowland - an extensive expanse of land nearly absent of local topography/relief. Appropriate for marsh, swamp, peatland, all tidal flats (mixed and coarse sediment, mud, sand), and inundated low-lying tundra shorelines.

foreshore – same as intertidal.

habitat – the living space for one or more organisms; it is described by the combined environmental parameters of biotic and abiotic factors (Osterkamp, 2008).

impermeable - a material which doesn't allow liquids or gases to pass through it.

infauna - the animals living in the sediments of the ocean floor or river or lake beds.

intertidal zone - the zone between the astronomical high-high water line and astronomical low-low waterline; is the section of shoreline that falls within the normal tidal range; is often further divided into three separate sub-zones (Owens, 2010).

lower intertidal zone - the lower approximate one-third of the intertidal zone.

mid intertidal zone - the middle approximate one-third of the intertidal zone.

nearshore subtidal – the region between the 0 and 30m isobath. The 30m isobath is taken as a reasonable outer limit for coastal benthic resources (Booth, Hay and Truscott, 1996).

upper intertidal zone - the upper approximate one-third of the intertidal zone, up to the mean high water mark.

micro-cliff - a micro-cliff is less than 2 meters in height and can only be composed of unconsolidated materials (sand, pebbles, etc.); it can never be composed of bedrock.

permeable - a material allowing liquids or gases to pass through it.

platform - near horizontal with an overall slope <5° (Owens, 2010).

ramp - inclined slope in the range of >5° to <35° (Owens, 2010).

SCAT – Shoreline Cleanup Assessment Technique. A systematic approach that uses standard terminology to collect data on shoreline oiling conditions and supports decision–making for shoreline clean–up (NOAA, 2010).

sediment - material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by water, wind, ice or mass-wasting and has come to rest on the earth's surface either above or below sea level. Sediment in a broad sense also includes organic remains; e.g., peat that has not been subject to appreciable transport (Hawley and Parsons, 1980).

slope - the across-shore rate of change in elevation for a given zone.

shoreline - the intersection of a specified plane of water with the beach; it migrates with changes of the tide or of the water level (Jackson, 1997).

substrate - material of which the shoreline is composed (mud, sand, pebble, cobble, boulder, rock, man-made, organic).

supratidal zone – the area above the mean high water mark that occasionally experiences wave activity; also referred to as the "splash zone" (Owens, 2010).

terrace - number of step-like ramps or platforms (Owens, 2010).

videography – video footage of the upper part of the intertidal zone which included integrated audio commentaries that provided descriptions of the coastline.

ENVIRONMENTAL SENSITIVITY MAPS

This Environmental Sensitivity Atlas covers the shoreline and the shore areas of the Beaufort Sea between 141°W (Alaska/Yukon border) and 120°W (Northwest Territories/Nunavut border), Banks Island to the north, and the East and Middle Channels of the Mackenzie River Delta, north of Inuvik. The shoreline has been divided into 9401 segments based on the shoreline type in the upper intertidal zone. Both the physical shoreline type and the ESI (Environmental Sensitivity Index) are displayed on the digital versions of the maps, but only the ESI is available on the printed maps. The ESI is a sensitivity mapping index which is widely used in the natural resource management community to standardize the mapping process and facilitates spill response. The shoreline type and ESI are displayed on 111 maps covering the entire Beaufort coast at a scale of 1:100,000. Mackenzie Delta maps are displayed on 14 maps at a scale of 1:50,000.

BEAUFORT REGION KEY MAP

ESI MAPS

Pre-planning and detailed knowledge of the area can help reduce the environmental impact of an oil spill. Environmental Sensitivity Index maps provide a concise summary of coastal resources that might be at risk. These maps contain information about shoreline sensitivity, biological resources and human resources. They are used to help plan shoreline cleanup strategies and establish protection priorities prior to a spill.

ESI Maps are comprised of three main datasets:

Shoreline Classification:

Shorelines are ranked based on a scale relating to sensitivity, natural persistence of oil, and ease of cleanup. The ranking is determined by four factors: relative exposure to wave and tidal energy, shoreline slope, substrate type, and biological productivity and sensitivity. (See the section 'The Environmental Sensitivity Index (ESI)' for more information.)

Biological Resources:

In this Atlas, biological resources are divided into four Categories: terrestrial mammals, marine mammals, birds, and fish, which are further divided into Groups based on their behaviour, morphology, and sensitivity to spills. Information is collected about species where a large number of individuals occur in a relatively high concentration; when species are present during vital life stages such as breeding, nesting and rearing; when the location of rare species is known; and in restricted areas important to migration patterns. Information about species location is displayed and, when possible, information about their seasonality and life cycle activities is included in accompanying tables.

Note: ESI maps show where these most sensitive species occur at key life stages. These maps don't necessarily show the entire ranges of sensitive species.

Human-use Resources:

Human-use resources include specific areas that have additional value and sensitivity because of their use. These areas include management areas (sanctuaries, parks, reserves, preserves, etc.), archaeological sites, historical sites, and cultural resource sites. Cultural resource sites include areas which are of importance both historically and presently to the Inuvialuit who rely on resources from the land for subsistence. They also include cultural sites located close to the intertidal zone which could be damaged or disturbed during oiling and subsequent cleanup procedures.

Note: Due to the sensitivity of archaeological sites, the exact locations of these resources cannot be displayed on the ESI maps. Please refer to the introduction map "Archaeological Sites" for an overview of sites in the region and contact the Prince of Wales Northern Heritage Centre for more detailed site information.

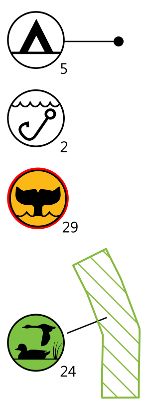
ESI ATLAS COMPONENTS

The systematic method for creating ESI maps, described below, was developed by the NOAA ESI project team (Peterson et al., 2002) and has been adopted for use in the Beaufort Coastal Altas ESI map series.

ESI Maps

The ESI maps use symbols and colours to show resource sensitivity to oil spills.

- Shorelines are colour coded to show sensitivity to oil spills. For example, warmer colors indicate the most sensitive shorelines, and cooler colors indicate the less sensitive.
- Biological and human-use resources are symbolized in the following manner:



Icons with a leader line represent a specific point location.

Icons with no leader line represent an undelineated area around the symbol.

Icons outlined in red indicate the presence of species at risk.

Polygons represent delineated areas of use. Corresponding icons are ususally located inside the polygon they represent, but may be placed outside the polygon and connected with a leader line. These polygons are filled with an appropriately coloured hatched pattern.

ESI Tables

Each ESI map is accompanied by tables presenting detailed information about species presence and site use. Table entries may include the following information:

- which species of animals are present and the months when they are present.
- when birds are performing breeding functions (including breeding, laying, hatching, and fledging), feeding, migrating, molting, nesting, staging, or wintering.
- when fish are performing breeding functions (spawning, etc.), feeding, or migrating.
- when marine/terrestrial mammals are are performing breeding functions (breeding, calving, pupping), feeding, or migrating.
- human-use site information including cultural sites and traditional harvesting areas.

Sample ESI table

①	② Group	③ ●	④ Species	⑤ Habitat Function	⑥ Months Present	⑦ Source
28	Pinniped		Ringed Seal	Feeding	JFMAMJJASOND	3
29	Polar Bear	●	Polar Bear	Breeding	JFMAMJJASOND	6
30	Polar Bear	●	Polar Bear	Feeding	JFMAMJJASOND	a
31	Whale	●	Bowhead Whale	Breeding	JFMAMJJASOND	a
32	Whale		Beluga Whale	Breeding	JFMAMJJASOND	a

How to read the ESI tables:

①	Unique ID	This number represents the unique combination of species, seasonality and life-history stage and source. This unique ID corresponds to the number listed below each icon on the facing map page.
②	Group Value	Biological resources are divided into four different Categories each with a reference colour. Each Category is broken down into Groups with unique icons to visually indicate the group of species or features present.
③	Status	A red dot next to a species name indicates that the species has either an endangered, threatened or special-concern status according to the Species at Risk Act (SARA) or the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Please refer to Appendix B at the end of this document for specific status information.
④	Species	The species name.
⑤	Habitat Function	The habitat function describes the species' use of a delimited area.
⑥	Months Present	This field represents the months when a species is present in the area. Black characters represent presence during the months indicated. When information about species presence is unavailable, the entire row is left grey.
⑦	Source	The source for the data. See page 54 for the complete list of sources.

Map Design

Resources are shown on ESI maps using symbols and colours. For biological species, each Category is represented by a standard colour (see table below). Icons (coloured background) are used when species occur in a relatively small area (such as a nesting site), and polygons (coloured outline/coloured hatch pattern) are used to indicate when species encompass a larger area. These polygons are coordinated in colour with the icons of species from the same Category.

Biological Resource	Icon Fill	Example	Polygon Pattern
Fish	Blue		
Birds	Green		
Marine Mammals	Brown		
Terrestrial Mammals	Brown		

Human-use Resource	Icon Fill	Example	Polygon Pattern
Fish	White		
Birds	White		
Marine Mammals	White		
Terrestrial Mammals	White		

Most human-use features are represented by a human-use point symbol (black outline/white background) with a leader line, since these features typically occur in small areas. Larger areas such as cultural-use sites are shown as polygons with black outlines and black hatching. Traditional knowledge about species location is shown with the corresponding species symbol (black outline/white background). The point symbol is shown with a white background to differentiate it from the biological data (coloured background). Polygons are coordinated in colour with the category colour but outlined in black to differentiate them from biological resources.

When a species is distributed across a broader geographic area on certain maps, its polygon is not placed on the printed maps as it would obscure other map features. The presence of that species is therefore indicated as "Present in..." in a small box on the map sheet (e.g., "Present across map sheet" or "Present in Beaufort Sea").

Location Name	Description
Present across map sheet	Present throughout the entire map sheet.
Present within map sheet	Present in an unspecified location within the map sheet. Used when location data was not precise or when the actual species name was not specified (i.e. goose sp. versus Canada Goose)
Present alongshore	Present in ocean waters from the shoreline to approximately 1 km off the coast.
Present in nearshore waters	Present in ocean waters from the shoreline to approximately 10 km off the coast (within the map sheet).
Present in offshore waters	Present in ocean waters beyond the nearshore zone (within the map sheet).
Present in coastal waters	Present in all ocean waters within the map sheet.
Present along coastline	Present on land from the shoreline to approximately 5 km inland.
Present in coastal lakes	Present in lakes that occur in topographic depressions which are seperated from the sea by narrow barriers of land.

INCORPORATION OF INUVIALUIT TRADITIONAL KNOWLEDGE

The Beaufort Sea Coastal Sensitivity Atlas combines both scientific data and traditional knowledge to present an overview of resources that are vulnerable to oil spills. Since the goal of the Atlas is to present sensitive coastal resources (biological and cultural), it was essential to identify sites which communities rely upon for subsistence and traditional purposes.

Inuvialuit traditional knowledge is a cumulative body of knowledge that is maintained by Inuvialuit individuals through traditional storytelling and songs, and through living on and using the land (ICC, 2006). This knowledge includes know-how, practices, and representations that are preserved and developed by the peoples over an extended period of time (ICC, 2006). It includes spiritual relationships, historical and present relationships with the natural environment, and the use of natural resources (ICC, 2006). Many sites are considered important and significant to the Inuvialuit people due to their long history in the region (ICC, 2006). Examples of significant sites include long-used hunting or gathering sites, burial sites, or geographic places which serve as reminders of an important event (ICC, 2006).

Traditional knowledge incorporated into the Beaufort Coastal Atlas includes the following sources of GIS and mapped data:

Project Title	Data type	Source
Innuvialuit Communitiy Conservation Plans (Inuvik, Tuktoyaktuk, Sachs Harbour, Aklavik, Ulukhaktok and Paulatuk)	▪ traditional hunting areas ▪ traditional camps ▪ cabins and cultural sites ▪ traditional knowledge of species habitat ▪ traditional burial sites	Joint Secretariat. 2009. Community Conservation Plans. Data Format: shapefile. (URL: http://www.jointsecretariat.ca/maps.html).
Mapping traditional knowledge related to the identification of ecologically and biologically significant areas in the Beaufort Sea	▪ traditional hunting and fishing sites ▪ traditional knowledge of species habitat and use	Hartwig. 2009. Mapping traditional knowledge related to the identification of ecologically and biologically significant areas in the Beaufort Sea.
Inuvialuit settlement region traditional knowledge report	▪ traditional hunting areas ▪ traditional camps ▪ traditional knowledge of species habitat ▪ traditional burial sites and cemeteries ▪ traditional trails	Inuvik Community Corporation, Tyktuuyaqtuuq Community Corporation and Aklarvik Community Corporation. 2006. Inuvialuit settlement region traditional knowledge report.
Net Environmental Benefit Analysis (NEBA) for oil spill response planning in the Beaufort Sea	▪ traditional hunting and fishing sites ▪ traditional knowledge of species habitat	Trudel. 2013. Net Environmental Benefit Analysis (NEBA) for oil spill response planning in the Beaufort Sea (in progress).
Arctic Environmental Sensitivity Atlas System	▪ traditional hunting and fishing sites ▪ traditional knowledge of species habitat ▪ important traditional sites	Arctic Environmental Sensitivity Atlas System (AESAS). 2004. Sustainable Resource harvesting-1987. Adapted from Beaufort Operational Maps 1-27 and Amundsen Operational Maps 1-19.

WORKS CITED

Arctic. 2013. Landscapes and Vegetation Zones. URL: http://arctic.ru/geography-population/landscapes-vegetation. (Accessed: November 5, 2013).

Arctic Canada. 2013. Flora of the Canadian Arctic. URL: http://www.sfu.ca/geog351fall02/gp2/WEBSITE/2_content_v.html. (Accessed: November 5, 2013).

Aylsworth, J.M., and Duk-Rodkin, A. 1997. Landslides and permafrost in the Mackenzie Valley. In Mackenzie basin impact study: final report. Edited by S.J. Cohen. Environmental Adaptation Research Group, Environment Canada. pp. 117-121.

Barnes, P.W., Rearic, D.M., and Reimnitz, E. 1984. Ice gouging characteristics and processes. In: Barnes, PW, Schell DM, Reimnitz E (ed.) The Alaskan Beaufort Sea: Ecosystems and Environment. Academic Press, New York, pp. 185-212.

Bates, R.L. and J.A. Jackson. 1980. Glossary of geology. 2nd Ed. American Geological Institute, Falls Church, Virginia. 749 pages.

Beaufort Sea Partnership (BSP). 2012. Tarium Niryutait Marine Protected Area. URL: http://www.beaufortseapartnership.ca/tnmp_area.html. (Accessed: August 13, 2013).

Beaufort Sea Partnership (BSP). 2009. Integrated Ocean Management Plan (IOMP) for the Beaufort Sea: 2009 and Beyond. 139 pages.

Bonsal and Kochtubajda. 2009. An assessment of present and future climate in the Mackenzie Delta and the near-shore Beaufort Sea region of Canada. International Journal of Climatology, Vol. 29, pp. 1780-1795.

Booth, J., hay, D.E., and Truscott, J. 1996. Standard Methods for Sampling Resources and Habitats in Coastal Subtidal Regions of British Columbia: Part 1: Review of Mapping With Recommendations. Canadian Technical Report of Fisheries and Aquatic Sciences. 2118: viii + 53 pages.

Bringué, M. and Rochon, A. 2012. Late Holocene paleoceanography and climate variability over the Mackenzie Slope (Beaufort Sea, Canadian Arctic). Marine Geology, Vol. 291-294, pp. 83–96.

Canadian Hydrographic Service (CHS). 1994. Sailing directions - Arctic Canada, Vol.1, Fourth Edition. Department of Fisheries and Oceans, Ottawa.

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

Coastal and Ocean Resources Inc. and Archipelago Marine Research Ltd (CORI and AMR). 2007. ShoreZone mapping data summary western Prince William Sound. CORI Project: 06-06. 80 pages.

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

Darnley Bay Resources Ltd. 2005. Darnley Bay Project Update. URL: http://www.darnleybay.com. (Accessed: January 13, 2005).

Department of Fisheries and Oceans (DFO). 2013a. The Canadian Arctic. URL: http://www.dfompo.gc.ca/science/coe-cde/ncaare-cneraa/index-eng.htm. (Accessed: April 10, 2013).

Department of Fisheries and Oceans (DFO). 2005. Marine ecosystem overview of the Beaufort Sea Large Ocean Management Area (LOMA). 110 pages.

Department of Fisheries and Oceans (DFO). 2013b. Tides, Currents and Waterlevels. URL: http://www.tides.gc.ca/eng. (Accessed: May 27, 2013).

Department of Fisheries and Oceans (DFO). 2008. Social, cultural and economic overview and assessment report for the Beaufort Sea Large Ocean Management Area. Prepared by: Social, Cultural and Economic Working Group. 132 pages.

Dietrich, J.R, Dixon, J., and McNeil, D.H. 1985. Sequence analysis and nomenclature of Upper Cretaceous to Holocene strata in the Beaufort-Mackenzie basin. In Current Research, part A, Geological Survey of Canada, Paper 85-1A, pp. 613-628.

Dome Petroleum Ltd., Esso Resources Canada Ltd., and Gulf Canada Resources Inc. 1982. Environmental impact statement for hydrocarbon development in the Beaufort Sea-Mackenzie Delta Region. Volume 3A: Beaufort Sea-Delta Setting.

Drummond, K.J. 2009. Northern Canada Distribution of Ultimate Oil and Gas Resources. Prepared for Northern Oil and Gas Branch. Indian and Northern Affairs Canada March 2009.

Dumas, J., Carmack, E.C., and Melling, H. 2005. Climate change impacts on the Beaufort Shelf land fast ice. Cold Regions Science and Technology, Vol. 42, pp. 41-51.

Dyke, L.D., Aylsworth, J.M., Burgess, M.M., Nixon, F.M., and Wright, F. 1997. Permafrost in the Mackenzie Basin, its influence on land-altering processes, and its relationship to climate change, pp. 111-116. In Mackenzie Basin Impact Study: Final Report. Edited by S.J. Cohen. Environmental Adaptation Research Group, Environment Canada.

Emergency Prevention, Preparedness and Response (EPPR). 1998. Field Guide for Oil Spill Response in Arctic Waters 1998. Environment Canada, Yellowknife, NT, Canada, 348 pages.

Environment Canada. 2013. Migratory Bird Sanctuaries. URL: http://www.ec.gc.ca/ap-pa/default.asp?lang=En&n=D1E052D8-1. (Accessed: August 13, 2012).

Environment Canada, Fisheries and Oceans Canada, and Government of the Northwest Territories (EC, FOC, and GNWT). 2014. NWT Species at Risk. URL: http://www.nwtspeciesatrisk.com/sites/default/files/pdf/SpeciesatRiskintheNWT_English.pdf?force=new. (Accessed: August 22, 2014).

Government of the Northwest Territories (GNWT). 2008. Official languages of the Northwest Territories. URL: http://www.ece.gov.nt.ca/files/publications/024-Official_Languages_Map-web.pdf. (Accessed: August 14, 2013).

Grenier, M., Demers, A.-M., Labrecque, S., Benoit, M., Fournier, R.A and B. Drolet. 2007. An object-based method to map wetland using Radarsat-1 and Landsat ETM images: test case on two sites in Quebec, Canada. Canadian Journal of Remote Sensing, Vol. 33, pp. 28-45.

Harney, J., Morris, M., and Harper, J. 2008. ShoreZone coastal habitat mapping protocol for the Gulf of Alaska. CORI Project: 08-01. 157 pages.

Hawley, J.W., and Parsons, R.B. 1980. Glossary of selected geomorphic and geologic terms. Mimeo. USDA Soil Conservation Service, West National Technical Center, Portland, OR. 30 p.

Hill, P.R., Héquette, A., Ruz, M-H., and Jenner, K.A. 1991. Geological investigations of the Canadian Beaufort Sea coast. Geologcial Survey of Canada open file report 2387. 348 pages.

Hopcroft, R., Bluhm, B., and Gradinger, R. 2008. Arctic Ocean Synthesis: Analysis of climate change impacts in the Chukchi and Beaufort Seas with strategies for future research. Institute of Marine Sciences, University of Alaska, Fairbanks.

International Union for Conservation of Nature (IUCN). 2008. Hope for a protected planted with protected areas. URL: http://www.iucn.org/about/work/programmes/gpap_home/pas_gpap/. (Accessed: August 13, 2013).

Inuuvik Community Corporation (ICC). 2006. Inuvialuit settlement region traditional knowledge report. Report Submitted to: Mackenzie Project Environmental Group, Calgary, Alberta. 200 pages.

IPIECA, International Marine Organization, and International Association of Oil and Gas Products (IPIECA, IMP, and OGP). 2011. Sensitivity mapping for oil spill response. OGP report number 000.

Jackson, J.A. (ed). 1997. Glossary of geology, 4th Ed. American Geological Institute, Alexandria, VA. 769p. ISBN 0-922152-34-9.

Lantuit, H., and Pollard, W.H. 2008. Fifty years of coastal erosion and retrogressive thaw slump activity on Herschel Island, southern Beaufort Sea, Yukon Territory, Canada. Geomorphology, Vol. 95, pp. 84–102.

Macdonald, R.W., Carmack, E.C., McLaughlin, F.A., Iseki, K., MacDonald, D.M., and O'Brien, M.C. 1989. Composition and modification of water masses in the Mackenzie shelf estuary. J. Geophysical Res. C. Oceans 94: 18057-18070.

Mackay, J.R. 1998. Pingo Growth and collapse, Tuktoyaktuk Peninsula Area, Western Arctic Coast, Canada: a long-term field study. Géographie physique et Quaternaire, Vol. 52, pp. 271-323.

Mackay, J.R. 1989. Ice-wedge cracks, Western Arctic coast. The Canadian Geographer, Vol. 33, 4 pages.

Michel, J., Christopherson, S. and Whiple, F. 1994. Mechanical protection guidelines. Research Planning Inc., NOAA, U.S. Coast Guards.

National Oceanic and Atmospheric Administration (NOAA). 2013. Preparing for Oil Spills in the Future Arctic. URL: http://oceanservice.noaa.gov/news/features/jun09/arctic.html. (Accessed: May 14, 2013).

National Oceanic and Atmospheric Administration (NOAA). 2010. NOAA's oil spill response: Shoreline Cleanup Assessment Technique. URL: http://www.noaa.gov/factsheets/new%20version/scat.pdf. (Accessed: November 7, 2013).

National Snow and Ice Data Centre (NSIDC). 2013. Climate vs. Weather. URL: http://nsidc.org/cryosphere/arctic-meteorology/climate_vs_weather.html. (Accessed: September 24, 2013).

Natural Resources Canada (NRCan). 2012. Geology and Geosciences. URL: http://atlas.nrcan.gc.ca/site/english/maps/geology.html#surficialmaterialsandglaciation. (Accessed: September 25, 2013).

Osterkamp, W. R. 2008. Annotated Definitions of Selected Geomorphic Terms and Related Terms of Hydrology, Sedimentology, Soil Science and Ecology. Reston, Virginia, Open File Report: 2008-1217.

Osterkamp, T.E. 2001. Sub-sea permafrost. In Steele, J. H., S. A. Thorpe, and K. K. Turekian, eds., Encyclopedia of Ocean SciencesEncyclopedia of Ocean Sciences. Academic Press, pp. 2902 -2912.

Overland, J.E. 2009. Meterology of the Beaufort Sea. Journal of Geophysical Research, Vol. 11, 10 pages.

Owens, E.H. 2010. Primary Shoreline Types of the Canadian North. 60 pages.

Owens, E.H., and Sergy, G.A. 2004. The Arctic SCAT Manual: A Field Guide to the Documentation of Oiled Shorelines in Arctic Regions, Environment Canada, Edmonton, AB, Canada, 172 pages.

Owens, E.H., and Sergy, G.A. 2003. The development of the SCAT process for the assessment of oiled shorelines. Mar. Pollut. Bull. 47, pp. 415–422.

Percy, R.J., LeBlanc, S.R., and Owens, E.H. 1997. An Integrated Approach to Shoreline Mapping for Spill Response Planning in Canada, in Proceedings 1997 International Oil Spill Conference, American Petroleum Institute, Washington DC, Pub. 4651, pp. 277-288.

Peterson et al., 2002. Environmental sensitivity index guidelines, v.ersion 3. NOAA Technical Memorandum NOS OR&R 11. 192 pages.

Pharand, D. 2007. The Arctic Waters and the Northwest Passage: A Final Revisit, Ocean Development and International Law, Vol. 38, pp. 3-69.

Phillips, L.M., Powell, A.N., Taylor, E.J., and Rexstad, E.A. 2007. Use of the Beaufort Sea by King Eiders Breeding on the North Slope of Alaska, J. Wildlife Manage. 71, pp. 1892-1898.

Prince of Wales Northern Heritage Centre (PWNHC). 2013. NWT Archaeological Reports. URL: http://www.pwnhc.ca/research/archrep/. (Accessed: August 13, 2013).

Ruffilli, D. 2011. Arctic marine and intermodal infrastructure: Challenges and the government of Canada's response. Publication No. 2011-77-E. Library of Parliament, Ottawa, Canada, pp. 1-8.

Ruz, M.H., Héquette, A., and Hill, P.R. 1992. A model of coastal evolution in a transgressed thermokarst topography, Canadian Beaufort Sea. Marine Geology, Vol. 106, pp. 251-278.

Smith, C.A.S., Meikle, J.C., and Roots, C.F. (Editors). 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313 pages.

Solomon, S. 2004. Geological Survey of Canada Atlantic Coastal Information System Legend - Glossary of Terms. 16 pages.

Solomon. S.M. 2002. Kitigaaryuit coastal stability baseline assessment. In Appendix B, Hart, E.J. 2002. Kitigaaryuit Archaeological Inventory and Mapping Project - 2001. Inuvialuit Social Development Program, Inuvik, NT.

Solomon, S.M. and Forbes, D.L. 1994. Impacts of climate change on the Beaufort Sea coastal zone, pp. 1810-1823. In Coastal Zone Canada '94, Cooperation in the Coastal Zone: Conference Proceedings, Sept. 20-23, 1994. Edited by P.G. Wells, P.J. Ricketts, S.M. Heming, J. Dale and G. R. MacMichael. Compiled and edited by: Coastal Zone Canada Association, Dartmouth, NS.

Tucker, W.B., Weeks, W.F., Frank, M. 1979. Sea Ice ridging over the Alaskan continental shelf. Journal of Geophysical Research, Vol. 84, pp. 4885-4897.

United Nations. 2006. The definition of the continental shelf and criteria for the establishment of its outer limits. URL: http://www.un.org/Depts/los/clcs_new/continental_shelf_description.htm. (Accessed: August 12, 2013).

Warner, B.G. and Rubec, C.D.A. 1997. The Canadian Wetland Classification System. Wetland Research Centre, University of Waterloo, ISBN 0-662-25857-6, 76 pages.

Washburn, A. L. 1979. Geocryology. London: Edward Arnold, 406 pages.

Wulder, M. and Nelson, T. 2003. EOSD Land Cover Classification Legend Report, Version 2. 81 pages.

PHOTO REFERENCES

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APPENDIX A – LIST OF SPECIES

Terrestrial Mammal

Group	Species - common name	*Scientific name*
Bear	American Black Bear	*Ursus americanus*
	Grizzly Bear	*Ursus arctos*
Ungulate	Barren-Ground Caribou	*Rangifer tarandus groenlandicus*
	Boreal Caribou	*Rangifer tarandus caribou*
	Caribou (other)/Reindeer	*Rangifer tarandus*
	Dolphin-Union Caribou	*Rangifer tarandus groenlandicus x pearyi*
	Moose	*Alces alces*
	Muskox	*Ovibos moschatus*
	Peary Caribou	*Rangifer tarandus pearyi*
	Porcupine Caribou	*Rangifer tarandus granti*
Canine	Arctic Fox	*Vulpes lagopus*
	Coyote	*Canis latrans*
	Grey Wolf	*Canis lupus*
	Red Fox	*Vulpes vulpes*
Feline	Canadian Lynx	*Lynx canadensis*
Weasel	American Marten	*Martes americana*
	American Mink	*Neovison vison*
	Least Weasel	*Mustela nivalis*
	Long-tailed Weasel	*Mustela frenata*
	River Otter	*Lontra canadensis*
	Short-Tailed Weasel (Ermine)	*Mustela erminea*
	Wolverine	*Gulo gulo*
Rodent	Alaska Vole	*Microtus abbreviatus*
	American Beaver	*Castor canadensis*
	Arctic Ground Squirrel	*Urocitellus parryii*
	Greenland Collared Lemming	*Dicrostonyx groenlandicus*
	Hoary Marmot	*Marmota caligata*
	Meadow Vole	*Microtus pennsylvanicus*
	Muskrat	*Ondatra zibethicus*
	North American Brown Lemming	*Lemmus trimucronatus*
	North American Porcupine	*Erethizon dorsatum*
	Northern Flying Squirrel	*Glaucomys sabrinus*
	Northern Red-Backed Vole	*Myodes rutilus*
	Taiga Vole	*Microtus xanthognathus*
	Tundra Redback Vole	*Clethrionomys rutilus*
	Tundra Vole	*Microtus oeconomus*
Other Small Mammals	Arctic Hare	*Lepus arcticus*
	Barren-Ground Shrew	*Sorex ugyunak*
	Snowshoe Hare	*Lepus americanus*
	Tundra Shrew	*Sorex tundrensis*

Marine Mammal

Group	Species - common name	*Scientific name*
Polar Bear	Polar Bear	*Ursus maritimus*
Pinniped	Bearded Seal	*Erignathus barbatus*
	Ringed Seal	*Phoca hispida*
	Walrus	*Odobenus rosmarus*
	Seals (Unspecified)	unspecified
Whale	Beluga Whale	*Delphinapterus leucas*
	Bowhead Whale	*Balaena mysticetus*
	Grey Whale	*Eschrichtius robustus*
	Killer Whale	*Orchinus orca*

Birds

Group	Species - common name	*Scientific name*
Waterfowl	American Widgeon	*Anas americana*
	Blue-Winged Teal	*Anas discors*
	Brant Goose/Black Brant	*Branta bernicla/nigricans*
	Canada Goose	*Branta canadensis*
	Canvasback	*Aythya valisineria*
	Gadwall	*Anas strepera*
	Greater Scaup	*Aythya marila*
	Greater White-Fronted Goose	*Anser albifrons frontalis*
	Green Winged Teal	*Anas creca*
	Lesser Scaup	*Aythya affinis*
	Lesser Snow Goose	*Chen caerulescens*
	Mallard	*Anas platyrhynchos*

Birds - continued

Group	Species - common name	*Scientific name*
Waterfowl (continued)	Northern Pintail	*Anus acuta*
	Northern Shoveler	*Anas clypeata*
	Redhead	*Aythya americana*
	Ring-Necked Duck	*Aythya collaris*
	Ross's Goose	*Chen rossii*
	Trumpeter Swan	*Cygnus buccinator*
	Tundra Swan	*Cygnus columbianus*
	Whistling Swan	*Olor columbianus*
	Wigeon (Other)	*Anas sp.*
Seaduck	Barrow's Goldeneye	*Bucephala islandica*
	Black Scoter	*Melanitta americana*
	Common Eider	*Somateria mollissima*
	Common Goldeneye (Bufflehead)	*Bucephala clangula*
	Common Merganser	*Mergus merganser*
	Harlequin Duck	*Histrionicus histrionicus*
	King Eider	*Somateria spectabillis*
	Long-Tailed Duck (Oldsquaw)	*Clangula hyemalis*
	Red-Breasted Merganser	*Mergus serrator*
	Spectacled Eider	*Somateria fischeri*
	Surf Scoter	*Melanitta perspicillata*
	White-Winged Scoter	*Melanitta fusca*
Seabird	Arctic Tern	*Sterna paradisaea*
	Black Guillemot	*Cepphus grille*
	Bonaparte's Gull	*Chroicocephalus philadelphia*
	Fork-Tailed Gull	*Xema sabini*
	Glaucous Gull	*Larus hyperboreus*
	Herring Gull	*Larus argentatus (/smithsonianus)*
	Iceland Gull	*Larus glaucoides*
	Ivory Gull	*Pagophila eburnea*
	Long-Tailed Jaeger	*Stercorarius longicaudus*
	Mew Gull	*Larus canus*
	Northern Fulmar	*Fulmarus glacialis*
	Parasitic Jaeger	*Stercorarius parasiticus*
	Pomarine Jaeger	*Stercorarius pomarinus*
	Ross's Gull	*Rhodostethia rosea*
	Thayer's Gull	*Larus thayeri*
	Thick-Billed Murre	*Uria lomvia*
Shorebird	American Golden Plover	*Pluvialis dominica*
	Baird's Sandpiper	*Calidris bairdii*
	Black-Bellied Plover	*Pluvialis squatarola*
	Buff-Breasted Sandpiper	*Tryngites subruficollis*
	Common Snipe	*Gallinago gallinago*
	Dunlin	*Calidris alpina*
	Eskimo Curlew	*Numenius borealis*
	Hudsonian Godwit	*Limosa haemastica*
	Killdeer	*Charadrius vociferus*
	Least Sandpiper	*Calidris minutilla*
	Lesser Yellowlegs	*Tringa flavipes*
	Long-Billed Dowitcher	*Limnodromus scolopaceus*
	Pectoral Sandpiper	*Calidris melanotos*
	Purple Sandpiper	*Calidris maritima*
	Red Knot	*Calidris canutus*
	Red-Necked Phalarope	*Phalarpus lobatus*
	Red Phalarope	*Phalaropus fulicarius*
	Ruddy Turnstone	*Arenaria interpres*
	Sanderling	*Calidris alba*
	Semipalmated Plover	*Charadrius semipalmatus*
	Semipalmated Sandpiper	*Calidris pusillus*
	Sharp-Tailed Sandpiper	*Calidris acuminata*
	Solitary Sandpiper	*Tringa solitaria*
	Spotted Sandpiper	*Actitis macularius*
	Stilt Sandpiper	*Calidris himantopus*
	Upland Sandpiper	*Bartramia longicauda*
	Wandering Tattler	*Tringa incana*
	Whimbrel	*Numenius phaeopus*
	White-Rumped Sandpiper	*Calidris fuscicollis*
	Wilson's Snipe	*Gallinago delicata*
Waterbird	Arctic Loon	*Gavia arctica*
	Common Loon	*Gavia immer*
	Horned Grebe	*Podiceps auritus*
	Pacific Loon	*Gavia pacifica*
	Red-Necked Grebe	*Podiceps grisegena*
	Red-Throated Loon	*Gavia stellata*
	Sandhill Crane	*Grus canadensis*
	Yellow-Billed Loon	*Gavia adamsii*

Birds - continued

Group	Species - common name	*Scientific name*
Raptor	Bald Eagle	*Haliaeetus leucocephalus*
	Golden Eagle	*Aquila chrysaetos*
	Gyrfalcon	*Falco rusticolus*
	Merlin	*Falco columbarius*
	Northern Goshawk	*Accipiter gentilis*
	Northern Harrier (Marsh Hawk)	*Circus cyaneus*
	Northern Hawk Owl	*Surnia ulula*
	Peregrine Falcon	*Falco peregrinus*
	Red-Tailed Hawk	*Buteo jamaicensis*
	Rough-Legged Hawk	*Buteo lagopus*
	Sharp-Shinned Hawk	*Accipiter striatus*
	Short-Eared Owl	*Asio flammeus*
	Snowy Owl	*Bubo scandiacus*
Landbird	Alder Flycatcher	*Empidonax alnorum*
	American Cliff Swallow	*Hirundo pyrrhonota*
	American Pipit	*Anthus rubescens*
	American Robin	*Turdus migratorius*
	American Three-Toed Woodpecker	*Picoides dorsalis*
	American Tree Sparrow	*Spizella arborea*
	Bank Swallow	*Riparia riparia*
	Blackpoll Warbler	*Setophaga striata*
	Bohemian Waxwing	*Bombycilla garrulus*
	Boreal Chickadee	*Poecile hudsonicus*
	Brown-Headed Cowbird	*Molothrus ater*
	Common Raven	*Corvus corax*
	Common Redpoll	*Carduelis flammea*
	Fox Sparrow	*Passerella iliaca*
	Gray Jay	*Perisoreus canadensis*
	Grey Cheeked Thrush	*Catharus minimus*
	Harris's Sparrow	*Zonotrichia querula*
	Hoary Redpoll (Arctic Redpoll)	*Carduelis hornemanni*
	Horned Lark	*Eremophila alpestris*
	Lapland Longspur	*Calcarius lapponicus*
	Northern Flicker	*Colaptes auratus*
	Northern Shrike	*Lanius excubitor*
	Northern Waterthrush	*Parkesia noveboracensis*
	Northern Wheatear	*Oenanthe oenanthe*
	Orange-Crowned Warbler	*Oreothlypis celata*
	Pine Grosbeak	*Pinicola enucleator*
	Red-winged Blackbird	*Agelaius phoeniceus*
	Rock Ptarmigan	*Lagopus muta*
	Rosy Finch	*Leucosticte tephrocotis*
	Ruby-Crowned Kinglet	*Regulus calendula*
	Rusty Blackbird	*Euphagus carolinus*
	Savannah Sparrow	*Passerculus sandwichensis*
	Say's Phoebe	*sayornis saya*
	Smith's Longspur	*Calcarius pictus*
	Snow Bunting	*Plectrophenax nivalis*
	Spruce Grouse	*Falcipennis canadensis*
	Tennessee Warbler	*Oreothlypis peregrina*
	Tree Swallow	*Tachycineta bicolor*
	Varied Thrush	*Ixoreus naevius*
	Water Pipit	*Anthus spinoletta*
	White-Crowned Sparrow	*Zonotrichia leucophrys*
	White-Winged Crossbill	*Loxia leucoptera*
	Willow Ptarmigan	*Lagopus lagopus*
	Wilson's Warbler	*Cardellina pusilla*
	Yellow Warbler	*Setophaga petechia*

Fish

Group	Species - common name	*Scientific name*
Marine Fish	Archer Eelpout	*Lycodes sagittarius*
	Arctic Alligatorfish	*Ulcina olrikii*
	Arctic Cod	*Boreogadus saida*
	Arctic Eelpout	*Lycodes reticulatus*
	Arctic Flounder	*Pleuronectes glacialis*
	Arctic Hookear Sculpin	*Artediellus unicinatus*
	Arctic Sculpin	*Myxocephalus scorpioides*
	Arctic Shanny	*Sticaeus punctatus*
	Arctic Skate	*Amblyraja hyperborea*
	Arctic Staghorn Sculpin	*Gymnocanthus tricuspis*
	Atlantic Poacher	*Leptagonus decagonus*
	Atlantic Spiny Lumpsucker	*Eumicrotremus spinosus*
	Aurora Eelpout	*Gymnelus retrodorsalis*
	Bering Flounder	*Hippoglossoides robustus*
	Bigeye Sculpin	*Triglops nybelini*
	Capelin	*Mallotus villosus*

Fish - continued

Group	Species - common name	*Scientific name*
Marine Fish (continued)	Daubed Shanny	*Leptoclinus maculatus*
	Dusky Snailfish	*Liparis gibbus*
	Eelpout (Other)	*Lycodes sp.*
	Fourhorn Sculpin	*Myoxocephalus quadricornis*
	Fourline Snakeblenny	*Eumesogrammus praecisus*
	Gelatinous Snailfish	*Liparis fabricii*
	Glacial Eelpout	*Lycodes frigidus*
	Greenland Cod	*Gadus ogac*
	Greenland Halibut	*Reinhardtius hippoglossoides*
	Hamecon	*Artediellus scaber*
	Kelp Snailfish	*Liparis tunicatus*
	Knipowitsch's Pout	*Gymnelus hemifasciatus*
	Leatherfin Lumpsucker	*Eumicrotremus derjugini*
	Longear Eelpout	*Lycodes seminudus*
	Northern Sand Lance	*Ammodytes dubius*
	Northern Wolffish	*Anarchichas denticulatus*
	Pacific Herring (Blue)	*Clupea pallasii*
	Pacific Sand Lance	*Ammodytes hexapterus*
	Pacific Tomcod	*Microgadus proximus*
	Pale Eelpout	*Lycodes pallidus*
	Pighead Prickleback	*Acantholumpenus mackayi*
	Polar Cod	*Arctogadus borisovi*
	Polar Eelpout	*Lycodes polaris*
	Ribbed Sculpin	*Triglops pingelii*
	Rough Hookear Sculpin	*Artediellus scaber*
	Saffron Cod	*Eleginus gracilis*
	Saddled Eelpout	*Lycodes mucosus*
	Sand Lance (Other)	*Ammodytes sp.*
	Sculpin (Other)	*Icelus sp.*
	Sea Tadpole	*Careproctus reinhardti*
	Shorthorn Sculpin	*Myoxocephalus scorpius*
	Shulupaoluk Eelpout	*Lycodes jugoricus*
	Skates (Unspecified)	*Bathyraja sp.*
	Slender Eelblenny	*Lumpenus fabricii*
	Slimy Sculpin	*Cottus cognatus*
	Spatulate Sculpin	*Icelus spatula*
	Spotted Wolffish	*Anarhichas minor*
	Starry Flounder	*Platichthys stellatus*
	Stout Eelblenny	*Anisarchus medius*
	Threespot Eelpout	*Lycodes rossi*
	Twohorn Sculpin	*Icelus bicornis*
	Two-Lip Pout	*Gymnelus bilabrus*
	Variegated Snailfish	*Liparis gibbus*
	White Sea Eelpout	*Lycodes marisalbi*
Anadromous and Freshwater Fish	Arctic Char	*Salvelinus alpinus*
	Arctic Cisco	*Coregonus autumnalis*
	Arctic Grayling	*Thymallus arcticus*
	Arctic Lamprey	*Lethenteron camtschaticum*
	Bering Cisco	*Coregonus laurettae*
	Broad Whitefish	*Coregonus nasus*
	Burbot (Loche)	*Lota lota*
	Chinook Salmon	*Oncorhynchus tshawytscha*
	Chum Salmon	*Oncorhynchus keta*
	Cisco	*Coregonus artedi*
	Coho Salmon	*Oncorhynchus kisutch*
	Dolly Varden	*Salvelinus malma*
	Finescale Dace	*Phoxinus neogaeus*
	Flathead Chub	*Platygobio gracilis*
	Inconnu	*Stenodus leucichthys*
	Lake Chub	*Couesius plumbeus*
	Lake Trout	*Salvelinus namaycush*
	Lake Whitefish (Humpback)	*Coregonus clupeaformis*
	Least Cisco	*Coregonus sardinella*
	Longnose Dace	*Rhinichthys cataractae*
	Longnose Sucker	*Catostomus catostomus*
	Nine-Spine Stickleback	*Pungitius pungitius*
	Northern Pike (Jackfish)	*Esox lucius*
	Pink Salmon	*Oncorhynchus gorbuscha*
	Pond Smelt	*Hypomesus olidus*
	Rainbow Smelt	*Osmerus mordax*
	Round Whitefish	*Prosopium cylindraceum*
	Slimy Sculpin	*Cottus cognatus*
	Sockeye Salmon	*Oncorhynchus nerka*
	Spoonhead Sculpin	*Cottus ricei*
	Squanga Whitefish	*Coregonus sp.*
	Three-Spine Stickleback	*Gasterosteus aculeatus*
	Trout Perch	*Percopsis omiscomaycus*
	Walleye	*Stizostedion vitreum*
	White sucker	*Castostomus commersonii*
Fish (unspec.)	Fish (unspecified)	*unspecified*

Habitat (Benthic)

Group	Species - common name	Scientific name
Aquatic	Blue Green Algae	*Anabaena sp.*
Vegetation	Brown Algae	*Laminaria solidunga*
	Brown Algae	*Pylaiella littoralis*
	Green Algae	*Chlorella marinus*
	Green Algae	*Ulothrix pseudoflacca*
	Green Algae	*Ulothrix flacca*
	Green Algae	*Stichococcus marinus*
	Green Algae	*Enteromorpha micrococca*
	Green Algae	*Enteromorpha percusa*
	Green Algae	*Enteromorpha prolifera*
	Green Algae	*Enteromorpha torta*
	Green Algae	*Ilea fulvescens*
	Red Algae	*Phyllophora truncata*
	Red Algae	*Ceratocolax hartzii*

Invertebrates

Group	Species - common name	Scientific name
Annelids	Annelids	*Ampharete vega*
	Annelids	*Artacama proboscidea*
	Annelids	*Trochochaeta carica*
	Annelids	*Maldane sarsi*
	Annelids	*Aricidea suecica*
	Annelids	*Paraonis gracilis*
	Annelids	*Onuphis conchylega*
	Annelids	*Pectinaria hyperborea*
	Annelids	*Onuphis quadricuspis*
	Annelids	*Laonice cirrata*
	Annelids	*Ampharete acutifrons*
	Annelids	*Spio filicornis*
	Annelids	*Aglaophamus neotenus*
	Annelids	*Prionospio cirrifera*
	Annelids	*Antinoella sarsi*
	Annelids	*Cirratulidae*
Arthropods	Amphipod	*Boeckosimus affinis*
	Amphipod	*Onisimus glacialis*
	Amphipod	*Pontoporeia affinis*
	Amphipod	*Haploops laevis*
	Amphipod	*Haploops tubicola*
	Amphipod	*Hippomedon abyssi*
	Amphipod	*Pontoporeia femorata*
	Amphipod	*Aceroides latipes*
	Cumacean	*Diastylis sulcata*
	Isopod	*Mesidotea entomom*
	Isopod	*Mesidotea sibirica*
	Isopod	*Mesidotea sabini*
	Isopod	*Gnathia stygia*
	Mystid	*Mysis femorata*
	Mystid	*Mysis relicta*
	Pink shrimp	*Pandalus borealis*
	Striped shrimp	*Pandalus montagui tridens*
Molluscs	Bivalve	*Macoma balthica*
	Bivalve	*Cyrtodaria kurriana*
	Bivalve	*Yoldiella intermedia*
	Bivalve	*Portlandia arctica*
	Bivalve	*Astarte borealis*
	Bivalve	*Astarte montagui*
	Bivalve	*Macoma calcarea*
	Bivalve	*Macoma spp.*
	Bivalve	*Macoma inconspicua*
	Blue mussel	*Mytilus edulis*
	Gastropod	*Cylichna alba*
	Greenland cockle	*Serripes groenlandicus*
	Greenland scallops	*Delectopecten greenlandicus*
	Iceland cockle	*Clinocardium ciliatum*

The list of species found in the Beaufort Sea region was compiled from the following sources:

Alexander, S.A., Barry, T.W., Dickson, D.L., Prus, H.D., and Smyth, K.E. 1988. Key areas for birds in coastal regions of the Canadian Beaufort Sea. Canadian Wildlife Service, Environment Canada. Edmonton, Alberta.

Canada's Polar Life. 2002. Animals. URL: http://www.polarlife.ca/organisms/fish/ frames_comm/eelpoutfr.htm. (Accessed: January 10, 2014).

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

Department of Fisheries and Oceans (DFO). 2005. Marine ecosystem overview of the Beaufort Sea Large Ocean Management Area (LOMA). 110 pages.

Governement of the Northwest Territories (GNWT), 2011. NWT Species at Risk. URL: http://nwtspeciesatrisk.ca/tiki/tikiindex.php?page=SearchRegion #inuvialuit. (Accessed: Nov 6, 2013).

Hopcroft, R., Bluhm, B., and Gradinger, R. 2008. Arctic Ocean Synthesis: Analysis of climate change impacts in the Chukchi and Beaufort Seas with strategies for future research. Institute of Marine Sciences, University of Alaska, Fairbanks.

Joint Secretariat. 2008a. Aklavik Inuvialuit community conservation plan. Prepared by the Community of Aklavik, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

Joint Secretariat. 2008b. Inuvik Inuvialuit community conservation plan. Prepared by the Community of Inuvik, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

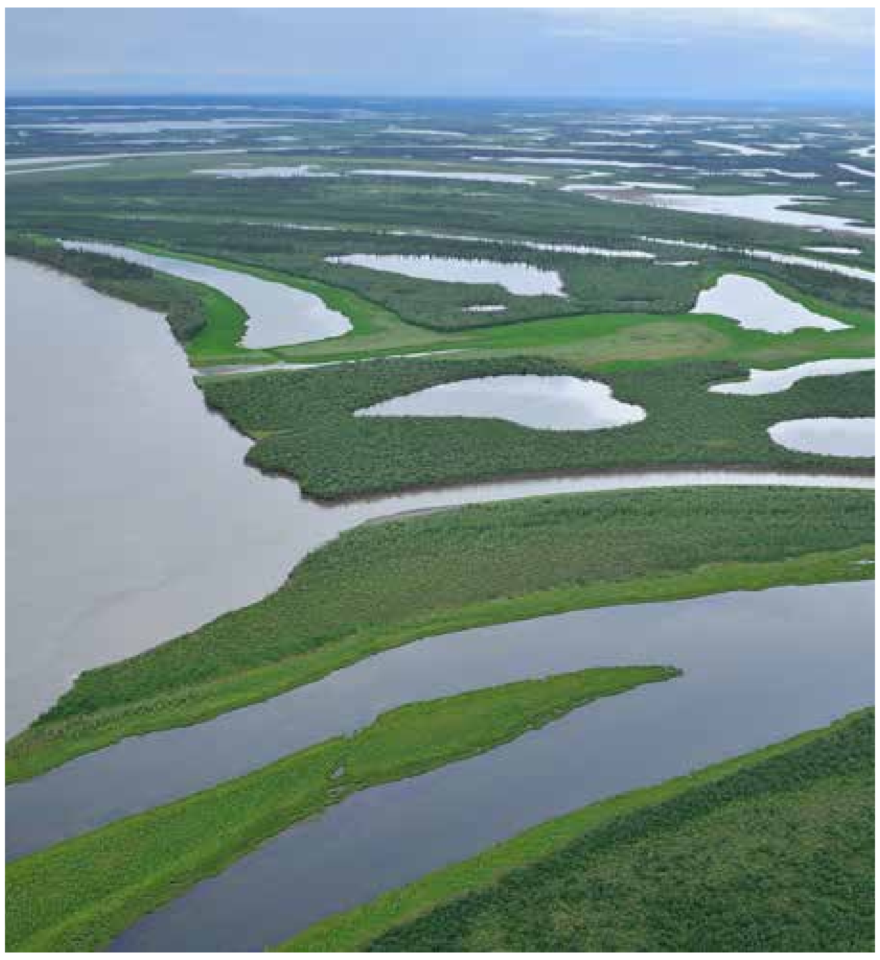
Joint Secretariat. 2008c. Olokhaktomiut community conservation plan. Prepared by the Community of Ulukhaktok, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

Joint Secretariat. 2008d. Paulatuk Inuvialuit community conservation plan. Prepared by the Community of Paulatuk, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

Joint Secretariat. 2008e. Sachs Harbour Inuvialuit community conservation plan. Prepared by the Community of Sachs Harbour, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

Joint Secretariat. 2008f. Tuktoyaktuk Inuvialuit community conservation plan. Prepared by the Community of Tuktoyaktuk, the Wildlife Management Advisory Council (NWT) and the Joint Secretariat.

Sale, R. 2006. A complete guide to Arctic Wildlife. Firefly Books Limited, Richmond Hill.



APPENDIX B – SPECIES AT RISK

(EC, FOC, AND GNWT, 2014)

Element	Species	Scientific name	COSEWIC	SARA
Mammals	Bowhead Whale	*Balaena mysticetus*	Special Concern	Special Concern
	Caribou (other) - [Boreal Caribou]	*Rangifer tarandus caribou*		
	Dolphin-Union Caribou	*Rangifer tarandus groenlandicus x pearyi*		
	Grey Whale	*Eschrichtius robustus*	Special concern	Special concern
	Grizzly Bear	*Ursus arctos*	Special Concern	
	Peary Caribou	*Rangifer tarandus pearyi*	Endangered	Endangered
	Polar Bear	*Ursus maritimus*	Special Concern	Special Concern
	Wolverine	*Gulo gulo*	Special Concern	
Birds	Bank Swallow	*Riparia riparia*	Threatened	
	Buff-breasted Sandpiper	*Tryngites subruficollis*	Special Concern	
	Eskimo Curlew	*Numenius borealis*	Endangered	Endangered
	Horned Grebe	*Podiceps auritus*	Special Concern	
	Peregrine Falcon	*Falco peregrinus*	Special Concern	Special Concern
	Red Knot	*Calidris canutus rufa*	Endangered	Endangered
	Red Knot	*Calidris canutus islandica*	Special Concern	Special Concern
	Rusty Blackbird	*Euphagus carolinus*	Special Concern	Special Concern
	Short Eared Owl	*Asio flammeus*	Special Concern	Special Concern
Fish	Dolly Varden	*Salvelinus malma malma*	Special Concern	
	Northern Wolffish	*Anarhichas denticulatus*	Threatened	Threatened
Plants	Hairy Braya	*Braya pilosa*	Endangered	

APPENDIX C – SHORELINE SUMMARY

Summary of helicopter videography collection by field campaign.

Location	Dates	Hours of Video	Distance Flown (km)
Beaufort Coast	July 26 - August 6, 2011	22	2,860
Mackenzie Delta	July 27, 2012	6.9	771
Banks Island	July 20 - 24, 2012	17.2	1,755
Total		46.1	5386

Summary of the shoreline segmentation by length (km) for each study site. Shoreline types shown in alphabetical order.

Shoreline Type:	NWT Mainland	Yukon Mainland	Mackenzie River	Banks Island	Total: Beaufort Coast
Bedrock Cliff/Vertical	138			56	194
Bedrock Platform	14			<1	14
Bedrock Sloping/Ramp	7				7
Boulder Beach or Bank	5			16	21
Driftwood	3	21	2		26
Ice-Poor Tundra Cliff	30			1	31
Ice-Rich Tundra Cliff	90	26	1	46	163
Inundated Low-Lying Tundra	197	37		131	365
Man-Made Permeable	3		<1		3
Man-Made Solid			1		1
Marsh	84	4	249	5	342
Mixed & Coarse Sediment Tidal Flat	17	4	1	21	43
Mixed Sediment Beach or Bank	1,188	269	41	1,106	2,604
Mud Tidal Flat	261	18	313	148	740
Mud/Clay Bank			141		141
Peat Shoreline	880	138	97	40	1,155
Pebble/Cobble Beach or Bank	27		1	337	365
Sand Beach or Bank	684	15	6	269	974
Sand Tidal Flat	495	4	1	26	526
Sediment Cliff	1		1	35	37
Snow/Ice	8			32	40
Vegetated Bank	<1		98		98
Total	4,131	537	950	2,271	7,889