FINAL REPORT
PREPARED FOR
TRANSPORT CANADA

Risk Assessment for Marine Spills in Canadian Waters

Phase 2, Part B: Oil and Select Hazardous and Noxious Substances (HNS) Spills North of the 60th Parallel North

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May 2014

WSP

SL ROSS

Risk Assessment for Marine Spills in Canadian Waters

Phase 2, Part B: Spills of Oil and Select Hazardous and Noxious Substances (HNS) North of the 60th Parallel North

Final Report

Presented to

Transport Canada

From

WSP Canada Inc.

Approved by: ______________________________
Jérôme Marty, Ph. D.

MAY 2014

131-17593-00

EXECUTIVE SUMMARY

This study evaluates the relative risk of pollution from ship-source spills of oil products and select hazardous and noxious substances (HNS) transported in bulk in Canadian waters north of the 60th parallel north, including waters connected to the Arctic region (Hudson Bay, James Bay, Ungava Bay and Labrador Sea).

Using data available for the last 10 years, the report also provides a geographic distribution of the relative risk of spills across Canada. Overall, the relative risk of spills in Canada is low compared to the rest of the world, as the results of low traffic and low spill frequencies. Within Canada, although the methodologies used to assess risk in southern Canada and in the Arctic differ, the relative risk of spills of refined cargo products and fuel is significantly higher in southern Canada, mainly in geographic sub-sectors with large ports. All sub-sectors in the Arctic are characterized by a relatively very low risk of spills (Maps 1 to 6). Within Canada, the relatively low risk of spills observed in the Arctic compared to the south stems from the low volume of oil moved as cargo and from the low number of transits for oil transported as fuel.

Due to significant differences in data available for the Arctic compared to the rest of Canada, a specific methodology was developed to best represent and compare the relative risk across the Arctic sector.

As with the southern study (WSP, 2014a), this risk assessment was produced for Transport Canada, following the 2010 recommendations of the Commissioner of the Environment and Sustainable Development (CESD). The Minister of Transport, in naming the Tanker Safety Expert Panel, also requested that the risk assessment be used as part of its review of Canada's preparedness and response measures for ship-source spills.

As part of this study, estimates of spill probabilities and impacts on the environment were combined to generate a relative estimate of risk. The results of this study provide a tool to compare risk values among regions across northern Canada.

The approach developed for this study involved the following key elements:

- Based on ecoregions and traffic density, Canadian waters north of the 60th parallel north were divided into 9 sectors, which were further divided into 18 sub-sectors. For each sub-sector, spill frequencies were produced for refined cargo (e.g. gasoline, diesel fuel) and fuel oil spills and related to an Environmental Sensitivity Index (ESI), which was then applied to generate a relative risk estimate.

- HNS risk values were not generated for the Arctic because of insufficient volumes and traffic. Only three select HNS products were moved in the Arctic over the last 10 years. Due to the small volume of HNS transported in the Arctic, the relative risk of a spill could not be estimated. As a result, the HNS section of this report only includes a description and the volumes of the substances being transported.
- Mean annual Canadian traffic data from vessels larger than 300 tonnes was derived using 2012 and 2013 satellite tracking information.
- Mean annual oil volumes were derived using Transport Canada's commodity movement data (2002 to 2012) for refined cargo products (e.g. gasoline, diesel fuel) only as crude oil is not currently transported in the Arctic.
- Oil spill frequencies were described for refined cargo products and fuel according to four spill volume categories ranging from 1 m^3 to 1,000 m^3 and greater. Spill frequencies were calculated using recorded oil spills in Canadian waters using the Canadian Coast Guard (CCG) incident database (MPIRS) as well as international casualty data from Lloyd's database. Risk calculations were only calculated for three spill volumes categories ranging from 10 to 1,000 m^3 and greater.
- Mean annual Canadian tonnages were estimated using Transport Canada's commodity data.
- The ESI was based on environmental geographic layers describing the physical, biological and human environments in each of the 18 sub-sectors. Metrics entered in ESI calculations were derived from Geographic Information System (GIS) tools.
- Shoreline type, wetlands and ice coverage data was used to calculate the Physical Sensitivity Indicator (PSI). Several datasets (coastal zone delineation, ecologically and biologically significant areas (EBSAs) and bird distribution) were combined to produce the Biological Resource Indicator (BRI). Similarly, social and economic data (coastal population index, tourism and national/international freight tonnage) was compiled to calculate the Human-Use Resource Index (HRI). All data collected to produce the Environmental Sensitivity Index (ESI) was retrieved from various federal departments of the Government of Canada.

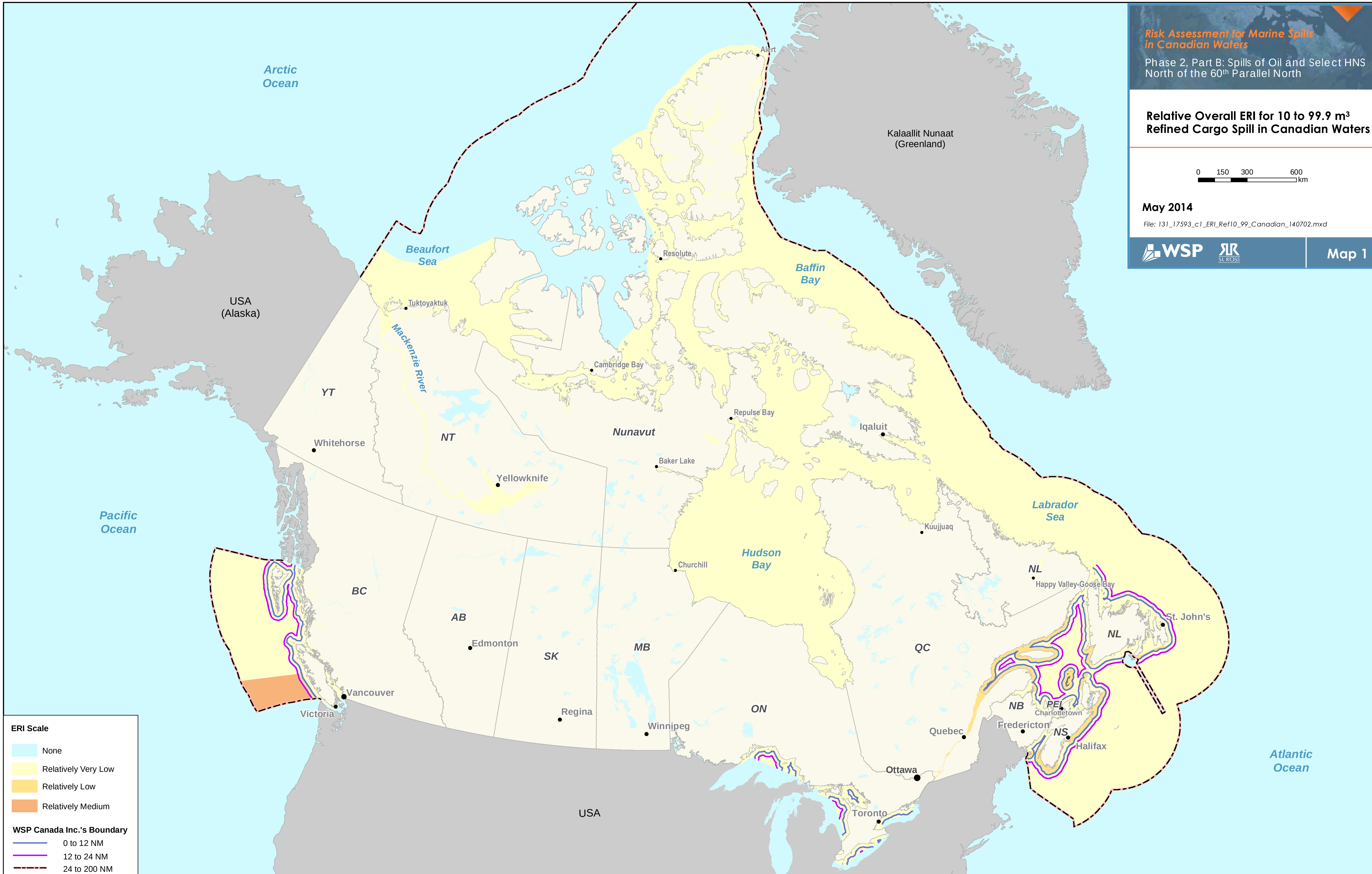
The methodology used in this risk assessment is based on large-scale data and therefore provides a relative Canadian-wide estimate of risk. The results from this study are meant to be interpreted on a large scale, as local factors are not included.

This report presents current oil spill risk results based on the most recent 10 years of available data (2002-2012) of oil movement in Canadian waters, combined with current environmental information and data sets. Appendix 2 describes the potential effects of future oil development projects in terms of tonnage and associated risks.

This report describes the data that has been collected and explains the methodology that has been applied to calculate relative risk estimates. Data limitations and assumptions are also explained. Recommendations have been provided to improve the methodology and refine risk estimates in the future.

The following summarizes the key results of this analysis:

- Spill frequencies of both refined cargo products and fuel follow a similar trend, with higher spill frequencies observed in the Labrador Sea-Hudson Bay corridor (sectors 5 to 8; Map 2.1) compared with the rest of the Canadian Arctic waters. The higher frequency values are related to a higher level of traffic. Higher spill frequencies are found for the 1 to 9.9 m^3 spill category of refined cargo products. Due to the high dissipation rate of refined cargo products (less than 5% remaining in the environment after 24hr under summer Arctic conditions; see p. 48), this spill category is not included in risk calculations. Beside this small spill size, higher frequencies are also observed for the 10 to 99.9 m^3 spill category, compared with the other two spill sizes (100 to 999.9 m^3 and 1,000 and greater).
- The highest spill frequencies were observed in the Labrador Sea sub-sector: a spill of fuel (10 to 99.9 m^3) is expected every 778 years whereas a spill of refined cargo products (same category) is predicted to occur close to every 3,000 years.
- The ESI score in the Canadian Arctic waters is variable among sub-sectors, with generally higher ESI scores in southern Arctic sub-sectors compared with the North. The BRI is the highest in the south of James Bay (sub-sector 6c) and in the south of the Beaufort Sea, at the Mackenzie River Delta (sub-sector 2a). The highest PSI values are James Bay (sub-sectors 6a and 6b) as well as Baffin Bay (sub-sector 8b). The highest HRI values are in the southern Canadian Arctic waters (James Bay, Baffin Bay and Labrador Sea sub-sectors).
- The ERI scores show similar trends for both refined cargo products and fuel oil, with similar risk observed in sub-sectors connecting the Labrador Sea to north of Hudson Bay. The highest risk values are observed for spills of 100 to 999.9 m^3 of fuel oil.
- The ERI scores for both refined cargo products and fuel oil indicate a low to very low risk of spills of all sizes in most sectors of the northwest Canadian Arctic waters.
- Overall, the probability of oil spills occurring in the Canadian Arctic waters is very low when compared with the South. Therefore, the risk of oil spills in Canadian Arctic waters is significantly lower than in the rest of Canada as a result of low probability of spills, lower level of traffic and low volumes of oil transported over the last 10 years.


Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil and Select HNS North of the 60th Parallel North
Relative Overall ERI for 10 to 99.9 m3 Refined Cargo Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c1_ERI_Ref10_99_Canadian_140702.mxd
WSP
Map 1
ERI Scale
None
Relatively Very Low
Relatively Low
Relatively Medium
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Arctic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
Pacific Ocean
Atlantic Ocean
Mackenzie River
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
YT
NT
Nunavut
BC
AB
SK
MB
ON
QC
NL
NB
PEI
NS
Alert
Resolute
Tuktoyaktuk
Cambridge Bay
Repulse Bay
Iqaluit
Baker Lake
Whitehorse
Yellowknife
Kuujjuaq
Churchill
Happy Valley-Goose Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Fredericton
Charlottetown
Halifax
Ottawa
Toronto

Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil and Select HNS North of the 60th Parallel North
Relative Overall ERI for 100 to 999.9 m³ Refined Cargo Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c2_ERI_Ref100_999_Canadian_140702.mxd
WSP
SL ROSS
Map 2
Arctic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
Pacific Ocean
Atlantic Ocean
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
Mackenzie River
YT
NT
Nunavut
BC
AB
SK
MB
ON
QC
NL
NB
PEI
NS
Alert
Resolute
Tuktoyaktuk
Cambridge Bay
Repulse Bay
Iqaluit
Baker Lake
Whitehorse
Yellowknife
Kuujjuaq
Churchill
Happy Valley-Goose Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Fredericton
Charlottetown
Halifax
Ottawa
Toronto
ERI Scale
None
Relatively Very Low
Relatively Low
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM


Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil Select HNS North of the 60th Parallel North
Relative Overall ERI for 1,000 to 9,999.9 m³ Refined Cargo Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c3_ERI_Ref1000more_Canadian_140702.mxd
WSP
SL ROSS
Map 3
ERI Scale
None
Relatively Very Low
Relatively Low
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Arctic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
Pacific Ocean
Atlantic Ocean
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
Mackenzie River
Alert
Resolute
Tuktoyaktuk
Cambridge Bay
Repulse Bay
Iqaluit
Baker Lake
Yellowknife
Whitehorse
Kuujjuaq
Churchill
Happy Valley-Goose Bay
St. John's
Charlottetown
Fredericton
Halifax
Quebec
Ottawa
Toronto
Winnipeg
Regina
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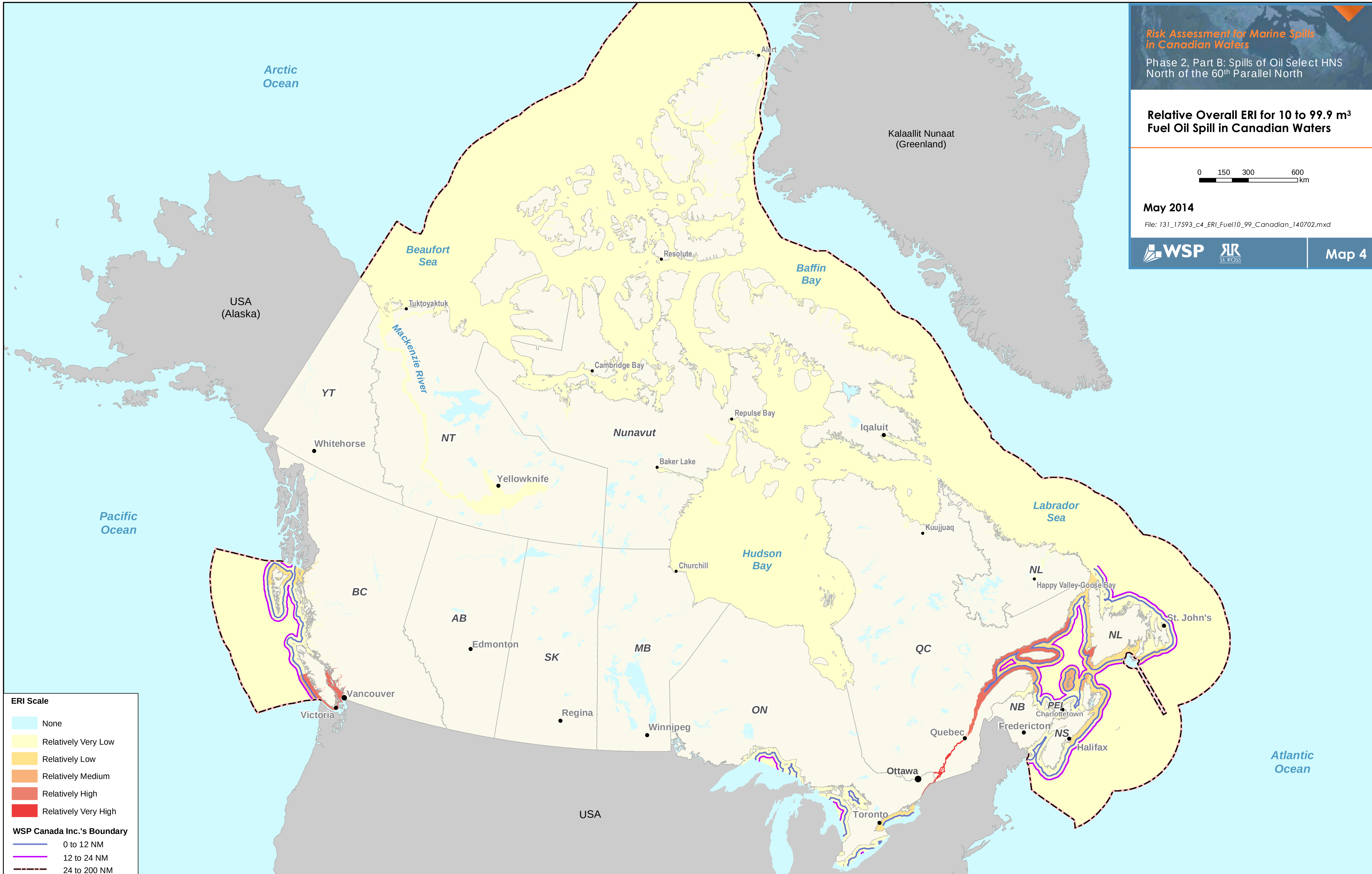
QC
NL
NB
PEI
NS



Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil Select HNS North of the 60th Parallel North
Relative Overall ERI for 10 to 99.9 m³ Fuel Oil Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c4_ERI_Fuel10_99_Canadian_140702.mxd
WSP
SL ROSS
Map 4
ERI Scale
None
Relatively Very Low
Relatively Low
Relatively Medium
Relatively High
Relatively Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Arctic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
Pacific Ocean
Atlantic Ocean
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
Mackenzie River
Alert
Resolute
Tuktoyaktuk
Cambridge Bay
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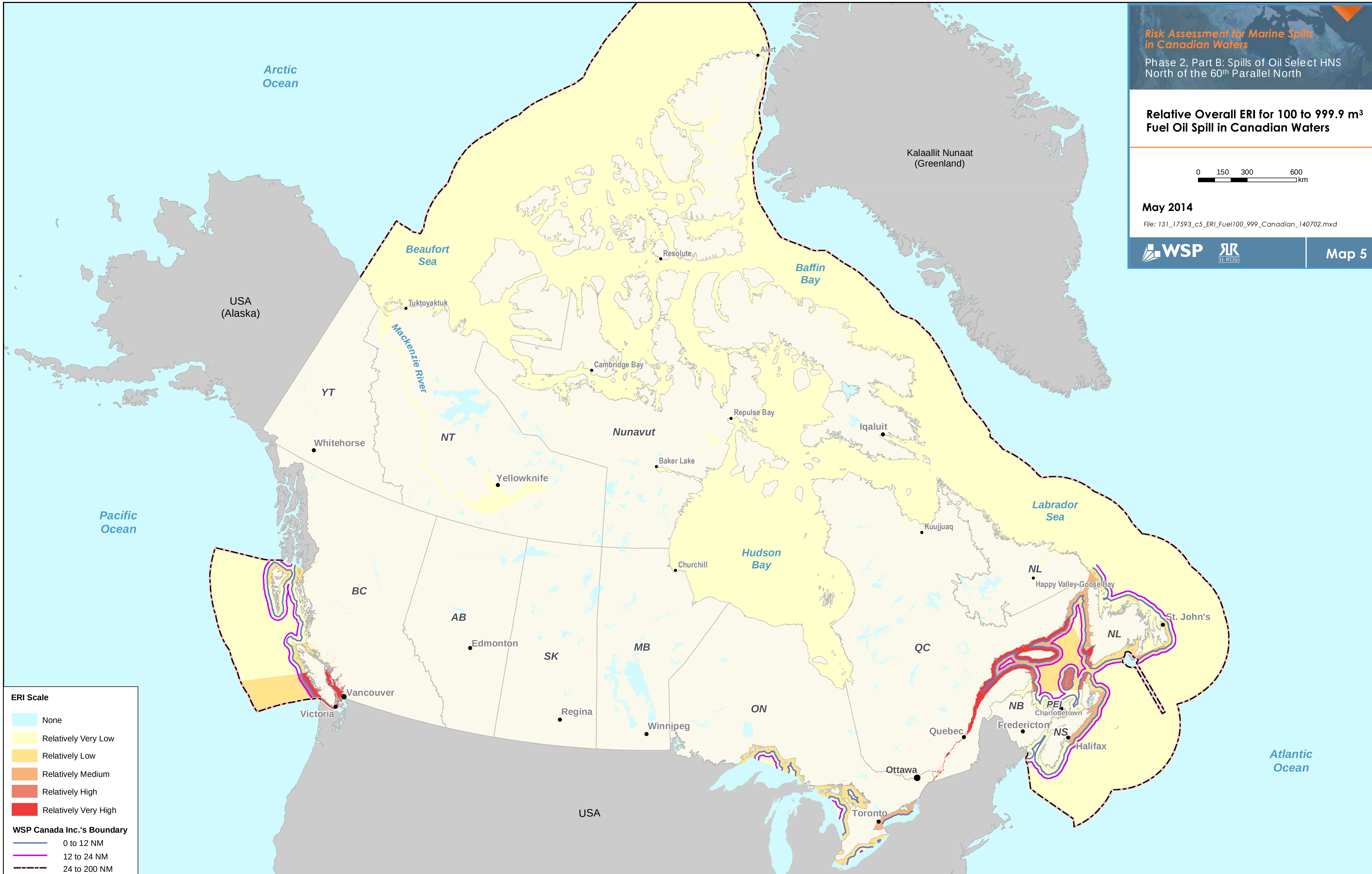
Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil Select HNS North of the 60th Parallel North
Relative Overall ERI for 100 to 999.9 m³ Fuel Oil Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c5_ERI_Fuel100_999_Canadian_140702.mxd
WSP
SL ROSS
Map 5
ERI Scale
None
Relatively Very Low
Relatively Low
Relatively Medium
Relatively High
Relatively Very High
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM
Arctic Ocean
Beaufort Sea
Baffin Bay
Kalaallit Nunaat (Greenland)
USA (Alaska)
Pacific Ocean
Labrador Sea
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QC
NL
NB
PEI
NS

Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil Select HNS North of the 60th Parallel North
Relative Overall ERI for 1,000 m to 9,999.9 m³ Fuel Oil Spill in Canadian Waters
0 150 300 600 km
May 2014
File: 131_17593_c6_ERI_Fuel1000more_Canadian_140702.mxd
WSP
SL ROSS
Map 6
Arctic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
Pacific Ocean
Atlantic Ocean
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
Alert
Resolute
Tuktoyaktuk
Mackenzie River
Cambridge Bay
Repulse Bay
Iqaluit
Baker Lake
Kuujjuaq
Churchill
Happy Valley-Goose Bay
St. John's
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Yellowknife
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Nunavut
BC
AB
SK
MB
ON
QC
NL
NB
PEI
NS
ERI Scale
None
Relatively Very Low
Relatively Low
WSP Canada Inc.'s Boundary
0 to 12 NM
12 to 24 NM
24 to 200 NM

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Reference to be cited:

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ASPPR	Arctic Shipping Pollution Prevention Regulations
AWPPA	Arctic Water Pollution Prevention Act
BRI	Biological Resource Indicator
CAA	Canadian Arctic Archipelago
CCEA	Canadian Council on Ecological Areas
CCG	Canadian Coast Guard
CESD	Commissioner of the Environment and Sustainable Development
CHS	Canadian Hydrographic Service
cP	Centipoise
CPI	Coastal Population Index
DEDTN	Department of Economic Development and Transportation of Nunavut
DFO	Fisheries and Oceans Canada
EBSA	Ecologically and Biologically Significant Area
EC	Environment Canada
EEZ	Exclusive Economic Zone
ERI	Environmental Risk Index
ESI	Environmental Sensitivity Index
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	Geographic Information System
GPS	Global Positioning System
GT	Gross Ton
HJBFB	Hudson Bay, James Bay and Foxe Basin
HNS	Hazardous and Noxious Substance

LIST OF ABBREVIATIONS (Cont.)

HRI	Human-Use Resource Index
IBA	Important Bird Area
IFTI	International Freight Tonnage Index
ITOPF	International Tanker Owners Pollution Federation
IUCN	International Union for Conservation of Nature
MCTS	Marine Communications and Traffic Services
MPIRS	Marine Pollution Incident Reporting System
NAO	North Atlantic Oscillation
NASP	National Aerial Surveillance Program
NAVTEX	Navigational Telex
NFPA	National Fire Protection Association
NFTI	National Freight Tonnage Index
NLS	Newfoundland and Labrador Shelf
NM	Nautical Miles
NOAA	National Oceanic and Atmospheric Administration
NORDREG	Northern Canada Vessel Traffic Services
NT/NU	Northwest Territories/Nunavut
PSI	Physical Sensitivity Indicator
RCMP	Royal Canadian Mounted Police
SA	Surface Area
SEA	Strategic Environmental Assessment
TC	Transport Canada
TI	Tourism Index

1. INTRODUCTION

1.1 Context

In the fall of 2009, the Commissioner of the Environment and Sustainable Development (CESD) completed an audit titled *Oil Spills from Ships* (Office of the Auditor General of Canada, 2010). The objective of the audit was to determine whether the Canadian Coast Guard (CCG), Transport Canada (TC) and Environment Canada (EC) were prepared to respond adequately to oil spills from ships. The audit, tabled in Parliament in December 2010, constituted Chapter One of the 2010 Fall Report of the CESD (Office of the Auditor General of Canada, 2010).

The CESD's report found that although TC and the CCG have completed risk assessments related to oil spills from ships, a consistent or systematic approach had not been used in the past. There also weren't any formal processes ensuring that risks were reassessed on an ongoing basis.

As a consequence, the CESD recommended that: "Building on the risk assessment conducted to date, Transport Canada and the Canadian Coast Guard should conduct a risk assessment related to ship-source oil spills covering Canada's three coasts. The risk assessment should be conducted in consultation with Environment Canada and the shipping industry. Transport Canada and the Canadian Coast Guard should put in place processes so that risks are reviewed on an ongoing basis and the risk assessment is updated as required. The Canadian Coast Guard should ensure that the risk assessment considers the three roles that it plays (federal monitoring officer, on-scene commander, and resource agency)."

While the three concerned departments agreed to implement this recommendation, TC's own research and analysis indicated that future planning for environmental response would benefit from broadening the scope of the CESD-recommended risk assessment to consider:

- The Great Lakes/St. Lawrence Seaway region (i.e., extend study beyond Atlantic, Pacific and Canadian Arctic waters); and,
- Potential ship-source spills of hazardous and noxious substances (HNS) (i.e., extend the study beyond oil spills to include other substances).

Risk assessments are segregated by geographic areas with sectors south of the 60th parallel north (i.e., Atlantic Coast, Pacific Coast, Estuary and Gulf of St. Lawrence, and the Great Lakes/St. Lawrence Seaway System) completed in one assessment and sectors north of the 60th parallel north (i.e., Canadian Arctic waters) addressed in a separate assessment.

This report specifically focuses on the relative risk caused by ship-source oil and select HNS spills north of the 60th parallel north. It follows previous studies on ship-source oil and select HNS spills south of the 60th parallel north (WSP, 2014a; 2014b). The Arctic sector was separated from the rest of Canada due to significantly lower traffic and volumes in this sector, allowing relative estimates of risk to be compared across Arctic sub-sectors.

1.2 Objectives

The objective of this study is to produce an estimate of relative risk for ship-source spills of oil and select HNS transported in bulk north of the 60th parallel north. The results of this study can be applied to further develop prevention, preparedness, response, mitigation, and recovery measures.

This study focuses on marine spills based on the most recent data available for the Canadian Arctic waters. Future projects and trends potentially influencing current risk values are discussed in Appendix 2.

1.3 Study Area

The study area for this report includes Canada's maritime zones located north of the 60th parallel north, as defined by Canada's *Oceans Act.*

The analyses were conducted in a series of sub-sectors included in the Exclusive Economic Zone (EEZ; 0 to 200 Nautical Miles (NM)) as well as the internal waters of the Canadian Arctic. In addition, the study includes one freshwater body, the Mackenzie River (and Great Slave Lake), as well as marine waters located south of the 60th parallel north but connected to Canadian Arctic waters (Hudson Bay, James Bay, Ungava Bay and Labrador Sea).

1.4 Limitations (specifically for Part B of Phase 2 of the study – for ship-source spills in the Canadian Arctic waters)

To facilitate the reader's understanding, it is important to present the limitations of this study. The implications of such limitations are further discussed in the interpretation of the results as well as in the recommendations.

The following are the limitations for the study regarding ship-source oil and select HNS spills north of the 60th parallel north:

- The study area is limited to Canada's maritime zones located north of the 60th parallel north, as defined by Canada's *Oceans Act,* and does not include rivers (with the exception of the Mackenzie River and Great Slave Lake), tributaries, and non-Canadian waters. The study also includes Hudson Bay's and Ungava Bay waters south of the 60th parallel north, James Bay (south of the 60th parallel north), and the Labrador Sea.
- Refined oil pollution sources are limited to ships (oil tankers, barges carrying oil as cargo, and other vessels) above 150 Gross Tons (GT). Fuel oil spills are determined for vessels above 300 GT. Offshore and onshore oil and gas development (offshore installations, exploration rigs and pipelines) as well as land-based oil/fuel storage installations/overwintering fuel barges are outside of the scope of this study. It should be noted that there is no data to suggest that the overwintering fuel barges are at a higher risk of spills.
- Oil is defined as refined cargo products and fuel (such as diesel). Presently, no crude oil is transported in the Canadian Arctic waters. Therefore statistics on spills of crude oil in the Canadian Arctic do not exist.
- This study is based on data obtained from various federal departments and agencies. In addition, traffic data, casualty data and oil movement data are acquired via Lloyd's and the International Tanker Owners Pollution Federation (ITOPF). Transit data was used as a proxy to estimate fuel movement and was calculated by counting routes based on satellite Automatic Identification System (AIS) tracks obtained from Exact Earth Spill data. The historical spill data was obtained from federal sources as well as from the NT/NU spill line.
- Based on a literature review, little information is available to estimate clean-up costs of spills in the Canadian Arctic region. Due to the lack of oil spill cost data, the ERI has been simplified to take into account this consideration.
- This study assesses the risk for a list of select HNS that are carried in bulk, and considered the most relevant in Canada (including south of 60th parallel north) based on the hazard and volume transported. Only three select HNS products were moved in the Arctic over the last 10 years. Due to the small volume of HNS transported in the Arctic, the relative risk of a spill could not be estimated. As a result, the HNS section of this report only includes a description and the volumes of the substances being transported.
- Five classes of HNS are considered: liquefied gases, petroleum products, organic substances, inorganic substances, and animal/vegetable oils.
- The analyses are based on data obtained from available sources.

- Tonnages of HNS transported in Canada are obtained from Transport Canada's commodity database.
- For the environmental sensitivity, data from federal sources (Aboriginal Affairs and Northern Development Canada, Environment Canada, Fisheries and Oceans Canada (DFO), Parks Canada, Natural Resources Canada, Statistics Canada, Transport Canada, and the Canadian Coast Guard) were used.
- Data from provincial, territorial and municipal sources were not considered, with the exception of provincial and territorial parks and protected areas. Gaps or uncertainty in the results are discussed and recommendations are made related to potential additional data sources to consider in future assessments.
- Weather data (temperature, precipitation, wind, fog, glaze, storms, surges), iceberg presence, and commercial hunting activities (birds and marine mammals) was not considered in the proposed calculation, although it is included in the discussion.
- No spill response is considered in this risk assessment. The results from the study assume the absence of a response and provide a 'worst case' scenario for each sub-sector.

2. METHODOLOGY

2.1 Scope

The methodology herein is for Phase 2, Part B of the risk assessment: ship-source oil spills and select HNS transported in bulk north of the 60th parallel north.

2.2 Definition of Arctic Coastal Sector and Sub-sectors

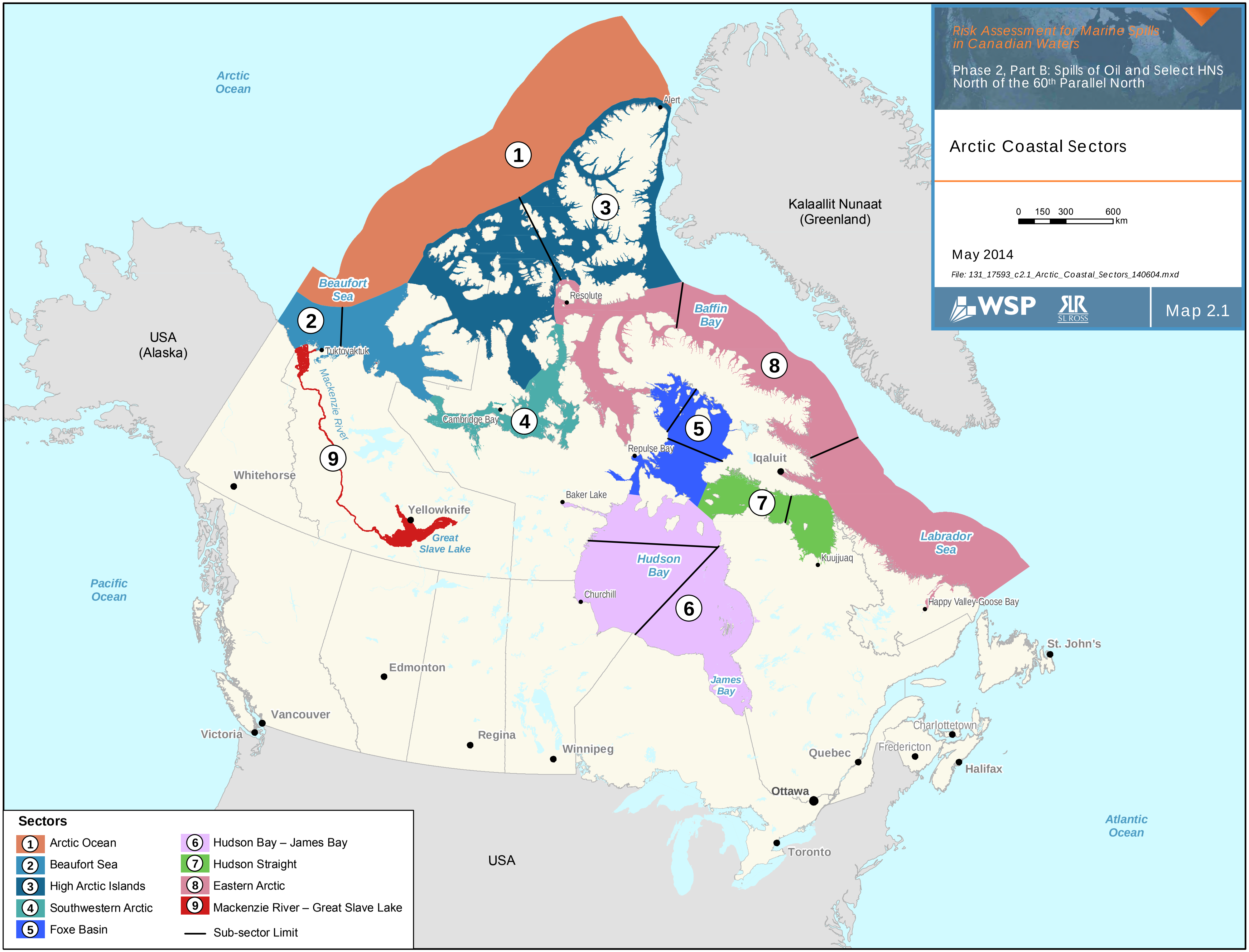
Given the large area of Canadian Arctic waters north of the 60th parallel north, it has been divided into nine main Arctic coastal sectors (Map 2.1), namely:

- Arctic Ocean (sector 1);
- Beaufort Sea (sector 2);
- High Arctic Islands (sector 3);
- Southwestern Arctic (sector 4);
- Foxe Basin (sector 5);
- Hudson Bay and James Bay (sector 6);
- Hudson Strait (sector 7);
- Eastern Arctic (sector 8); and,
- Mackenzie River – Great Slave Lake (sector 9).

This division of the Arctic region was defined using the distribution of ecoregions following the classification by DFO as well as the current marine transport corridors.

Several Arctic coastal sectors (2, 3, 5, 6, 7 and 8) are divided into smaller sub-sectors. The lateral boundaries of the sub-sectors were chosen to divide each main sector into segments to provide the most accurate calculation when generating transit numbers and associated volumes.

The boundaries between sectors and sub-sectors were adjusted to best represent the continuity in marine transport corridors.



Risk Assessment for Marine Spills in Canadian Waters
Phase 2, Part B: Spills of Oil and Select HNS North of the 60th Parallel North
Arctic Coastal Sectors
0 150 300 600 km
May 2014
File: 131_17593_c2.1_Arctic_Coastal_Sectors_140604.mxd
WSP
SL ROSS
Map 2.1
Sectors
1 Arctic Ocean
2 Beaufort Sea
3 High Arctic Islands
4 Southwestern Arctic
5 Foxe Basin
6 Hudson Bay – James Bay
7 Hudson Straight
8 Eastern Arctic
9 Mackenzie River – Great Slave Lake
Sub-sector Limit
Arctic Ocean
Pacific Ocean
Atlantic Ocean
Beaufort Sea
Baffin Bay
Labrador Sea
Hudson Bay
James Bay
Great Slave Lake
Mackenzie River
Kalaallit Nunaat (Greenland)
USA (Alaska)
USA
Alert
Resolute
Tuktoyaktuk
Cambridge Bay
Repulse Bay
Iqaluit
Baker Lake
Kuujjuaq
Churchill
Whitehorse
Yellowknife
Happy Valley-Goose Bay
St. John's
Edmonton
Vancouver
Victoria
Regina
Winnipeg
Quebec
Charlottetown
Fredericton
Halifax
Ottawa
Toronto

In total, the oil and HNS spill risks are presented as an average value (ERI – Environmental Risk Index) for:

- 1 sub-sector in sector 1;
- 2 sub-sectors in sector 2;
- 2 sub-sectors in sector 3;
- 1 sub-sector in sector 4;
- 3 sub-sectors in sector 5;
- 3 sub-sectors in sector 6;
- 2 sub-sectors in sector 7;
- 3 sub-sectors in sector 8; and,
- 1 sub-sector in sector 9.

2.3 Oil Spill Risk Assessment Methodology

2.3.1 General Approach

The general approach for the oil spill risk assessment involved the following key elements:

- The Arctic coastal waters were divided into 9 main sectors, some of which were further divided into smaller sub-sectors, for a total of 18 sub-sectors;
- Shipping densities as well as vessel types and size distribution in each sub-sector were estimated from satellite AIS tracks;
- Oil spill frequencies for ships was obtained from the most recent 10 years of Canadian and worldwide accident data;
- The Environmental Sensitivity Index (ESI) was calculated based on physical, biological and human metrics that are further mapped to illustrate their spatial distribution in each sub-sector;
- The overall ERI was the product of ESI and spill frequency for each type of oil product. The relative risk values are mapped to allow comparisons between Arctic sectors and sub-sectors.

2.3.2 Data Collection

Different datasets were required to calculate the probability and the potential impact of hypothetical oil spills. Specific details on the data assembled for this study is provided in the following sections. An evaluation of data quality and the limitations of these datasets is provided in the subsequent phases of work. This analysis will provide insight on potential over/under estimations, and will assist in identifying data gaps where more detailed datasets would be beneficial to refine the overall study.

2.3.2.1 Vessel Traffic Data

In order to generate an estimate of the probability of oil spills in Canadian waters, Canadian traffic data was retrieved from Canadian sources. The Transport Canada Commodity database was used for volumes (refined cargo products), the AIS tracking data was used to infer transits, and spill frequencies were calculated based on historical spill data from the Marine Pollution Incident Reporting System (MPIRS) database and the NT/NU spill line.

Due to the low incidence of events in Canadian waters, worldwide casualty data (Lloyd's data) was used to estimate the probability of medium and large-scale spills. In order to produce an estimate of casualty frequency, casualties were divided by worldwide traffic data. Thus, frequencies are calculated as global estimates (based on Canadian data where available, and worldwide data for larger spill sizes) and also refined for a set of selected countries characterized as having similar fuel handling practices/shipping regulations to Canada. These frequencies are multiplied by specific traffic data for each sub-sector identified above.

Using Arctic spills data, an incident rate based solely on spills in Canadian waters north of the 60th parallel north was compared with national spill frequencies. As there have been no spills reported in all but the smallest size category, a spill frequency similar to the south of the 60th parallel north study was applied. Using Canadian frequencies, it is likely that the Arctic estimates are overestimated and therefore provide a worst case scenario.

2.3.2.2 Environmental Data

The impacts on physical, biological and human environments were identified from data provided by federal authorities and used to qualify environmental sensitivity. To integrate this sensitivity into the risk assessment, the following components of the physical, biological and human environments were considered:

- Physical environment: bathymetry, tide, littoral geomorphology, physical oceanography and ice conditions;
- Biological environment: fishes, birds, coastal zone, ecologically and biologically significant area (EBSA), and protected areas; and,
- Human environment: port activity, tourism employment intensity and, coastal population density.

These components are based exclusively on international and federal data provided by federal ministries (DFO, EC and TC). With the exception of information on protected areas, data from provincial, territorial and municipal governments have not been included in this study.

The produced metrics are mapped to present their spatial distribution and facilitate the interpretation.

2.3.3 Arctic Chart Quality

There was some concern that there may be an elevated frequency of spills in the Arctic as a whole and in some parts of the Arctic specifically related to the poor quality of navigational information, and consideration was given to applying an increased spill frequency factor in such cases based on chart quality. The subject was discussed with the Canadian Hydrographic Service (CHS), who described their ongoing program for classifying chart quality. According to their classification system, only two areas of the Arctic qualify for the highest of their three-tiered ranking (those areas are portions of the Beaufort Sea and in the Foxe Basin, both of which have been recently surveyed with regard to planned development activities). Most other areas have second-level ranking, mainly related to the age of the surveys and the technology available at the time of survey to accurately define sounding locations. Effort are ongoing to improve overall chart quality according to a priority process related to marine and industrial activities.

Based on the overall mediocre or poor quality of charts in the Arctic, it was thought to be unreasonable to apply increased weighting to the spill frequency in specific areas. One of the considerations was the fact that there has not been a significant number of reported spill incidents related to navigational issues, according to the spill statistics used in the present study. One reason for this may be that, for the most part, marine traffic in the Arctic is performed by long-time operators who use up-to-date charts and are familiar with their routes.

2.3.4 Spill Frequency Methodology

The methodology for estimating spill frequency for the Arctic is similar to that developed for the southerly waters of Canada (Phase 1; WSP, 2014a), with a few exceptions and points of interest noted below.

As in the south, spill frequencies are estimated separately for different categories of oil products (refined cargo product carried as cargo, and oil carried as fuel) and for four defined spill size categories (10 to 99.9 m^3; 100 to 999.9 m^3; 1,000 to 9,999.9 m^3 and 10,000 m^3 and greater). However, the spill frequency for refined cargo products carried as cargo and oil carried as fuel are both estimated to be zero for the 10,000 m^3 and greater category as there have not been any records of spills of this magnitude over the past 10 years worldwide. In the case of oil carried as fuel, a spill of more than 10,000 m^3 is not likely to occur, given the volumes of fuel carried by even the largest vessels worldwide. Spills of oil carried as cargo are estimated as a rate per volume of cargo carried; spills of oil carried as fuel are estimated as a rate per vessel transit.

Additional analysis was performed to evaluate the frequency of small spills of 1 to 9.9 m^3 of refined cargo products in the Arctic. Based on current spill statistics for the Canadian Arctic, refined cargo spills are the most common spills for this spill size compared to spills sources. This spill size could originate from vessels but also from the transfer of refined cargo products from a vessel to land. Due to limited infrastructure in the Arctic, it is likely that more frequent spills may occur during loading/unloading events.

- Crude oil is not transported as cargo in the Arctic, so this category of spill was not addressed, as it was in the Phase 1 study (WSP, 2014a).
- As in the Phase 1 study, spill frequencies were based on Canadian spill statistics except for the larger spill size categories, in which there have been no such reported incidents in the most recent ten years of record. Worldwide accident statistics were used for these categories.
- Due to the absence of large spill sizes, spill frequency is calculated for three spill sizes: 10 to 99.9 m^3; 100 to 999.9 m^3 and ≥1,000 m^3.
- Additional calculations are performed for the small size spill category, 1 to 9.9 m^3, for refined cargo products.

2.3.5 Environmental Sensitivity Index (ESI)

The ESI is developed to assess the sensitivity of the environment to oil spills. Its purpose is to quantify the relative risk associated with oil spills in Canadian Arctic waters, by converting the estimates of oil spill frequencies into indicators of environmental risk.

The following sub-sections describe the approach used and detail each of the indicators that compose the ESI.

2.3.5.1 General Approach

Based on existing literature (Office of Response and Restoration, 2013; DNV, 2011; Cohen, 2010; NOAA, 2002), a relative index (the ESI) is selected to evaluate the sensitivity of each zone. The ESI incorporates three indicators:

- The Physical Sensitivity Indicator (PSI) is the degree of difficulty involved in the coastal clean-up operations.
- The Biological Resource Indicator (BRI) is the sensitivity of natural resources that are affected by an oil spill.
- The Human-Use Resource Index (HRI) is the direct commercial losses caused by a spill, in addition to an evaluation of the damage caused to social resources and the disruption to human activities.

The relative weight of each indicator is based on a review of cost breakdowns of worldwide oil tanker spills from 1992 to 1997 (DNV, 2001). This breakdown is consistent with the weights used by Cohen (2010).

$$ESI = 0.3(PSI) + 0.5(BRI) + 0.2(HRI)$$

Although this method allows for a relatively good quantification of environmental sensitivity, it has some limits:

- The indicators (PSI, BRI and HRI) are each expressed as average values representing an entire zone. They characterize the general sensitivity for each of the zones. The overall index is not representative of the sensitivity of specific locations but is an average for the entire zone length. These indicators are considered as global (large scale) indicators.
- The use of averaged ESI values inevitably results in a loss of sensitivity detail within each zone. For example: a relatively small high-sensitivity area within a zone might be concealed if it is surrounded by relatively low-sensitivity zones.

2.3.5.2 Physical Sensitivity Indicator (PSI)

For the Arctic, the presence of ice during most of the year is the main characteristic of this region, thus the presence of ice is considered as a shoreline type. In the subarctic sector, such as in the Hudson Bay (for the purpose of this study included in the Arctic region), ice is present during winter months. The annual ice melting leaves the shoreline free of ice for about five to six months per year. The lack of information regarding the shoreline types in the absence of ice leaves us with two shoreline categories: 1) iced shorelines and 2) free of ice shorelines. For the PSI calculation purposes, it is assumed that free of ice shorelines[1] are most sensitive as the presence of ice prevents the oil from reaching the shoreline. The two ranks used for PSI calculation are as follows:

- Presence of ice (iced shorelines): Rank 1; and,
- Absence of ice (free of ice shorelines): Rank 2.

The PSI for the Arctic region is calculated based on the same relationship as with other sectors. It is calculated as a function of the ranks for each shoreline type as follows:

$$PSI_{type} = Rank / 2$$

Since these two different shoreline types may coexist, the average PSI of the sub-sector is calculated based on the length (L) of each type of shoreline (iced and ice free shorelines) divided by its total length. In addition, the surface area (SA) of the ice cover at the end of June (before melting) is also considered in the PSI calculations to include the effect of the presence of sea ice during most of the oil transfer operation in Arctic. This PSI component is calculated based on the SA in each sub-sector divided by the total surface area of the sub-sector:

$$PSI_{sub-sector} = \sum_{types} \frac{L_{component}}{L_{total}} PSI_{type} + \sum_{types} \frac{SA_{component}}{SA_{total}} PSI_{type}$$

$L_{component}$ = length of the considered component

L_{total} = total length of the sub-sector

$SA_{component}$ = surface area of the considered component

SA_{total} = total surface area of the sub-sector

PSI_{type} = physical sensitivity indicator (PSI) in a given sub-sector

[1] In the present study, free of ice shorelines are shorelines free of ice during summer season. The ice is present on these coasts during winter season.

It should be noted that because of the lack of information regarding shoreline type in this area, the Arctic region is analysed independently of other sectors under study (WSP, 2014a). The PSI calculation and comparison with other sectors is possible when the shoreline type is available.

2.3.5.3 Biological Resource Indicator (BRI)

Distribution of biological resources in Canadian Arctic waters is highly variable, although they are generally more abundant during the summer. To account for this variability, a similar method to that developed by DNV (2011) is used to create a BRI.

For the purpose of this study, the BRI is calculated as follows:

$$BRI_{sub-sector} = \sum \frac{L_{component}}{L_{total}} W_{component} + \sum \frac{SA_{component}}{SA_{total}} W_{component}$$

$L_{component}$ = length of the considered component
L_{total} = length of the sub-sector
$SA_{component}$ = surface area of the considered component
SA_{total} = surface area of the sub-sector
$W_{component}$ = component sensitivity weighting.

The biological components considered for the BRI are: protected areas, coastal zone, and birds, as well as interest areas, such as EBSAs. These interest areas show particular characteristics which are important for some biological functions (reproduction, concentration, feeding) for marine fauna. To each of these components, a weight has been attributed that reflects their estimated overall ecological sensitivity to oil spills (Table 2.1). This weighting scheme is primarily based on the DNV study (2011) that uses a scale from 1 to 25. The specific weight attributed to each component is based on the Strategic Environmental Assessment (SEA) for the Gulf of St. Lawrence study (GENIVAR, 2013) and from other marine environmental studies (dredging, harbour, etc.).

2.3.5.4 Human-Use Resource Index (HRI)

The human environment differs greatly in the Arctic compared to sectors south of the 60^{th} parallel north. The low density of the population, the great distances between communities, the strong presence of traditional subsistence activities, and the relative lack of unified statistics require an adjustment to the HRI indicator to capture the specific features of the Arctic.

Table 2.1 Sensitivity Weighting and Justification for Selected Biological Components

Component	Description	Weight (W)	Justification
Protected Area	• UNESCO sites • Ramsar sites • Important Bird Area (IBA) • Federal and provincial protected areas	25	A high sensitivity weighting is given to this component because these sites represent, as defined by IUCN (2008), a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values.
Species at risk	• Species' critical habitats identified in a recovery strategy or in an action plan	25	A high sensitivity weighting is given to this component because these critical habitats are necessary for the survival or recovery of a red-listed wildlife species.
Coastal Zone	• Coastal zone (0-50 m depth) in marine environment	20	A high sensitivity weighting is given to this component because it is in this zone that the shoreline habitats of specific interest are concentrated. These habitats (e.g., wetlands, laminaria beds, coral or sponge reef) are necessary for several biological functions (spawning, nesting, wintering and alimentation) of many species.
Bird	• Legal bird colony • Concentration area	15	A medium-high sensitivity weighting is given to this component because birds affected by an oil spill have less chance of survival because of the irreversible consequences to their plumage as well as their physiological response.
Interest Area	• Ecologically and biologically significant area (EBSA) • Fisheries Closure Area (Mackenzie)	10	A medium sensitivity weighting is given to this component since most of the marine mammals and fishes using Canadian waters have a high capacity of avoidance. Moreover, plankton and invertebrates are important in the food chain and their large geographical distribution makes them relatively resilient to an oil spill.

In the Arctic, assessing human activity related to each sub-sector is extremely complex and no simple indicator monitoring the sensitivity of human activity to marine spills exists. Therefore, the proposed methodology uses a combination of four indicators:

- Coastal population index (CPI);
- Tourism index (TI);
- International freight tonnage index (IFTI); and,
- National freight tonnage index (NFTI).

Adapted from DVN (2011) and based on a previous WSP study (2014), the HRI formula is:

$$HRI = 0.7(CPI) + 0.2(TI) + 0.05(IFTI) + 0.05(NFTI)$$

Details on the chosen indicators are presented below.

The HRI in the Australian risk assessment study (DNV, 2011) is based on three indicators: fishing intensity, passenger vessel intensity, and the presence of national parks. DNV proposed a weight of 0.8 for the fishing industry and 0.2 for the tourism industry (0.1 for the passenger vessels and 0.1 for the presence of national parks).

In the oil spill risk assessment (WSP, 2014a), a similar approach is used, which includes additional components to reflect the particularity of the Canadian economy and to fit the datasets available. The HRI used in this study is based on three indicators: population density, tourism and freight port tonnage.

Assessing the human use sensitivity in the Arctic presents several challenges. This section explains the choices that were made in terms of HRI in the Arctic.

Coastal Population Index (CPI)

The general aim of the Coastal Population Index (CPI) is to establish a metric that measures the value of the coastal human activities in the Arctic region. It takes into account the population density to establish the human use value of the coasts for each of the sub-sectors. Since the majority of the population in the area of study is Inuit, this indicator captures explicitly the human use for these communities.

The proposed CPI encompasses, to some extent, fisheries activities in the Arctic. Fisheries and hunting of large mammals are key activities for Arctic communities dependant on their natural environment for subsistence. As a surrogate to traditional fishing and hunting activities, the CPI was applied, based on the hypothesis that non-commercial hunting and fishing activities would increase commensurate with increased population densities.

The contribution of commercial and sustainable fisheries is also a key element of the Arctic territory economy. The royalties paid to the Nunavut government by offshore turbot and shrimp fishing companies amounts to several millions of dollars a year. Arctic char fishing benefits the communities in terms of food replacement and outside sales. Although banned for export to the European Union, sealing is still part of the culture and the tradition of the communities and offers a local food source as well as raw material for traditional practices and the commercial clothing industry. Accordingly, these activities are vulnerable to marine spills.

The large scale approach applied in this risk assessment limits the incorporation of commercial fisheries as these activities may not be associated with coastal environments. Large fishing vessels active in the Arctic may transit from Canadian Arctic waters to locations outside of the area (e.g., Greenland) to unload their catches, therefore, although data exists to describe the economic value of a given fishing activity, it is difficult to associate the value to the geographic breakdown applied for each index. Additional research and methodology would be required to capture commercial fisheries in a regional risk assessment.

In regards to the human value of the water use, (DNV, 2011) noted that “Human population could be considered by itself as an indicator of the human-use value of nearby environments, or as a weighting on other indicators, such as national parks. However, this would be very sensitive to the distance threshold used in selecting coastal population, or would require an integration taking into account accessibility, which would be too complex for the present study” (DNV, 2011). However, based on the coastal location of the vast majority of the communities in the Arctic, the distance threshold does not apply; therefore, coastal population must be considered for the human-use value of water.

The proportion given to the CPI in the HRI formula (0.7) encompasses the traditional fisheries and sealing (weight = 0.55) and water use (weight = 0.15).

The commercial fishing industry and the presence of the local population in the fishing industry are both expected to increase in the near future (Standing Senate Committee on Fisheries and Oceans, 2004). With the expected growth of fishing activities in the Arctic region, and for resource management purposes, it is assumed that detailed fishing statistics will be collected in the future. Assuming that this data will be available, the fishing statistics should be included in a future HRI calculation.

Tourism Index (TI)

The tourism industry in the Canadian Arctic is poised to grow in the future, with the opening of the Northwest Passage potentially leading to expanded tourism possibilities. Currently, the Baffin region is by far the most visited area as shown in the latest tourism diagnosis by the Department of Economic Development and Transportation of Nunavut (DEDTN, 2008). There is also significant tourism development in Nunavik and numerous outfitters operate around James Bay and Hudson Bay. However, available tourist data comes from a variety of sources with differing purposes and it likely would not demonstrate the proper representation for the purpose of this study.

As an example, it would have been possible to use cruise sailing lines as a tourism indicator but it would have neglected the tourism generated by fishing and hunting activities, which is also important. Instead, in the absence of a detailed number of annual tourists for each of the communities, the presence of a national park is considered as a good indicator of the tourism sensitivity to a marine spill (based on DNV, 2011). In the Canadian Arctic, national parks are mostly visited by population from northern communities and therefore represent a key resource (or important ecosystem services) to local populations. In this study, a similar weight as the tourism employment indicator used in oil spill risk assessment (WSP, 2014a), TI = 0.2, was applied.

International and National Freight Tonnage Index (IFTI and NFTI)

In a previous oil spill risk assessment (WSP, 2014a), total annual port tonnage, domestic and international, is used as an indicator of the human economic sensitivity related to port activities. As mentioned before, the commercial ports in Canada play a large role in allowing business to reach overseas markets.

In this study, freight port tonnage was divided into two categories: IFTI and NFTI. As demonstrated by SNC Lavalin (2011), domestic maritime transportation plays a significant role in the economic welfare of the arctic communities. It provides the goods and necessities for these communities while the international freight is more of a driver of economic activities.

The overall weight for the shipping activities is 0.1, and it is split equally between international and domestic shipping activities.

The domestic shipping activities of the port of Deception Bay is treated as international shipping activity because it focuses on economic activities (nickel-copper concentrate shipping) rather than on goods and necessities transportation.

Table 2.2 Component Description and Justification

Component	Description	Weight	Justification
Coastal Population Index (CPI)	Relative coastal population in each sub-sector.	0.70	Due to limitation in applying commercial fishing values, it is used as a proxy to estimate the importance of fishing, sealing and coastal value of the communities.
Tourism Index (TI)	Presence of a protected area in each sub-sector.	0.20	In the absence of detailed tourism statistics, it is used to identify the landmark that attracts both cruise ships and tourists.
International Freight Tonnage in Port Index (IFTI)	Relative international tonnage in each sub-sector.	0.05	Identifies the port activities related to commercial activities.
National Freight Tonnage in Port Index (NFTI)	Relative national tonnage in each sub-sector.	0.05	Identifies the activities related to the provision of supplies and commodities in the communities.

2.3.6 Environmental Risk Index (ERI)

2.3.6.1 Selection of Risk Metrics

The ERI is calculated as a metric describing the relative risk sensitivity of each sub-sector to oil spills. This index allows the integration of environmental and spill size considerations into the risk analysis. The proposed ERI calculation for oil spills north of the 60th parallel north differs from that presented in DNV (2011) and is applied in the oil spill risk assessment south of the 60th parallel north (WSP, 2014a). Based on a literature review, little information is available to estimate clean-up costs of spills in the Arctic region. Due to the lack of oil spill cost data, the ERI has been simplified to take into account this consideration. The ERI is defined as:

$$ERI = F \times Q \times ESI$$

where F is the frequency of oil spills (described as return period), Q is the spill size (m^3) and ESI, the environmental sensitivity index in a sub-sector.

The return period is simply the inverse of the estimated frequency (e.g., if the frequency per year is 0.01 the return period is once per 100 years).

2.3.6.2 Use of ERI

This section aims to describle the range of values for the ERI. The ERI is graphically presented using five risk categories (relatively very low, relatively low, relatively medium, relatively high and relatively very high).

For each sub-sector, an ERI is determined for each oil spill size category and oil type. The results are featured on individual sector maps in order to localize the relative environmental risks related to oil spills.

From an emergency planning point of view, ERI can be interpreted as a relative measure of the importance of risks associated with oil spills. A large ERI value implies a relatively higher risk of economic and environmental damage. Consequently, this index can be applied to to reduce damages in Arctic waters if combined with emergency planning by authorities.

Colors used to illustrate ERI values (maps presented in Chapter 4) are defined based on a scale adapted to best represent the gradient of variation within the ERI data.

2.4 HNS Spill Risk Assessment Methodology

2.4.1 General Approach

The proposed method to process and analyze HNS data is similar to that developed in the select HNS risk assessment south of the 60th parallel north (WSP, 2014b). Based on commodity data, the tonnage of select HNS transported in the Arctic sector over the last 10 years is too low to assess a risk value. Overall, of the select substances for the study (WSP, 2014b) only three substances are identified as being transported in the Arctic: naphthalene, lead concentrate and ammonium based fertilizers (ex: ammonium nitrate).
Specifically, 3 shipments of fertilizers occurred over the last 10 years, with a mean volume of 5,740 t. In 2002, 3 shipments of lead concentrate occurred (volume: 52,400 t). Finally, naphthalene was moved 37 times between 2002 and 2005, for a mean volume of 178 t/y. Most of the volume was moved in 2002 (491 t) and 2004 (170 t) and less than 50 t were moved in subsequent years.

Consequently, the report on HNS in the Arctic is limited to a description of the current substances being transported.

3. CHARACTERISTICS OF OIL SPILLS CAUSED BY VESSEL TRAFFIC AND MAIN IMPACTS

3.1 General Aspects of Spill Fate and Behavior

The fate and behavior of oil spilled at sea will be largely dependent on oil properties. These properties may be affected by different weathering processes.

3.1.1 Physical Properties of Oil

There are four key physical properties of interest:

- Density is a measure of the oil's weight per unit volume (commonly expressed in grams per millilitre [g/ml]). The density of the oil when compared to the density of water is important to take into consideration in the event of a spill. If the oil density is less than water – 1.0 g/ml for freshwater and about 1.03 g/ml for salt water – it floats, otherwise it will sink.
- Viscosity is a measure of a fluid's resistance to flow, (expressed in centipoise [cP]). Oil viscosity is critical in dispersant work because thin, non-viscous oils (<2,000 cP) are readily dispersible, but heavy, highly-viscous oils (>10,000 cP) are not. Viscosity is also important when recovering oil with skimmers and transferring it with pumps. For a given oil type, viscosity will be greater in cold waters.
- Surface Tension is an indicator of an oil's tendency to spread and disperse, and is measured in milliNewtons per metre (mN/m).
- Pour Point is a measure of the temperature below which oil will not flow. It represents the point at which the oil starts to solidify or gel as it cools and is measured in temperature units as either degrees Fahrenheit or Celsius.

3.1.2 Oil Weathering Processes

When oil is spilled at sea, it is subject to several weathering processes (Figure 3.1). The main processes that will influence the persistence and environmental effects are drifting (advection), spreading, evaporation, oxidation, natural dispersion-dissolution of oil in water, water-in-oil emulsification and sedimentation).

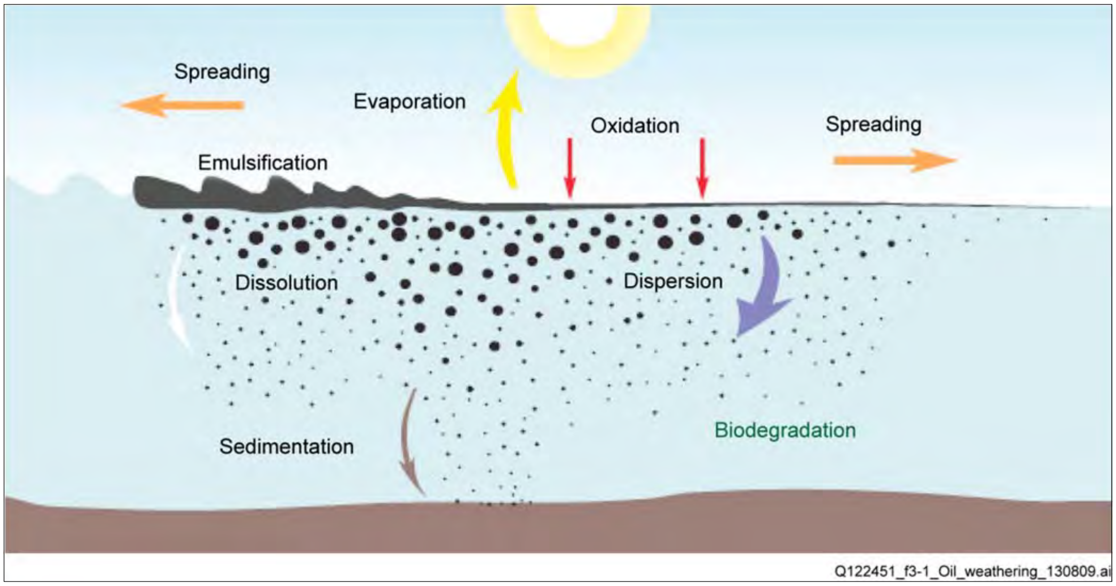


Figure 3.1 Oil Weathering Processes

3.1.2.1 Spreading

When oil is in contact with water, it spreads and thins on the surface of the water, forming a thin slick. Spreading is important because it:

- Causes large increases in the surface area of the spill; and
- Leads to decreases in the thickness of the oil.

Spreading curves can be used to provide a rough approximation of the spill area over time for a given spill volume. Computer-based models give accurate indications that take into account additional variables such as changes in oil properties and wind and current effects. Whether spreading curves or computer modelling is used, they provide an idealized or theoretical description of spreading, and are based on a continuous slick of uniform thickness. The difference between the two forms of modelling is that after the first few hours of an oil spill occurring in the environment, an oil slick is seldom of a continuous and uniform thickness.

The relatively fast rate of oil spreading is demonstrated in Figure 3.2. This model, which originated from a methodology first developed in the late 1970s, is still used extensively today.

Figure 3.2 shows that for a spill of 1,000 m^3 (6,300 barrels), the total slick area reaches about 10 km^2 in one or two days.

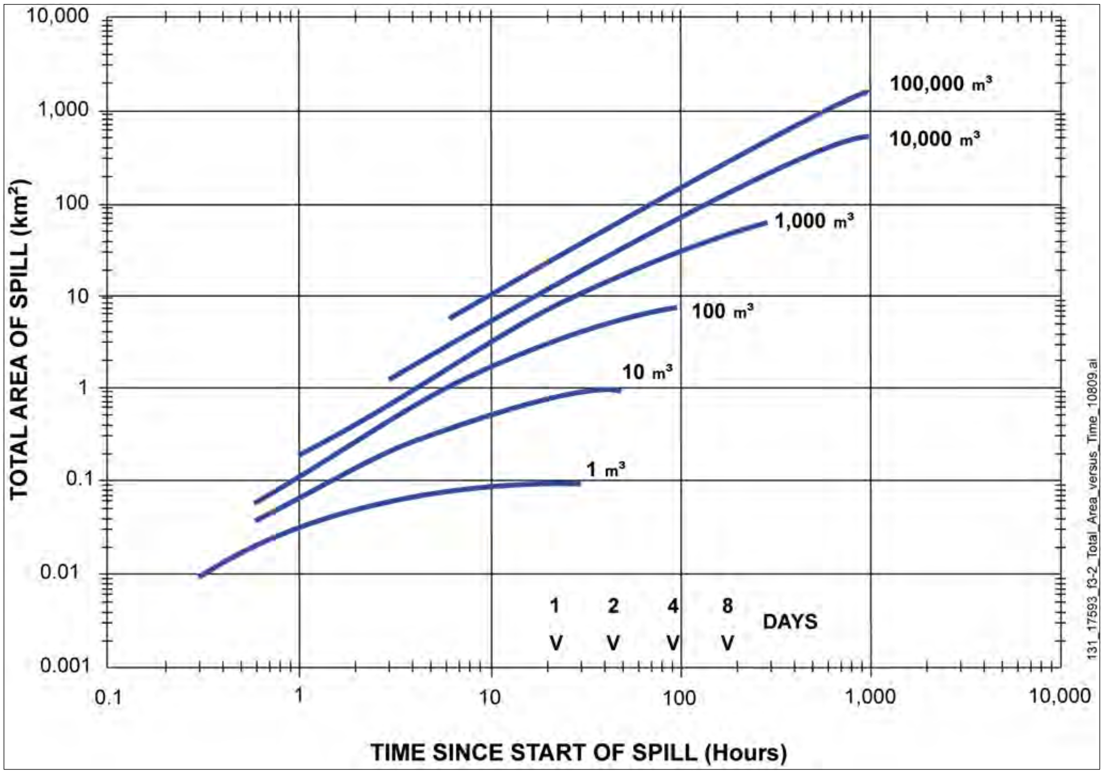


Figure 3.2 Total Area of Slick (thick + thin) versus Time

3.1.2.2 Spill Movement

As soon as oil is spilled, it spreads out over the sea surface. An oil slick is carried by the surface layer (the upper few centimetres) of water. The driving force for this surface layer includes wind, the local components of large-scale circulation patterns, tidal influences, and freshwater inflows.

An approximation of slick movement can be made using some very simple methods: A slick can move at about 3% of the wind speed at 10 to 15 degrees to the right of the wind direction due to the Coriolis effect, with the speed and direction modified by the addition of other water currents. Other currents (tidal, freshwater influences) are added to the wind effects using vector addition.

Computer-based models can be used to estimate the movement of a spill, and they typically use a basic calculation procedure similar to this vector technique. The advantage of computer models is the ability to store and use large quantities of historical current and weather information that may vary for a specific location and the time of year. Note that the main problem in estimating slick movements during a spill is generally the unavailability or poor quality of local water current data, rather than a poor understanding of how a slick moves due to wind and current forces.

3.1.2.3 Evaporation

As soon as oil is spilled, the lighter, more volatile hydrocarbons begin to evaporate. This is important for two reasons. First, for light refined cargo products, evaporation leads to a significant reduction in the total spill volume. Second, evaporation leads to changes in the properties of the oil, which in turn may affect other weathering processes such as dispersion and emulsification. The volatile light ends come out of solution when the oil is exposed to the atmosphere. It is the proportion of these light ends that will determine the evaporative potential of a given oil. All light refined cargo products, such as gasoline, have a high proportion of light ends that will tend to evaporate from a slick on open waters. Oil evaporation is controlled by several factors such as:

- Slick thickness – the thinner the slick, the more surface area of the slick is exposed to the atmosphere, and hence available for evaporation; therefore, the evaporation rate increases and the slick thickness declines;
- Temperature – oil will evaporate faster with higher temperatures, just as water evaporates faster on a hot day. Note that although evaporation rates will be decreased in cold temperatures, gasoline will still evaporate at freezing temperatures; and,
- Wind speed – the greater the wind speed, the greater the potential evaporation rate.

These three factors can be modeled and used to make predictions based on the slick thickness, temperature, and wind speed for a given spill.

An example of evaporative loss for light refined cargo products is presented hereafter: for a slick of 1 mm or less, wind speeds of 20 km/h, and water temperatures of 5° C, the volume loss would be in the range of 25 to 30% within 12 hours, and up to 50% within one day.

Empirical evaporation curves can be useful to make rough estimations of evaporative loss; a more accurate calculation would require computer modeling that would take into account the change in slick thickness over time.

3.1.2.4 Oxidation

Oils react chemically with oxygen either breaking down into soluble products or forming persistent compounds called tars. This process is promoted by sunlight and the extent to which it occurs depends on the type of oil and the form in which it is exposed to sunlight. However, this process is very slow and even in strong sunlight, thin films of oil break down at no more than 0.1% per day. The formation of tars is caused by the oxidation of thick layers of high viscosity oils or emulsions. This process forms an outer protective coating of heavy compounds that result in the increased persistence of the oil as a whole.

3.1.2.5 Dispersion

Natural dispersion, as opposed to dispersion following the addition of chemical dispersing agents, can be an important process for oil removal from the water surface. Dispersion is a natural mixing process in which small droplets will tend to be permanently suspended in the water column, their natural buoyancy unable to overcome the forces of large scale mixing currents through the water body (Figure 3.3). Agitated sea conditions will enhance oil dispersion – which will help oil degradation by microorganisms. Oil dispersion can also be enhanced using natural or chemical dispersants.

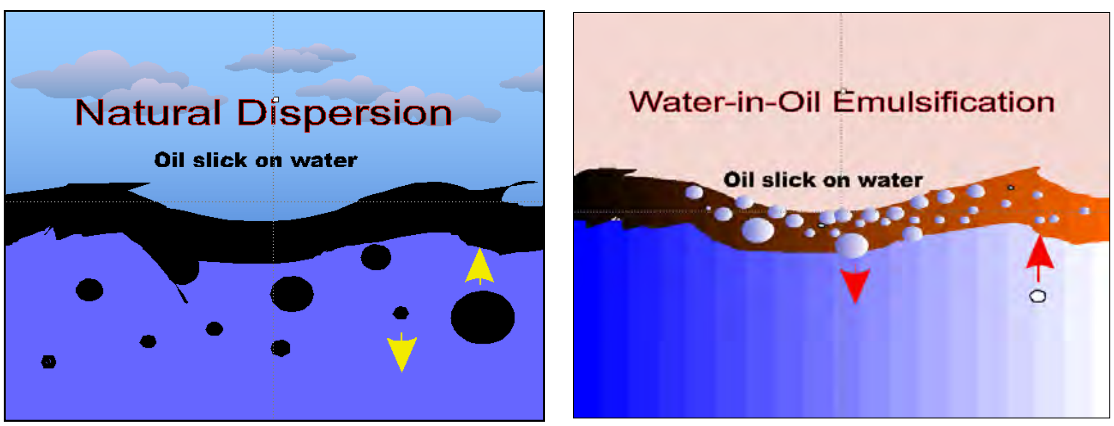


Figure 3.3 Natural Dispersion and Formation of Water-In-Oil Emulsion

3.1.2.6 Emulsification

Emulsification is important because:

- It is a process in which water droplets are incorporated into the slick, leading to increases in the total volume of spilled product between three and four times; and
- It leads to tremendous increases in the viscosity of the slick, which makes it resistant to natural and chemical dispersion and makes it more difficult to recover with skimmers and transfer with pumps.

Emulsification tends to compete with the dispersion process in that dispersion will essentially cease once oil emulsifies. Water droplets become entrained into oil slicks when resurfacing water droplets rise under and re-coalesce into a slick or when water is mixed directly into the slick by waves. In some oils, the emulsions formed are unstable and the water droplets themselves coalesce and settle out of the oil. However, in other oils, the emulsions are stabilized by asphaltenes and resins that accumulate on the surfaces of the water droplets, preventing them from coalescing.

Oils with an asphaltene content greater than 0.5% tend to form stable emulsions which may persist for many months after the initial spill has occurred. Those oils containing a lower percentage of asphaltenes are less likely to form emulsions and are more likely to disperse.

3.1.2.7 Sedimentation

Some heavy refined cargo products have densities greater than 1.0 and so will sink in fresh or brackish water. Sinking mostly occurs due to the adhesion of particles of sediment or organic matter to the oil. Shallow waters are often laden with suspended solids providing favourable conditions for sedimentation. It should be noted that when small oil droplets are coated with very fine minerals, they form oil-mineral-aggregates of neutral buoyancy which are easily degraded and dispersed in the marine environment.

3.1.2.8 Biodegradation

Micro-organisms in seawaters can partially or completely degrade oil to water soluble compounds and eventually to carbon dioxide and water; however, some compounds in oil may still not degrade. The main factors affecting the efficiency of biodegradation are the levels of nutrients (nitrogen and phosphorus) in the water, the water temperature and the ambient level of oxygen. The biodegradation process is thus more efficient at the oil-water interface due to the availability of oxygen. Oil droplets formation (either by natural or chemical dispersion), will enhance the surface area of the oil and increases biodegradation.

3.2 Main Environmental, Economic and Social Impacts Associated with Marine Oil Spills

Ship-source oil spills have the potential to cause significant environmental damage and create economic losses, upsetting the quality of life in coastal and inland water environments. Primarily due to the reinforcement of international laws and conventions, the total number and volume of tanker spills have decreased since the 1970s despite increases in hydrocarbon shipping (Boile *et al.,* 2005; Burgherr, 2007). According to Burgherr (2007), the total volume of oil from tanker spills was reduced by 56% from the 1970s to the 1980s and by 9% from the 1980s to the 1990s. Nevertheless, many spills are still occurring in ecologically and socio-economically sensitive areas as a consequence of trajectories of major transport routes.

An extensive review of potential environmental effects related to an accidental oil spill was carried out for the Government of Quebec, in the context of the *Strategic Environmental Assessment of Hydrocarbons Exploration and Development in the Anticosti, Madeleine and Baie des Chaleurs Basins* (SEA2) (GENIVAR, 2013). The purpose of this report was to examine effects of hydrocarbons exploitation in Quebec's part of the Gulf of St. Lawrence and the Baie des Chaleurs. The findings of this report are relevant for oil spills in all of the Canadian waters. For additional information of environmental and socio-economic effects of potential oil spills, the reader is therefore referred to this report.

This section briefly assesses the potential environmental, economic and social effects of ship-related oil spills. In the following sub-sections, a brief overview of effects (magnitude, degree, etc.) is presented as well as the short-term and long-term effects of a potential oil spill.

3.2.1 Generalities

Before identifying the specific effects of an accidental oil spill, it is important to understand the particular conditions which may influence the magnitude, the degree, the nature and the duration of these effects.

The magnitude of effects caused by a spill is closely related to the characteristics of the receiving environment:

- Site-specific physical characteristics (e.g., shoreline habitat, sediment type, topography, currents, hydrology);
- Coastal resources in the area of influence of the spill;
- Physiological and behavioural characteristics of coastal resources (e.g., avoidance behaviour); and,
- Type and intensity of human activities.

The degree of effects is also related to the type and the volume of the spill and various exposure features:

- Chemical characteristics of oil types (e.g., toxicity, absorption rates of living organisms, etc.);
- Volume of the oil spill and exposure concentrations in various media (e.g. air, water, sediments, soil and food);
- Exposure media category, such as a direct exposure (water, sediments and air) or an indirect exposure (food);
- Exposure duration (acute, chronic); and,
- Period of year when a spill occurs (related to the lifecycle of marine resources, the weathering of oil, etc.).

Particularly in Canadian Arctic waters where it may take time to initiate clean-up, the type and the effectiveness of the clean-up response will be decisive factors both in the nature of the environmental and socio-economic damages and on the intensity of these damages. Clean-up attempts (including both chemical and physical methods) can occasionally be more damaging to the natural environment than the oil itself, with indirect effects (especially due to trophic web interactions and biogenic habitat loss) that expand beyond the initial direct losses and delay the recovery process (Peterson *et al*., 2003; Vandermeulen and Ross, 1995; Zhu *et al*., 2004).

Large-scale spill events can result in effects that are both direct (e.g. acute-phase mortality of aquatic life, contamination of fishing gear, etc.) and indirect (e.g. chronic mortality due to ingestion of polluted food, bioaccumulation through the food web, contamination of drinking water intake sites, etc.). Indirect and chronic exposure effects on the natural environmental have been shown to sometimes persist for decades (Culbertsen *et al*., 2008a; 2008b; Peterson *et al*., 2003; Matkin *et al*., 2008), which can also be the case for socio-economic effects. In general terms, the magnitude of socio-economic effects is highly dependent on the intensity of the human activity in the surrounding environment of the oil spill, with more important effects found close to urban areas, productive fishery grounds, and recreational and tourist areas.

Effects on natural habitats from oil spills occurring in freshwater will resemble those of marine spills (Steen *et al.,* 1999); however, spills in freshwater have a much higher potential of contaminating water supplies (surface as well as groundwater), affecting areas of concentrated populations, manmade structures and other human activities (NOAA, 1994).

3.2.2 Effects

The main potential environmental effects associated with oil spills are the contamination of the natural environment, as well as littoral and coastal infrastructure. Contamination could also alter the quality of fishery and prompt significant negative socio-economic effects.

A list of potential effects associated with ship-related oil spills is provided in Table 3.1. Effects have been categorized as either short-term or long-term. The *Exxon Valdez* oil spill triggered an increase in available scientific literature on the subject. Many of the long-term effects listed are derived from research carried out after this event.

3.2.2.1 Short-Term Effects

During the acute exposure phase, floating oils, and to a lesser extent beached oils, are the primary stressors for aquatic resources that are in direct contact with oil, such as birds, marine and freshwater mammals as well as intertidal flora and fauna (Hartung, 1995). Oiling of fur or feathers causes loss of insulating capacity and can lead to death and mass mortality from hypothermia, drowning and ingestion of hydrocarbons (Peterson *et al*., 2003). Recent studies show that even small quantities of oil in the environment can induce mortality in aquatic birds (GENIVAR, 2013).

Effects related to oil spills are often difficult to evaluate: one to two years after the *Deepwater Horizon* spill in the USA, there was still no clear depiction of the short-term (and long-term) effects on habitats, marine organisms and fisheries (Sumaila *et al*., 2012; McCrea-Strub *et al*., 2011). Other specific uncertainty factors add to this difficulty, e.g. Williams *et al.* (2011) report an important underestimation of cetacean mortality related to oil pollution, as on average only 2% of carcasses are recovered. With regard to humans, effects measured in terms of economic losses vary greatly depending on how far reaching the assessment is carried out. As such, research on the economic losses related to the *Deepwater Horizon* incident indicated effects on the fishery industry, tourism, and restaurants as well as other service-based sectors (GENIVAR, 2013).

As stated previously, environmental effects are not only dependent on the volume of oil in the habitat, but also on the timing and the location of a spill in relation to lifecycles and habitat requirements of potentially affected species. Sensitivity of aquatic biota to hydrocarbon pollution is species-specific and relies on the physiological and behavioural characteristics, as well as the type of oil contaminating the environment (Zhu *et al*., 2004). Generally, avoidance behaviour, observed for many marine birds, seals and cetaceans, can significantly reduce direct effects (Hartung, 1995). Sessile benthic species are relatively more sensitive, but the absence of avoidance behaviour has also been documented for some species of cetaceans (Matkin *et al*., 2008).

Other particular species-specific behaviours will also place certain aquatic fauna at a particular risk to petroleum pollution, as is the case for deep water divers with their indiscriminating feeding and inhalation of large volumes of air before dives (NOAA, 2010).

3.2.2.2 Long-Term Effects

Long-term effects are related to the persistence of oil in the environment (Section 3.1.2). The ingestion of contaminated food (such as oiled mussels), may represent the most important exposure pathway for aquatic fauna during a chronic phase. Chronic exposure to contaminated sediments is also important for fauna or vegetation.

The long-term effects of an oil spill also include the spinoffs on associated market sectors. Moreover, large-scale oil spills might have considerable long-term consequences on social structure and public health, interfering with traditions and causing cultural disruptions (GENIVAR, 2013; Ngaio and Sumaila, 2012).

The duration of effects depends on both ecological and market recovery times. Ecological recovery is measured by how quickly individuals and populations of species return to pre-spill conditions. It is determined by factors such as oil type, exposure duration, water temperature, degree of weathering, spill response and the individual and species-specific life history traits. In most environmental habitats, recovery is completed within 2-10 years after a spill event, but in some exceptional cases, such as in salt marshes, effects may be measurable for decades after the event (Kingston, 2002). In the case of the *Exxon Valdez* oil spill in Prince William Sound (Alaska, USA) in 1989, the persistence of sub-surface oil in sediments and its chronic exposure continues to affect some of the wildlife through delayed population reductions, indirect effects and trophic interactions 20 years beyond the acute phase of the spill (EVOSTC, 2010). Four decades after the oil spill In Wild Harbour (USA), *Spartina alterniflora* beds had a reduced stem density and biomass (Culbertsen *et al*., 2008a) and mussels in oiled locations showed decreased growth and filtration rates (Culbertsen *et al*., 2008b).

Long-term effects on the population in the aquatic environment (especially on mobile fauna) are especially difficult to confirm. Benthic invertebrates may be more at risk than fish species due to the fact that more or less sessile organisms are likely to suffer higher initial rates of mortality and exhibit long recovery times as a result of exposure to oil-saturated habitats (McCrea-Strub *et al*., 2011). Nearshore demersal fish can also suffer from long-term chronic exposure, as indicated in masked greenlings and crescent gunnels by biomarkers on hydrocarbons 10 years after the *Exxon Valdez* spill (Jewett *et al*., 2002). Mortality in sea ducks due to chronic exposure was also reported many years after the spill (Peterson *et al*., 2003; Jewett *et al*., 2002) and other results indicate that effects on cetacean populations can last beyond 20 years after the acute exposure phase (Matkin *et al*., 2008; EVOSTC, 2010).

Market recovery estimations are based on the time required for effected industries to be fully restored to pre-spill conditions (Sumaila *et al*., 2010). The length of time required is influenced by the duration of the aquatic area closures (e.g. commercial fisheries, recreational fisheries), the public perceptions on seafood safety and the perceived effects of the aesthetic quality of the environment. Even after the full ecological recovery of the aquatic resources, fisheries can be far from re-established, as is still the case for herring fisheries in the *Exxon Valdez* spill area (Sumaila *et al*., 2012; EVOSTC, 2010). As reviewed by GENIVAR (2013), negative perceptions associated with the quality of fishery products, even for fisheries that have not been contaminated and also for regions not directly affected by the spill, can be far more important than the direct economic losses. This also holds true for the tourism sector and all other related spinoff sectors.

Table 3.1 Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental		
Sediment Quality	• Contamination of coastal sediments by hydrocarbons.	• Sediments may act as long-term reservoirs for biologically available hydrocarbons, implying the chronic exposure of toxic compounds to aquatic life (Peterson *et al*., 2003).
Water Quality	• Deterioration of water quality.	• Deterioration of water quality.
Riparian and Aquatic Vegetation	• Die-off caused by contact with oil spill or chemical products used to mitigate the oil spill (Zhu *et al*., 2004; Hatcher and Larkum, 1982). • Reproduction in population or growth-rate or abnormal growth after initial impact (Zhu *et al*., 2004). • Damage to the riparian habitats due to clean-up activities (Vandermeulen and Ross, 1995).	• Loss of habitat or flora species conducive to the presence of several wildlife species for feeding, shelter and spawning. • Chronic contamination of eelgrass beds growing in sheltered bays (Zhu *et al*., 2004; Culbertsen *et al.,* 2008a). • Modification of algal composition favoring opportunistic plants (EVOSTC, 1994).
Plankton	• Acute mortality of specimens in contact with oil spill (Almeda *et al*., 2013; GENIVAR, 2013). • Decrease of planktonic abundance and diversity (Almeda *et al*., 2013).	• Sublethal effects on zooplankton including alterations in feeding, development and reproduction (Almeda *et al.,* 2013). • Bioaccumulation of oils in zooplankton leading to negative trophic interactions (Peterson *et al*., 2003; Almeda *et al.,* 2013).
Invertebrates	• High acute mortality of specimens in contact with oil spill (bilvalves, crabs, shrimps) (Sumaila *et al.,* 2010). • Mortality of eggs and larvae leading to the decrease in recruitment. • Decreased growth rate of invertebrate larvae (GENIVAR, 2013). • Alteration of composition and abundance of benthic fauna. • Mortality of intertidal or nearshore communities due to clean-up activities such as hot water and high pressure (EVOSTC, 1994).	• Chronic mortality of shellfish species that burrow in contaminated sediments. • Decrease of invertebrate abundance and diversity, food intake and growth rate (Culbertson *et al*., 2008a; 2008b). • Absorption, ingestion and bioaccumulation of hydrocarbons in organs and tissues making them unsuitable for consumption. • Contamination of invertebrates leading to negative trophic interactions (transfer of toxic compound to higher trophic levels). • Alteration of structural composition of invertebrate communities (privileging or more tolerant species). Note: Suspension-feeding clams and mussels concentrate and slowly metabolize hydrocarbons, which leads to chronically elevated tissue contamination (Peterson *et al*., 2003).

Table 3.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental (cont.)		
Fishes	• Acute mortality of specimens in contact with oil spill, especially for nearshore fish (direct physical effects such as coating of gills and suffocation). • Diminution of abundance in heavily contaminated areas (avoidance behavior). • Reduction in food availability because of possible contamination of invertebrates, fish and plankton. • Mortality of eggs and larvae. • Altered natural behaviors related to predator avoidance or feeding.	• Chronic mortality of resident species (abnormal functioning of gills, increased hepatic enzymes, decreased growth, organ damage) (GENIVAR, 2013). • Ingestion and absorption of hydrocarbons in organs and tissues, which can make it unsuitable for consumption (GENIVAR, 2013). • Decrease in recruitment, food intake and growth rate. • Deterioration of the quality of spawning areas, feeding areas and shelters due to contaminated riparian habitats. • Reduced and altered embryo development (Peterson *et al.*, 2003, Murakamia *et al.*, 2008). • Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) has population consequences through indirect effects on growth, deformities, and behavior with long-term consequences on mortality and reproduction (Peterson *et al.*, 2003). • Modified migratory pathways (IPIECA, 2007).
Mammals	• Acute mortality of specimens in contact with oil spill (especially young individuals and mammals with fur, such as sea-otters, seals or polar bears) (Williams *et al.*, 2011). • Reduction in food availability because of possible contamination of invertebrates, fish and plankton. • Diminution of abundance in heavily contaminated areas (avoidance behavior). • Relocation of population due to increased acoustic noise from clean-up vessels, decreased food availability, etc. (Ackleh and Loup, 2012). • Irritation of eyes and respiratory membranes (Hartung, 1995). • Reduction in filtration capacity (baleen whales). Note: Oil coats the furs of marine mammals with furs. This leads to a decrease in the fur's natural ability to insulate the animal's body, which may lead to hypothermia and possibly death in exposed animals.	• Increased mortality rates due to chronic exposures of resident species (Peterson *et al*., 2003). • Reduction in the size of mammal populations (Matkin *et al*., 2008). • Absorption of hydrocarbons in certain tissues and organs leading to sublethal effects. • Substantial effects over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions (Peterson *et al*., 2003).

Table 3.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Environmental (cont.)		
Birds	• Acute mortality of specimens in contact with oil spill (especially diving birds and shorebirds) due to alteration of buoyancy (leading to drowning) or reduced thermal insulation causing hypothermia (Hartung, 1995). • Mortality due to excessive preening leading to ingestion of oil. • Starvation due to increase in energy demands (Hartung, 1995). • Mortality of chicks due to parenting failure (mortality of adults).	• Increased mortality rates due to chronic exposures (Peterson *et al.*, 2003). • Ingestion of food leading to absorption of hydrocarbons in certain tissues and organs (Hartung, 1995). • Ingested oil can cause lethal and sublethal effects including damage to the liver, pneumonia and brain damage (Hartung, 1995). • Reduction of nesting and feeding areas due to contaminated riparian and pelagic habitats. • Reduced reproductive success (reduction of fertility, egg laying and hatching, abandon of nests, and alteration of parental behavior). • Contamination of eggs in nests which leads to mortality of chicks or abnormalities. • Reduced chick growth. • Reduction in mean eggshell thickness and strength (Stubblefield *et al.*, 1995). • Substantial impacts over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions in socially organized species (Peterson *et al.*, 2003).

Table 3.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Economic		
Commercial Fisheries, Related Spinoff Sectors	• Reduced fish catches (value or quantity). • Soiling and contamination of fishing gear and vessels (until complete disappearance of oil from the region) resulting in an increase in operation costs (additional cleaning and maintenance costs; GENIVAR, 2013). • Reduced income due to the suspension of fishing and hunting (polluted zones and presence of clean-up activities; GENIVAR, 2013). • Decreased income from seal hunting due to loss of value of stained seal furs, if it is still always possible to go hunting.	• Tainting and associated economic effects: negative perception associated with the quality of fishery products, even for regional fisheries that have not been contaminated (GENIVAR, 2013). • Decrease in economic spinoffs for certain sectors (transportation, etc.). • Increased vessel costs for fishermen due to increased distances to resources (relocation of resources and fishing) (IPIECA, 2007).
Shipping	• Significant increase in regional maritime and inland waterway traffic caused by the activities of containment, clean-up and recovery made by boat. • Disruption or delays of port activities due to contaminated waters or infrastructures. • Interruption or delays of shipping due to contaminated waters in seaways. • Interruption of shipping in case of contaminated ship hulls (Stratfor, 2010).	n/a
Employment and Investment	• Significant loss of income and employment for communities whose economy is mainly based on fishing and tourism. • Increased costs associated with the practice of certain activities, such as fishing. • Decreased revenue to ferry service providers (reduced tourism) or increased revenue due to ferry traffic from spill clean-up crews.	• Significant loss of income and employment for communities whose economy is mainly based on fishing and tourism. • Significant loss of income for all spinoff sectors related to fisheries and tourism (GENIVAR, 2013).
Tourism and Recreation	• Interference with touristic and recreational activities (whale watching excursion, scuba diving, sailing, sea kayak, etc.). • Decline in recreational fishing (closures, fear of contamination, unavailability of boats and congestion at sites outside the affected area) (EVOSTC, 1994). • Decreased revenue to ferry service providers.	• Decrease of the economic spinoffs of the sector. • Displacement of touristic and recreational activities to neighbouring (non-contaminated) coastal or inland water communities or possible decrease of tourism also in these regions due to regional tainting (GENIVAR, 2013). • Decrease in cruise-related tourism. • Decline in recreational fishing: closures, fear of contamination, unavailability of boats and congestion at sites outside the affected area (EVOSTC, 1994; Butler and Sayre, 2010).

Table 3.1 (cont.) Potential Environmental and Socio-Economic Effects due to Oil Spills in Canadian Waters.

Component	Potential Effect	
	Short-Term	Long-Term
Social		
Aboriginal's Use	• Interference with Aboriginal marine use activities.	• Decrease of the economic spinoffs associated with commercial fisheries. • Decrease of traditional fishing holding spiritual and cultural significance (affecting the social, cultural, educational and other benefits from activity) (Ngaio and Sumaila, 2012). • Cultural dislocation, psychological stress and disruption of social infrastructure (Ngail and Sumaila, 2012). • Health of population directly affected.
Landscape	• Spoiling of aesthetic quality and disruptive activities of clean-up crews. • Alteration of the landscape quality.	• Alteration of the integrity of coastal and sub-marine archaeological resources and heritage sites (listed or not) (GENIVAR, 2013). • Persistent sub-surface reservoirs of petroleum drifting on beaches (GENIVAR, 2013).
Health and Quality of Life	• Increased psychological stress (due to oil spill) resulting in direct health effects such as stomach aches, headaches, and insomnia (GENIVAR, 2013).	• Cultural dislocation, psychological stress and disruption of social infrastructure (Ngaio and Sumaila, 2012). • Health of population directly affected (anxiety, post-traumatic stress disorder, depression, etc.) (GENIVAR, 2013; Ngaio and Sumaila, 2012).

4. ARCTIC COAST

4.1 Sector Description

4.1.1 Physical Components

The Canadian Arctic waters are divided by DFO (2010) into three ecozones, which show particular physical characteristics: The Beaufort Sea, the Canadian Arctic Archipelago (CAA), and the Hudson Bay, James Bay, and Foxe Basin (HJBFB). The Newfoundland and Labrador Shelf (NLS) and two freshwater bodies (Great Slave Lake and Mackenzie River) are also included in this study. A brief description of each of them is discussed in the following paragraphs.

The Beaufort Sea is important for the subsistence and culture of local communities. Located on the Beaufort continental shelf, the area is characterized by a relatively short ice-free season, causing high loading of sediment and freshwater from the Mackenzie River during the spring and summer, and the Cape Bathurst polynyas[2] and associated flaw leads[3]. The polynyas, flaw leads, and estuarine regions are considered to be areas of relatively high productivity and diversity. They are very important for mammals; looking for oxygen access in the case of aquatic fauna or for fishing/hunting activities in the case of polar bears. Water column salinity, temperature, and freshwater content are influenced by the outflow of the Mackenzie River and oceanic circulation patterns (i.e. the Beaufort Gyre). The continental shelf is a critical interface linking terrestrial and freshwater processes/impacts with this marine area (DFO, 2010).

The Canadian Arctic Archipelago is a major pathway for the exchange of heat and freshwater in the Arctic. Water is transported through Lancaster Sound/Barrow Strait, Jones Strait, or Nares Strait into Baffin Bay. The volume of water, the freshwater content, and heat fluxes through the CAA have extensive seasonal and inter-annual variability. The CAA contains 50% of the total Arctic continental shelf area indicating that this area is important for total Arctic primary and secondary production. The substantial ice cover of this area makes it difficult to access, especially the northern portion where ice cover is extensive even in summer. The CAA encompasses the majority of remaining multi-year sea ice habitat in the Canadian Arctic. Variation in climate conditions is a critical driver for ecosystem functioning in the area and also future accessibility of the Arctic (DFO, 2010).

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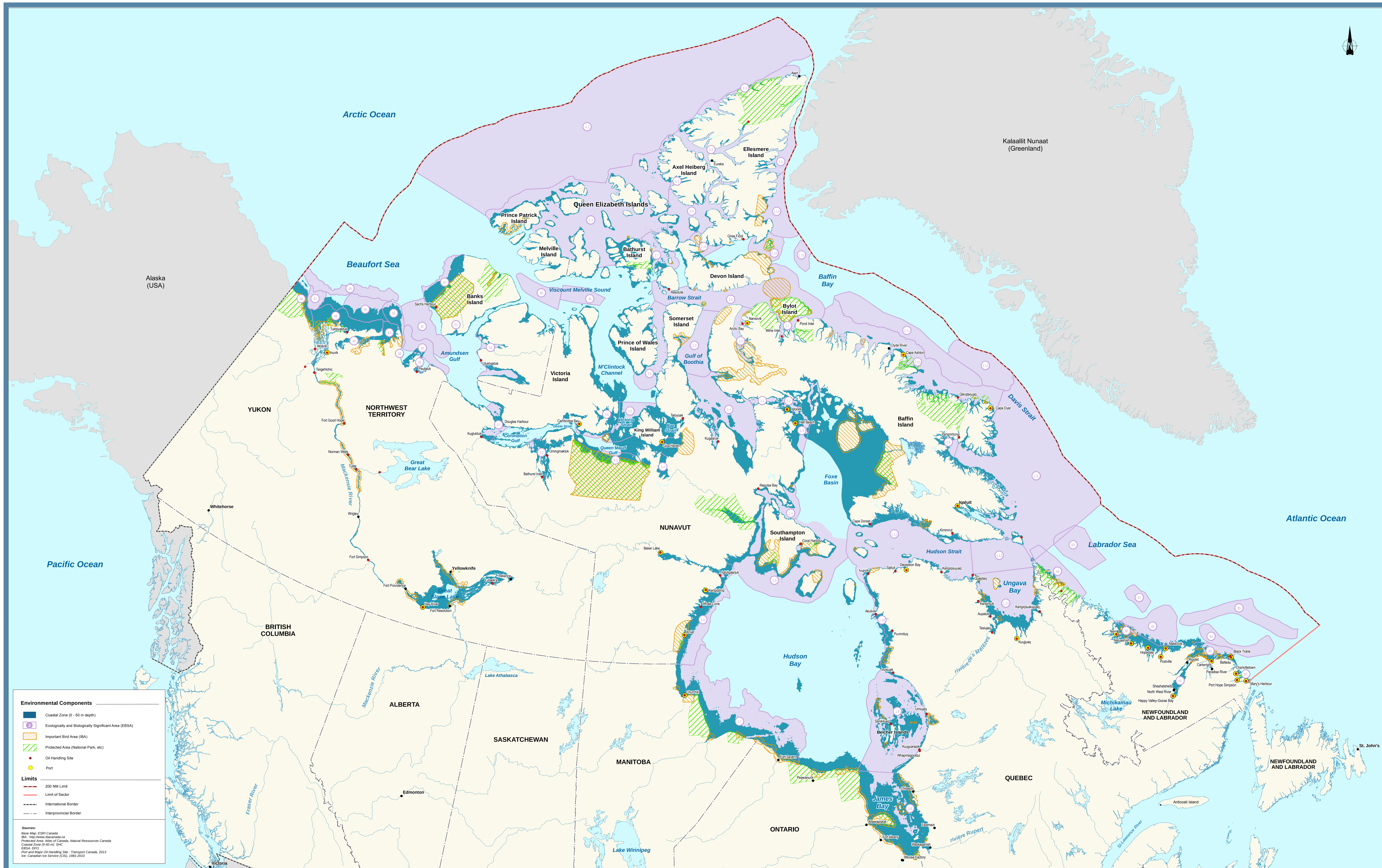
2 Area of open water surrounded by ice.
3 A passage-way between drift ice and fast ice which is navigable by surface vessels.

HJBFB is a unique semi-enclosed Arctic marine area. The extreme southerly extent of Arctic waters and complete seasonal sea-ice cover creates habitat for Arctic marine mammals. Estuarine habitats are also important within the HJBFB due to the large volume of freshwater runoff, and unique coastal habitats are created by the continued rebound of land from the Laurentian ice sheet. Hydroelectric development and river flow alteration have had significant impacts on the coastal habitats of the HJBFB. This area becomes completely ice free during summer; however, the presence of winter sea ice is a critical platform for marine mammals and local communities (DFO, 2010).

The NLS area extends off the eastern coast of Canada, and encompasses one of the largest continental shelves in the world. Ranging from the northern tip of Labrador south, the NLS is greater than 2.5 million km^2 and exhibits significant variation in seabed structure and habitat that is represented by extensive coastal forms, offshore banks, slopes and canyons. The North Atlantic Oscillation (NAO), the dominant atmospheric pattern in the North Atlantic Ocean, has been a dominant factor in recurrent atmospheric oscillations in the North Atlantic Ocean and thereby the NLS exhibits considerable variability. Variation in the NAO is related to many climatic, oceanographic and ecological features in the marine ecosystems of Newfoundland and Labrador, including iceberg flows, ocean temperatures, the strength of the Labrador Current, and the distribution and biology of many species (DFO, 2010).

The Mackenzie River ecosystem flows 4,241 km from British Columbia to its mouth of the Beaufort Sea of the Arctic Ocean. The average annual discharge is 9,910 m^3/s and accounts for 60% of the freshwater that flows into the Arctic Ocean from Canada (MRBB, 2003). The Mackenzie River's outflow greatly influences the local climate above the Arctic Ocean with large amounts of warmer freshwater mixing with the cold seawater. Permafrost underlies about 75% of the basin. Located at the beginning of the Mackenzie River watershed, Great Slave Lake is the deepest lake of this ecosystem. Its surface area is 28,568 km^2 – the fourth largest lake in Canada – and its volume is approximately 2,088 km^3 of water (MRBB, 2003).

About 51% of the entire sector's shoreline is ice-free by the end of September (Map 4.1), the time of the year where the ice cover is the smallest. Based on the most recent 10-year June ice-cover data (e.g. just before the beginning of the intensive navigation season), the majority of the sector is covered by ice (97%).



Ice-covered in September 10

Ice-covered in June 25

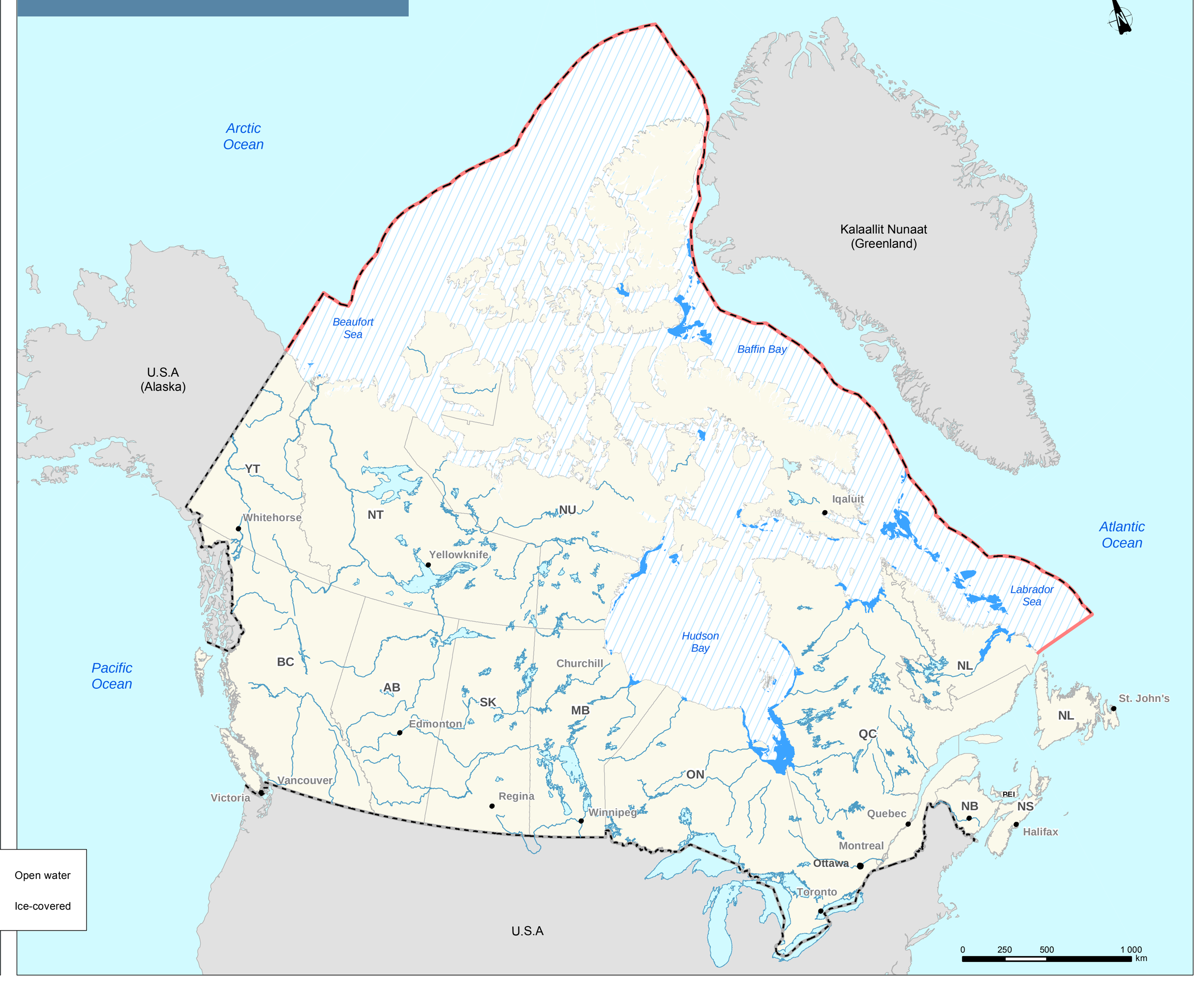


Table 2 Characteristics of Ecologically and Biologically Significant Areas (EBSA) in Eastern Arctic.

EBSA	Particular Characteristics
14. Eclipse Sound / Navy Board Inlet	• Migration corridor for narwhal and beluga whale. • Feeding area for narwhal, beluga whale and killer whale. • Aggregation area for ringed seal and harp seal. • Staging area for seabirds. • Nesting and feeding area for seabirds. • Presence of Baffin Bay narwhal, Eastern High Arctic/Baffin Bay beluga whale, two special-status species.
15. Admiralty Inlet	• Marine fish aggregation area. • Migration corridor for marine mammals. • Feeding area for narwhal and bowhead whale. • Presence of seabird colonies (fulmars). • Nesting and feeding area for seabirds. • Presence of Baffin Bay narwhal, one special-status specie.
16. Prince Regent Inlet	• Presence of polynyas. • Nursery area for bowhead whale. • Migratory corridor for marine mammals and Arctic charr. • Feeding area for narwhal, Arctic charr and seabirds. • Seaduck moulting area. • Presence of Eastern High Arctic/Baffin Bay beluga whale, ECWG bowhead whale and Baffin Bay narwhal, three special-status species.
17. Gulf of Boothia	• Migratory corridor and nursery area for bowhead whale. • Migratory area for narwhal and Arctic charr. • Denning, feeding and rearing area for polar bear. • Feeding area for bowhead whale and narwhal. • Presence of ECWG bowhead whale and Baffin Bay narwhal, two special-status species.
18. Peel Sound	• Presence of polynyas. • Largest Canadian Arctic population of narwhal. • Marine fish aggregation area. • High benthic diversity and production. • Feeding area for narwhal and beluga whale. • Presence du Eastern High Arctic/Baffin Bay beluga whale and Baffin Bay Narwhal, two special-status species.
19. Lancaster Sound	• Presence of polynyas. • Migratory corridor for marine mammals. • High benthic diversity and productions. • Highest density of polar bears. • Nesting and feeding area for over 1,000,000 seabirds and seaducks. • Walrus haul-out sites. • Feeding area for polar bear. • Presence of Eastern High Arctic/Baffin Bay beluga whale, ECWG bowhead whale, Baffin Bay narwhal and ivory gull, four special-statut species.
20. Wellington Channel	• Presence of polynyas. • Presence of Ross's gull nesting population. • Walrus haul-out sites. • Nesting and feeding area for seabirds and seaducks (eiders). • Feeding area for polar bear (summer) and walrus. • Presence of Ross's gull, one special-status specie.
21. Hatton Basin/Labrador Sea / Davis Strait	• Presence of polynyas in Cumberland Sound and Frobisher Bay. • Diversity of deep water corals and sponge beds. • Overwintering area for marine mammals. • High biological productivity. • Feeding area for hooded seal, harp seal and polar bear. • Breeding area for hooded seal. • Shrimp aggregation area. • Migratory corridor for bowhead whale. • Presence of seabird colonies. • Marine fish aggregation area. • Haul-out sites, ice-edge winter habitat and migration corridor to Greenland for walrus. • Overwintering area for ivory gull. • Nesting and feeding area for seabirds and seaducks. • Presence of ivory gull, harlequin duck, wolfish, Western and Eastern High Arctic / Baffin Bay beluga whale, ECWG bowhead whale and Baffin Bay narwhal, some special-statut species.
22. Cumberland Sound	• Beluga whale summer habitat. • Feeding and nesting area for seabirds. • Feeding and foraging area for beluga whale. • Presence of Cumberland Sound beluga whale, one special-status specie.
23. Baffin Island Coastline	• Nursery area for bowhead whale. • Migratory corridor for marine mammals and Arctic charr. • Aggregation area for corals and marine fishes. • Presence of seabird colonies. • Haul-out sites and feeding area for walrus. • Denning, feeding and rearing area for polar bear. • Nesting and feeding area for seabirds. • Presence of ivory gull, one special-status specie.
24. Baffin Bay Shelf Break	• Marine fish aggregation area. • Migratory corridor for marine mammals. • Aggregation area for corals and sponges. • Presence of Baffin Bay narwhal and ECWG bowhead whale, two special-status species.
25. Southern Baffin Bay	• Coral aggregation area, including the black coral. • Overwintering area for narwhal and bowhead whale. • Narwhal feeding area. • Presence of Baffin Bay narwhal and ECWG bowhead whale, two special-status species.
26. Northern Baffin Bay	• Sea pen aggregation area.
27. North Water Polynya	• Presence of polynyas, including the largest and most productive polynya in the Arctic. • Presence of the most of Canadian population of ivory gull. • Feeding area for marine mammals and polar bear. • Nesting and feeding area for seabirds. • High biological productivity. • High benthic diversity and productivity. • Haul-out sites (winter and summer) and migration corridor for walrus. • Presence of ivory gull, one special-statut specie.
28. Eastern Jones Sound	• Presence of polynyas. • Largest colony of black-legged kittiwakes in Nunavut. • Atlantic puffin breeding area. • Haul-out sites and feeding area for walrus. • Feeding area for marine mammals and polar bear. • Seabird staging area and seaduck moulting area. • Presence of seabird colonies. • Feeding and breeding area for seabird. • Presence of ivory gull, one special-status specie.
29. Cardigan Strait / Hell Gate	• Presence of polynyas. • Presence of a distinct western Jones Sound walrus population. • Walrus haul-out sites. • Nesting and feeding area for seabirds. • Walrus feeding area.

Source: DFO, 2011

Table 5 Characteristics of Ecologically and Biologically Significant Areas (EBSA) in in Beaufort Sea.

EBSA	Particular Characteristics
62. Hershel Island / Yukon North Slope	• Spawning and breeding areas for polar bear, Arctic cod, black guillemot, beluga whale, bowhead whale and shorebirds. • Nursery and rearing areas for beluga whale, bowhead whale, polar bear and black guillemot. • Feeding area for beluga whale, bowhead whale, polar bear, benthos, anadromous fishes and phalaropes. • Migratory corridor for polar bear, beluga whale, bowhead whale, brants, seaducks, anadromous fishes, phalaropes and gulls. • Seasonal refugia for beluga whale, bowhead whale, fishes, polar bear, seaducks (moulting area), anadromous fishes and gulls. • Depleted populations of Dolly Varlen charr in the Rat and Big Fish rivers.
63. Mackenzie Trough	• Spawning and breeding areas for seals and polar bear. • Nursery and rearing areas for seals and polar bear. • Feeding area for seals, polar bear and bowhead whale. • Migratory corridor for bowhead whale. • High benthos diversity and productivity.
64. Beluga Bay	• Spawning area for herring. • Nursery and rearing areas for gulls, tundra swan, brants, shorebirds, white-fronted goose, snow goose, beluga whale, polar bear and shellfish. • Feeding area for beluga whale, gulls, polar bear and herring. • Migratory corridor for brants, white-fronted goose, beluga whale and tundra swan. • Seasonal refugia for tundra swan, white-fronted goose and beluga whale.
65. Kugmallit Corridor	• Spawning and breeding areas for herring and polar bear. • Nursery and rearing areas for ringed seal, gulls, polar bear and beluga whale. • Feeding area beluga whale, polar bear and ringed seal. • Migratory corridor for beluga whale, polar bear, white-fronted goose, anadromous fishes and bowhead whale. • Presence of pighheaded prickleback population in Tuktoyaktuk harbour, a special-status species. • High ichthyoplankton diversity and productivity.
66. Beaufort Sea Shelf Break	• Breeding area for polar bear. • Polar bear are known to move offshore on pack ice. • Feeding area for marine fish, polar bear and bowhead whale. • Migratory corridor for seaducks and polar bear. • High phytoplankton diversity and productivity.
67. Husky Lakes	• Spawning and breeding areas for ringed seal, herring, lake trout and brants. • Presence of 10% of the Canadian brant population. • Nursery and rearing areas for ringed seal, gulls, lake trout and brants. • Feeding area for beluga whale, lake trout, gulls, cormorants and ringed seal. • Migratory corridor for migratory birds. • Seasonal refugia for cackling goose, white-fronted goose, seaducks, tundra swan and brants.
68. Liverpool Bay	• Spawning and breeding areas for seals, polar bear and brants. • Nursery and rearing areas for seals, polar bear, gulls, tundra swan, brants and Arctic tern. • Aggregation area for bowhead whale. • Feeding area for seals, polar bear, shorebirds, gulls, bowhead whale and seaducks. • Migratory corridor for bowhead whale and seaducks. • Seasonal refugia for white-fronted goose, tundra swan, seaducks and brants.
69. Horton River	• Nursery and rearing areas for polar bear. • Feeding area for beluga whale, bowhead whale, polar bear and Arctic charr. • Migratory corridor for beluga whale, bowhead whale and Arctic charr. • High diversity and productivity of meiofauna.
70. Langton Bay (rejected EBSA)	• Feeding area and migratory corridor for beluga whale.
71. Hornaday River	• Spawning and breeding areas for herring. • Nursery and rearing areas for ringed seal. • Feeding area for broad whitefish, bowhead whale, ringed seal and Arctic charr. • Migratory corridor for Arctic charr, beluga whale, seals, broad whitefish and bowhead whale. • High zooplankton diversity and productivity.
72. Pearce Point	• Spawning and breeding areas for ringed seal, polar bear and seabirds. • Nursery and breeding areas for ringed seal, polar bear and seabirds. • Feeding area for beluga whale, polar bear, marine fish, Arctic charr and bowhead whale. • Migratory corridor for beluga whale, bowhead whale and Arctic charr.
73. De Salis Bay	• Spawning and breeding areas for seaducks and brants. • Nursery and rearing areas for polar bear, brants and seaducks. • Feeding area for Arctic charr, bowhead whale, seals and beluga whale. • Migratory corridor for Arctic charr, bowhead whale, seals and beluga whale. • Seasonal refugia for seaducks.
74. Thesiger Bay	• Spawning area for capelin. • Nursery and rearing areas for seals, polar bear and capelin. • Feeding area for seals, polar bear, beluga whale and capelin. • Migratory corridor for Arctic charr, beluga whale, polar bear and seaducks. • Presence of walrus and peregrine falcon, two special-status species.
75. Walker Bay	• Breeding area for migratory birds. • Nursery and rearing areas for seals, polar bear and migratory birds. • Feeding area for Arctic charr, seals, polar bear and shellfish. • Migratory corridor for Arctic charr, seals, polar bear and migratory birds. • Seasonal refugia for seaducks.
76. Minto Inlet / Kuujjua River	• Breeding area for migratory birds. • Nursery and rearing areas for seals, gulls and polar bear. • Feeding area for Arctic charr. • Migratory corridor for migratory birds and Arctic charr.
77. Albert Islands / Safety Channel	• Spawning area for capelin. • Nursery and rearing areas for seals, polar bear, migratory birds, capelin, seaducks and gulls. • Feeding area for seals, polar bear, Arctic charr, capelin, marine fish and migratory birds. • Migratory corridor for migratory birds, Arctic charr and seaducks. • Seasonal refugia for marine fish and seaducks.
78. Cape Bathurst Polynya	• Breeding area for polar bear. • Feeding area for beluga whale, polar bear, seabirds and ringed seal. • Migratory bird for polar bear.
79. Kagloryuak River	• Breeding areas for migratory birds and seaducks. • Nursery and rearing areas for seals, polar bear and migratory birds. • Feeding area for Arctic charr, seals, whitefish and polar bear. • Migratory corridor for Arctic charr, migratory birds and seaducks.
80. Viscount Melville Sound	• Data deficient.
81. Banks Island Flaw Lead	• Feeding area for beluga whale, seaducks, seabirds, ringed seal and polar bear. • Migratory corridor for beluga whale, seaducks and seabirds. • Seasonal refugia for beluga whale.
82. Shallow Bay	• Spawning and breeding areas for ringed seal, polar bear, herring, gulls and beluga whale. • Nursery and rearing areas for gulls, beluga whale, ringed seal, polar bear and herring. • Feeding area for beluga whale and anadromous fish. • Migratory corridor for shorebirds, brants, phalaropes, beluga whale, white-fronted goose, anadromous fish and snow goose. • Seasonal refugia for beluga whale and anadromous fish.

Sources: DFO, 2011; Cobb et al., 2008; Paulic et al., 2009

Table 4 Characteristics of Ecologically and Biologically Significant Areas (EBSA) in Arctic Basin and Arctic Archipelago.

EBSA	Particular Characteristics
56. Arctic Basin Multi-year Pack Ice	• Presence of polynyas. • Presence of unique structural and physical habitats associated with ice cover and Arctic Basin shelf break. • Presence of under-ice communities which are supplied nutrient-rich Pacific water from upwellings along the Arctic Basin shelf break. • Denning, feeding and summer refugia for polar bear.
57. Ellesmere Island Ice Shelves	• Presence of under-ice communities.
58. Nansen, Eureka and Greely Fjords	• Presence of unique fish communities. • Aggregation area for polar bear and ringed seal.
59. Archipelago Multi-year Pack Ice	• Largest Arctic archipelago in the world. • Last remaining island pack ice refugium. • Nesting area for ivory gull (Seymour Island). • Presence of under-ice communities. • Nesting and feeding area for seabirds. • Denning, feeding and rearing area for polar bear. • Summer refugia habitat for polar bear. • Presence of ivory gull, one special-status specie.
60. Norwegian Bay	• Presence of the most genetically differentiated population of polar bear. • Feeding area for marine mammals. • Feeding and rearing area for polar bear. • Summer refugia habitat for polar bear.
61. Princess Maria Bay	• Walrus haul-out sites. • High productivity. • Feeding area for walrus, narwhal and seals. • Presence of Baffin Bay narwhal, one special-statut specie.

Source: DFO, 2011

Table 6 Type of Marine and Coastal Protected Area

Protected Area Type	Number	Surface Area (km²)
International Designation		
Important Bird Area	121	262,109.6
YUKON TERRITORY		
Federal Designation		
National Park of Canada	2	9,775.3
Provincial Designation		
Natural Environment Park	1	112.9
NORTHWEST TERRITORIES		
Federal Designation		
Marine Protected Area	3	1,749.6
Migratory Bird Sanctuary	10	22,140.7
National Park of Canada	2	12,189.8
Provincial Designation		
Gwich'in Conservation Zone	1	2,291.8
Gwich'in Heritage Conservation Zone	1	8.9
Territorial Park (Natural Environment Park)	1	28.0
NUNAVUT		
Federal Designation		
Migratory Bird Sanctuary	21	90,875.5
National Park of Canada	8	100,149.2
National Wildlife Area	10	8,973.2
Provincial Designation		
Historic Park	1	14.0
Territorial Park	1	0.1
Territorial Park – Campground	1	< 0.1
Territorial Park – Community Park	3	51.2
MANITOBA		
Federal Designation		
National Park of Canada	2	11,462.6
Provincial Designation		
Wildlife Management Area	2	2,596.0
ONTARIO		
Federal Designation		
Migratory Bird Sanctuary	1	191.2
Provincial Designation		
Provincial Park	1	23,134.4
QUEBEC		
Federal Designation		
Migratory Bird Sanctuary	1	96.2
NEWFOUNDLAND AND LABRADOR		
Federal Designation		
Marine Protected Area	3	60.1
National Park of Canada	1	9,696.8
Provincial Designation		
Ecological Reserve	2	24.0
Total	**200**	**557,731.2**

Source: Canadian Council on Ecological Areas (CCEA), 2011.

Table 1 Characteristics of Ecologically and Biologically Significant Areas (EBSA) in the Hudson Bay Complex.

EBSA	Particular Characteristics
1. Fury and Hecla Strait	• Migration corridor for marine mammals. • Denning area for polar bear. • Nursery area for bowhead whale. • Presence of Eastern Canada-West Greenland bowhead whale (ECWG bowhead whale), one special-status specie.
2. Igloolik Island	• Presence of polynya. • Walrus haul-out sites. • Migration corridor for marine mammals and Arctic charr. • Feeding area for walrus and Arctic charr. • Nursery area for bowhead whale. • Presence of ECWG bowhead whale, one special-status specie.
3. Rowley Island	• Preferred habitat for walrus. • Migration corridor. • Walrus haul-out sites. • Feeding area for walrus. • Presence of ECWG bowhead whale, one special-status specie.
4. Repulse Bay / Frozen Strait	• Presence of polynya. • Feeding area during summer for marine mammals and seabirds. • Iceland gull concentration area. • Presence of Northern Hudson Bay narwhal, ECWG bowhead whale and Northern Hudson Bay-Davis Strait Atlantic walrus, three special-status species.
5. Southampton Island	• Presence of seabird colonies, including the largest single colony of common eiders in Nunavut. • Migration corridor for marine mammals. • Denning area and summer refugia for polar bear. • Walrus haul-out sites. • Nesting and feeding area for seabirds. • Feeding area for walrus. • Presence of ECWG bowhead whale, one special-status specie.
6. Western Hudson Bay Coastline	• Migration corridor for Arctic charr and polar bear (fall). • Beluga whale aggregation area. • Feeding area for Arctic charr.
7. Southwestern Hudson Bay Estuaries	• World's largest summering beluga whale aggregation area. • Denning, rearing and feeding area for polar bear. • High benthic diversity and production. • Presence of Western Hudson Bay beluga whale, Ross's gull and Western Hudson Bay polar bear, three special-status species.
8. James Bay	• Presence of a variety of warm water species that are relicts and rare or absent in other Eastern Arctic waters. • Summer and wintering areas for beluga whale. • Most southerly location used by polar bears in the world. • Presence of eelgrass beds. • International importance for Hudsonian godwit and red knot (staging). • Haul-out sites and feeding area for walrus. • Denning and feeding area for polar bear. • Beluga whale aggregation area. • Migration corridor and feeding area for cisco and broad whitefish. • Feeding and staging area for shorebird and waterfowl. • Feeding and moulting area for seaduck, including black scoter. • Presence of Northern Hudson Bay-Davis Strait Atlantic walrus, Eastern Hudson Bay beluga whale and red knot (rufa subspecies), three special-status species.
9. Belcher Islands	• Presence of polynyas. • Possible overwintering area for beluga whale. • Presence of eelgrass beds. • Entire world population of resident Hudson Bay common eider subspecies during summer and winter (between 100,000 to 200,000 birds). • Walrus haul-out sites. • Summer beluga whale aggregation area at estuaries. • High benthic diversity and productivity. • Bearded seal aggregation area. • Feeding area for walrus and polar bear. • Nesting and feeding area for seabirds. • Presence of Northern Hudson Bay-Davis Strait Atlantic walrus and Eastern Hudson Bay beluga whale, two special-status species.
10. Eastern Hudson Bay Coastline	• Migration corridor for Eastern Hudson Bay beluga whale.
11. Western Hudson Strait	• Migration corridor for marine mammals. • Presence of seabird colonies (murres) as well as feeding and nesting area for seaducks (eiders). • Haul-out sites and feeding area for walrus. • Killer whale aggregation area. • Overwintering area for bowhead whale and beluga whale. • Presence of sponge beds. • Presence of Western and Eastern Hudson Bay beluga whale, ECWG bowhead whale and Northern Hudson Bay-Davis Strait Atlantic walrus, three special-status species.
12. Eastern Hudson Strait	• Migration corridor for marine mammals. • Presence of sponge beds and coral reefs. • Overwintering area for beluga whale and bowhead whale. • Walrus haul-out sites. • Nesting and feeding area for seabirds. • Presence of Western and Eastern Hudson Bay beluga whale, ECWG bowhead whale, Northern Hudson Bay-Davis Strait Atlantic walrus and ivory gull, four special-status species.
13. Ungava Bay	• Largest number of breeding thick-billed murres in Canada. • Presence of corals. • Seasonal refugium for polar bear. • Presence of seabird colonies. • Nesting and feeding area for seaducks (eiders). • Breeding, rearing and feeding area for polar bear. • Presence of Ungava Bay beluga whale, one special-status specie.

Source: DFO, 2011

Table 3 Characteristics of Ecologically and Biologically Significant Areas (EBSA) in Western Arctic.

EBSA	Particular Characteristics
30. Lambert Channel	• Presence of polynyas. • Feeding and staging area as well as migration corridor for seabirds.
31. Bathurst Inlet	• Feeding area for seabirds and ringed seal. • Aggregation area for marine fishes and ringed seal.
32. Queen Maud Gulf Coastline	• Migration corridor for Arctic charr. • Arctic charr feeding area.
33. Chantrey Inlet	• Migration corridor for Arctic charr. • Feeding area for ringed seal and Arctic charr.
34. King William Island	• Possible enhanced productivity based on tidal mixing. • Feeding area for ringed seal and polar bear. • High benthic diversity and productivity.
35. Southern Victoria Island Coastline	• Migration corridor for Arctic charr. • Arctic charr feeding area.
36. Yukon North Slope	• Presence of one of two black guillemot colonies in Inuvialuit Settlement Region (ISR). • Possible kelp beds. • Migration corridor for Arctic cisco and Dolly Varden charr. • Migration corridor and feeding area for marine mammals. • Presence of depleted populations of Dolly Varden charr, one special-statut specie.
37. Trough Mackenzie	• Feeding area and migration corridor for bowhead whale, beluga whale and ringed seal. • Feeding and breeding area for polar bear. • High benthic diversity and productivity.
38. Beaufort Shelf	• Feeding area and migration corridor for polar bear. • Marine fish aggregation area. • Bowhead whale feeding area. • Migration corridor for beluga whale. • High benthic diversity and productivity.
39. Shallow Bay	• Aggregation area for beluga whale and ringed seal. • Presence of beluga whale.
40. Beluga Bay	• Aggregation area for beluga whale, seabirds and ringed seal.
41. Husky Lakes	• Spawning, nursery and feeding area for lake trout. • Breeding, rearing and feeding area for ringed seal. • Migration corridor and feeding area for seabirds and seaducks. • Beluga whale aggregation area.
42. Kugmallit Corridor	• Migration corridor and feeding area for ringed seal. • Presence of pigheaded prickleback, one special-status specie.
43. Cap Bathurst Polynya	• Presence of polynyas. • Staging and feeding area for seaducks. • Feeding area and migration corridor for marine mammals, including seals. • High benthic diversity and productivity.
44. Banks Island Shorelead	• Staging and foraging area for seaducks. • Feeding area for bearded seal.
45. Pearce Point	• Presence of one of two western Arctic black guillemot colonies. • Presence of the only colony of thick-billed murres in western Canadian Arctic and only colony of this subspecies in Canada. • Rearing area for ringed seal. • Rearing and feeding area for polar bear. • Breeding, rearing and feeding area for seabirds. • Migration corridor for marine mammals, including bowhead whale and beluga whale.
46. Hornaday River	• Possible kelp beds. • Rearing and feeding area for ringed seal. • Migration corridor for Arctic charr, bowhead whale and beluga whale. • Bowhead whale feeding area. • Pacific herring aggregation area.
47. Kagloryuak River	• Migration corridor for Arctic charr. • Breeding, rearing and feeding area for ringed seal. • Feeding area for seabirds and polar bear.
48. Prince Albert Sound	• Migration corridor for Arctic charr. • Feeding area and migration corridor for seabirds and seaducks. • Breeding, rearing and feeding area for ringed seal. • Presence of Northern wolfish, one special-status specie.
49. Walker Bay	• Migration corridor for Arctic charr. • Feeding area for ringed seal, bearded seal, seabirds and seaducks.
50. Minto Inlet	• Migration corridor for Arctic charr. • Feeding area and migration corridor for seabirds. • Rearing and feeding area for ringed seal.
51. De Salis Bay	• Migration corridor for Arctic charr. • Nesting and feeding area for seabirds and seaducks. • Rearing and feeding area as well as migration corridor for marine mammals.
52. Thesiger Bay	• Presence of polynyas. • Possible kelp beds. • Aggregation area for benthic communities and beluga whale. • Migration corridor for capelin and Arctic charr. • Feeding area for seals, polar bear and beluga whale. • Presence of walrus and peregrine falcon, two special-status species.
53. Viscount Melville Sound	• Beluga whale feeding area. • Rearing and feeding area for polar bear.
54. Horton River	• Presence of diverse meiofauna communities. • Migration corridor and feeding area for marine mammals. • Migration corridor for Arctic charr. • Breeding area for polar bear.
55. Liverpool Bay	• Possible kelp beds. • Nesting, staging and feeding area for seabirds and seaducks. • Feeding and rearing area for polar bear. • Zooplankton community aggregation area. • Migration corridor and feeding area for marine mammals.

Source: DFO, 2011

Risk Assessment for Marine Spills in Canadian Waters

Phase 2, Part B: Spills of Oil and Select HNS North of the 60th Parallel North

Arctic Coast Sector

0 50 100 200 300 km

May 2014

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WSP SL ROSS

Map 4.1