HUDSON STRAIT SHIPPING STUDY
PHASE 1 – STUDY TO DETERMINE THE SOCIO-ECONOMIC, CULTURAL, OCEANOGRAPHIC AND ECOLOGICAL IMPACT AND RISK OF SHIPPING THROUGH THE HUDSON STRAIT

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SUMMARY OF REVISIONS

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ACRONYMS AND NOMENCLATURE

‘	feet
AIS	Automatic Identification System
CAFF	Conservation of Arctic Flora and Fauna
CCME	Canadian Council of Minister of the Environment
CIS	Canadian Ice Service
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSAS	Canadian Science Advisory Secretariat
dB	Decibels
Deg C	Degrees Celsius
DFO	Department of Fisheries and Oceans
dwt	Deadweight tonne
ESBA	Ecologically and Biologically Significant Areas
FAO	Food and Agriculture Organization of the United Nations
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information System
Gov’t	Government
gt	Gross tonne
HFO	Heavy Fuel Oil
HS	Hudson Strait
Hz	Hertz
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature
kHz	Kilohertz
km	kilometres
LAT/LONG	Latitude/Longitude
m	metre
MARPOL	International Convention for the Prevention of Pollution from Ships
MASIE	Multi Sensor Analysed Sea Ice Extent
MCTS	Marine Communications and Traffic Services
MV	Merchant Vessel
N/A	Not Applicable
N	North
NAFO	North Atlantic Fisheries Organization
NAVTEX	Navigational Telex
NEAS	Nunavut Eastern Arctic Shipping Inc.
NOAA	National Oceanic and Atmospheric Administration

NORDREG	The Canadian Coast Guard Arctic Canada Traffic System
NSIDC	National Snow Ice Data Centre
NW	North West
NWMB	Nunavut Wildlife Management Board
O&G	Oil and Gas
PAME	Protection of the Arctic Marine Environment
PDE	Probability Density Estimation
PDF	Portable Document Format
QC	Quebec
SAR	Search And Rescue
SARA	Species At Risk Act
SE	South East
SECA	Sulphur Emission Control Area
SFA	Shrimp Fishing Area
SOLAS	International Convention for the Safety of Life at Sea
SST	Sea Surface Temperature
t	tonne
TEK	Traditional Ecological Knowledge
W	West
WWF	World Wildlife Fund

1 INTRODUCTION

This is a compilation of the first four in the series of reports that have explored various aspects of the socio-economic, cultural, oceanographic and ecological impact and risk of shipping through the Hudson Strait (HS). This work is on behalf of the World Wildlife Fund (WWF). Funding for the project has been provided by Fednav, Canada's largest ocean-going bulk cargo transportation company, who undertake many operations in the Canadian Arctic.

Hudson Strait is both a destination and a gateway. The level of future shipping traffic and its impacts depend not only on local factors but also on the development of ports, communities, mining, tourism, and fisheries throughout Hudson Bay and in the Arctic as a whole. This makes the preservation of the health of the ecosystems particularly challenging, and requires a sharing of responsibilities amongst multiple stakeholders. This project as a whole is intended to provide a compendium of information that can be used to inform and guide a range of future activities relating to sustainable development in and utilizing Hudson Strait.

This report collects the first Phase of the project which consisted of four tasks:

1. Shipping analysis for Hudson Strait
2. Development of socio-economic, cultural, oceanographic and ecological information inventories
3. Risk and impact assessment
4. Gap analysis

2 TASK 1: SHIPPING ANALYSIS

This first Task of the project presents a complete overview of all significant vessel traffic in the Hudson Strait from 2007 to 2013. The traffic has been analyzed to derive key marine traffic characteristics including as traffic type classified by industry (commercial, fisheries, government, research, etc.), vessel particulars (size, type, etc.), and voyage particulars (cargo, speed, season, etc.).

A Geographic Information System (GIS) representation of all marine traffic for the area has been created, including frequencies of voyages by vessel type, voyages by industry sector, estimates of cargo quantities carried annually, and fuel use. This report presents selected data and results of analyses in graphical format. The full database incorporated in the GIS will be utilized in subsequent phases of the project.

2.1 Baseline Data and Assumptions

2.1.1 Study Area and Baseline Data

The baseline data used for the study is a compilation of vessel particulars sourced from NORDREG reports and other databases within the public domain or held by Vard Marine Inc. (formerly STX Canada Marine Inc.). Vessel traffic data is based on a compilation of NORDREG data from 2007 to 2013. This most recent period is also the timeframe for which the best quality of data is available, following the introduction of mandatory reporting requirements to NORDREG in 2008. Prior to this traffic information is somewhat less complete and consistent.

The vessels required to report to NORDREG are larger than 300 gt or, for tug/barge combinations, have an aggregate size larger than 500 gt. Smaller craft do not have to report, though some do as a precautionary measure. Therefore, the baseline data does not include small recreational craft or fishing vessels. Almost all of these will belong to local inhabitants, though a number of adventure tourists do visit the Arctic in most years.

For the purpose of defining a scope for vessel traffic for this study, the Hudson Strait includes the Strait itself, the uppermost portion of Deception Bay, and begins between the Northern tip of Labrador and the Southern tip of Resolution Island in the East, and ends at Baffin Island at approximately 77 degrees east and a boundary incorporating Salisbury, Nottingham, Putnam and Mill islands. Figure 2.1 illustrates the study area (outlined in red) as well as an overlay of vessel traffic between 2007 and 2013.

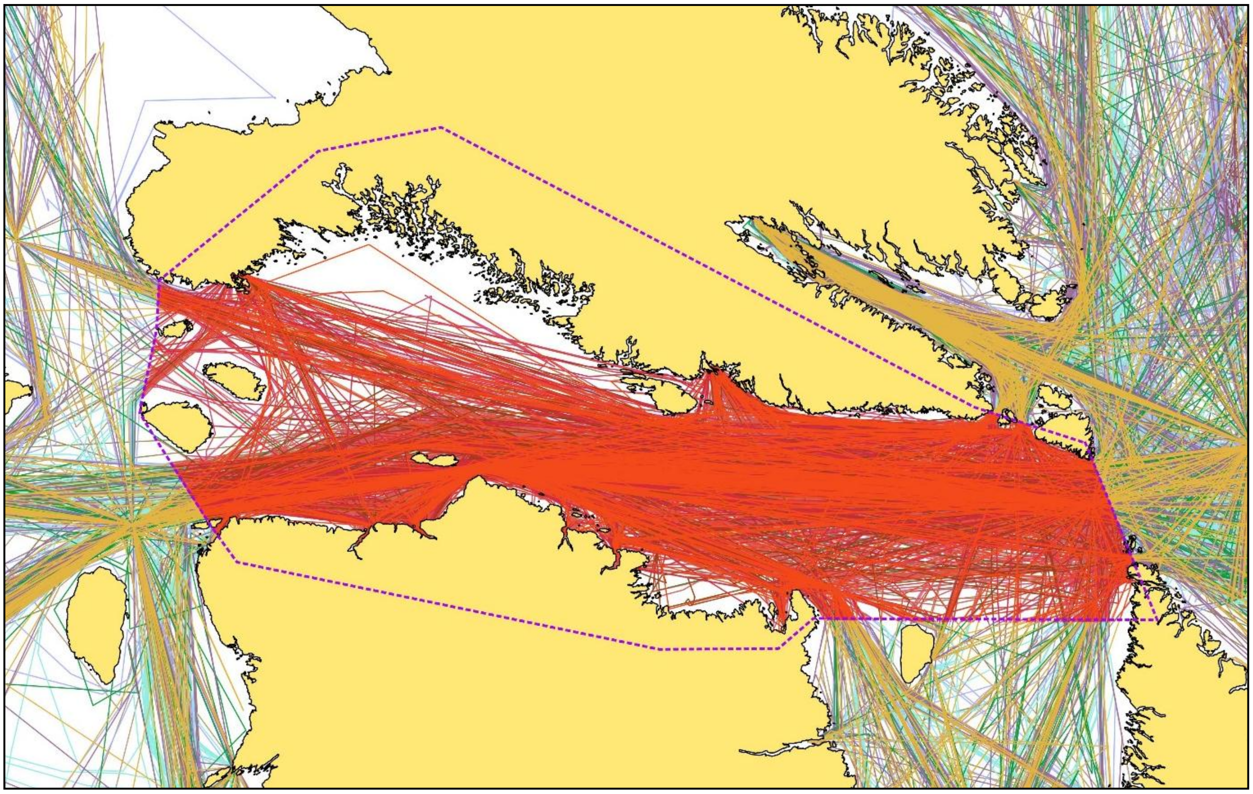

Figure 2.1: Study Area and Vessel Traffic

2.1.2 Key Assumptions

A number of assumptions have been made to facilitate compilation of vessel traffic data for the Hudson Strait. Despite some challenges in obtaining comprehensive data on the exact activities of each vessel relevant to the study, the overall data set does provide a clear representation of relative levels and types of vessel traffic in the area.

2.1.2.1 Vessel particulars

Vessel particulars including size, speed, tonnage, and capacity are primarily provided by NORDREG reports submitted by the vessel's operators, and in some cases data held in Vard databases and research through public sources. Information provided to NORDREG is not always accurate or complete. Vard has not undertaken a comprehensive check of the data, but has corrected some obvious errors and omissions where possible using general "as-built" vessel data typically available through public sources. However, in a limited number of cases the information in the database may not reflect the vessel's actual characteristics or operations. In a few cases information or may simply not be available at all.

The set of vessels with questionable or missing details is however relatively evenly distributed amongst most of the identified vessel types for the study. Therefore the average transit speeds, sizes, and tonnages for each different vessel types should be equally representative of the class despite any data gaps.

2.1.2.2 Seasonality

The seasons have been delineated based on historical ice conditions and the options available to operators during the time of year rather than calendar dates for seasons. Vessel traffic has been categorized by season using the following guidelines:

Table 2.1: Shipping Seasons

Season	Applicable Months
Winter	December to March (Some years with favourable ice conditions may allow extension of the fall season safely into December for a limited number of ships)
Spring	April to May (Generally the worst ice conditions, very little traffic)
Summer	June to September (Typically the busiest time of year, particularly in July and August)
Fall	October to November

2.1.2.3 Fuel Types

Larger vessels such as bulk carriers, tankers, general cargo vessels and large passenger ships are assumed to be burning HFO or IFO unless specifically known to use other fuel.

Smaller vessels such as fishing vessels, tugs, smaller passenger vessels, as well as all coast guard icebreakers, are assumed to be burning diesel unless specifically known to use other fuels.

Vessels where fuel type is uncertain such as seismic survey ships, are generally assumed to burn IFO/HFO unless specifically known to use other fuels.

Note that the fuel type refers to the fuel burned by the vessel's prime propulsion plant, and does not include fuel burned by auxiliary diesel generators used for hotel services or to power ship equipment such as bow thrusters and deck machinery. Ships may also have auxiliary boilers for heating. The fuel used in these systems is a relatively small fraction of total consumption (except for large passenger vessels) and has not been accounted for in the database.

2.1.2.4 Cargo Types

Bulk carriers trading exclusively in and out of Churchill are assumed to be exporting bulk grain products. They are assumed to arrive at Churchill in ballast, and leave carrying their full capacity of grain products.

Bulk carriers trading exclusively in and out of Deception Bay are assumed to be carrying ore. These ships may also carry general cargo and/or bulk and containerized petroleum products when inbound to mine sites.

Tankers are assumed to be carrying only petroleum products (as opposed to other liquid chemical products). Tankers inbound to the Arctic are assumed to be initially loaded to 98% capacity by volume.

General cargo may include a combination of break-bulk construction materials, consumer goods, development modules, containerized goods, containerized petroleum products, as well as other deck cargo such as vehicles and machinery.

Tugs are listed as not carrying cargo, however some communities and mine sites (such as Baker Lake, where access by large vessel is more restricted) are occasionally supplied by tug and barge, and may include the same types of cargo as the “general” category listed above.

2.2 Hudson Strait Shipping Analysis

All vessel traffic data available to the project has been analyzed based on industry sector, vessel particulars (size, type, ice class, etc.), and voyage particulars (cargo, speed, season, domestic vs. international).

For the purposes of the GIS-based traffic overview, vessel traffic can be visualized by vessel type, vessel characteristics, and voyage type, all of which will be leveraged in subsequent phases of the project.

2.2.1 Overview

Table 2.2 provides an overview of the results of the data analysis and the nature of the traffic present in the Hudson Strait since 2007[1].

Table 2.2: Breakdown of Hudson Strait Traffic

Year	2007	2008	2009	2010	2011	2012	2013	Total	Average
Unique vessels entering the Hudson Strait	63	54	56	60	64	54	32	227	59
Total vessel voyages within the Hudson Strait	181	180	172	95	210	136	33	1,007	176
Total distance sailed by all vessels within the Hudson Strait (km)	133,506	121,578	126,837	146,912	137,651	135,073	43,075	844,632	133,593

2.2.2 Industry Sectors

Each industry’s activity in the Hudson Strait is reasonably consistent year on year. The following table summarizes each sector’s traffic.

Table 2.3: Traffic Assessment by Industry Sector

Sector	% of Traffic	Traffic Assessment
Domestic Supply	54%	Domestic resupply/sealift operations make up over half the traffic in the Hudson Strait based on distance travelled. Sealift operations occur at a number of communities directly accessible via the Strait such as Salluit and Kimmirut. Additionally, the Strait is the means of access used by sealift operators to call on all communities in Hudson Bay, as well as almost all communities in the Eastern Arctic, most of which are entirely dependent on sealift operations for all their consumer, commercial, and construction needs.

[1] Data for 2010 and 2013 recorded the number of vessel voyages differently from the rest of the data set, and has not been used in the calculation of the overall average number of transits through the Hudson Strait. Data from 2013 did not record all vessel types, and has not been used for the calculation of the average number of unique vessels or the average distance sailed.

Sector	% of Traffic	Traffic Assessment
Mining and Minerals Extraction	14%	Mining traffic consists of supply to and export from the Raglan and Nunavik mines in Deception Bay, as well as supply to mine sites such as Baker Lake which do not export their product by ship. Traffic includes bulk carriers for exports, and a mix of tankers, tug and barge, and general cargo ships for supply. It should be noted that inbound bulk carriers will sometimes carry supplies into mine sites.
Oil and Gas Exploration	1%	No oil and gas development is occurring in the Hudson Strait, however a limited number of vessels have occasionally used the Strait to access Hudson Bay, as well as entry to and egress from the interior Arctic Archipelago and Northwest Passage.
Shipping	15%	The port of Churchill is served by direct rail transhipment of grain products from central Canada. While the dissolution of the Canadian Wheat Board may affect the level of traffic in and out of Churchill in the future, to date it sees frequent bulk carrier exports of grain to foreign destinations on a condensed schedule considering the short season in which conventional (non-ice classed) bulk carriers may safely enter and exit Hudson Bay via the Hudson Strait.
Fishing	1%	No active fishing occurs in the Strait, however a limited number of fishing vessels pass through the eastern most limits of the Strait in transit between NAFO fishing zones and their home ports. Fishing vessels occasionally transit the Strait to take on crew or as part of research activities, however there is no licensed commercial fishing in the Strait.
Government Activities	9%	Government vessels (primarily Coast Guard icebreakers) frequently transit the Strait performing research activities, navigational assistance, community visits, and other activities.
Tourism	5%	Passenger vessels use the Hudson Strait both to access the interior Arctic and Hudson Bay and to visit communities within the Strait.
Other	1%	Other types of activity include scientific research and ocean survey vessels performing research in the area, as well as tugs transiting to their home ports or assisting with towage of other vessels.

Figure 2.2 represents all of vessel traffic inside the study's bounds for the period between 2007 and 2013.

Table 2.4 provides a breakdown of vessel characteristics by industry sector for the Hudson strait. Note that while the table provides only an overview, complete yearly totals for each feature of the table are calculated and will be used as part of the analysis performed in subsequent phases of the project.

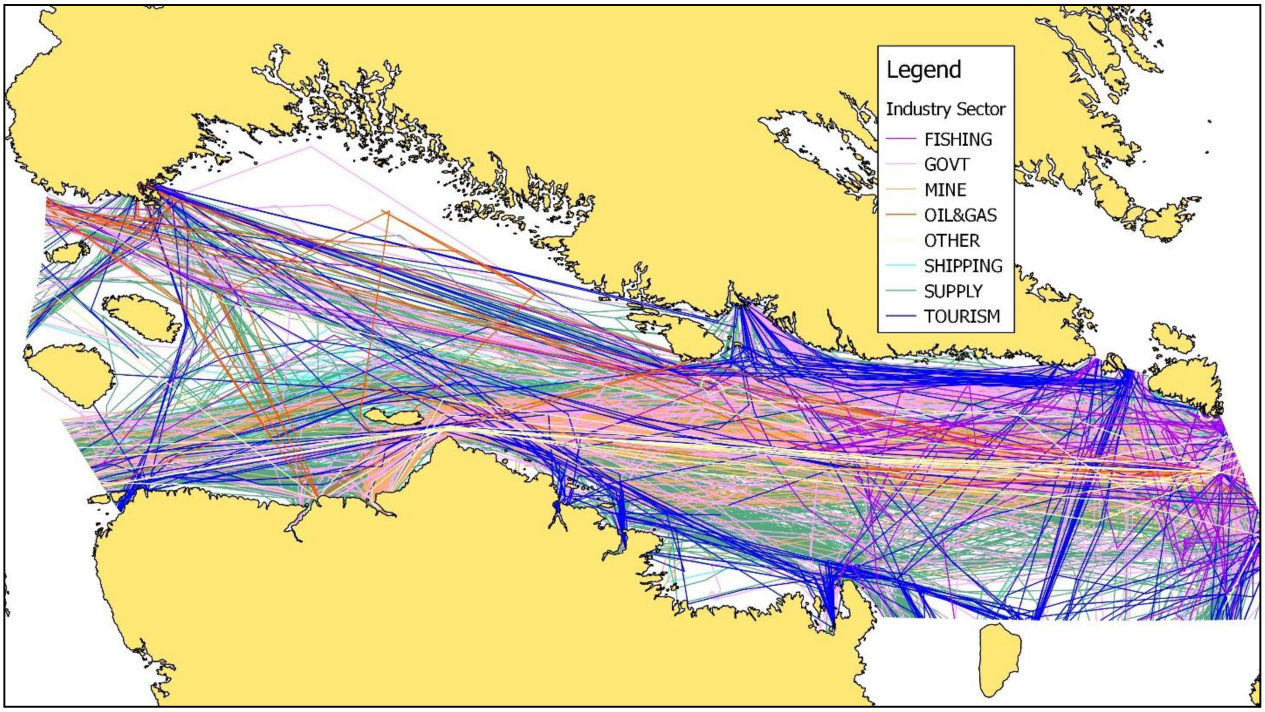

Figure 2.2: All Hudson Strait Vessel Traffic Categorized by Industry Sector, 2007-2013

Table 2.4: Breakdown of Hudson Strait Traffic by Industry Sector from 2007-2013

Industry Sector	Supply	Mining	Oil &Gas	Shipping	Fishing	Gov't	Tourism	Other
Total Unique Vessels	57	23	2	97	13	14	16	5
Annual Average	21	5	1	16	3	6	5	1
% of Annual Average	*36%*	*9%*	*1%*	*28%*	*6%*	*10%*	*8%*	*2%*
Total Transits	549	132	10	153	28	69	53	53
Annual Average	95	24	2	26	5	12	9	3
% of Annual Average	*54%*	*14%*	*1%*	*15%*	*3%*	*7%*	*5%*	*1%*
Total distance sailed (km)	440,627	96,982	8,601	159,080	113,39	75,580	42,435	9,988
Annual Average (km)	68,613	15,571	1,434	25,640	1,861	12,134	6,675	1,665
Average voyage length (km)	803	735	860	1,040	405	1,095	801	188
% of Annual Average	*51%*	*12%*	*1%*	*19%*	*1%*	*9%*	*5%*	*1%*
Est. Average gt (t)	7,152	9,983	13,693	21,527	1,518	4,416	6,828	4,964
Est. Average dwt (t)	128,42	25,757	7,579	34,679	990	1,887	1,342	11,388
Est. Average Length (m)	104	144	91	183	50	81	100	91
Est. Common Fuel Type	IFO	IFO	IFO/Diesel	HFO	Diesel	Diesel	IFO/Diesel	

Figure 2.3, Figure 2.4, and Figure 2.5 provide a further breakdown of selected sector traffic for clarity.

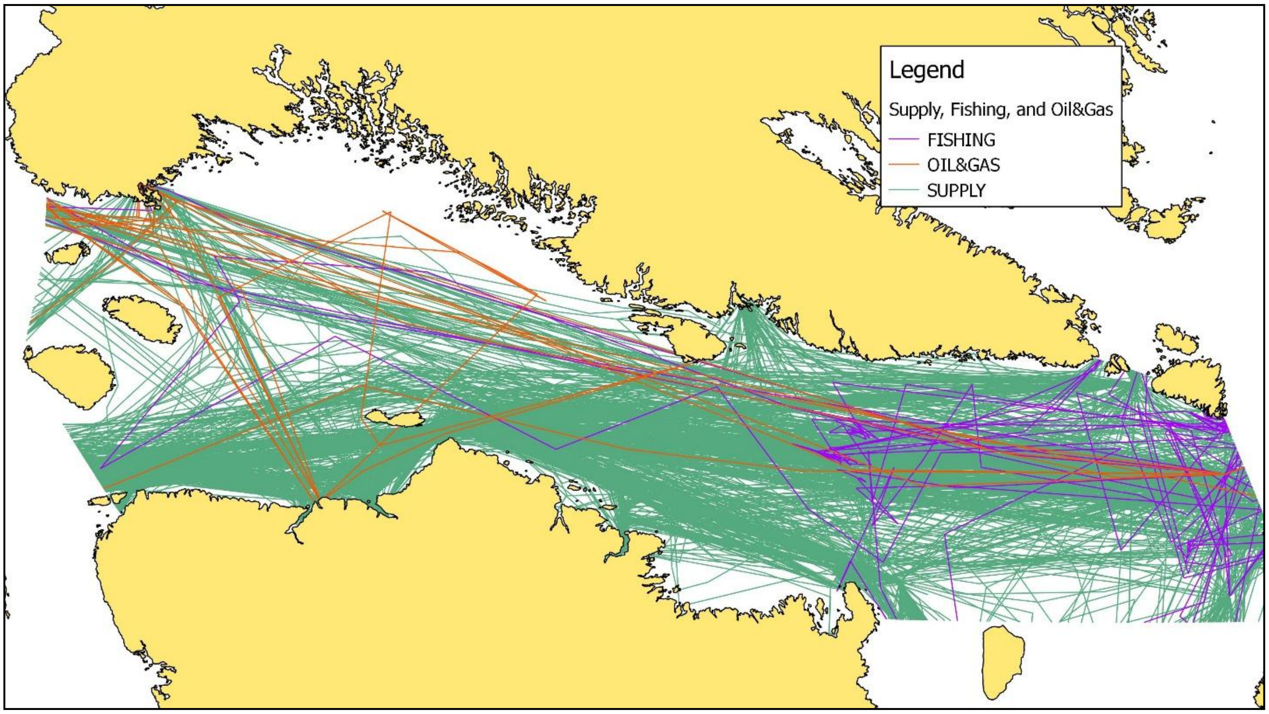

Figure 2.3: Vessel Traffic for Fishing, Oil and Gas, and Supply Sectors, 2007-2013

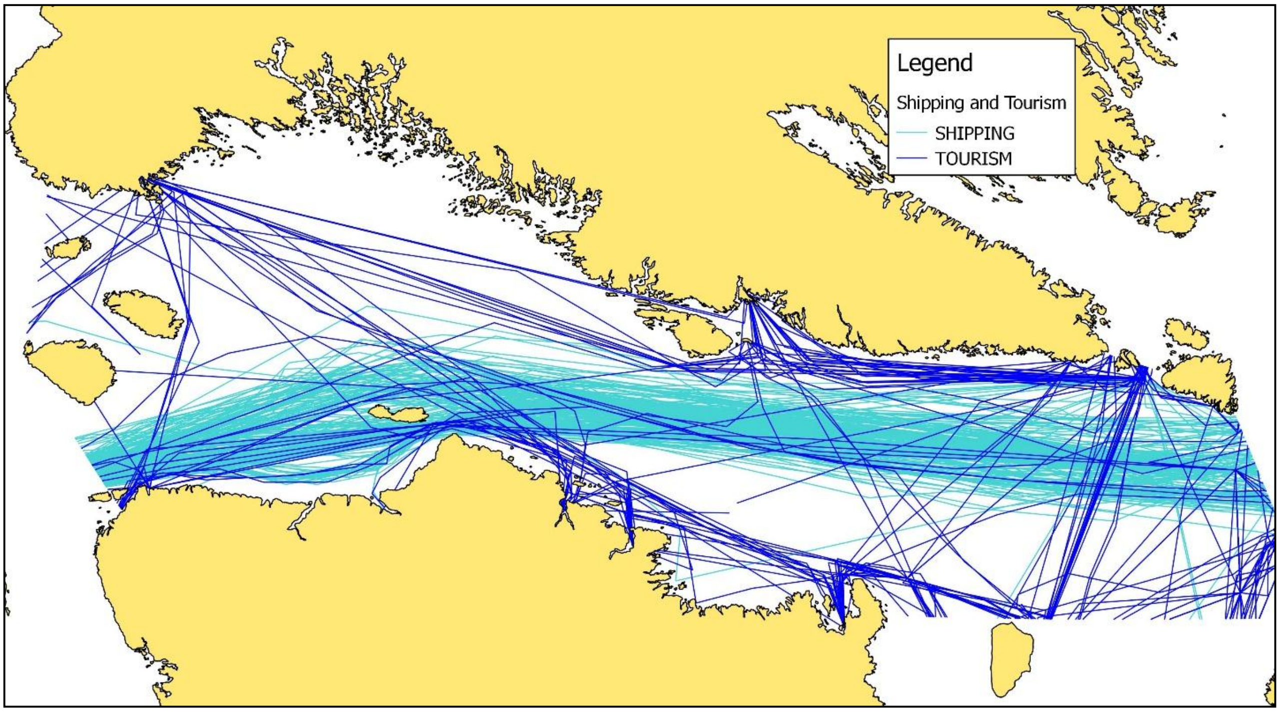

Figure 2.4: Vessel Traffic for Shipping and Tourism Sectors, 2007-2013

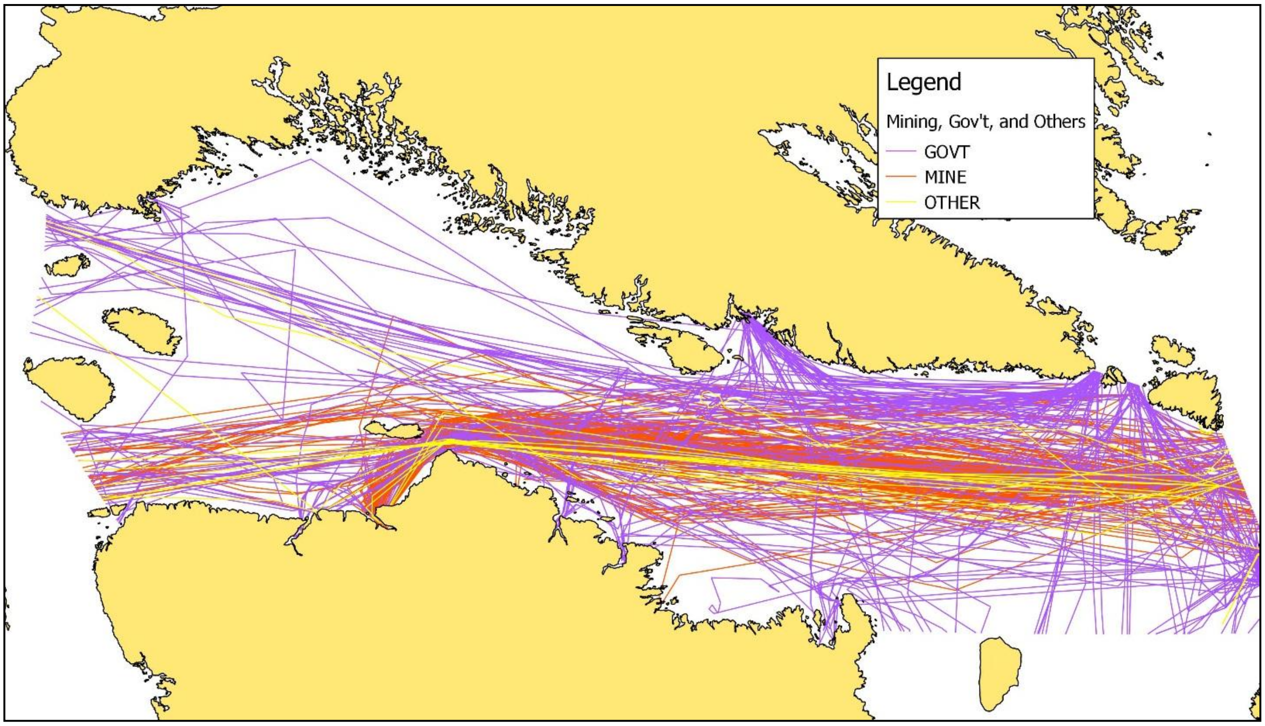

Figure 2.5: Vessel Traffic for Government, Mining, and other Sectors, 2007-2013

2.2.3 Vessel Characteristics

Table 2.5 provides an overview of the key characteristics of vessels operating in the Hudson Strait, as well as the breakdown of their sailing distances, seasons[2], frequencies[3].

Table 2.5: Breakdown of Hudson Strait Traffic by Vessel Type

Vessel Type	Bulk Carrier	General Cargo	Fishing Vessel	Tanker	Tug	Passenger Vessel	Gov't Icebreaker	Other
Total Unique Vessels	94	40	13	23	23	16	12	9
Annual Average	17	13	3	8	6	5	6	2
% of Annual Average	*28%*	*23%*	*6%*	*13%*	*10%*	*8%*	*9%*	*3%*
Total Transits	158	408	28	195	83	53	66	16
Annual Average	27	71	5	34	14	9	11	3
% of Annual Average	*16%*	*40%*	*3%*	*20%*	*8%*	*5%*	*6%*	*2%*
Distance sailed (km)	155,686	325,778	11,339	155,160	68,865	42,435	73,680	11,689
Annual Average (km)	25,533	50,416	1,861	24,845	10,496	6,675	11,819	1,948
Average voyage length (km)	985	798	405	796	830	801	1116	731

[2] Note that a limited number of sailings do not have date stamp information available and therefore the seasonal distribution for sailings by vessel type does not represent 100% of the data used by the project.
[3] Note that the years 2010 and 2013 collate the number of voyages in a different manner that all other years, and are not used in the calculation of average number of yearly voyages.

Vessel Type	Bulk Carrier	General Cargo	Fishing Vessel	Tanker	Tug	Passenger Vessel	Gov't Icebreaker	Other
% of Annual Average	*19%*	*38%*	*1%*	*19%*	*8%*	*5%*	*9%*	*1%*
Spring traffic %	*1.3%*	*1.2%*	*3.6%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Summer traffic %	*67.1%*	*61.0%*	*28.6%*	*69.2%*	*51.8%*	*92.5%*	*56.1%*	*18.8%*
Fall traffic %	*29.1%*	*28.4%*	*64.3%*	*27.7%*	*41.0%*	*1.9%*	*39.4%*	*0.0%*
Winter traffic %	*1.3%*	*6.4%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Est. Average gt (t)	21,648	11,570	2,021	13,841	548	7,031	6,762	
Est. Average dwt (t)	35,513	15,540	1,008	24,082	633	1,305	2,804	
Est. Average Length (m)	186	142	57	152	41	99	97	
Est. Common Fuel Type	HFO	IFO	Diesel	IFO	Diesel	IFO/Diesel	Diesel	

2.2.4 Cargo Quantities and Characteristics

The main cargoes carried through the Hudson Strait include ore, dry bulk, petroleum products, and general cargo.

Ore products currently consist primarily of nickel-in-concentrate being exported from the Raglan and Nunavik mine sites via Deception Bay. These exports are primarily on purpose built ice classed bulk carriers including the MV Arctic and the MV Nunavik[4] which have capacities of approximately 28,000 dwt, and occasionally by other vessels with capacities anywhere from 10,000 dwt to in excess of 40,000 dwt. This study will use an estimated average capacity of 28,000 dwt to model the type of vessel used for most of the voyages.

Dry bulk consists primarily of grain products shipped out of Churchill, through the Strait and overseas. Dry bulk is carried by bulk carriers with capacities ranging from 10,000 dwt to over 58,000 dwt. The average capacity for the study's dataset is approximately 35,000 dwt.

Petroleum products are shipped through the Hudson Strait in order to supply both communities and industrial sites. Petroleum is primarily carried by tankers with capacities ranging from approximately 10,000 m^3 to 20,000 m^3 when loaded to 98%. This study will assume an average capacity of 13,800 m^3 based on the capacities of the vessels for which data is available and the frequency with which they sailed in the Hudson Strait. Additionally, petroleum products may be shipped in tank barges towed by tugs. For the purposes of this study, it is assumed that approximately 1/3 of the tug traffic in the Hudson Strait will be towing tank barges, and that based on a transport Canada registry of barges these barges could be characterized with approximate particulars of a length of 50 m, gross tonnage of 320 t, and dwt capacity of 600 t (which for diesel provides a capacity of 750 m^3).

General cargo is difficult to classify, however in the Canadian Arctic is will consist of a mix of containerized goods, construction materials, assembled modules, vehicles, equipment, and more. Commercial shipping operators generally assign a ratio of 1 t to 1 m^3 for general cargo. However, Arctic sealift operators such as NEAS use a ratio of 2.5 t to 1 m^3 as much of their cargo is relatively high density, such as vehicles and building supplies. General cargo

[4] The Nunavik entered service in 2014 and consequently is not captured in the current database; however this vessel will be a significant contributor to traffic in future years.

ships operating the Arctic have typical capacities in the 8,000 dwt to 17,000 dwt range. For the purposes of this study, an average capacity of 12,000 dwt is used.

General cargo often includes containerized petroleum products, and similarly some ore carriers will deliver petroleum supplies to mine sites when inbound. These products are however not broken out from dry cargo in the table below due to the lack of available data detailing cargo manifests.

Note that vessels will not necessarily be carrying cargo on each transit into the Hudson Strait.[5] Table 2.6 provides estimates of the quantity of cargo shipped through the Strait for a given year, and notes only the number of vessel transits where the vessel will be carrying cargo. As a result, the average number of annual voyages for certain categories shown in Table 2.4 and Table 2.5 may not match Table 2.6 below.

Table 2.6: Annual Cargo Flow Estimates in the Hudson Strait

Cargo Type	Estimate Total Annual Voyages	Estimated Vessel Capacity	Estimated Annual Cargo Quantity
Petroleum products (tankers)	24	13,800 m³	331,200 m³
Petroleum products (barges)	5	750 m³	3,750 m³
Petroleum products (bulk/mining inbound)	~10	unknown	unknown
Total			**334,950** m³
General cargo (vessels)	35	9,600 t	840,000 m³
General cargo (barges)	5	600 t	7,500 m³
Total			**847,500** m³
Dry Bulk	26	35,000 t	**910,000** t
Ore	10	28,000 t	**560,000** t

2.2.5 Vessel Destinations in the Hudson Strait

While vessel traffic in and out of Churchill does not make port or other destination calls within the Hudson Strait, much of the traffic from the mining, tourism, and government sectors does. The communities of Ivujivik, Salluit, Kangiqsujuaq, Quaqtaq, and Killiniq are all along the southern portion of the Hudson Strait, and Cape Dorset and Kimmirut are along the North. All receive visits from supply and government vessels. Cape Dorset, Kangiqsujuaq, Kimmirut, and Ivujivik are frequent (by Arctic standards) tourist destinations.

Additional points of interest include both inlets with access to the Raglan and Nunavik mine roads which are used by almost all mining traffic in the Strait, as well as the bay south of Quaqtaq and the less trafficked eastern Raglan access which are frequented by tourist vessels.

[5] The Vard shipping database will consider a ship's "voyage" complete if the ship is idle for more than 3 days, and will create a new "voyage" record for the ship once it resumes sailing. As a result, ships which load cargo relatively quickly before sailing their return voyage (such as bulk grain carriers) will have a single "voyage" record for their inbound (no cargo) and outbound (with cargo) trips to a port. Other vessels such as general cargo ships performing sealift operations may have the inbound and outbound portions of their voyage split into multiple records.

Government and tourist vessels will occasionally make short calls at other locations, and other industry sectors will occasionally make calls at locations in the Strait, however for the purposes of this study Table 2.7 provides an estimate of the number of annual port calls by vessels from the mining, supply, tourism, and government sectors at the main points of interest in the Hudson Strait.

Table 2.7: Estimated Annual Visits to Ports of Call in the Hudson Strait

Location	Mining Traffic Visits	Tourism Traffic Visits	Supply Traffic Visits	Government Traffic Visits
Ivujivik	None	1-3	2-4	0-1
Cape Dorset	None	2-4	3-6	0-1
Salluit	None	None	2-3	0-1
Raglan West	20+	None	3-5	0-2
Raglan East	4-5	1-4	None	0-2
Kangiqsujuaq	None	2-6	2-4	0-2
Kimmirut	None	2-5	2-4	2-5
Quaqtaq	None	None	2-3	0-1
South of Quaqtaq	None	2-6	None	0-2
Killiniq	None	0-1	1-3	1-3

Figure 2.6 shows a visual representation of traffic by industry sector, overlaid with the ports of call from Table 2.7 above.

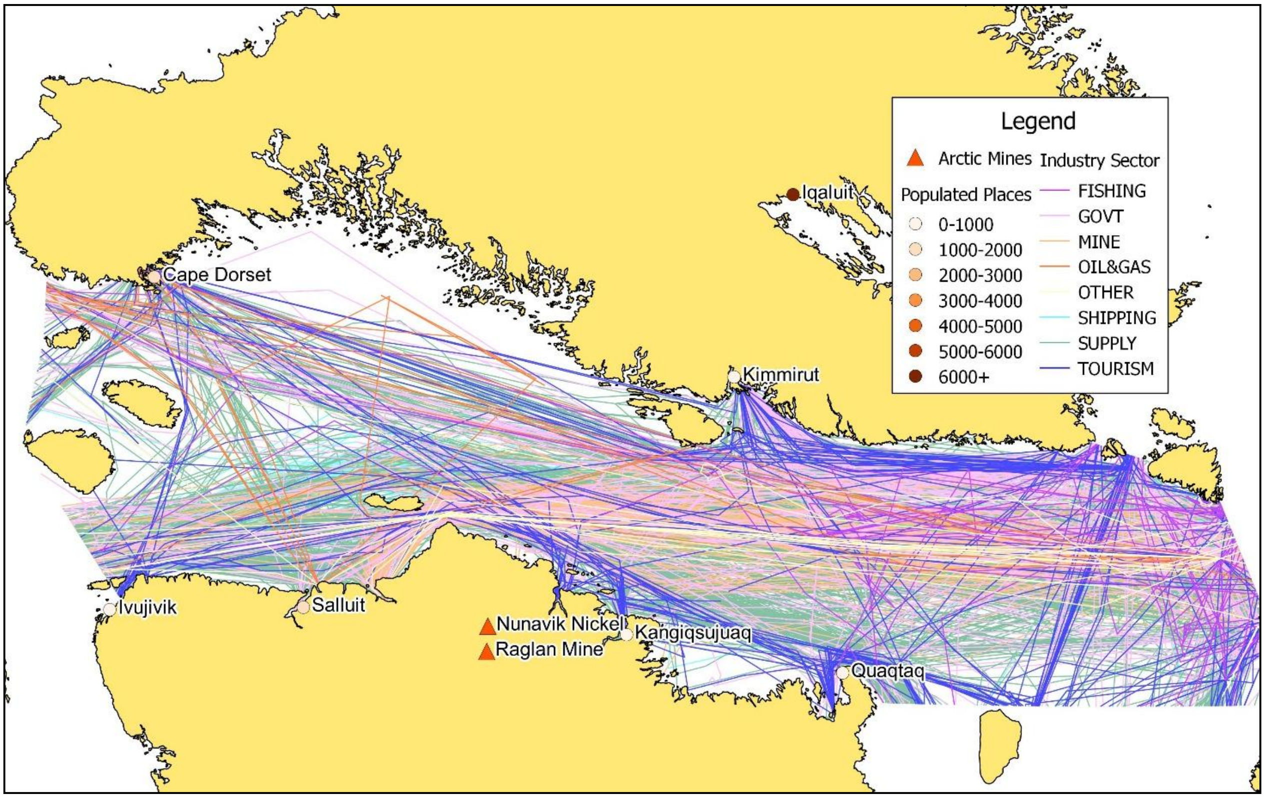

Figure 2.6: Ports and Traffic Flow in the Hudson Strait

3 TASK 2: SOCIO-ECONOMIC, CULTURAL, OCEANOGRAPHIC, AND ECOLOGICAL INVENTORIES

The second Task of the project presents an inventory of data sources describing the physical and social makeup of the Hudson Strait. Sources include oceanographic, cultural, and socio-economic data suitable for describing the human and physical environment for the study area. Sources also include extensive ecological species-specific data for marine mammals, seabirds, subsistence and commercial fisheries; addressing (when available) population (abundance and seasonal distribution) and suitable habitat, migration routes, marine protected areas and parks.

The data gathering and cataloging effort was focused on information which will be useful in evaluating the impacts of ship traffic in the Hudson Strait in subsequent project tasks. The results are described in the remainder of this report.

3.1 Overview of Results

At the time of first issue, this report collected a total of 58 data sources for socio-economic, cultural, oceanographic, and ecological information. The following summarizes the results for each aspect of the data collection work:

Socio-Economic: Data has been collected describing transport, navigation, and supply infrastructure locations, population size and change trends, as well as macro-scale economic drivers in the shipping industries operating in the Hudson Strait.

Cultural: Data has been collected covering community consultations on sustainability and development, as well as locations of protected areas, sensitive areas, and traditional harvesting areas likely to intersect with vessel traffic.

Oceanographic: Data has been collected which provides a comprehensive view of bathymetry, sea ice conditions and seasonal forecasts, temperature and weather, and currents and tides for the entire study area.

Ecological: Data has been collected describing the estimated and observed ranges and populations for the entire range of species likely to be impacted by shipping, including cetaceans, pinnipeds, polar bears, seals, birds, fish, invertebrates and other sea based life.

Sections 3.2 and 3.3 of the report provide detailed descriptions of key features of these data sources, including useful figures and tables of values and commentary on specific data sources of note.

Section 6 provides complete reference details for each data source.

Annex A provides a comprehensive list of the data sources in a tabular format, citing references for the data sources, the available format of spatial and temporal data, and an indicative evaluation of the quality of the data source as an input to the risk assessments to be completed in Task 3 of the project.

3.2 Socio-Economic, Cultural, and Oceanographic Data

The Hudson Strait is characterized by a deep middle channel, relatively strong currents and high tides. During the winter season it is entirely ice covered. The ice coverage is dynamic, with numerous leads, cracks, polynas, and other features occurring predictably each season.

These features are favourable for a number of marine mammals including cetaceans and seals, who depend on the ice and winter access to the water beneath it.

The Hudson Strait experiences both transient ship traffic from Churchill and the interior of the Arctic, as well as traffic to a number of small communities on its banks. Much of the activity in the strait is centered on the Raglan and Nunavik mines, located at Deception Bay.

The communities along the Strait are currently experiencing modest population and economic growth. Supplies for these communities are exclusively imported via ship delivery during the summer and fall seasons, as well as by limited aircraft access at local airstrips. Facilities for both air and sea supply are basic – sea supply is typically via barge and beach landing, while air facilities are typically gravel runways suitable for smaller aircraft.

3.2.1 Socio-Economic and Cultural Data

Socio-economic data collected for the project includes metrics for population centres within the study area and their growth/decline rates, as well as locations of airports, common marine supply chain locations, and other key infrastructure.

3.2.1.1 Census Data and Population Trends

The previous two national Census submissions have been obtained in order to discern the trend in population change for communities along the Hudson Strait. The data suggests that most communities within the study area are experiencing modest to moderate population growth. The following figure shows the relative rate of growth for these communities (a measure of the % population growth divided by the overall population size). Upwards arrows in green represent growth, downwards arrows in pink represent reduction.

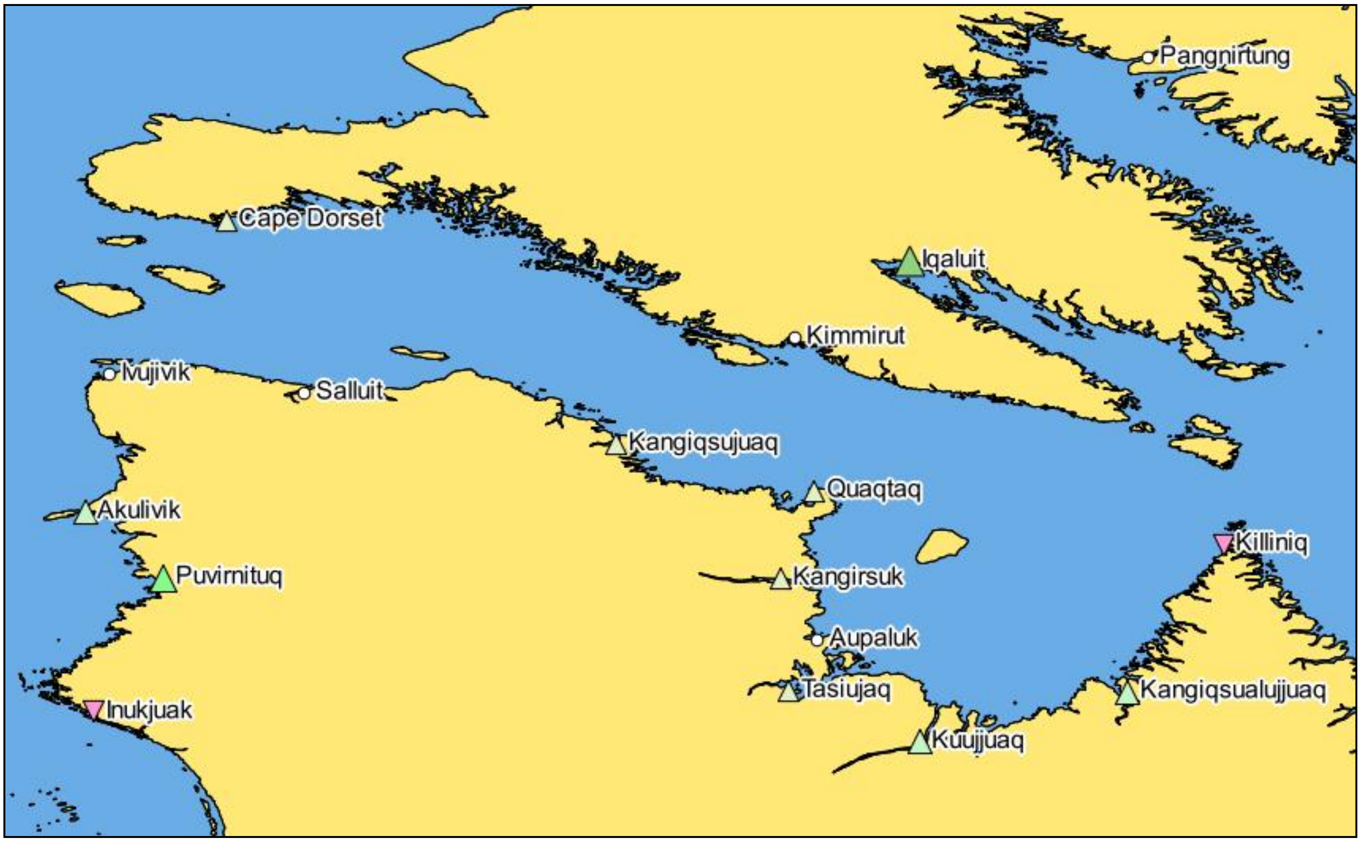

Figure 3.1: Population change in the Hudson Strait.

3.2.1.2 Local Employers and Key Economic Drivers

The key economic drivers in the region are mining and mineral extraction, fishing, as well as tourism. In Task 1, the project has collected data describing:

- The production capacity and workforce size for the mining sector, as well as frequency of product exports by ship through the Hudson Strait. This data as applicable to the economic impact on communities within the Hudson Strait is primarily concerned with the Raglan and Nunavik mines.
- The approximate number of trips made by fishing vessels as well as estimates of their crewing requirements.
- The frequency and passenger count for tourist vessels stopping at communities in the Hudson Strait.

3.2.1.3 Navigation, Access, and Transport

There are a number of local airports adjacent to the Hudson Strait. Most serve as the sole access to the community when ship visits are not possible. Airports in the region are generally smaller, using packed gravel runways. With the exception of Kattiniq (Donaldson), all have less than 4000' of runway available and are generally limited to smaller prop driven aircraft.

There are few permanent navigation aids in the Hudson Strait, with most vessel traffic relying on charts and satellite and radio systems. The Hudson Strait is covered by NAVTEX, and there is a MCTS station at the North-East boundary of Ungava Bay and the Hudson Strait.[6] There are also a limited number of shore lights all located in the South-West portion of the Strait.

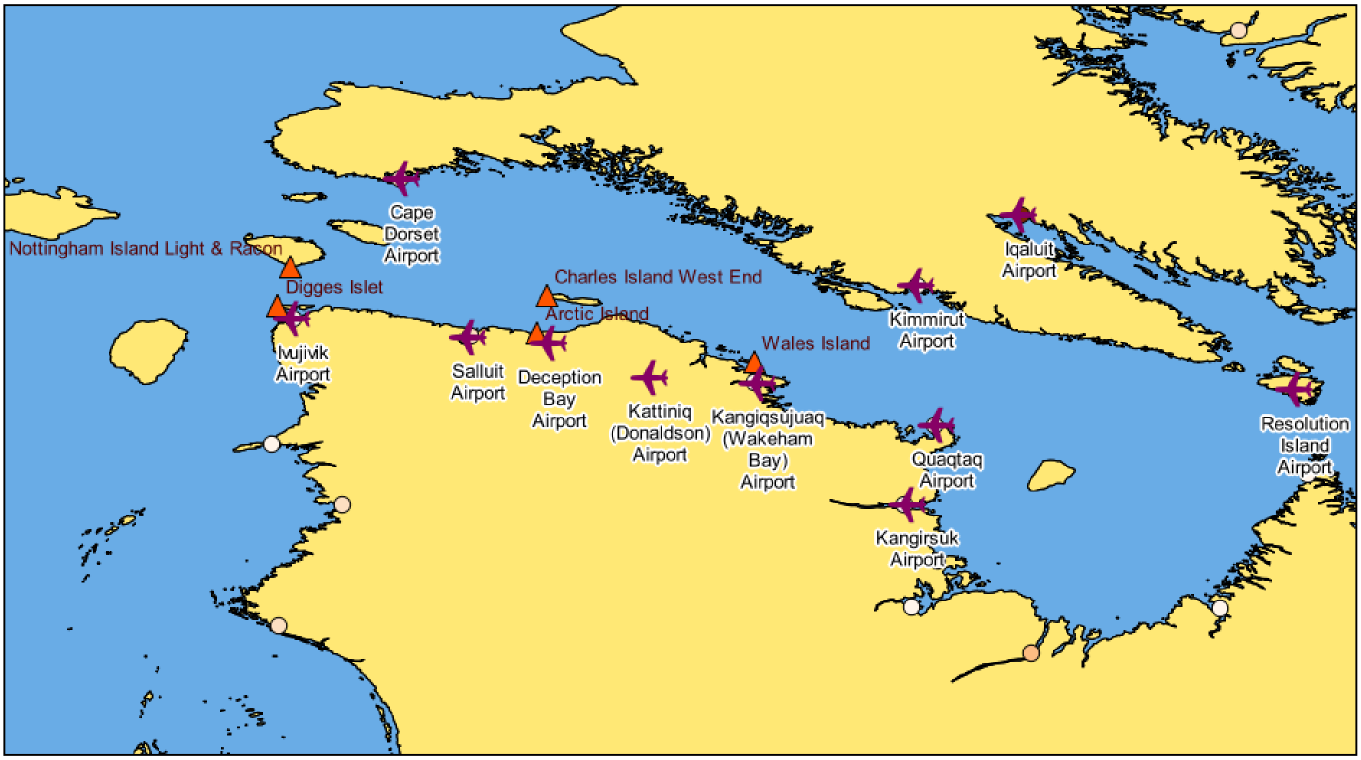

Figure 3.2: Airports and navigations aids in the Hudson Strait

3.2.1.4 Significant or Protected Regions

There are several Territorial and National parks within the boundaries of the study area, including Katannilik Territorial Park and bird/wildlife sanctuaries on Mallik Island, Sakkiak Island, and Alareak Island, all near Cape Dorset. The boundaries for all such areas have been collected as part of this Task.

3.2.1.5 Culturally Significant Regions (local)

Both the North and South borders of the Hudson Strait have been and continue to be used as traditional resource areas for activities including shore and boat based fishing, hunting, and whaling. Several communities in the Hudson Strait such as Salluit are heavily dependent on sustenance fisheries as a key food source and perceive increased vessel activity in these regions as a risk to the productivity of their harvesting activities.[7]

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[6] Arctic Voyage Planning Guide. Fisheries and Oceans Canada. 2014.
[7] Nunavut Planning Commission, Sept 2013. Summary of Community Meetings on the Draft Nunavut land Use Plan. Salluit, June 4-5 2013.

Shapefiles representing these areas have been collected as part of this task. The following figure provides a view of these areas: Pink regions represent general harvest areas important to sustenance of the local communities (such as fishing for Arctic char) and green represent special harvest areas used for culturally significant hunting activities.

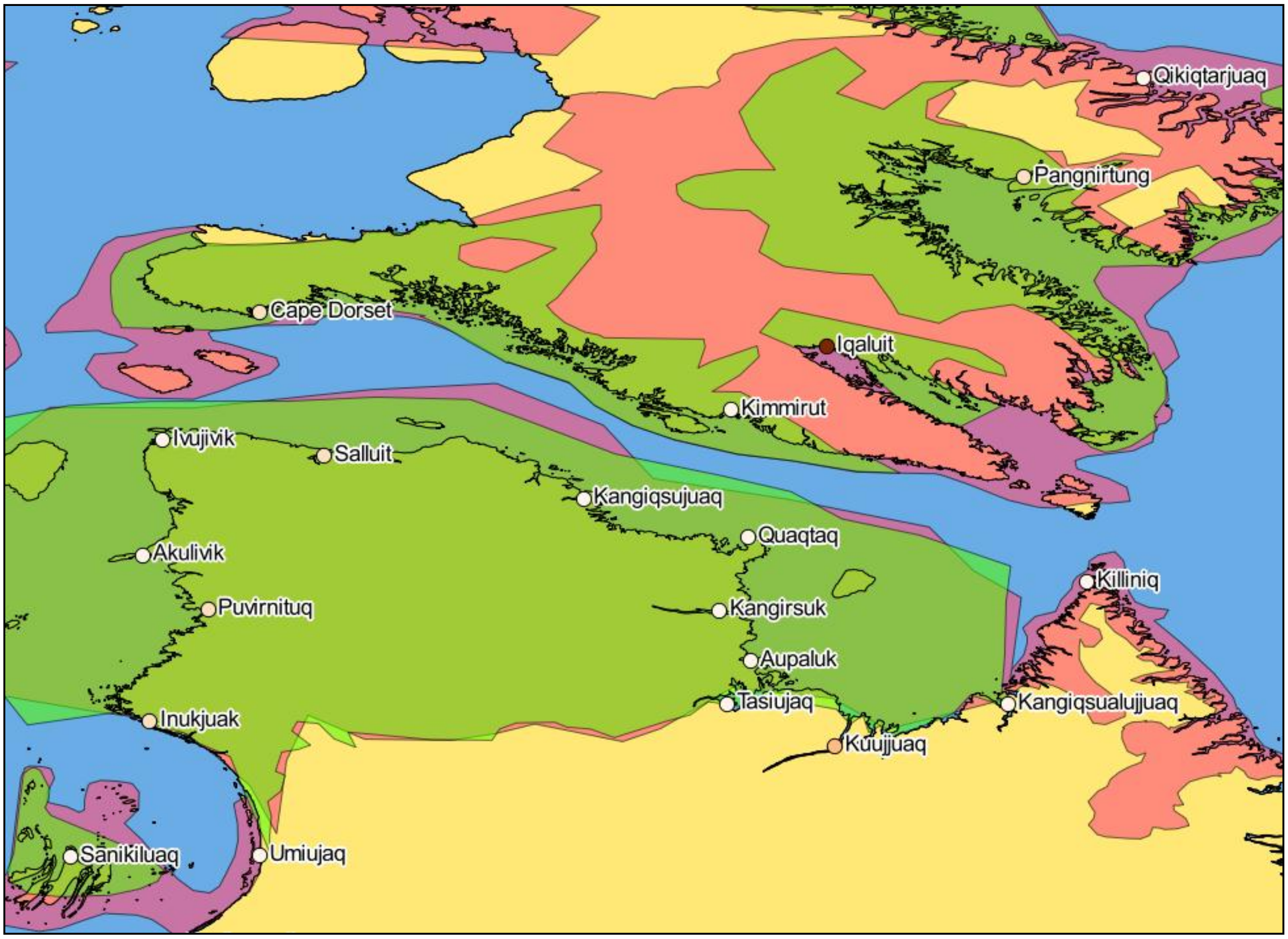

Figure 3.3: Harvest Areas in the Hudson Strait

3.2.2 Detailed Results – Oceanographic Data

The oceanographic data set includes GIS-ready data covering sea ice distribution, sea ice extent, sea surface temperature data, currents and tidal ranges, observed (land) temperature records, and bathymetry data.

3.2.2.1 Sea Ice Charts

Sea Ice data was obtained from the Canadian Ice Service (CIS), published online via the National Snow Ice Data Centre (NSIDC). The data is available as standard GIS shapefiles[8]. CIS data is divided into 5 regions; Eastern Arctic, Western Arctic, Hudson Bay, Canada's

[8] An archive of past ice charts is available at: ftp://sidads.colorado.edu/pub/DATASETS/NOAA/G02171/

East Coast, and the Great Lakes. The Hudson Strait is covered by the "Hudson Bay" data set. The following figure shows an example of the data imported into a GIS, focused on the Hudson Strait. The figure shows the state of sea ice at the second week of June, 2014. Lighter shades of blue represent areas of lower ice concentration.

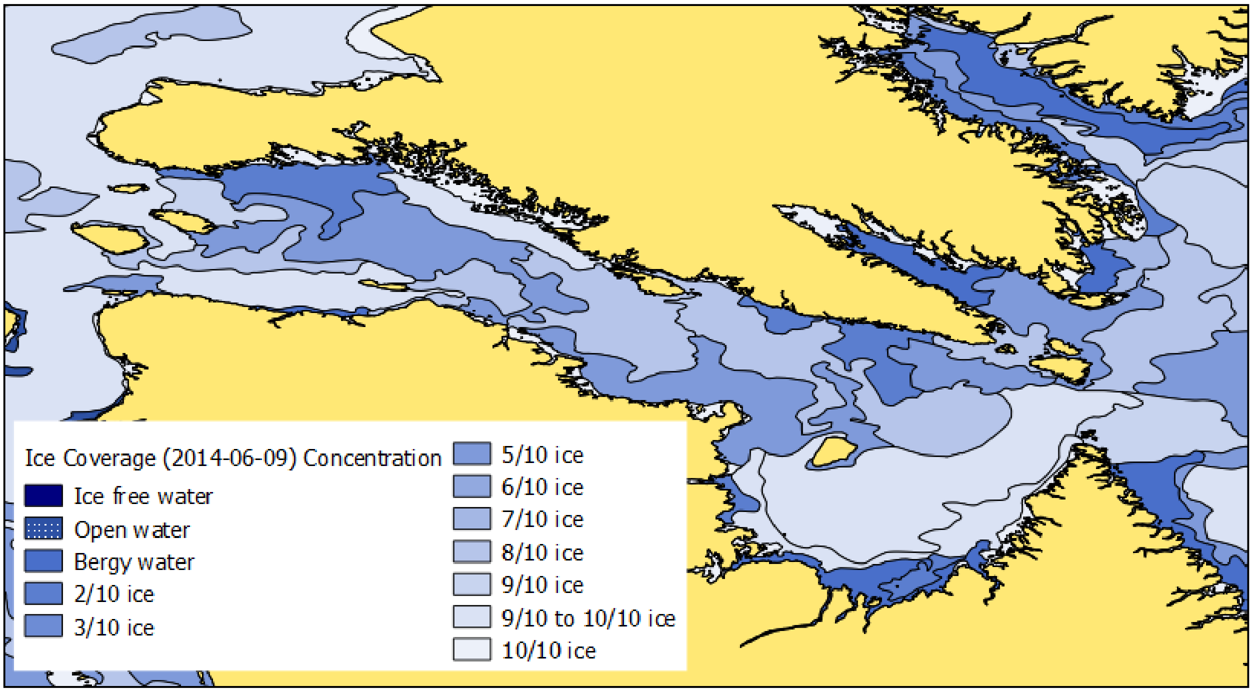

Figure 3.4: Example daily sea ice chart from the CIS

Temporal coverage currently available to the project includes 2006 to current week data. The overall data quality is very high, as the data provides detailed descriptions of ice conditions with a high level of confidence for all but the most difficult to remotely resolve types of ice.

3.2.2.2 Sea Ice Extent

Sea ice extent data was obtained from Multi Sensor Analysed Sea Ice Extent (MASIE) data published by the NSIDC[9]. MASIE data is not as detailed as CIS data, however it provides a useful approximation (at a ~4km resolution) of the total area of the Arctic covered by ice (regardless of ice thickness, makeup, or age) for any given day.

3.2.2.3 Sea Ice Index

The sea ice index is a monthly maximum sea ice extent calculation provided through the NSIDC[10]. This calculated vale offers historical maximums back to 1979 by month of the year, as well as total mean extend for each month based on the entire temporal record.

[9] Data available at: http://nsidc.org/data/masie/
[10] Data available at: http://nsidc.org/data/g02135

3.2.2.4 Sea Ice Freeze-Up and Break-Up

The sea ice coverage in the Hudson Strait will vary from year to year, however the notional dates for freeze up and break up are available from the CIS[11]. For the Hudson Strait, break-up is typically in the first days of July except for some areas near Baffin Island and the top of Ungava Bay. Freeze-up dates are typically the first days of December, with the exception of the Eastern-most portion of the Straight where it may occur 1-2 weeks earlier.

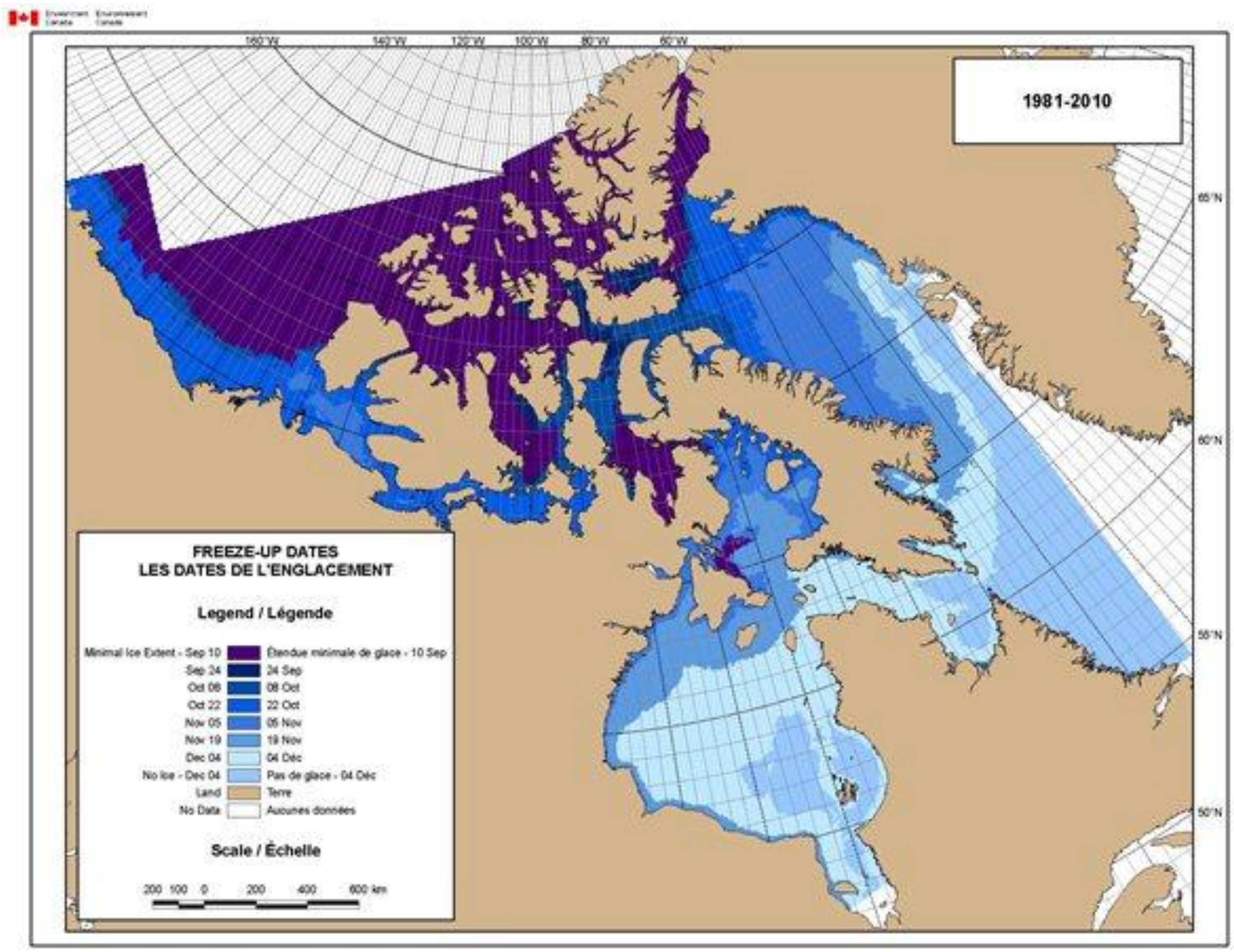

Figure 3.5: Indicative sea ice freeze-up dates

[11] Season outlooks for ice break-up and freeze-up available at: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=E568E9D7-1

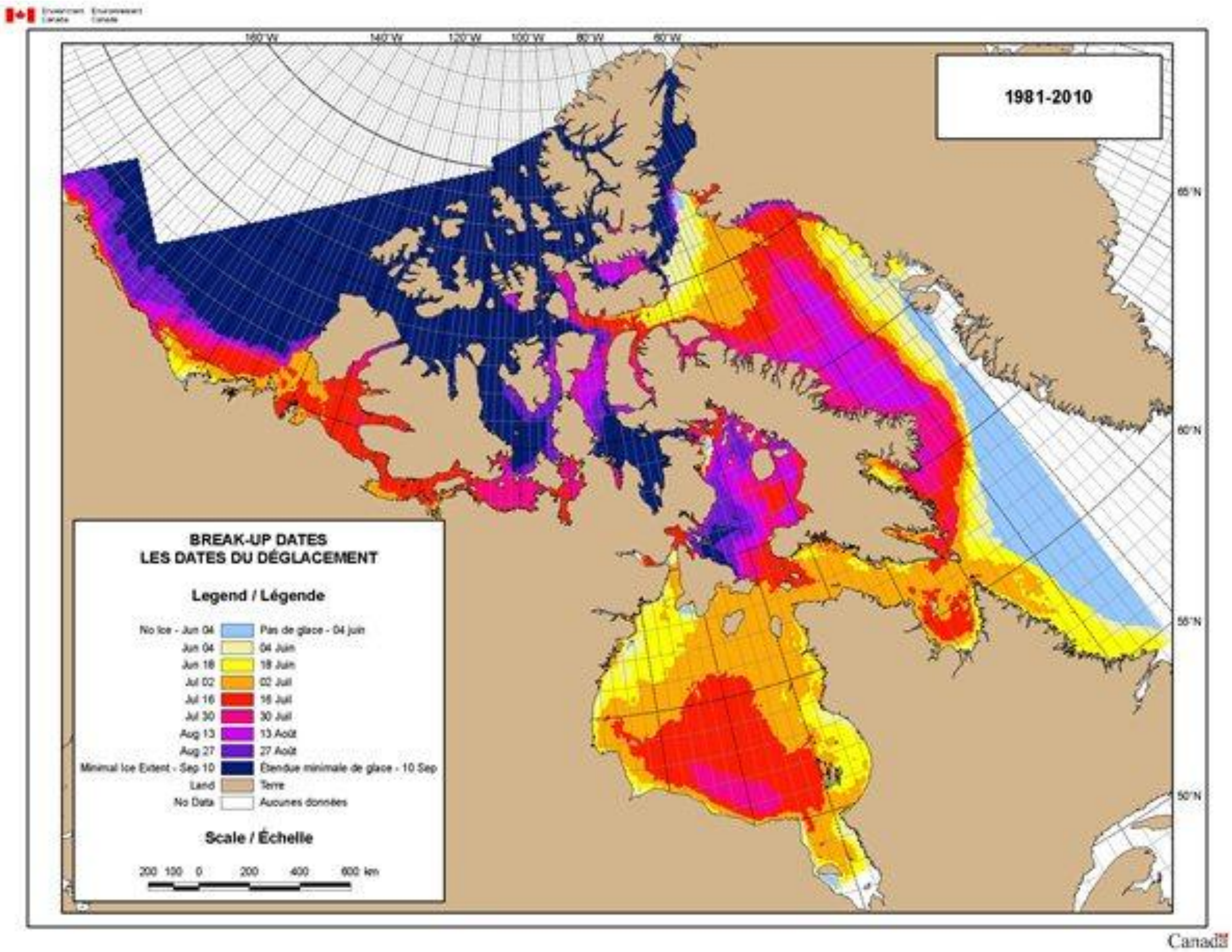

Figure 3.6: Indicative sea ice break-up dates

3.2.2.5 Sea Surface Temperature

Sea surface temperature (SST) data is provided by NOAA[12]. Satellite instrumentation is used to calculate the temperature at sea surface level. The analysis uses an interpolation of local and satellite SST's as well as SST's simulated by sea-ice cover.

The NOAA SST data product is available at a number different resolutions and temporal frequencies. For the purposes of this project the data set used represents a one degree by one degree grid, packaged into a mean temperature for incremental one week periods. NOAA also publishes monthly and long-term mean data should longer frequencies be required for a particular analysis or assessment.

The following figure shows the mean sea surface temperature for the week of June 6-12, 2010.

[12] http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html

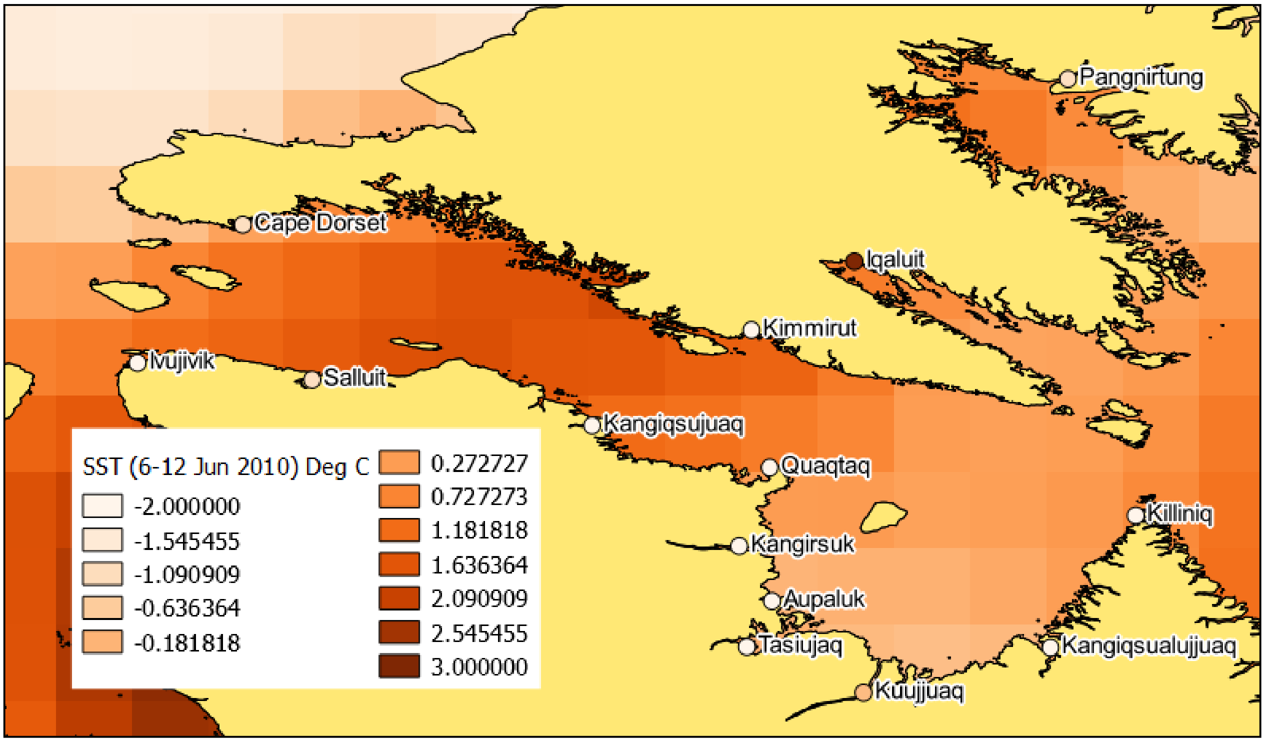

Figure 3.7: Example mean SST chart

Temporal coverage currently available to the project includes 1982 to 2014. The overall data quality is good, as the NOAA satellite equipment used in collecting the data has been shown to correlate well with direct observations.

3.2.2.6 Observed Temperature Records

Directly observed temperature and meteorological data is available as a historical record for a number of stations inside the study area. Historical data is published by the NOAA National Climatic Data Centre.[13]

Data current to 2014 is available for:

- Cape Dorset (64.23 N, 76.53 W)
- Iqaluit (63.75 N, 68.55 W)
- Resolution Island (61.583 N, 64.65 W)

This data set includes daily observations for precipitation (both rain and snow) as well as maximum and minimum observed air temperatures for each site, dated back to 2004/2005 for Iqaluit and Cape Dorset, and 1964 for Resolution Island. Historical data is available for a

[13] An interactive map of weather sites and data availability is available at: http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=temp&layers=1

number of additional sites within the project boundary if required, both through NOAA and Environment Canada[14].

3.2.2.7 Currents

The flow of currents in the Strait is in opposing directions with currents moving into the Arctic along Baffin Island, and out from Hudson Bay along Northern Quebec into the Labrador Sea, also cycling through Ungava Bay. The following figure shows the general current flows in the Strait and surrounding waters.

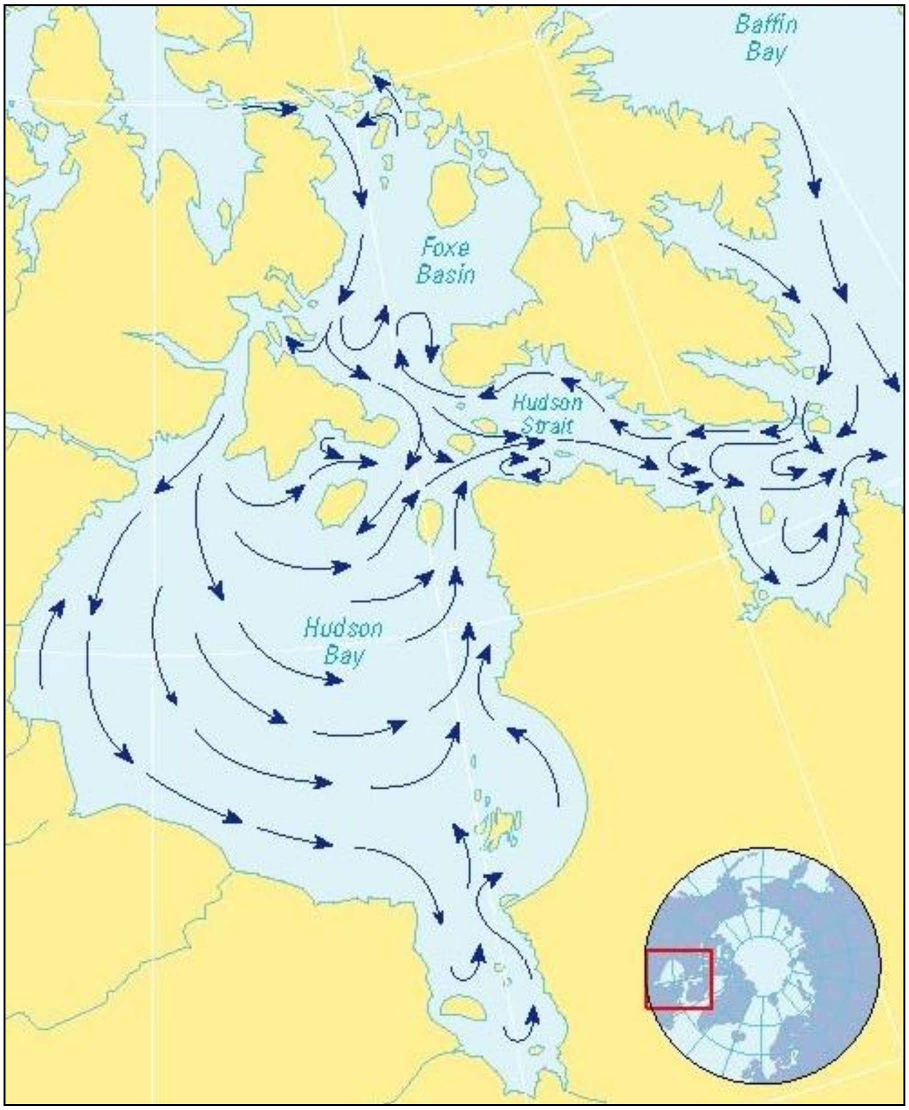

Figure 3.8: Indicative current directionality in the Hudson complex (GRID Arendal)

[14] Available at: https://weather.gc.ca/marine/weatherConditions-currentConditions_e.html?mapID=06&siteID=04201&stationID=WKW

A number of studies have been conducted since the early 1980s to measure and model current flow in the Strait. A number of direct measurements of currents as well as numerical models are available and have been collected for use by the project.

3.2.2.8 Tidal Ranges

Tidal ranges in the Hudson Strait are available from monitoring stations at various locations within the study area[15].

- Port De Boucherville, Nunavut
- Digges Harbour, Nunavut
- Sugluk, QC
- Deception Bay, QC
- Douglas Harbour, QC
- Doctor Island, QC
- Wakeham Bay, QC
- Stupart Bay, QC
- Koartac, QC
- Ashe Inlet, Nunavut
- Lake Harbour, Nunavut
- Acadia Cove, Nunavut
- Lower Savage Islands, Nunavut

Both the Baffin Island and Quebec borders of the Hudson Strait experience significant tidal ranges. Some of the highest tidal ranges are seen at Ashe Inlet, Nunavut, and Wakeham Bay, Quebec, and are over 11 metres. These are amongst the highest tides in the world.

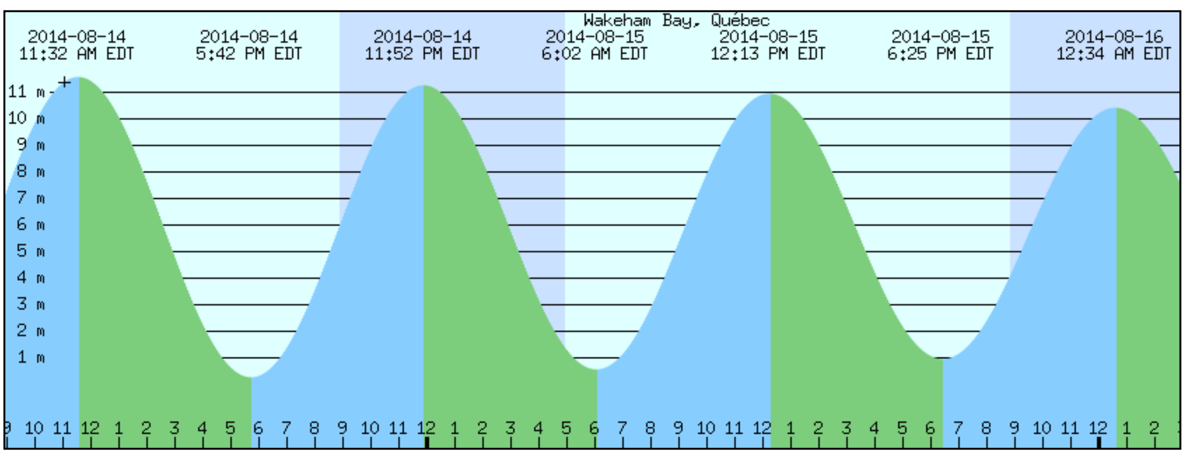

Figure 3.9: Tidal ranges for Wakeham Bay, Quebec from monitoring station

15 http://tides.mobilegeographics.com/index.html

3.2.2.9 Bathymetry Data

Bathymetric data has been obtained from General Bathymetric Chart of the Oceans (GEBCO) published through the British Oceanographic Data Centre[16].

The dataset provides sufficient resolution for the study. Published in 2008, the data is available as a 30 arc-second grid of global elevations, providing a continuous elevation model for both ocean and land. The basis for the data set is a combination of ship soundings and interpolation between sounding points from satellite instrument gravity data.

The Hudson Strait has areas with water depths over 1000' at its Eastern extremity, and areas approaching 900' near Ivujivik and Salluit.

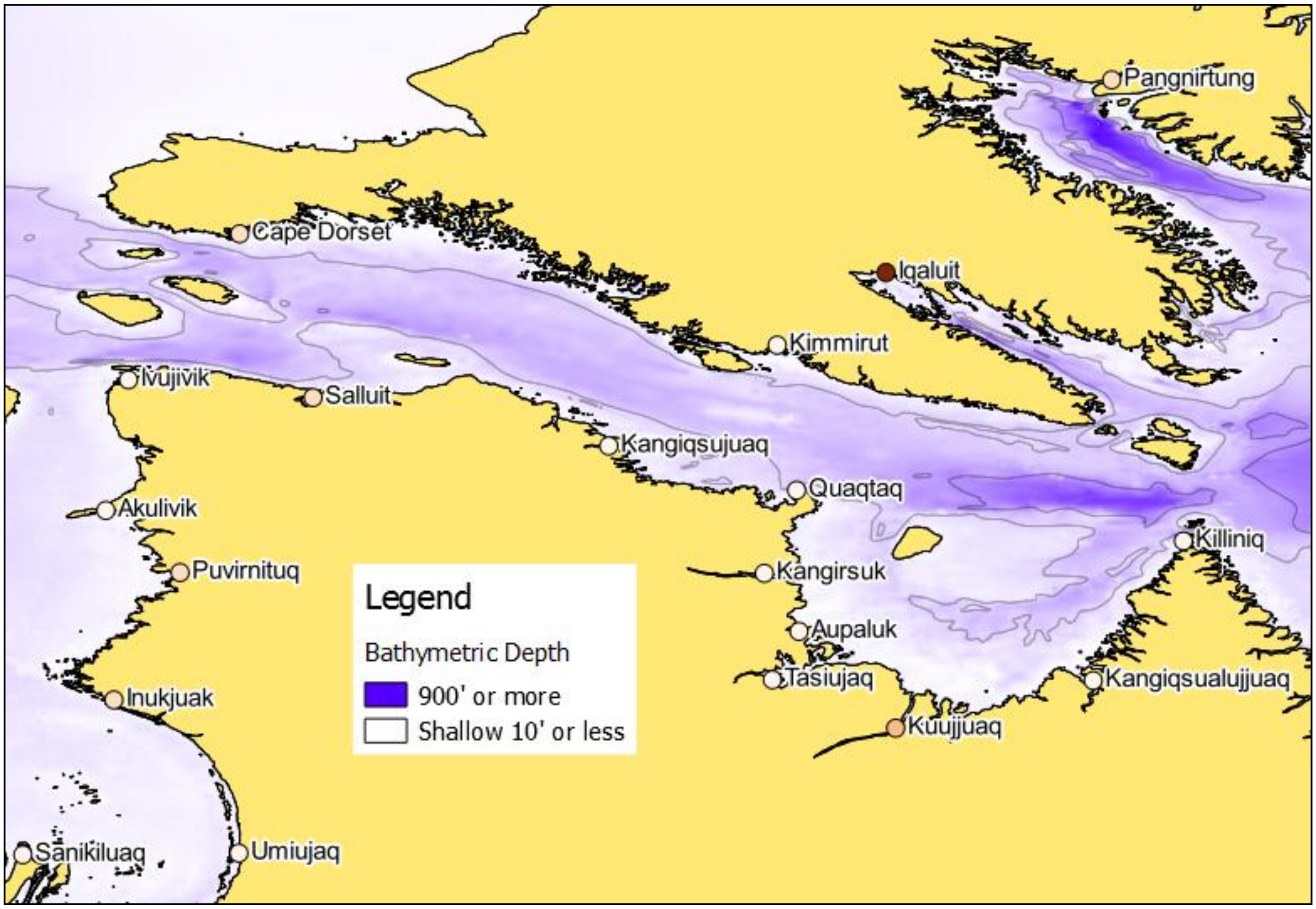

Figure 3.10: Bathymetric map of the Hudson Strait and surrounding waters

3.3 ECOLOGICAL DATA

The Hudson Strait ecosystem is characterized by the penetration of Arctic marine water, which enables a considerable diversity of species to live, breed, or migrate in this area. An

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[16] https://www.bodc.ac.uk/data/online_delivery/gebco/gebco_08_grid/

important migration channel, especially for marine mammals, this ecosystem supports approximately one hundred species of fish[17] and invertebrates. The Hudson Strait is an important seasonal habitat for large concentrations of internationally important migratory species.

The sea ice supports seals upon which the polar bear depend. Millions of geese and shorebirds feed and/or breed in the coastal saltmarshes, productive eelgrass beds provide food for multitudes of waterfowl on their way to and from breeding habitat in the Arctic Islands, and the rivers' estuaries provide vital habitat for anadromous fish and beluga whales.

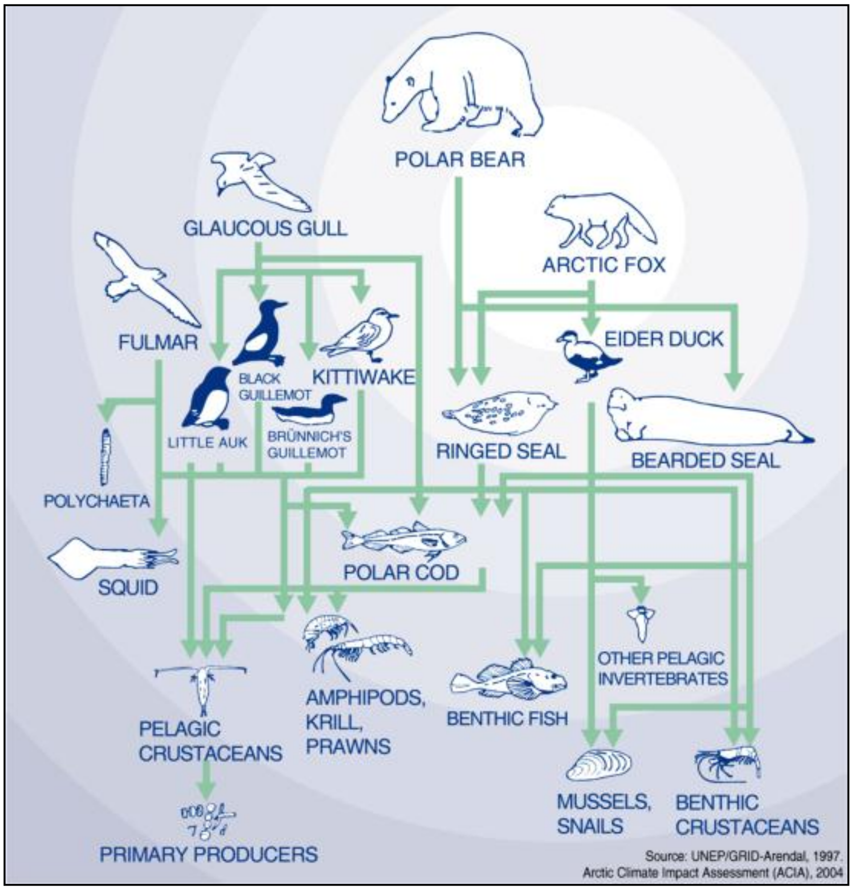

Figure 3.11: The Arctic food web

The species that are assumed to be the more likely impacted by marine traffic are marine mammals, seabirds, and commercially important fishes, crustaceans, and mollusks. While there is a lack of biological information on the latter species, marine mammals are well described for the Hudson Strait.

In 2011, a national Canadian Science Advisory Secretariat (CSAS) science advisory process was held in Winnipeg, Manitoba to provide science advice on the identification of Ecologically

17 Stewart and Lockhart 2004

and Biologically Significant Areas (EBSAs) in the Canadian Arctic based on guidance developed by Fisheries and Oceans Canada. The Hudson Strait has been identified as an important area to be eventually protected. In their report, a team of experts identifies the importance of the Hudson Strait as an EBSA (zones 1.11 & 1.12) for the Canadian Arctic. Reasons are "Migration pathway for Eastern Hudson Bay beluga", "Migration corridor for marine mammals", "Seabird colonies (murres) and seaduck testing (eiders) and foraging sites", "Walrus haulout sites", "Killer whale", "Overwintering bowhead and beluga", and "Sponge beds"[18]. All references to these specific characteristics are evaluated below.

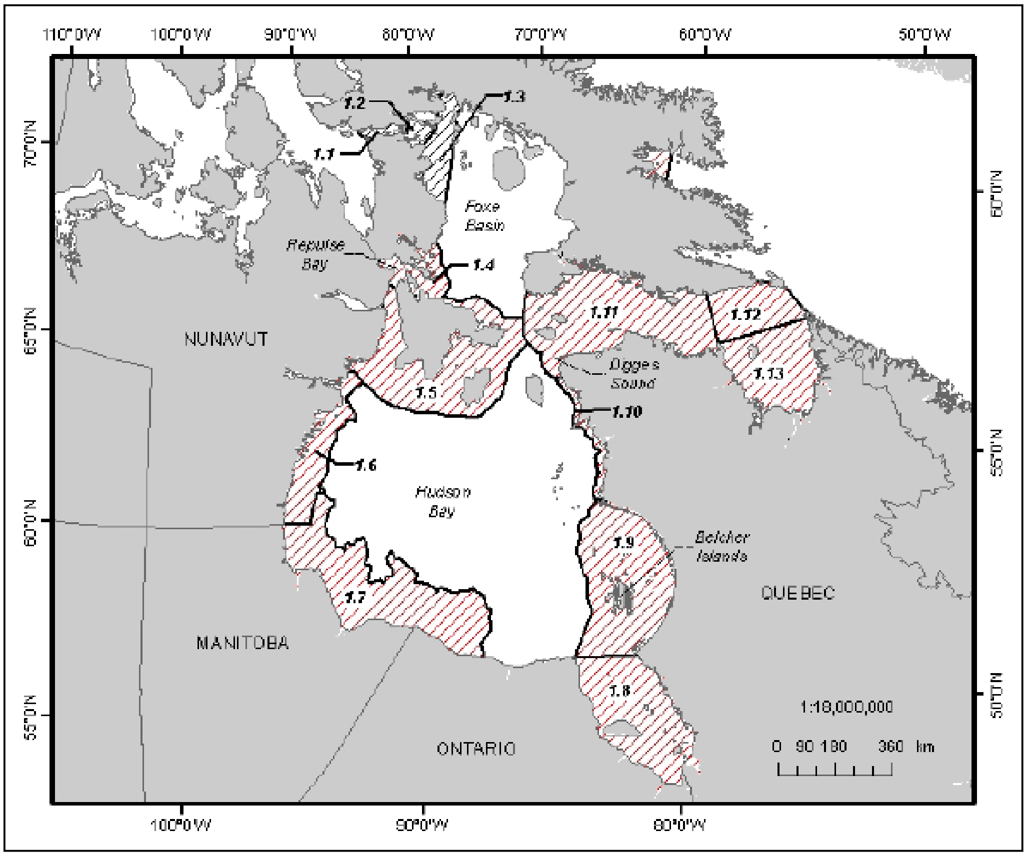

Figure 3.12: Ecologically and Biologically Significant Areas (EBSAs) in the Hudson complex.

Numerous sources of information are available for the spatial-temporal distribution of biodiversity in the Hudson Strait. – See Annex A for a complete list. They were published in peer-review journals, as governmental reports, reports on Traditional Ecological Knowledge (TEK), or as internal report done by consultants for the industry (i.e., Baffinland or Hydro Québec). Marine mammal, birds, fish and invertebrate experts working in the Canadian Arctic were contacted to validate this list and ensure it covers the most pertinent and updated data for the Hudson Strait. The following are some of the most important data sources.

[18] CSAS 2011

a. **Hudson Strait Marine Mammal Aerial Surveys by LGL Ltd.**: In 2013, LGL conduced an important aerial survey of the area, to document the winter distribution and abundance of whales within Hudson Strait where shipping for Baffinland's Mary River project has recently been approved[19]. Although designed specifically for cetaceans, this survey provides a great deal of information on all marine mammals of the area, and has the advantage of covering the whole Hudson Strait.

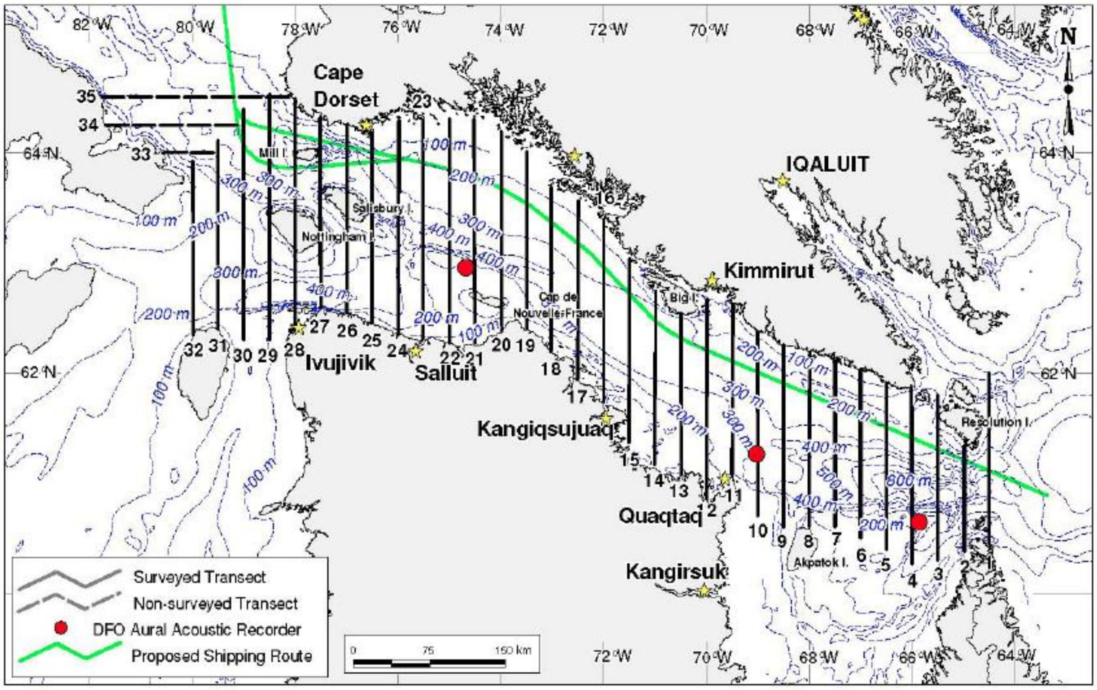

Figure 3.13: LGL aerial surveys coverage

The limited information on cetacean distribution and abundance in Hudson Strait during the ice-covered season certainly contributes to uncertainty in the impact of ship traffic predictions on marine mammals. The aerial survey results presented in Elliott *et al.* (2013) serve as a basis for future monitoring of marine mammals along the shipping route in Hudson Strait.

b. **DFO Acoustic Recorders**: In September 2011, DFO deployed three acoustic recorders in Hudson Strait to study ambient noise levels. LGL's survey was design to fly over these acoustic recorders in order to link data from the acoustic recorders with marine mammal observations made during the aerial surveys. The recorders were retrieved in summer 2012 and the data are currently being analysed by Dr. Yvan Simard, at DFO. In its survey report, LGL states that based on preliminary analyses, bowhead whale, beluga, walrus, and bearded seal calls were recorded[20]. Dr. Simard provided no

[19] Elliott *et al.* 2013
[20] Dr. Yvan Simard, DFO, pers. comm., January 2013

additional information to M Expertise Marine after being contacted. Data are still being analysed and are not officially published.

c. **Canadian Science Advisory Secretariat (CSAS) reports from DFO:** The Canadian Science Advisory Secretariat coordinates the peer review of scientific issues for the Department of Fisheries and Oceans. CSAS also coordinates communication of the results of the scientific review and advisory processes. Reports on the status of fish, invertebrate and marine mammal stocks, environmental and ecosystem overviews. The Hudson Strait area is studied by many projects covered by the CSAS, and this represents an important source of information for results presented in this report. These documents can be found publically on their website at http://www.isdm-gdsi.gc.ca/csas-sccs/applications/Publications/index-eng.asp

d. **ArcticData**: ArcticData is a web portal where we can find access to data collected and developed through the activities of the Conservation of Arctic Flora & Fauna (CAFF) and Protection of the Arctic Marine Environment (PAME) Working Groups of the Arctic Council.

3.3.1 Cetaceans

Hudson Strait is considered to be an important overwintering area for many cetaceans, including bowhead whales (*Balaena mysticetus*), beluga whales (*Delphinapterus leucas*), and narwhals (*Monodon monocerus*), and also an important migration zone for cetaceans of the Arctic.

3.3.1.1 Bowhead Whale

Hudson Strait is a key wintering area for the Eastern Canada-West Greenland population of bowhead whales that is considered of Special Concern by the committee on the Status of Endangered Wildlife in Canada (COSEWIC) (currently no status under the Species At Risk Act; SARA). This population is currently thought to number ~6,344 whales[21]. These bowheads summer in Foxe Basin, Hudson Bay, the Canadian High Arctic, and along the east coast of Baffin Island.

A total of 8 studies describe the distribution of Bowhead whales in the Hudson Strait. Most studies on Bowhead whales are done by telemetry, on whales tagged in Foxe Basin or the West coast of Greenland. Hudson Strait is shown to be a wintering ground [22] and an important migration corridor, where whales will pass between November and January on their journey to their wintering ground[23], and between April and July when they move to their summering ground[24].

Using satellite-linked telemetry, studies of bowhead whale movements were conducted by Dueck et al. (2006) from 2001 to 2003. Four whales were tagged in 2001, and 28 over the next four years. Figure 3.14 shows the movements, by month, of the bowhead whales

[21] IWC 2009
[22] Hide-Jorgensen *et al.* 2006
[23] Hide-Jorgensen *et al.* 2011; Dueck *et al.* 2006
[24] Pomerleau *et al.* 2011

locations based on telemetry. Numbers for colour codes refer to calendar months, indicating that whales are seen in the HS in November, December and January.

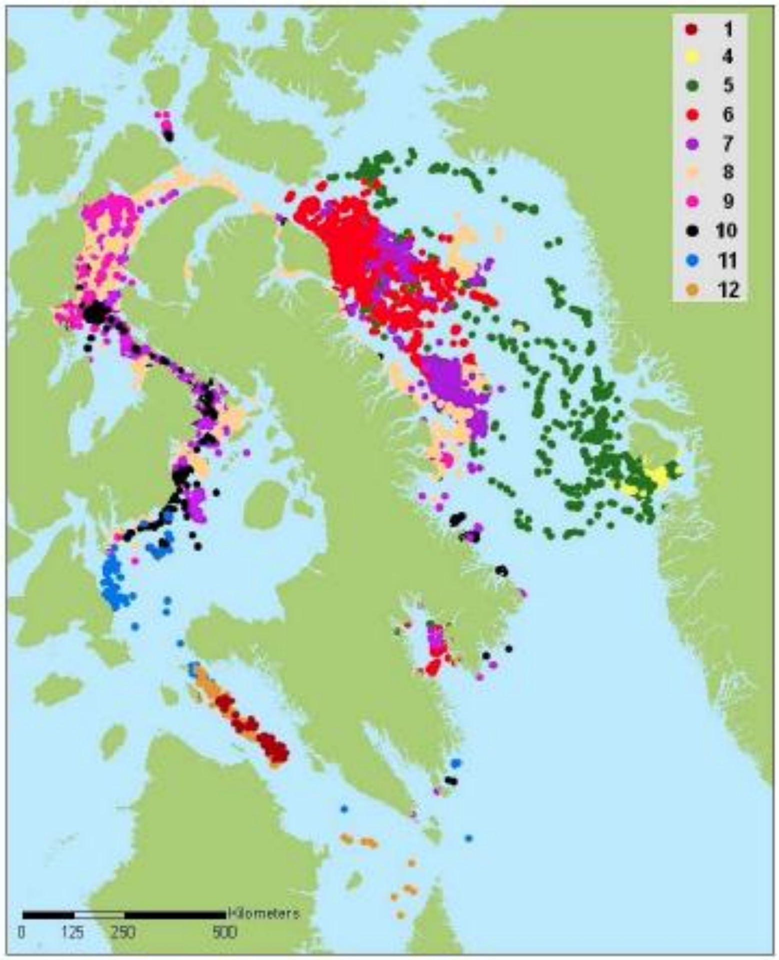

Figure 3.14: Seasonal (monthly) distribution of Bowhead whales (from Dueck *et al.* 2006)

Pomerleau *et al.* (2011) showed the probability of resident (foraging) mode relative to transient (searching) mode, and the HS seems indeed to be a transient zone, except for the NW area, near Cape Dorset, where there is a foraging zone.

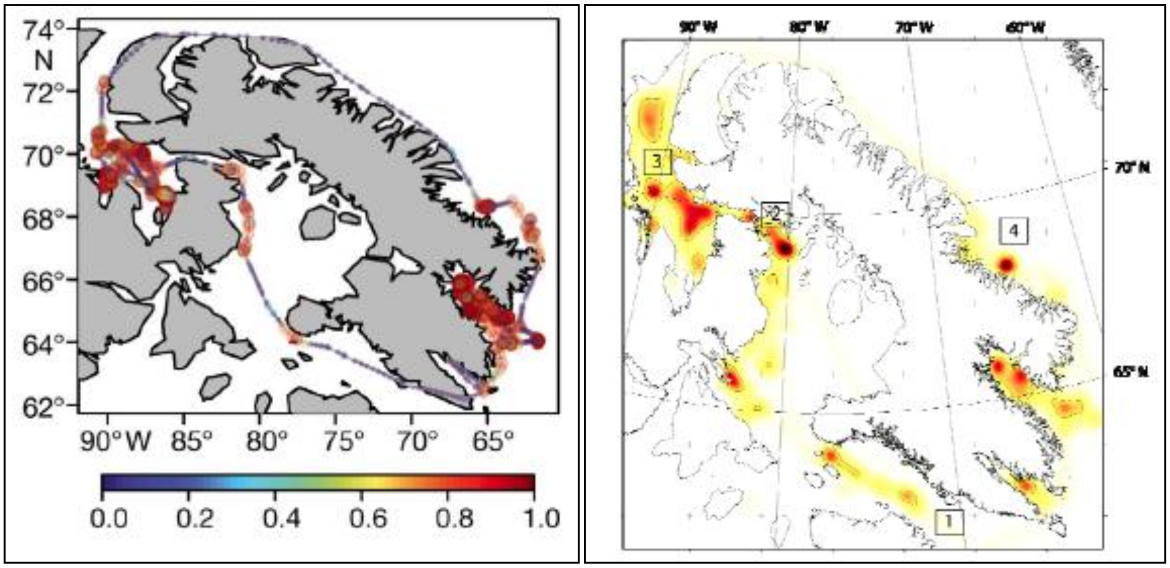

Figure 3.15: Potential foraging and transient zones (from Pomerleau *et al.* 2011), and potential summer habitat (from CSAS 2008)

Potentially important summer habitat (from 2002-2006) also include the Hudson Strait with a similar area in the NW of the HS, and another hotspot in the central portion of the HS, off the coasts of Charles Island near Salluit, QC[25].

Wheeler *et al.* (2012) provided a habitat suitability model for Bowhead whales, showing that whales have more chances to be seen on the coasts along the Hudson Strait than offshore.

[25] CSAS 2008

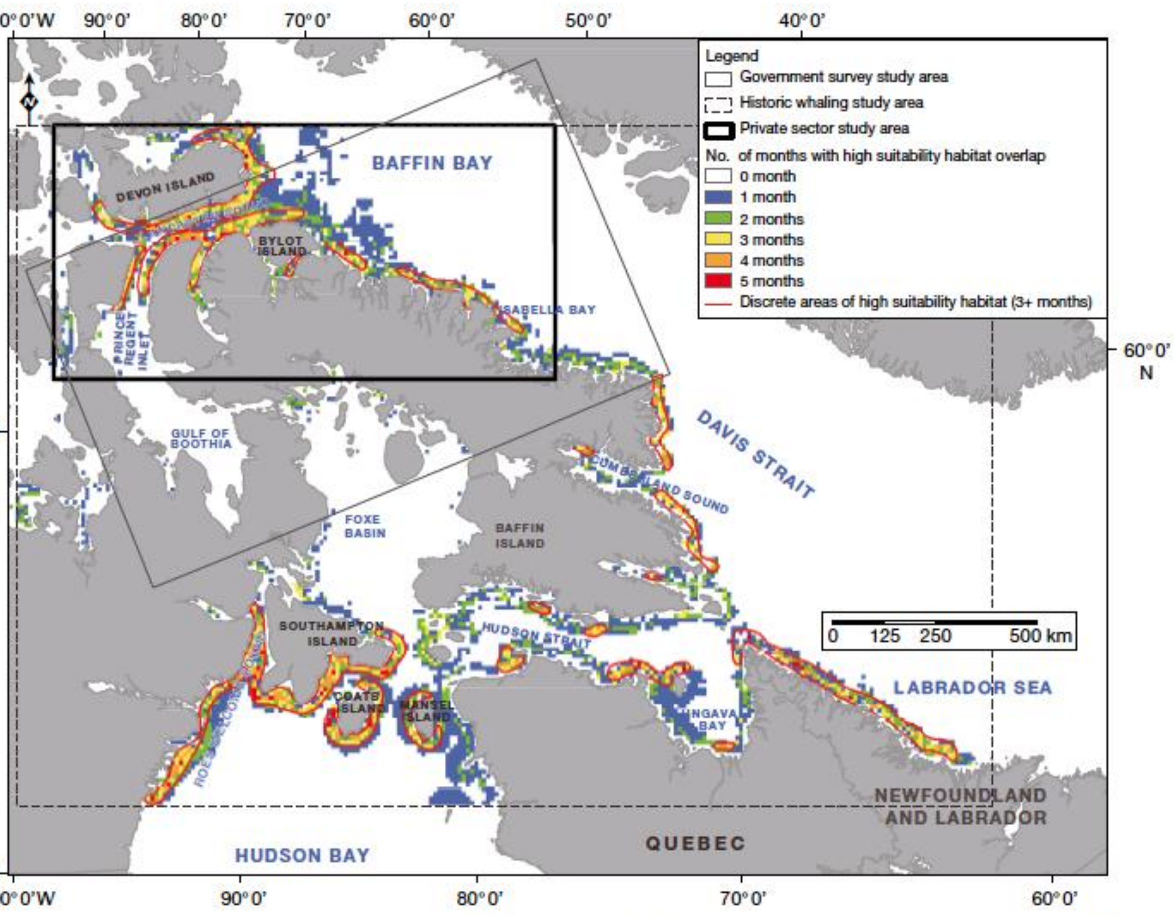

Fig. 4. *Balaena mysticetus.* Composite highly suitable habitat map from June to October; discrete clusters (3, 4, or 5 months) of highly suitable habitat outlined in red; produced by ecological niche factor analyses (ENFA) of 3 bowhead location datasets in the eastern Canadian Arctic

Figure 3.16: Bowhead whale habitat suitability model from Wheeler *et al.* (2012)

Traditional ecological knowledge data from the communities of the Nunavut (northern shore of the Hudson Strait) show that Bowhead whales are known to be seen in the Hudson Strait[26], six maps are based on TEK are available in this report, showing location and migration routes of Bowheads in Nunavut. The following figure is an example of one such map.

[26] NWMB 2000

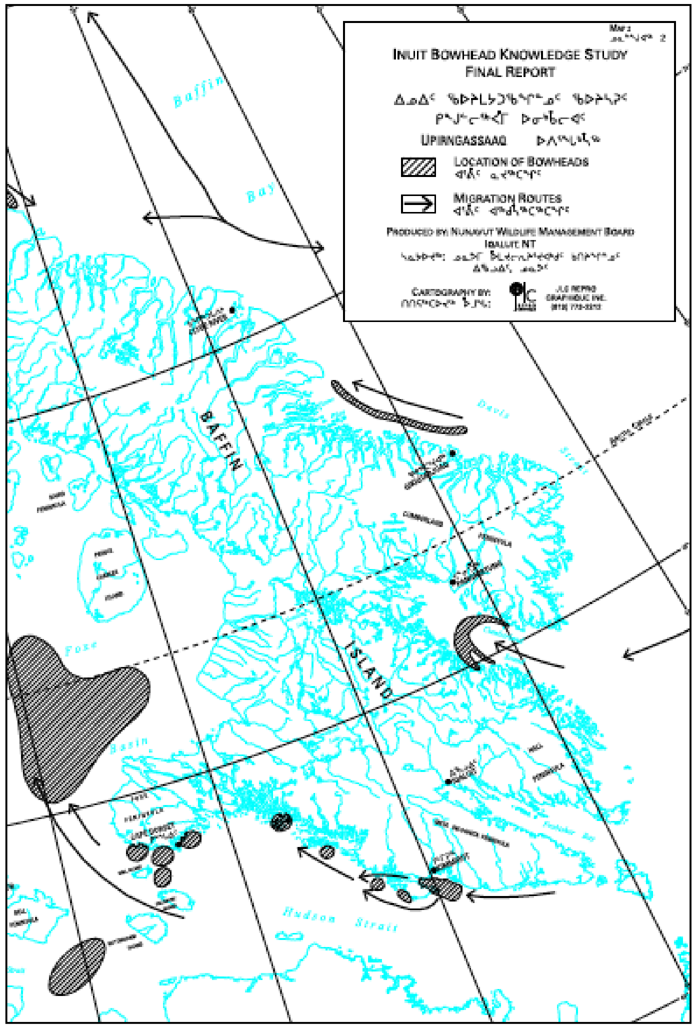

Figure 3.17: Sample Bowhead whale distribution map from local knowledge

Transect surveys done by LGL[27] document 27 sightings of Bowhead whales totalling 35 individuals observed. Bowhead whales were primarily found in the central portion of Hudson Strait in areas of heavier ice and at farther distances from major shorelines. There were also several bowhead sightings in the western portion of the survey area. Bowheads were only observed in the eastern portion of the survey area. Bowheads were observed less frequently in areas of nilas sea ice; they were typically associated with older sea ice of substantial thickness.

Elliott *et al.* (2013) estimate the abundance of bowhead whales within the study area to be approximately 1,607 to 1,752 based on mean densities of 1.10 and 1.43 bowheads/100 km^2. These abundance estimates for bowhead whales are similar to the estimates that were done in 1981 by Koshi and collaborators[28].

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[27] Elliott *et al.* 2013
[28] Koshi *et al.* 2006

Elliott *et al.* (2013) also identified factors affecting abundance and distribution for Bowhead whales. Sighting densities were significantly related to water depth, indicating that bowhead whales in Hudson Strait prefer areas where water depths are greater than ~300 m. These findings agree with those reported in 1981 by Koshi *et al.* (2006) but differ from the inferences presented in Ferguson *et al.* (2010). The results of the Hudson Strait surveys agree with other aerial survey results of bowhead wintering areas where bowheads have been found in heavier ice habitats[29].

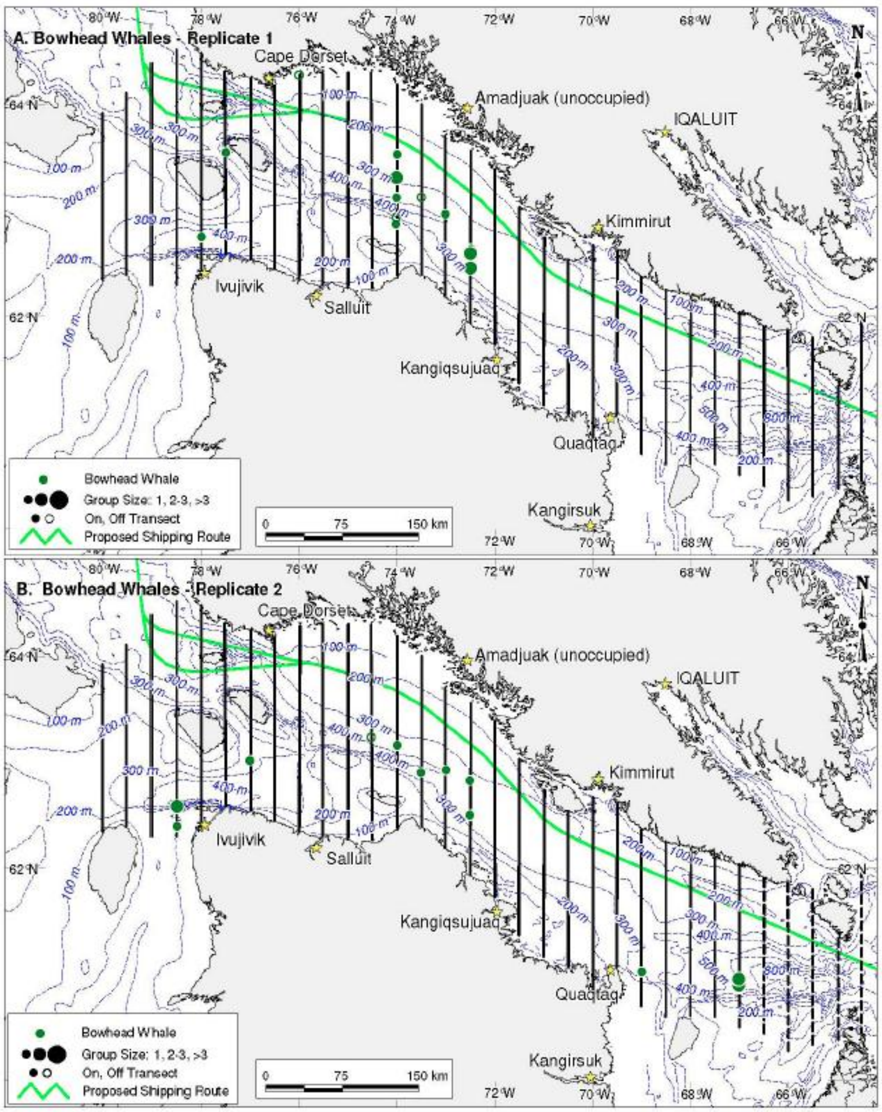

Figure 3.18: Bowhead whale sightings from LGL aerial surveys

29 McLaren and Davis 1982, 1983

3.3.1.2 *Beluga Whale*

Three of the four beluga populations[30] that occur in the eastern Canadian Arctic are known or thought to winter in and near Hudson Strait. The Western Hudson Bay population is considered of special concern by COSEWIC whereas the Eastern Hudson Bay population and Ungava Bay population are considered endangered by COSEWIC (2014). The most recent population estimates for the Western Hudson Bay population and Eastern Hudson Bay population are ~57,000[31] and 3,100 whales[32], respectively.

The wintering location of Western Hudson Bay belugas has not been clearly established, but it is thought to be in Hudson Strait and off the coast of Labrador[33]. Belugas arrive in Hudson Strait by late October to early November. Spring migration occurs during late April to May[34]. Eastern Hudson Bay belugas are thought to winter primarily in Hudson Strait, though some individuals have been found as far east as northern Labrador during winter and spring[35].

There were 6 studies covering the spatial-temporal repartition of beluga in the Hudson Strait. Here again, the HS is mostly used as a migration zone, and belugas are seen in the area in fall, during their journey from the Hudson Bay to the Atlantic waters. This is documented both by TEK[36] and telemetry[37]. Most of the telemetry data cover the fall and winter, and few information is available for the summer repartition of beluga whales. One survey was done in 2010[38], but the information is not published yet.

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[30] There is recent evidence that beluga whales that occur in James Bay constitute a distinct stock and indications that some of these animals may constitute a separate population of beluga whales (Postma *et al.* 2012).
[31] Richard (2005)
[32] Doniol-Valcroze *et al.* 2011
[33] Richard *et al.* (1990); Richard (1993); Richard and Orr (2003, 2005)
[34] Sergeant (1973)
[35] Kingsley *et al.* (2001); Lewis *et al.* (2003)
[36] Hammill and Lesage (2009); Lewis *et al.* (2009)
[37] Bailleul *et al.* (2002); Smith *et al.* (2005); Lewis *et al.* (2009), Pew (2014)
[38] Jean-François Gosselin, Maurice-Lamontagne Institute, DFO, pers. comm.

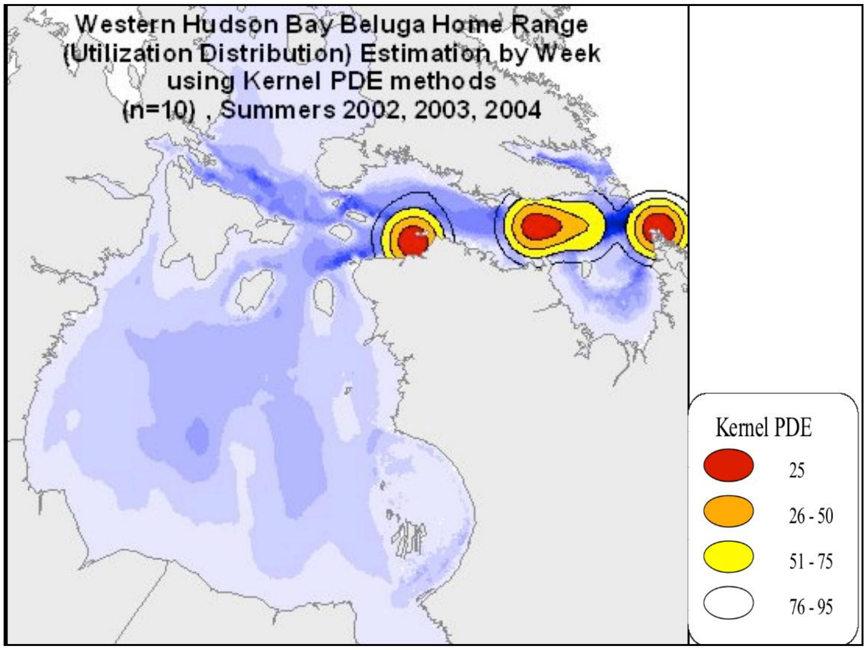

Figure 3.19: Estimated home range of tagged beluga (Smith *et al.* 2005)

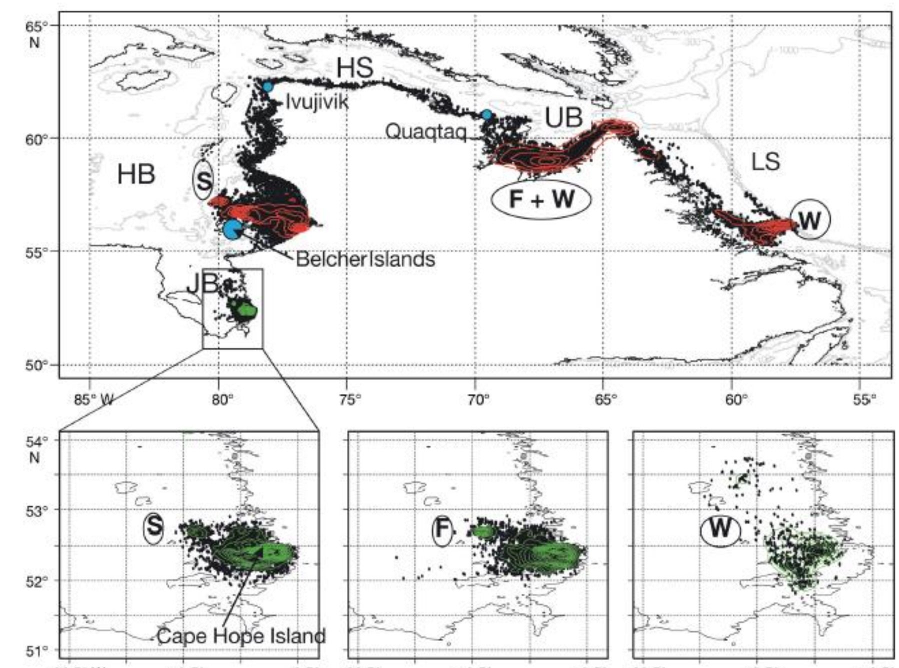

Fig. 1. *Delphinapterus leucas*. Hudson Bay beluga complex showing all locations recorded during the study (black dots). Density curves (95%) in red indicate the main residency areas of eastern Hudson Bay (HB) belugas in summer (S), fall (F) and winter (W). Density curves (95%) in green indicate the same for belugas in James Bay (JB). HS: Hudson Strait, UB: Ungava Bay, LS: Labrador Sea

Figure 3.20: Recorded beluga locations from Bailleul *et al.* 2000

Bailleul and colleagues indicate that *“during their seasonal migration, belugas remained close to the coastline, a migration strategy that may allow them to benefit from the northward-flowing current that prevails along the east side of Hudson Bay”*[39].

The Hudson Bay Beluga Project from Pew (2014) shows the telemetry data of 6 beluga whales tagged in Foxe Basin. On this interactive map (www.oceansnorthportal.org/flexviewers/HudsonBayBelugaWebmap1/), we see that 4 of the 6 belugas are actually tracked in the Hudson Strait and showing once again that they come in the HS during the summer (last tracking data was June 10, 2013).

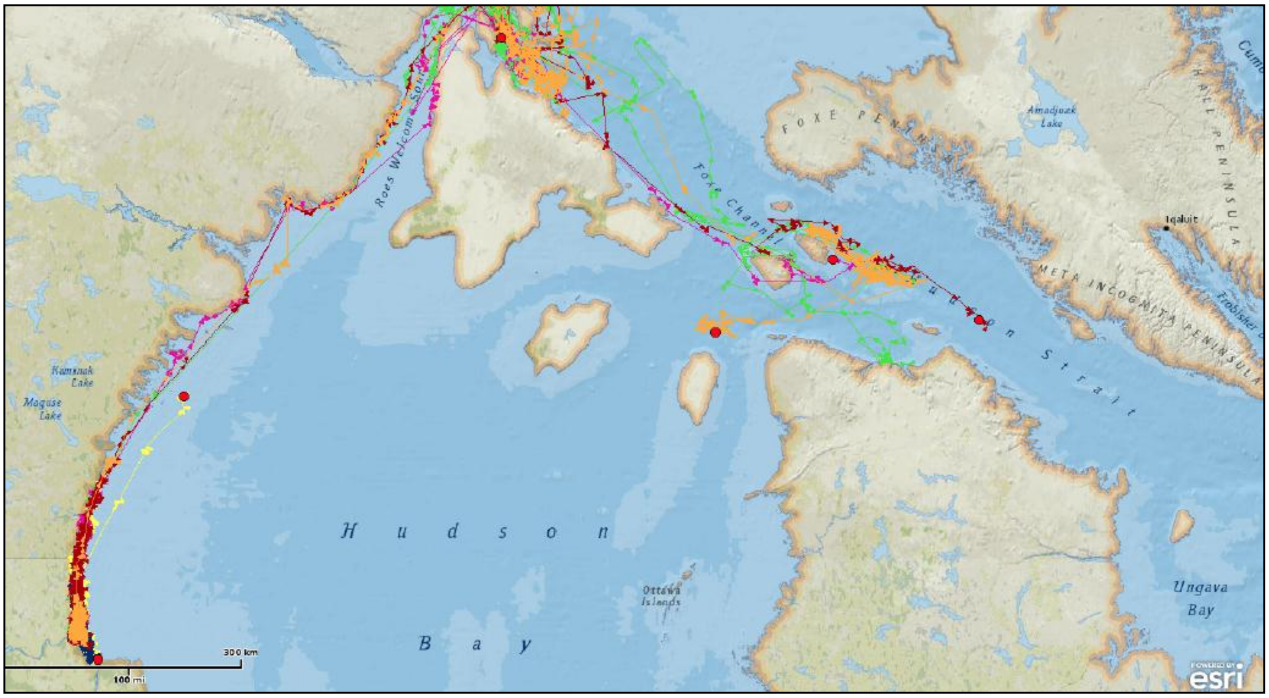

Figure 3.21: Telemetry of tagged beluga for Pew’s Hudson Bay Beluga Project

In the LGL report to Baffinland mines[40], a total of 247 sightings of beluga whales totaling 550 individuals observed is documented. Belugas were the most numerous marine mammal observed during this multi-species survey; they were seen everywhere throughout Hudson Strait, but were observed more frequently in the central portion of the HS, except in the western area where more sightings occurred closer to the southern Hudson Strait shoreline. Elliott *et al.* (2013) estimated an overall abundance (for March 2012) of about 27,264 to 29,335 animals in the HS. Based on the most recent population estimates for the Western Hudson Bay population (~57,000 belugas[41]) and Eastern Hudson Bay population (3,100 belugas[42]), almost half of these beluga whales may have been in the Hudson Strait in March.

[39] Bailleul *et al.* (2012)
[40] Elliott *et al.* (2013)
[41] Richard (2005)
[42] Doniol-Valcroze *et al.* (2011)

The factors affecting abundance and distribution seemed to be ice cover, water depth, and longitudinal zone. Beluga whales showed a preference for areas with intermediate ice cover. During the March 1981 aerial survey of Hudson Strait, Finley *et al.* (1982) reported that belugas showed a preference for areas with 50-90% pack ice cover. In both 1981 and 2012 surveys, belugas were found widely distributed in the offshore pack ice of Hudson Strait[43]. LGL's results on beluga distributions (univariate and multivariate analyses) in 2012 indicated that belugas in Hudson Strait preferred areas where water depths were greater than ~300 m with sightings peaking at ~500 m depth.

[43] Finley *et al.* (1982)

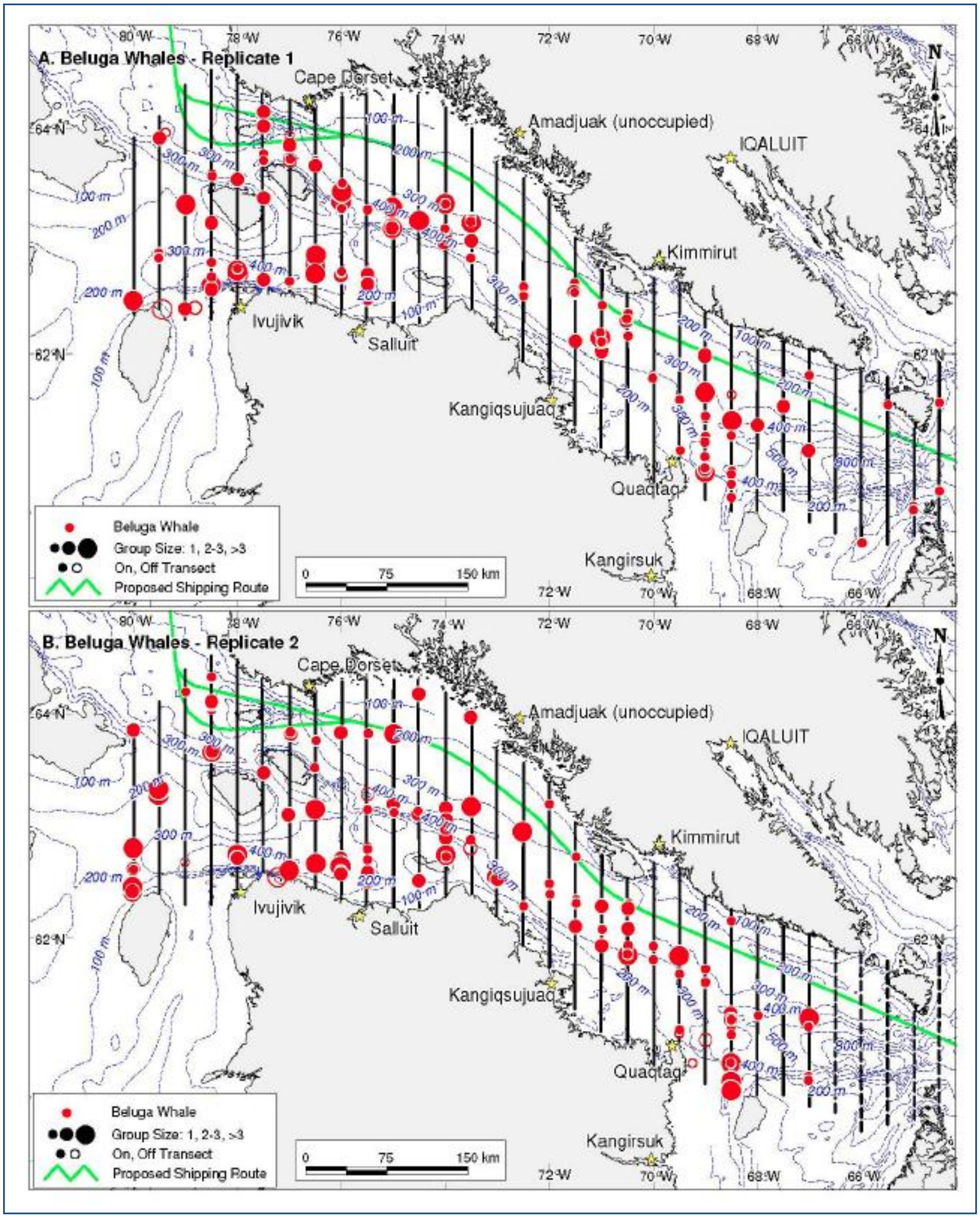

Figure 3.22: Beluga sightings from LGL aerial surveys

3.3.1.3 Narwhal

The Hudson Bay narwhal population is considered of special concern by COSEWIC[44]; it is not currently listed under SARA. Recent aerial surveys conducted by DFO in August 2011 indicate that the Northern Hudson Bay narwhal population numbers 12,485[45]. The Hudson Bay narwhal population is thought to winter in eastern Hudson Strait[46]. At least some narwhals from Hudson Bay winter outside of Hudson Strait—about 100-200 km east of Resolution Island[47].

Two sources of information are documenting the use of the Hudson Strait by narwals. The first one, by Westdal *et al.* (2010) document telemetry data on 9 narwals tagged in 2006 and 2007, showing that the HS is an important migration route, from their summer grounds in Repulse Bay to their winter grounds in the Labrador Sea. Narwals seem to pass by the Foxe Channel, in the NW side of the HS, and then move along the southern part of the HS, before to reach Resolution Island, SE of Baffin Island (Figure 3.23).

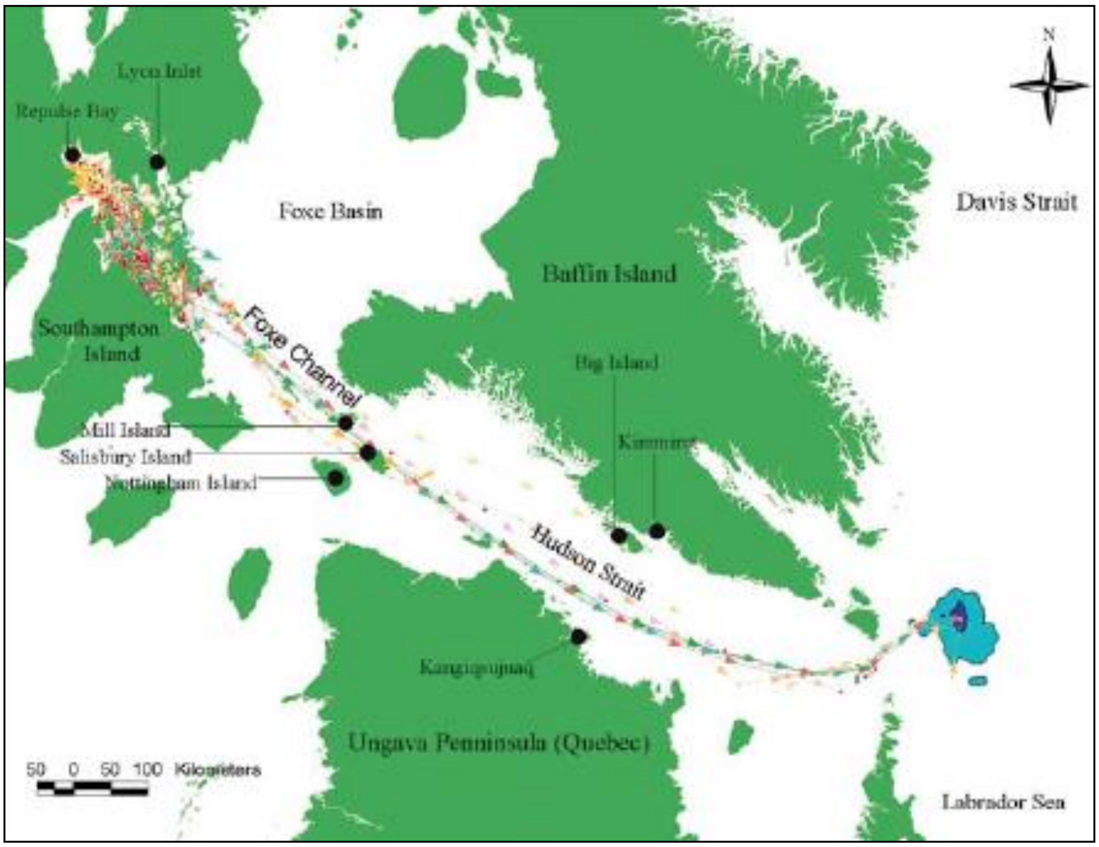

Figure 3.23: Tracking of 9 narwals tagged in 2006-2007, from their summer ground to their winter ground (Westdal *et al.* 2010)

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[44] COSEWIC (2004)
[45] Asselin *et al.* (2012)
[46] Richard (1991); Koski and Davis (1994)
[47] Westdal *et al.* (2010)

During the LGL aerial surveys in 2012[48], there were 53 sightings of narwhals totalling 92 individuals observed on transect. The distribution of narwhals was not as "continuous" across Hudson Strait as was the distribution of belugas. Also, most narwhals were observed well seaward of the Hudson Strait coast. Like bowheads, narwhals were typically observed in areas with heavy ice cover. Both satellite transmitter data and traditional knowledge document the Hudson Strait to be a migration route for the narwals. Their summer home range seems to be Lyon Inlet and Repulse Bay in Nunavut. They leave the area from September to early-November, and seem to use the same migration route from year to year: starting north of Southampton Island, they pass through Foxe Channel into Hudson Strait. All animals tagged moved into Hudson Strait, passing north of Nottingham Island but on both sides of Salisbury and Mill Islands. Narwals arrive in their wintering area by late December. Thus, we can assume that they are in the Hudson Strait from September to December, using more the southern part of the HS for their migration route.

Narwhal abundance estimates was estimated to be between 5,157 and 12,949 narwhals in the HS[49]. Approximately 40-100% of the northern Hudson Bay population of narwhal may overwinter in Hudson Strait. It seems unlikely that 100% of the narwhal population occurs within Hudson Strait in March given what is presented in Westdal *et al.* (2010). As was the case for bowheads and belugas, there was considerable evidence that water depth affected narwhal sighting densities. Elliott *et al.* (2013) analyses indicated that narwhals in Hudson Strait preferred areas with deeper water. Also, ~93% of all narwhal sightings were recorded in areas classified as having "pan" ice and the majority of sightings (~91%) occurred in areas with ice coverage >70%.

[48] Elliott *et al.* (2013)
[49] Elliott *et al.* (2013)

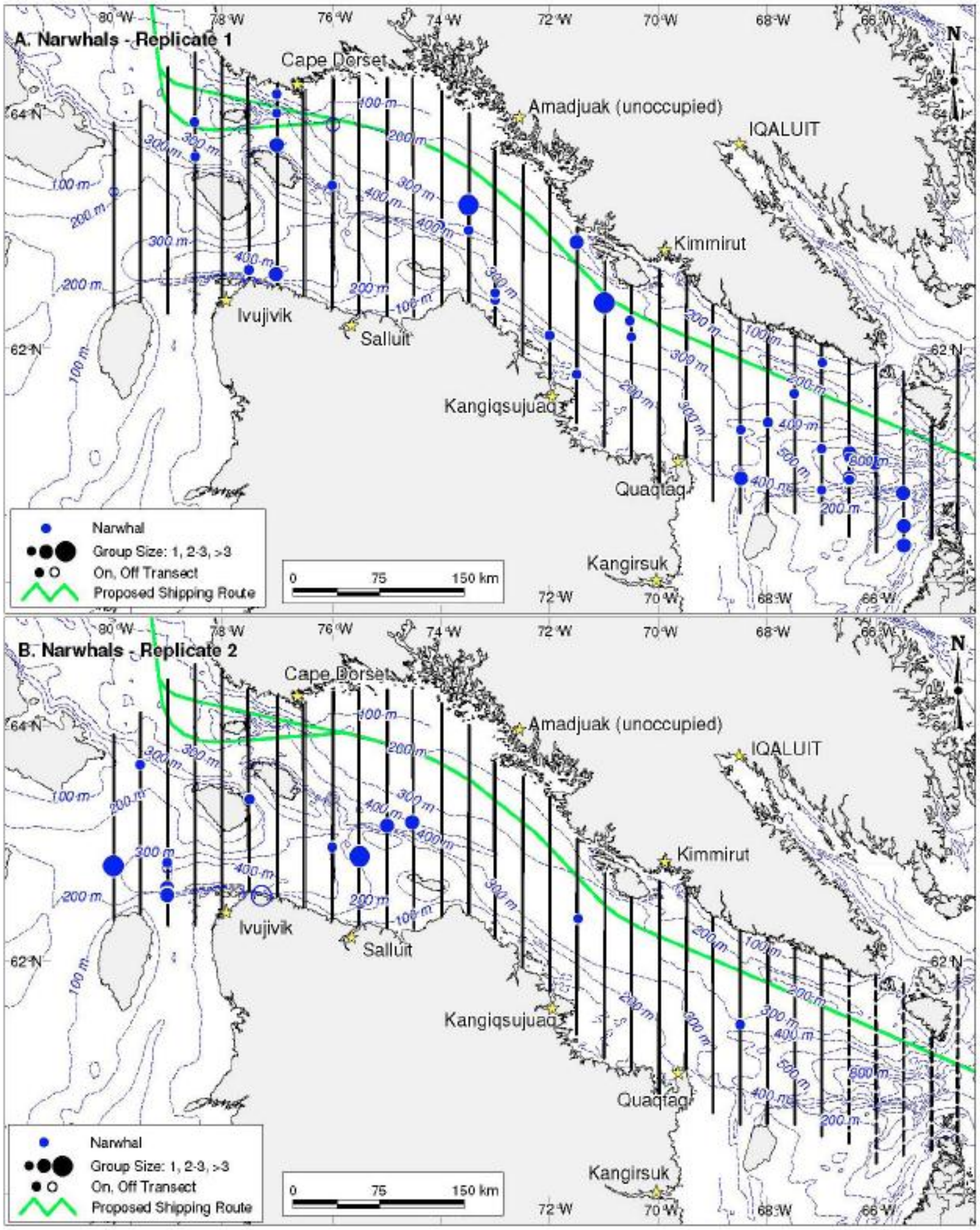

Figure 3.24: Narwhal sightings from LGL aerial surveys

3.3.1.4 Killer Whale

Although Killer whales (*Orcinus orca*) are known to be occurring in the HS, only one source of information was found, which is based on TEK[50]. The authors collected Inuit knowledge on killer whales through 105 semi-directed interviews in 11 Nunavut communities from 2007

[50] Higdon *et al.* (2013)

to 2010. Their results present killer whale movement patterns, and number of interviewees identifying each area as a movement or migration corridor.

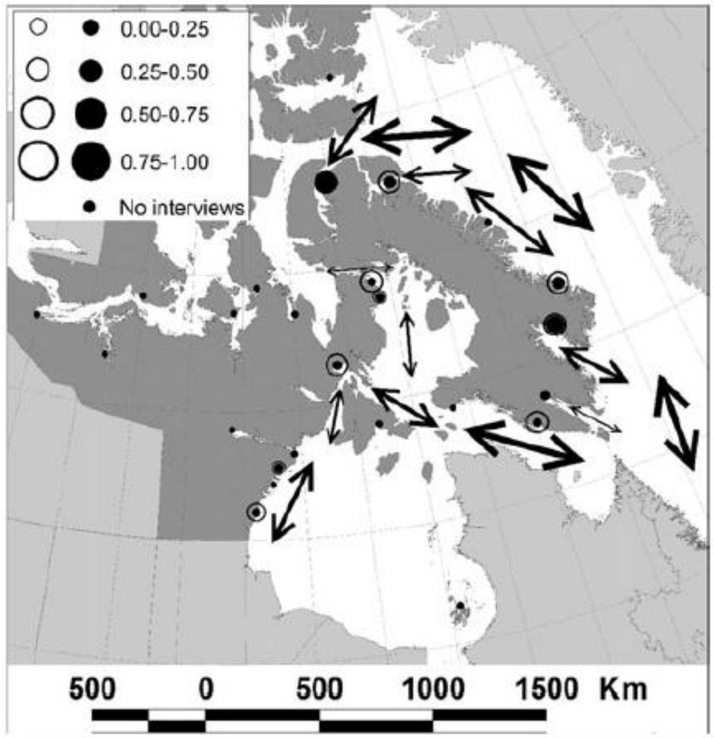

Fig. 4. Map showing frequency of killer whale sightings among interviewees in the 11 Nunavut communities visited and Inuit observations and knowledge of killer whale movements and suspected migration routes. Size of community symbols indicates the proportion of interviewees that had 'many' killer whale sightings (black inner circles) and the proportion with 'many' or 'some' combined (open outer circles). Arrows summarize killer whale movement patterns, with thickness approximately proportional to the number of interviewees identifying each area as a movement or migration corridor.

Figure 3.25: Killer whale distribution and frequency of sightings based on TEK (105 interviews in 11 Nunavut communities from 2007 to 2010).

3.3.2 Pinnipeds

3.3.2.1 Walrus

Walruses (*Odobenus rosmarus*) are considered of special concern by COSEWIC but have no status under SARA. Hudson Strait is an important overwintering area for walruses and the ice edge through the HS is thought to be an important habitat feature for walruses[51]. There is no reliable population estimate for the Northern Hudson Bay-Davis Strait population

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[51] Stephenson and Hartwig (2010)

that occurs in Hudson Strait but numbers may range from 4,000-6,000 individuals[52]. Walruses are associated with pack ice.

A total of six papers were found to describe the seasonal and spatial distribution of walrus in the HS. Most of the information comes from population assessments[53] and TEK[54].

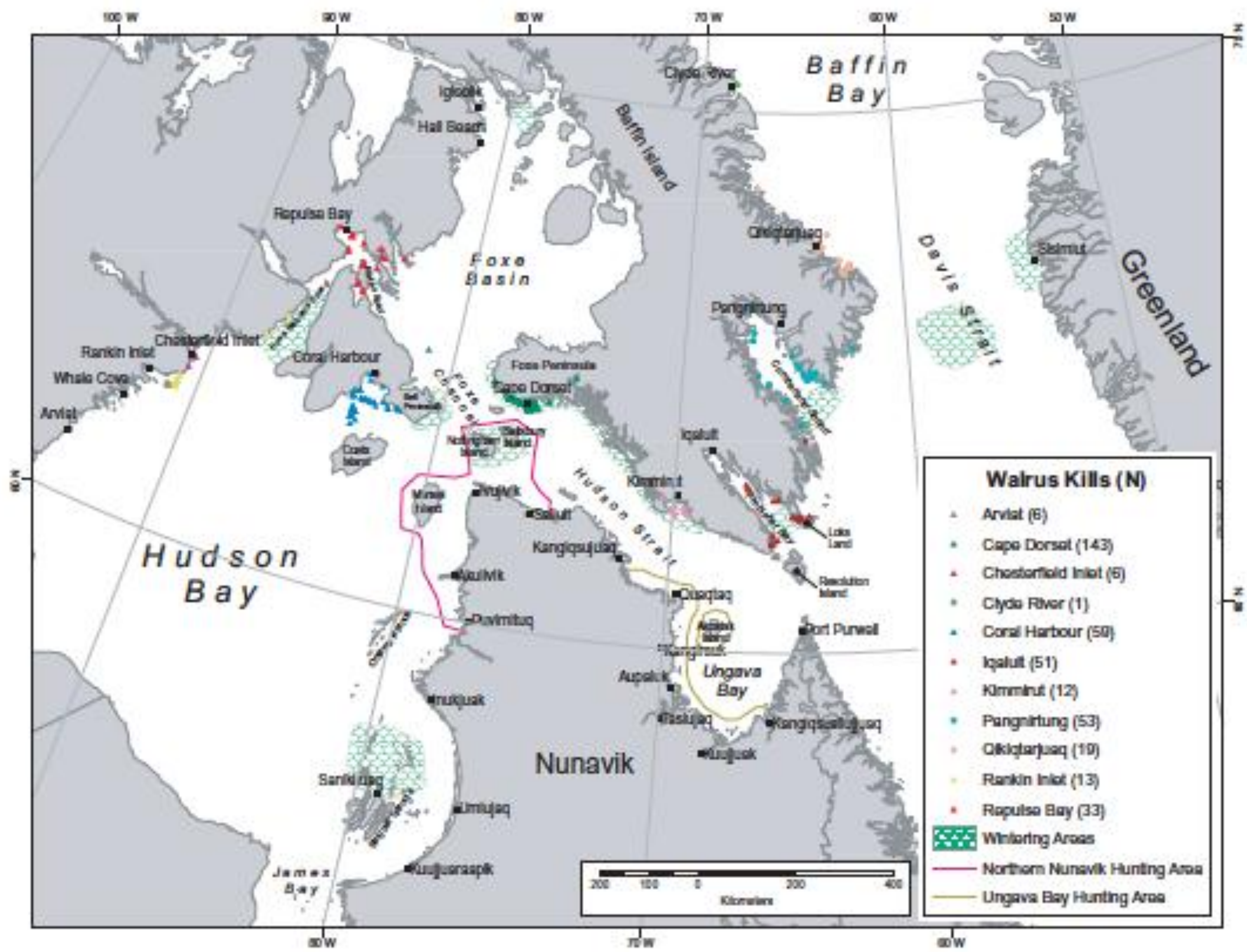

FIG. 6. Hudson Bay–Davis Strait walrus harvesting locations for Arviat, Cape Dorset, Chesterfield Inlet, Clyde River, Coral Harbour, Iqaluit, Kimmirut, Pangnirtung, Qikiqtarjuaq, Rankin Inlet, and Repulse Bay (Priest and Usher, 2004), Nunavik harvesting areas (interpreted from COSEWIC, 2006), and wintering areas (Born et al., 1995). Each kill symbol may represent more than one animal killed; N is the number of walruses reported by each community in the Priest and Usher (2004) database.

Figure 3.26: Walrus hunting activity in and around the Hudson Strait (Stewart 2008)

[52] COSEWIC (2006)
[53] Born *et al.* (1995), COSEWIC (2006); Stewart (2008)
[54] Reeves (1995), Stewart (2008)

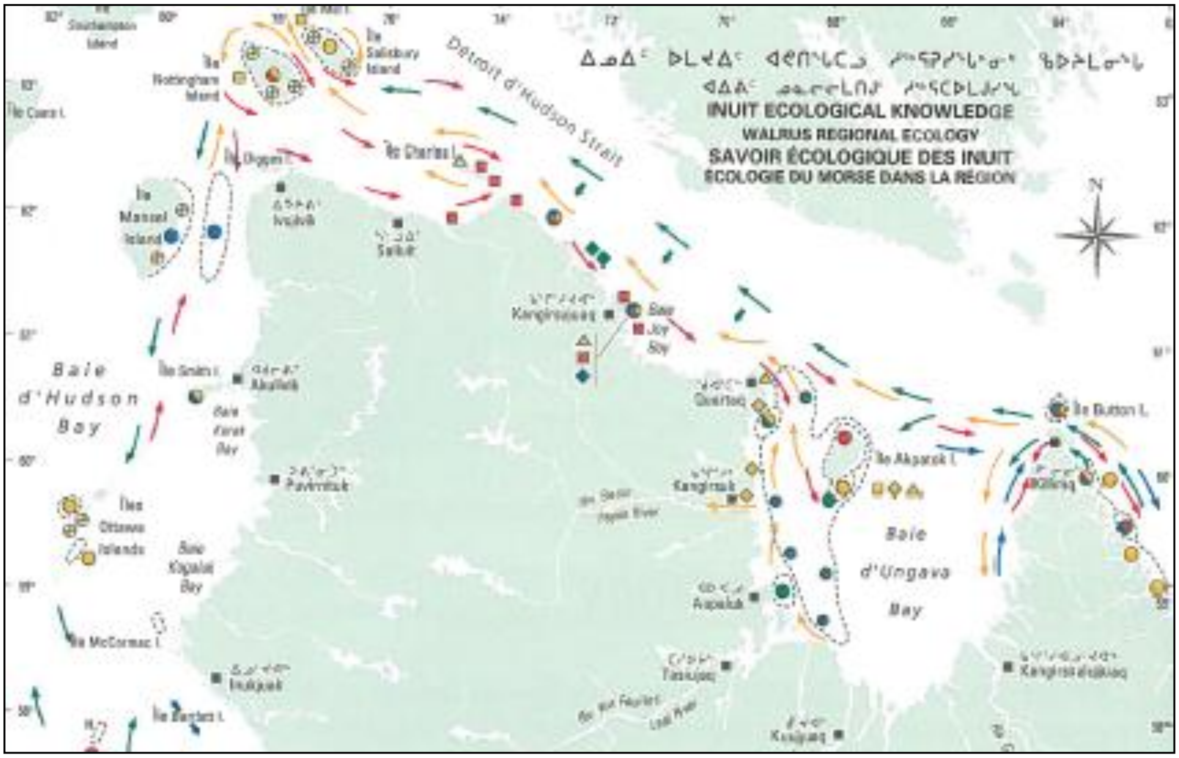

Figure 3.27: Inuit TEK for walrus regional ecology in Nunavik (Makivik data; Sears 1995)

Mallory and Fontaine[55] mention that Akpatok Island is a traditional hunting ground for walrus for nearby Inuit communities[56].

Finally, Elliott *et al.* (2013) document 49 sightings of walruses, totalling 55 individuals observed during their transect survey. About half (56%) of the walruses were hauled out on the ice. Walruses were mostly seen in the central and western portions of Hudson Strait. Throughout the survey, walrus sightings were more frequent along the coasts of Hudson Strait within lighter ice areas composed of nilas and small ice pans. Although Elliott *et al.* (2013) aerial surveys were not designed specifically for walruses, abundance estimates offer insight into the numbers of walruses that occur in the study area during winter. The estimated abundance of walruses within the study area ranged from 4,675 to 6,020, which is what is also suggested by COSEWIC[57].

In contrast to overwintering whales, walruses preferred areas of Hudson Strait with relatively shallow water. After accounting for other factors, walrus sightings peaked at water depths of 100 m and sighting rates were generally higher in areas with depths <200 m[58].

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55 Mallory and Fontaine (2004)
56 Citing Hentzel (1992)
57 COSEWIC (2006)
58 Elliott *et al.* (2013)

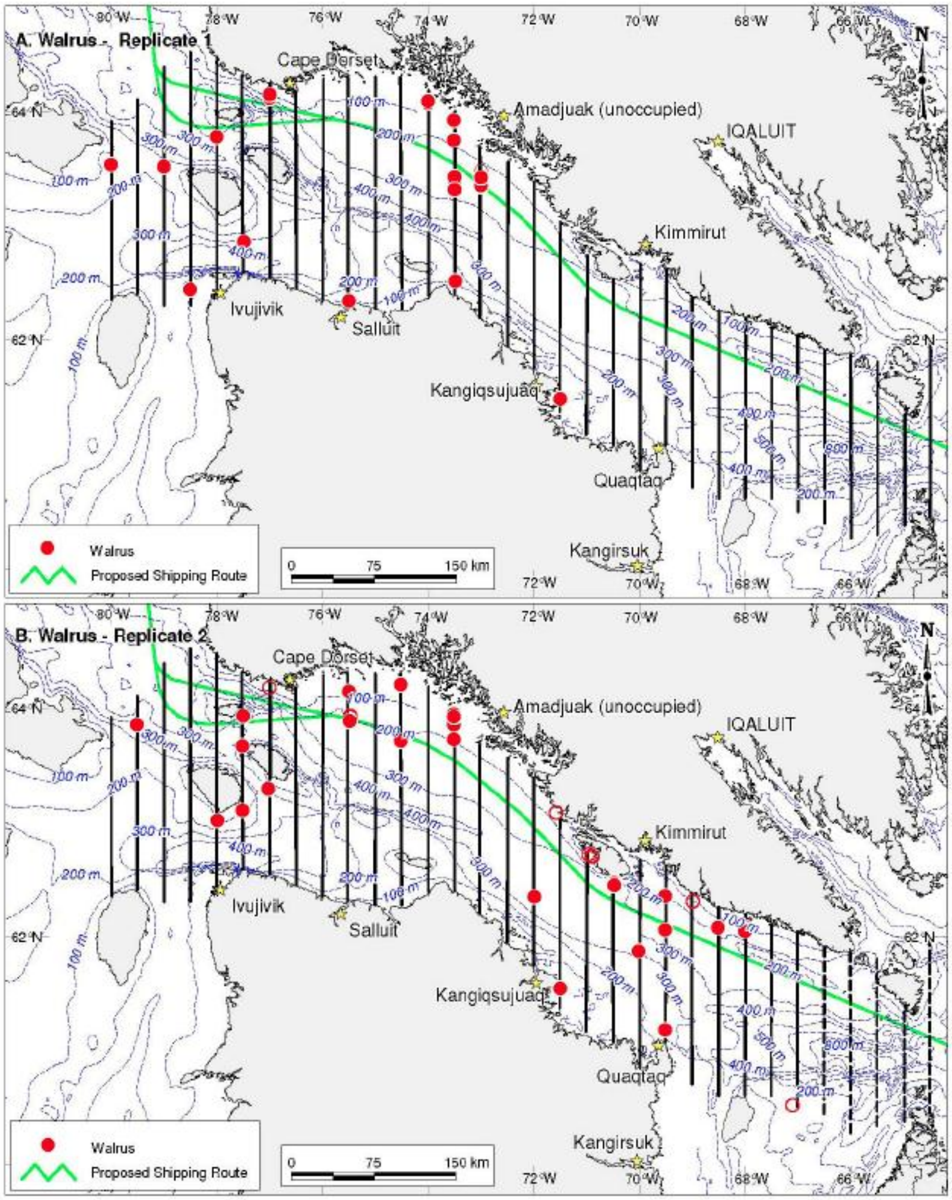


Figure 3.28: Walrus sightings from LGL aerial surveys

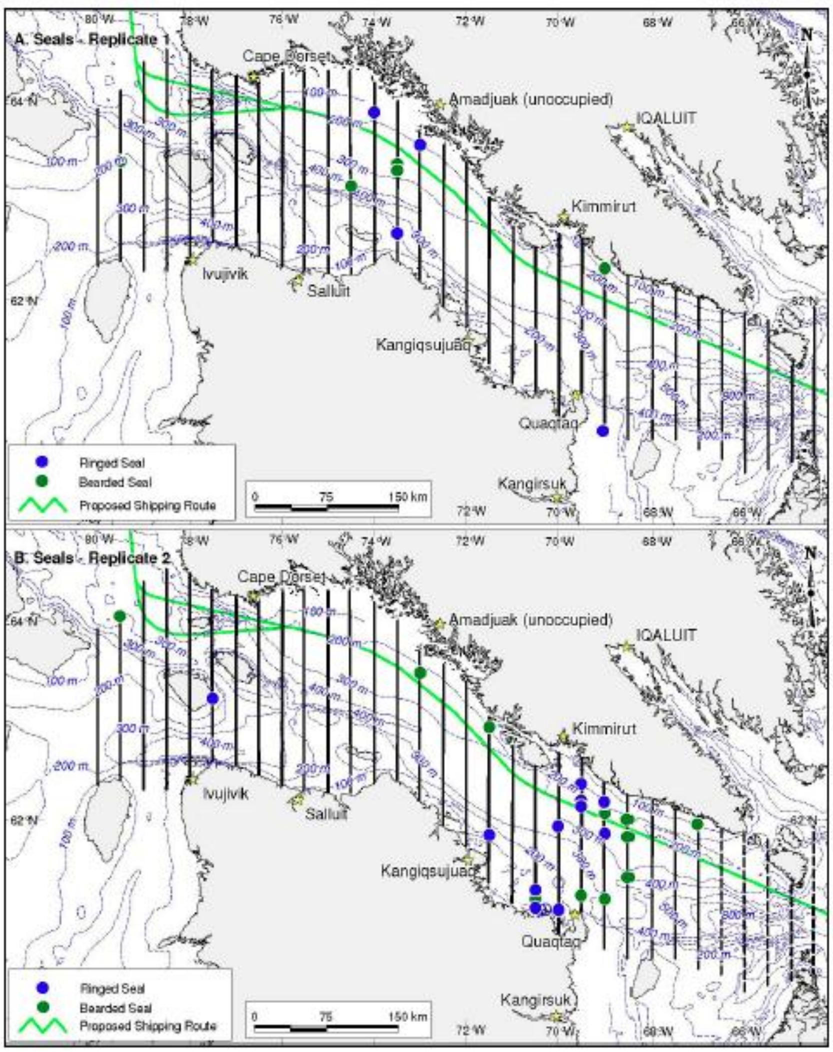
3.3.2.2 Seals

Ringed seals (*Pusa hispida*) are not considered at risk and bearded seals are considered data deficient by COSEWIC. No reliable population estimates exist for these species[59]. However, Cleator suggested an estimate of >190,000 bearded seals occur in Canada[60]. The

[59] Elliott *et al.* (2013)
[60] Cleator (1996)

population of ringed seals in the Canadian arctic is thought to be at least a few million[61]. This species primarily occurs in the landfast ice, but little is known about their distribution in Hudson Strait[62]. Bearded seals (*Erignathus barbatus*) primarily occur in areas of pack ice and relatively shallow water (e.g., <200 m[63]).

The only information available for seals in the Hudson Strait come from the LGL survey[64], and unfortunately the survey was not designed for the detection of seals. Ringed and bearded seals were observed in similar numbers (22 ringed seals and 20 bearded seals). Most sightings occurred while surveying the East zone of Hudson Strait. Identified seals were most frequently recorded (65-73%) hauled out on the ice versus in water.



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[61] Reeves (1998)
[62] Elliott *et al.* (2013)
[63] Burns and Frost (1979_
[64] Elliott *et al.* (2013)

Figure 3.29: Seal sightings from LGL aerial surveys

3.3.3 Polar Bear

Both the Foxe Basin and Davis Strait subpopulations of polar bears occur in Hudson Strait[65]. The Davis Strait subpopulation was estimated at 2,100[66]. The polar bear was listed as a species of special concern under SARA in October 2011; it is also considered special concern by COSEWIC[67].

The most important source of information on polar bears in the Hudson Strait come from the CAFF report "Arctic Flora and Fauna; status and conservation"[68]. This map originally comes from IUCN's Polar Bear Specialist Group showing that HS is an area of stable polar bear populations, estimated to about 1500 (very rough estimate) individuals for the HS sector[69].

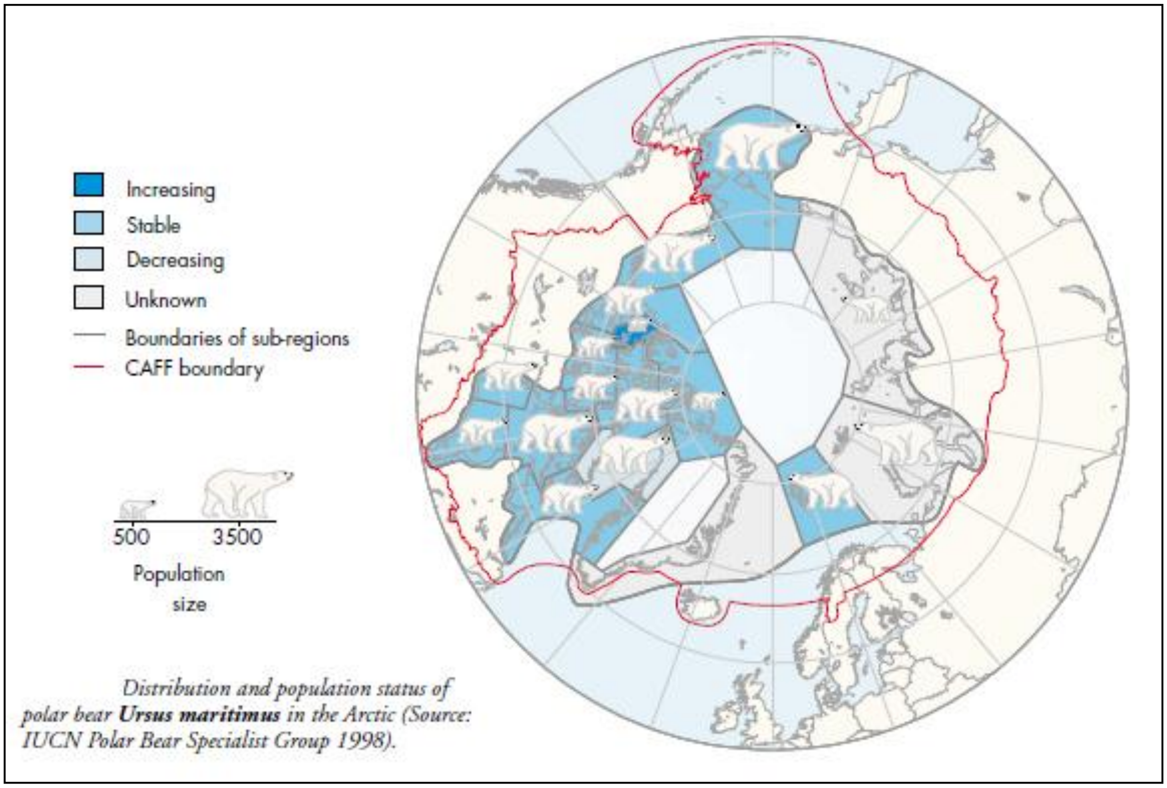

Figure 3.30: Polar bear distribution population status from CAFF 2001

[65] Elliott *et al.* (2013)
[66] Peacock *et al.* (2006)
[67] COSEWIC (2008)
[68] CAFF (2001)
[69] IUCN, Polar Bear Specialist Group (1998)

Another similar distribution map is presented by CAFF in their "Arctic Biodiversity Trends 2010 – Selected indicators of change"[70] and available on CAFF's Arctic Data website. Shapefiles of this map are available.

Figure 3.31: Polar bear population trends from Kurvits *et al.* 2010

Polar bears were the least common marine mammal species seen during LGL aerial surveys[71]. There were four sightings of individual polar bears observed on transect. During a transit between transects, a group consisting of an adult female and two cubs was observed. Polar bear tracks on the ice were seen on 56 occasions. In his report, Elliott *et al.* (2013) mention however that this survey was not done specifically to assess seals and polar

[70] Kurvits *et al.* (2010)
[71] Elliott *et al.* (2013)

bear populations, therefore we must see this as “opportunistic data” rather than a precise assessment for polar bears.

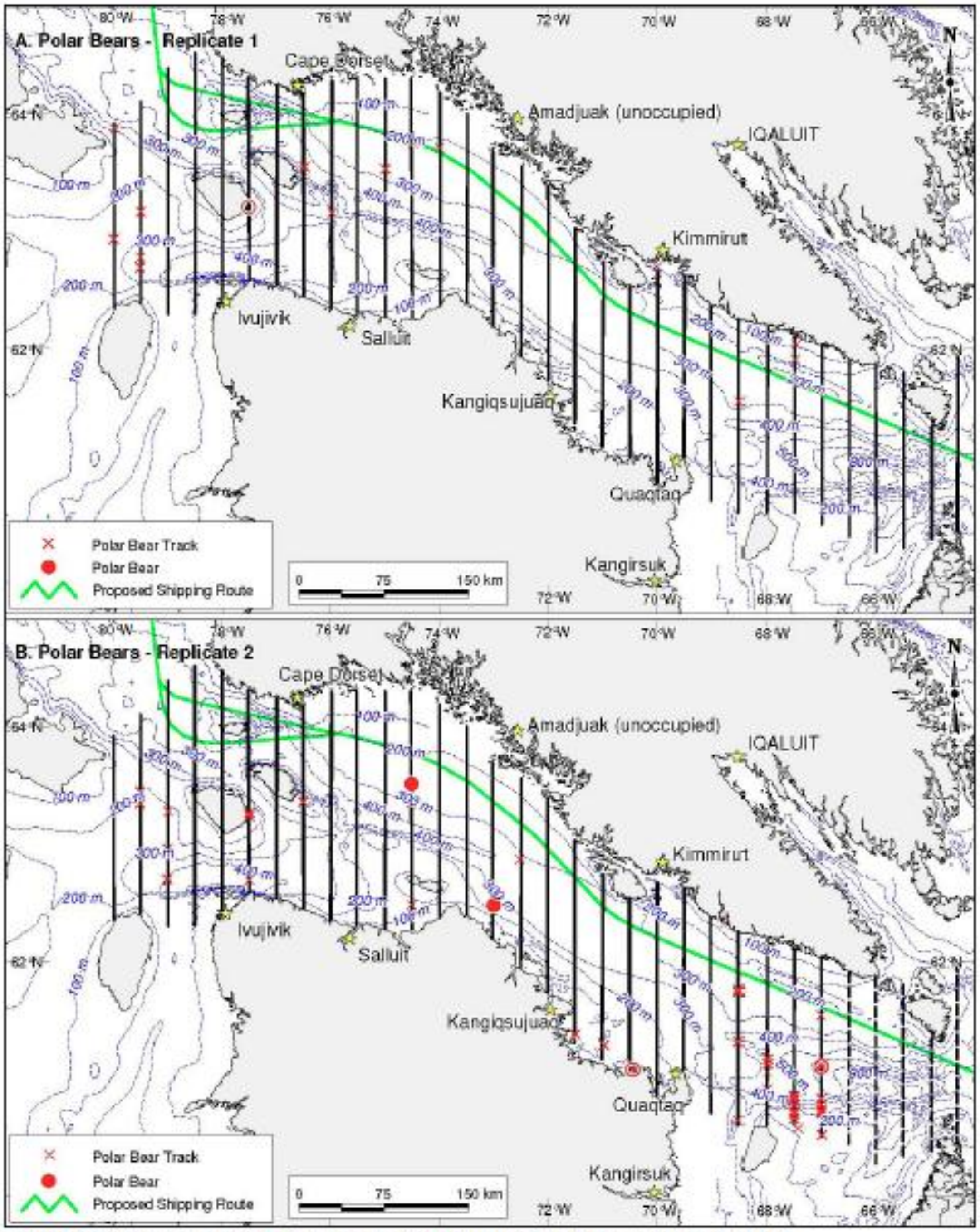

FIGURE 25. Polar bear sightings and tracks during (A) Replicate 1 and (B) Replicate 2.

Figure 3.32: Polar bear sightings during LGL’s marine mammal aerial surveys

3.3.4 Sea Birds

Mallory and Fontaine did an exhaustive study on key marine habitat sites for migratory birds in Nunavut in 2004. This is the most reliable source of information available for seabirds in the Hudson Strait. Data are provided by colonies/islands (see an example for the Coats Island).

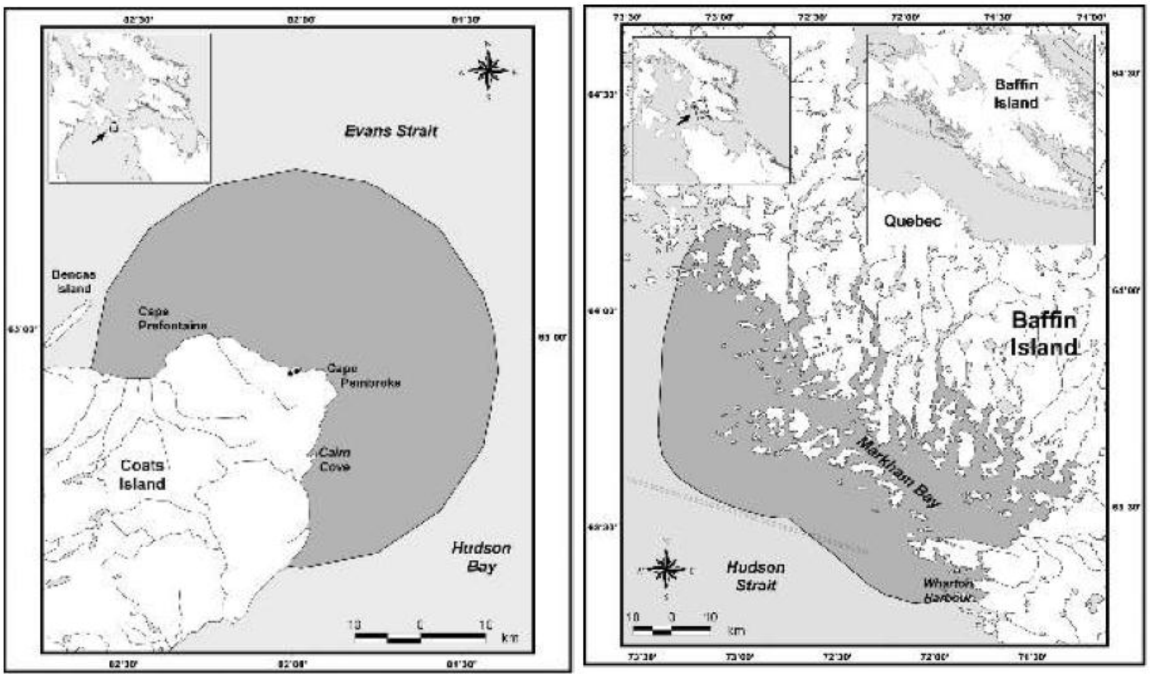

Figure 3.33: Example migratory bird distributions

The main species seen in the HS area are Thickbilled Murre (*Uria lomvia*) and Common Eiders (*Somateria mollissima*). The HS is mainly occupied by Thick-billed Murres, with three colonies in the eastern part, and one in the western part. Information is also available in this paper on Black Guillemots (*Cepphus grylle*), Glaucus Gulls (*Larus hyperboreus*), Peregrine Falcons (*Falco peregrinus*), Iceland Gulls (*Larus glaucoides*), Herring Gulls (*Larus argentatus*), Arctic Terns (*Sterna paradisaea*), and Atlantic Puffins (*Fratercula arctica*). Shapefiles are available through CAFF's Arctic Data website[72].

[72] Based on Kurvits *et al.* (2010)

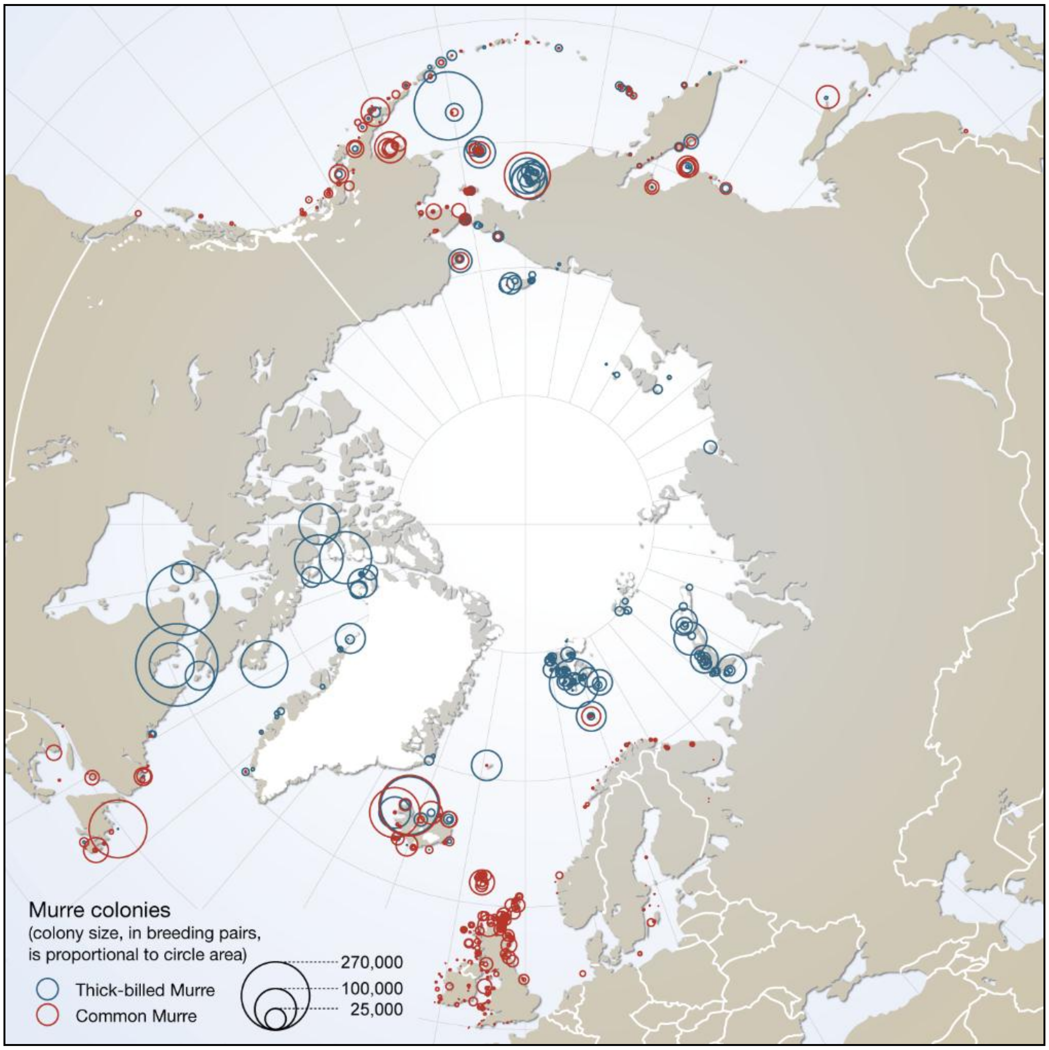

Figure 3.34: Thick-billed and common Murre colonies distribution (from CAFF online database).

3.3.5 Fish

Only 3 sources of information document the spacio-temporal distribution of fishes in the Hudson Strait. All data sources are somehow approximate, based on general knowledge of the global distribution of these fish species in the Arctic.

The most important species found in this area is Arctic Char (*Salvelinus alpinus*), for which Kurvits and collaborators document the distribution for HS[73]. This data is available as shapefiles on CAFF's Arctic Data website. The map presented in this study suggests that most of the northern and southern coasts of the HS area are part of the species' range,

[73] Kurvits *et al.* (2010)

except for the SE point of Baffin Island. The following figure shows that the Hudson Strait is designated as a habitat for Arctic char, however the limits of its distribution are uncertain.

Figure 3.35: Arctic Char distribution

Greenland halibut (*Reinhardtius hippoglossoides*) is also present in the area. A general study made by NOAA in 1988 show that the general distribution of the species includes the eastern part of the Hudson Strait.

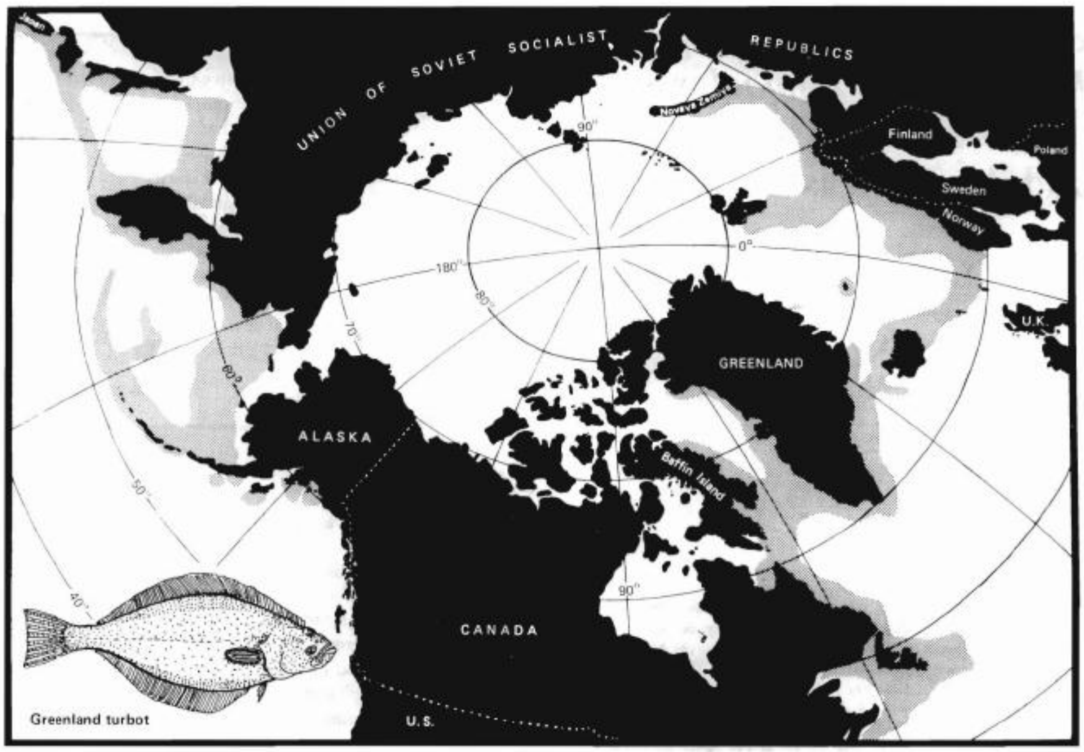

Figure 3.36: Distribution of Greenland Halibut (shaded area)

A recent paper from CSAS also documents the location of the 3 species of wolfish from trawl survey in 1978-2010. At least 2 of the 3 species seem to be found in the Hudson Strait. Authors of this study provided the shapefiles for more precision.

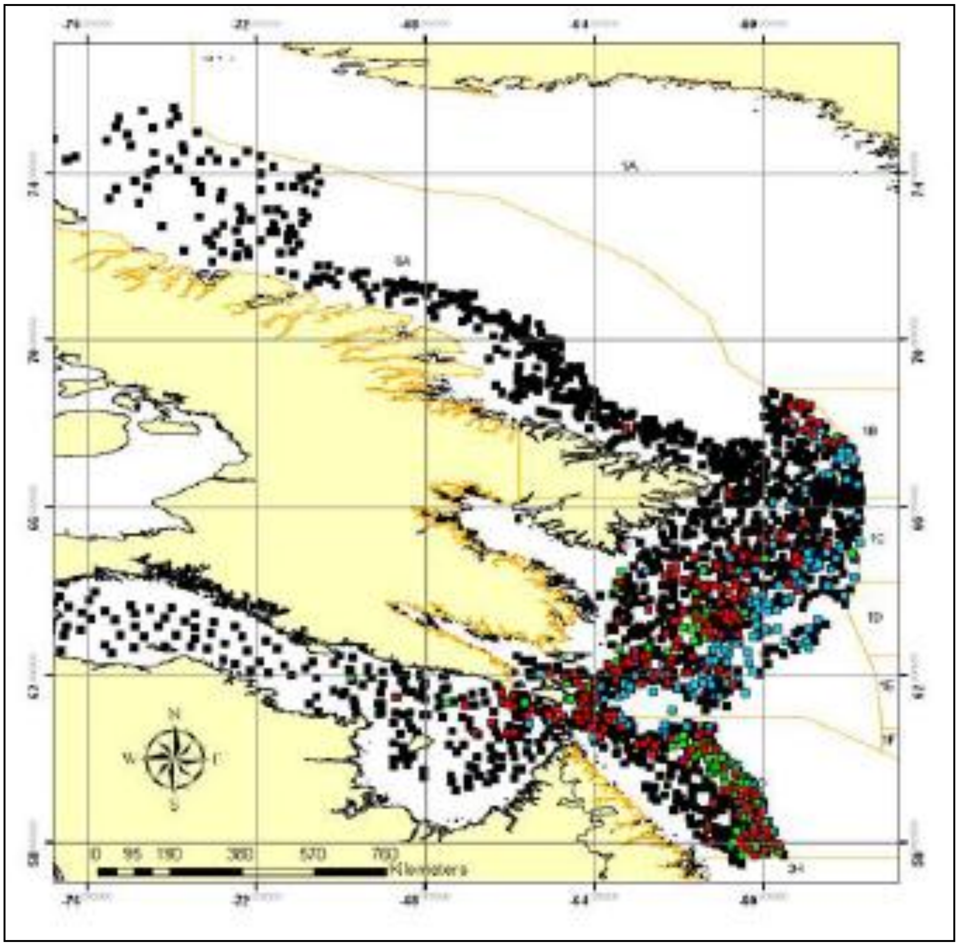

Figure 3.37: Locations of Northern (blue), Spotted (red), and Atlantic (green) wolffish catches, 1978-2010.

3.3.6 Mollusks and Crustaceans

Two species are fished and managed by DFO in the Canadian Arctic, and for which we thus have spatio-temporal distribution data for the Hudson Strait. First, two species of shrimp, northern shrimp (*Pandalus borealis*) and striped shrimp (*P. montagui*) occur in the "Shrimp Fishing Area" (SFA) 3 in the Canadian Arctic. This data is based on DFO survey of SFA3 in 2009[74].

[74] CSAS (2010)

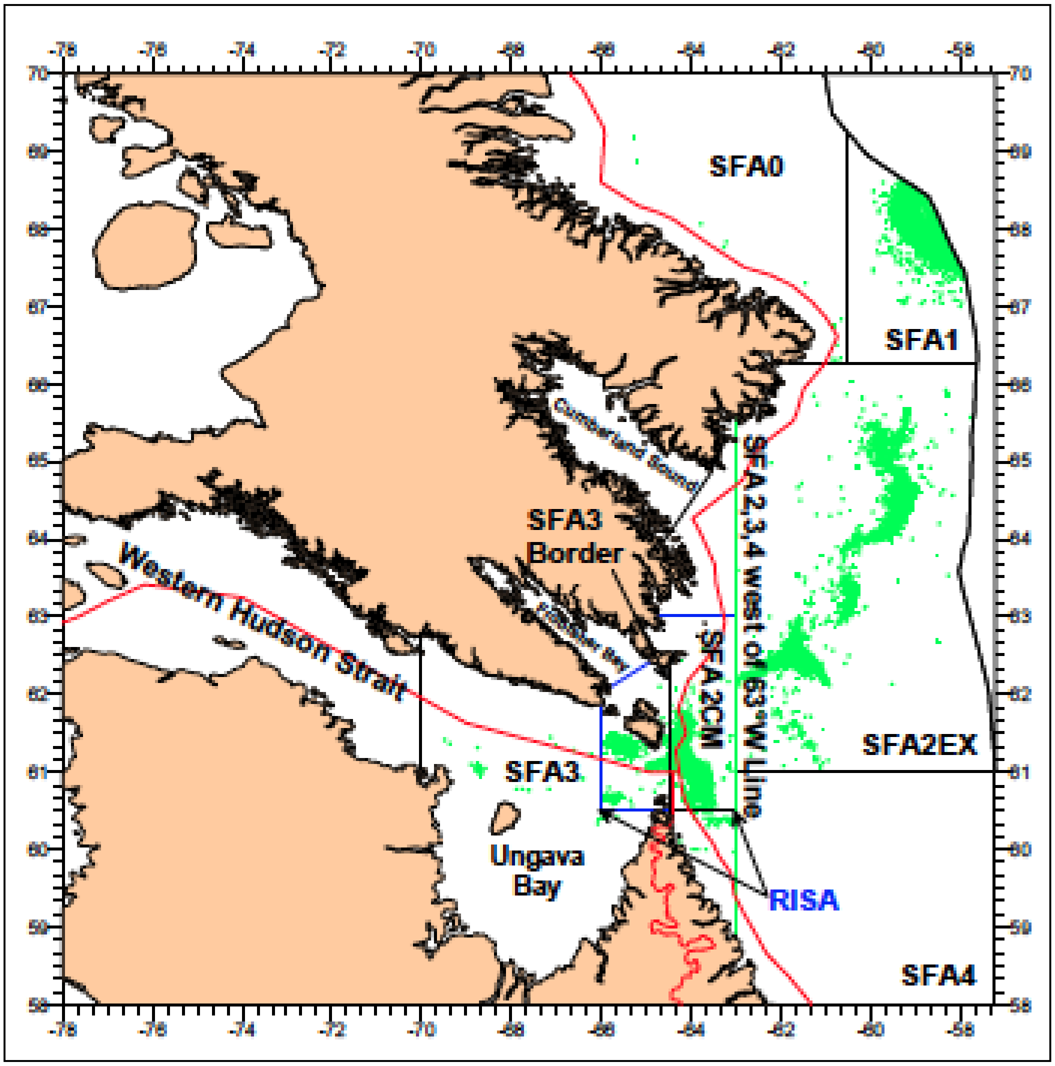

Figure 3.38: Fishing areas in and near the Hudson Strait from 1985 to 2009. Green points are fishing locations.

Information on Iceland Scallop (*Chlamys islandica*) is found in Lambert and Préfontaine[75]. This paper documents the harvesting of non-traditional marine resources. Abundance and distribution of this species is based 2084 dredge tows made between 1984 and 1992.

[75] Lambert and Préfontaine (1995)

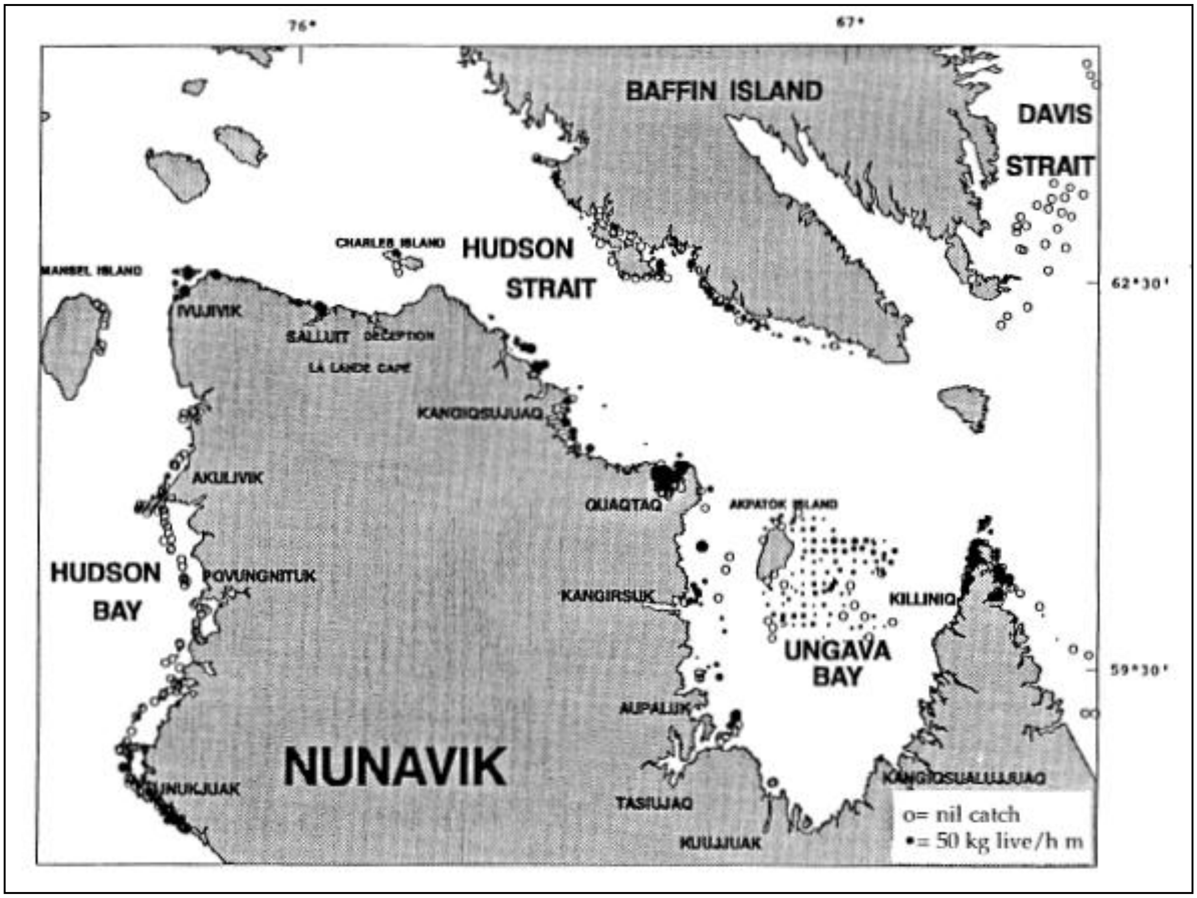

Figure 3.39: Exploratory fishing in Nunavik from 1984 to 1990. The size of the filled circles is proportional to the scallop catch. Empty circles represent nil catch.

3.3.7 Benthos

Despite the increasing amount of work done in the Canadian Arctic in the last decade, little information is available for benthic invertebrates in the specific region of the Hudson Strait. However, partly because the United Nations general assembly's sustainable fisheries resolutions underlined the importance of corals and sponges in marine ecosystems, this group is the one of only for which information is starting to appear for the Hudson Strait in the literature.

Kenchington and colleagues studied the location of significant concentrations of Nephtheid soft corals and sponges in HS collected from research vessel surveys[76]. This is based on a methodology developed by NAFO and which meet the FAO guidelines for vulnerable marine ecosystem components[77]. The HS area is well covered in their results, and they show that

[76] Kenchington *et al.* (2010)
[77] FAO (2009)

sponges and corals are mainly found in the north shores of the HS. Since these are benthic invertebrates that are fixed, temporal data is less important.

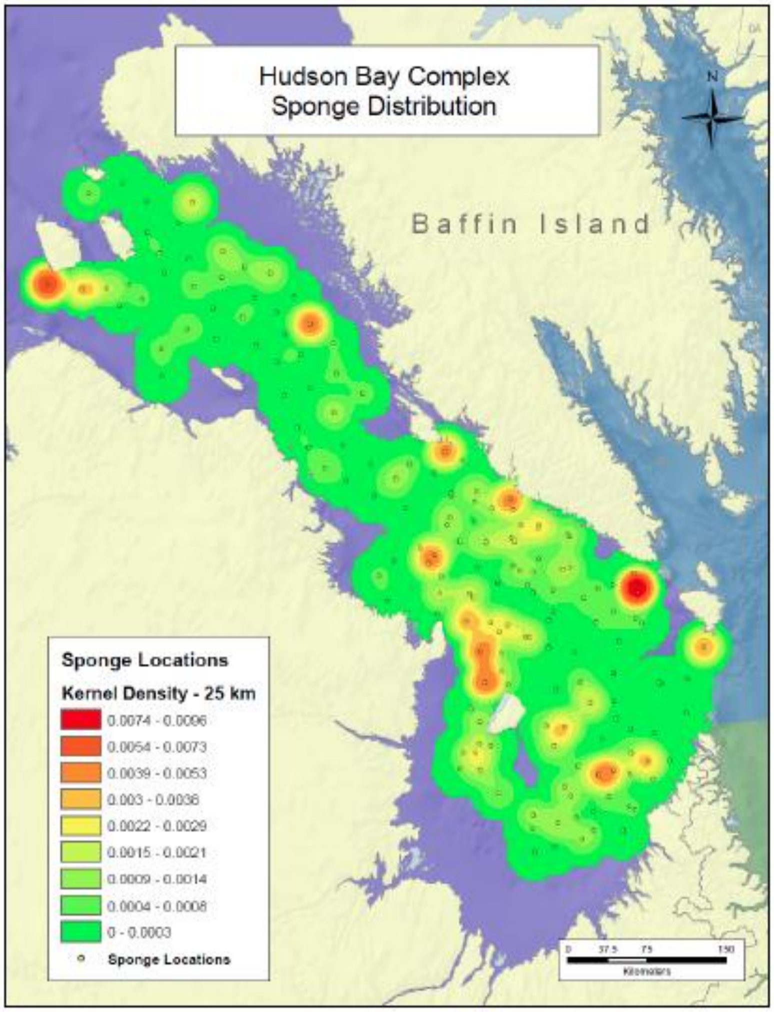

Figure 3.40: Sponge distribution in the Hudson Strait

3.3.8 Invasive Species

Few data sources are yet available to describe invasive species (or potential invasion) in the Hudson Strait. A recent study by Goldsmith and collaborators[78] show that in the HS area, Deception Bay has the port with the higher probability of invasive (cryptogenic) species coming from ships. This study only covers 3 ports in the HS area, but indicates clearly the need to get more data on invasive species in the upcoming years.

[78] Goldsmith *et al.* (2014)

4 TASK 3: RISK ASSESSMENT

The third Task of the project presents a risk assessment of shipping activity in the Hudson Strait. Specifically, it identifies, classifies and addresses event-based and operational risks posed by shipping to the social, environmental, and ecological environment of the Hudson Strait.

The risk assessment is focused on risks from the interactions between shipping and the environment specific to the Hudson Strait, and generally excludes more generic shipping risks which are well understood. The results are described in the remainder of this report.

4.1 OVERVIEW OF APPROACH

This report assesses a number of different risks posed by the intersection of ship traffic and the environment of the Hudson Strait. In some cases, the risks are unique to the local environmental or socio-economic situation, and in other cases the risks are common to the shipping industry, but have different consequences or severities due to the location.

A starting point for risk identification is that all ships are complying with the relevant domestic and international legislation for the voyages they are undertaking. This includes the international SOLAS and MARPOL conventions, the Canadian Arctic Shipping Pollution Prevention Regulations, and the Canada Shipping Act as appropriate. These requirements are intended to reduce the risks which they address to societally acceptable levels. Therefore, it should be expected that whenever a risk is assessed as being unacceptably high, this is a result of one of the following possibilities:

a. Existing requirements do not address the risk;

b. Local factors significantly increase the probability of an occurrence;

c. Local factors significantly aggravate the consequences of an occurrence;

d. Local factors lead to different perceptions of acceptable levels of risk.

At the highest level, the risk assessment considers two categories for risk – disruptions to habitat and the social-economic environment, and risk posed by shipping activities and operations. These two categories naturally include a certain amount of overlap. The task treats risk assessment in a top-down fashion – specifically, key risks are identified at the highest level, then the underlying causes are listed, and finally potential outcomes or impacts are explored. The task does draw a number of distinctions between risks with different characteristics. The following explains some of these different categories of risk:

Event-based vs. operational risk: The task makes the distinction between risks based on a discrete event with a discrete probability of occurrence (such as a vessel being holed by ice) and risks based on regular operations with an estimated frequency of occurrence (such as noise emissions from engines/vibration).

Destination traffic vs. through-traffic: The task makes the distinction between risks associated with traffic passing through the Hudson Strait sailing to a destination outside the Hudson Strait, and traffic entering the Strait sailing to a local destination. This distinction is important due to distinctions between traffic types, activities, and seasonality.

Scope-specific vs. generic risk: There are a large number of risks associated with any operation of ships. This task, as much as possible, limits the scope of risks investigated to those assessed as being particularly important to the Hudson Strait or at least the Canadian Arctic in general. This includes risks relatively specific to the Hudson Strait (for example, interaction between ship traffic and ecological factors unique to the region) as well as common risks whose outcomes or impact severities are altered by the Hudson Strait (such as the additional difficulties associated with hydrocarbon cleanup in ice infested waters).

A risk inventory has been developed summarizing nature of each hazard, potential causes, and potential outcomes. The work has then further explored the outcomes, impacts, and potential mitigation strategies for a number of specific risks identified as being of particular importance, severity, or having a clear need for further study.

4.2 Risk ASSESSMENT

The main tool that has been used in assessing risks is the matrix shown in Figure 4.1: Risk Evaluation Matrix. The matrix considers the probability of the risk event occurring, and the potential severity of the consequences for all of health and safety, environmental impact, and economic impact.

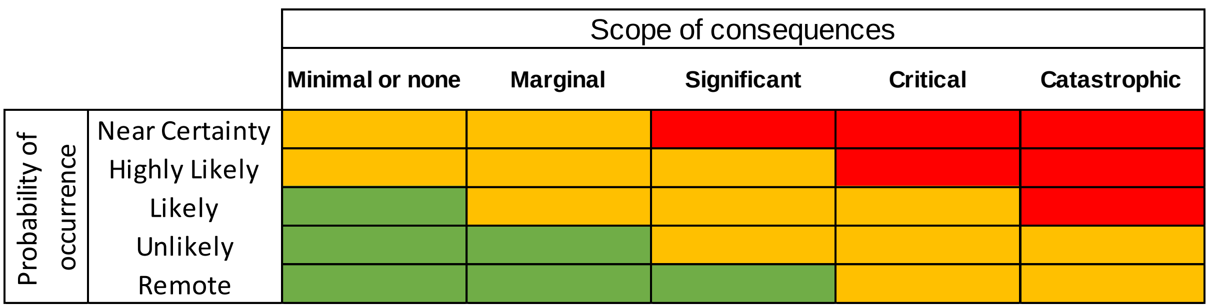

Figure 4.1: Risk Evaluation Matrix

The following table describe the definitions used to evaluate and rate risk events:

Table 4.1: Risk Assessment – Probability of Occurrence

Risk Level	Frequency (per ship voyage)
Remote	1/10000 or less
Unlikely	1/1000
Likely	1/100
Highly Likely	1/10
Near Certainty	1/1 and above

Note that the rating for consequence scope or severity has been assigned based on a qualitative weighted average of all possible consequences for a given risk. For example, an event which results in moderate consequences on almost every occurrence (such as a spill from a floating hose) would likely be rated as more severe than an event with a number of different possible outcome severities (such as ice impact) where the more likely outcomes are of minimal impact. The level of severity assigned to a risk's consequences is defined as follows:

1. Minimal or none: Consequences are limited in impact, with no known potential for long-term damage to business, persons, or the environment.
2. Marginal: Consequences have potential for immediate harm to persons, business, or the local environment.
3. Significant: Consequences present immediate, significant harm (such as injury or loss of life, temporary significant environmental disruptions) with some potential for longer term effects.
4. Critical: As above, except with high probability of lasting effects, such as reduced business potential, or lasting impact on population levels of important species.
5. Catastrophic: Unacceptable immediate impacts, and potentially irreparable long-term damage.

In the above evaluation, green results are low overall risk, and need no further action. Yellow are medium risk, and should be evaluated in the context of how a ship operators does its business and should be individually evaluated and mitigated where it is technically and economically feasible to do so. Red are high risk, and should normally be considered to require additional mitigation measures.

The risk analysis has been divided into 2 broad categories:

1. **Habitat, ecosystem, and socio-economic disruptions**. The Hudson Strait is characterized by a deep middle channel, relatively strong currents and high tides. During the winter season it is entirely ice covered. The ice coverage is dynamic, with numerous leads, cracks, polynas, and other features occurring predictably each season. These features are favourable for a number of marine mammals including cetaceans and seals, who depend on the ice and winter access to the water beneath it. Disruptions to the environment in the Hudson Strait includes risks such as:

    a. Physical Impact – Direct physical impact between vessels and animals.

    b. Environmental Disruptions – Immediate environmental disruptions such as operational noise, hydrocarbon or other discharges, waves/wakes, and the destruction of ice cover used as migration or hunting routes.

    c. Ecological Disruptions – Longer-term issues such as the introduction of invasive species or permanent dislocation of animals from regular ranges or habitats.

    d. Cultural Impact – Risks to local communities such as loss of culturally significant hunting resources, or tourism traffic in excess of local communities' capacities.

    Noise emissions are a potential type of disruption due to the dependence of almost all marine mammals on sound for every functional aspect of their lifecycle. The real effects of noise on marine mammals are not well understood, which makes the assessment of risk problematic. Similarly, the cumulative effects of low levels of water- and airborne pollutants are not well known.

Another less immediate but “new” type of risk is the rapid growth of recreational traffic overwhelming local infrastructure. Rapid growth of tourism traffic in the Arctic and the Hudson Strait may present more opportunities for operators to lead larger parties on shore excursions. This introduces the risk that the communities being visited will not have sufficient infrastructure in terms of social, sanitation, resources (fuel, supplies), and health/response to accommodate such large groups. This could have consequences ranging from short-term inconvenience to the community to longer term problems of supply shortages, cultural disruptions, or excessive strain on limited infrastructure.

2. **Shipping and operational risks**. These risks are often the same fundamental risks present for the shipping industry worldwide, however Arctic considerations such as harsh climate and remoteness either exacerbate the risk or introduce additional consequences to its occurrence.

   The Hudson Strait experiences both through ship traffic from Churchill and the interior of the Arctic, as well as destination traffic to a number of small communities on its shores. Much of the activity within the Hudson Strait (as opposed to through-traffic) in the strait is centered on the Raglan and Nunavik mines, located at Deception Bay. A modest amount of localized sealift and tourism traffic is also present in the strait, as well as occasional scientific and seismic surveys.

   The communities along the Strait are currently experiencing modest population and economic growth. Supplies for these communities are imported via ship delivery during the summer and fall seasons, as well as by limited aircraft access at local airstrips. Facilities for both air and sea supply are basic – sea supply is typically via barge and beach landing, while air facilities are typically gravel runways suitable for smaller aircraft.

   Shipping operations in the area involves hazards such as:

   a. Capsize, grounding, collisions – Rescue, salvage, and cleanup are all more difficult in the Arctic.

   b. Other, less immediately catastrophic incidents such as equipment failure, loss of ship control, ice collisions/besetment – As above, with the exception of ice issues, these are risks present throughout the industry, but can quickly escalate or pose more significant consequences due to the nature of the Hudson Strait and its remoteness from any rescue or salvage services.

   c. Risks posed by sealift and resupply operations – spills or cargo loss occurring during supply of fuels, cargos, to communities.

   All of these risks have the potential to lead to a number of serious consequences with one of the key issues being pollutant spills, as they impact not only local wildlife, but could potentially damage communities, disrupt sustenance harvesting, and due to their immediate visibility and relatively well understood consequences could easily damage an operator’s reputation and ability to do business in the region. While the risk of releasing pollutants via various incidents is present globally, the remoteness, lack of response infrastructure, harsh conditions, and relative fragility of the Arctic environment dramatically amplify the immediate and long term consequences of such an incident occurring.

4.2.1 Risk Inventory

The risks in the table have been evaluated in accordance with the process described in Section 4.2. Note that in many cases there is not sufficient data available on the true probability of occurrence or the extent of the consequences for the risk, which will be factored into the evaluation. The headings used in the table are defined as follows:

Table 4.2: Risk Table Glossary

Heading	Description
Risk	Name or short description of risk.
Level	Results of risk evaluation (High, Medium, or Low)
Oper. Risk	For risks associated with continuous operations
Event Risk	For risks associated with discrete events
Description or Cause	Additional details or sub-categories
Influence of Arctic	Why the risk is important for voyages in the Hudson Strait, or how the risk's consequences could be influenced by the Hudson Strait
Immediate Cause	Why the risk manifests
Underlying Cause	Underlying reasons for risk - typically arctic shipping conditions or local environmental sensitivities
Transit vs Destination Traffic	Is the risk primarily associated with traffic transiting the Hudson Strait, or traffic travelling to a destination within the Strait?
Current Mitigation	Current regulatory or operational risk mitigation items
Probability or Frequency	How likely is or how often does the risk manifest
Immediate Consequences or Effects	Consequences immediate to the manifestation of the risk
Potential Consequences or Effects	Consequences arising or continuing in the long-term as a result of risk manifestation
Suggested Mitigation	Suggestion(s) for potential mitigation measures

Table 4.3: Risk Inventory and Assessment Table

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
Habitat, ecosystem, and Social Disruption														
Cetacean strike	01	MED		YES	Vessel in transit strikes a cetacean, causing injury or death	Numerous intersections between cetacean migratory and feeding grounds and shipping activities in the Hudson Strait	Transit of waters used by cetacean species	Inadequate data on likely locations and seasonal habits of cetaceans available to mariners. Difficulty identifying animals in transit.	Both, more likely with destination traffic (shipping lane is closed during the overwintering season)	None	Unknown. Likely higher in the winter season.	Injury or death of animal	Lasting negative impact on animal populations already at risk (decrease in population trends), change in the distribution patterns (linked to a potential change in food availability)	Reduction of transit speed coupled with forward watchkeeping. Passive or active acoustic detection systems, acoustic deterrents, route planning.
Other species strikes	02	MED		YES	Icebreaking operations in ice features occupied by marine mammals.	Seals, walrus, polar bear, all use ice coverage for mobility	Transit through ice coverage used by species for mobility	Inadequate data on ranges and habits of animals using ice coverage.	Both, more likely with destination traffic (shipping lane is closed during the overwintering season)	None	Unknown. Likely higher in the winter season.	Injury or death of animal	Lasting negative impact on animal populations already at risk (decrease in population trends), change in the distribution patterns (linked to a potential change in food availability)	Reduction of transit speed coupled with forward watchkeeping. Passive or active acoustic detection systems, acoustic deterrents, route planning.
Disruption of fish stocks	03	MED	YES		Shipping patterns cause key species such as Arctic char to shift population centres	Unknown	Transit of waters where fish stocks exist	Inadequate data on fish stock locations (and relative effect of noise on fish)	Both	None	Unknown	Risk of shortages for local sustenance fisheries	Potential for negative impact on sustenance food sourcing though fishing is unknown	Data collection to establish delineation of sensitive areas for shippers, and avoidance of sensitive areas
Icebreaking - ice environment change	04	LOW	YES		Vessel icebreaking activities change the ice landscape	Ice coverage used for various reasons by numerous species	Icebreaking activity alters ice regime	Inadequate data on ice coverage usage by animals.	Destination only (currently no icebreaking activities on route to Churchill)	None	High (seasonal)	Interruption of floes used by land mammals, creating openings in the ice which will not be seasonally repeatable.	Unknown	Data collection to establish delineation of sensitive areas for shippers, and avoidance of sensitive areas

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
Wake wash disruptions (general)	05	LOW	YES		Wake wash from ships passing causing rapid and localized changes in current patterns, leading to habitat disruption.	Unknown	Transit of habitat of Arctic Char and other important species	Inadequate data on fish and other lower animals potentially affected.		None	Unknown	Loss of habitat, fish more available to predators, dewatering that may expose fish larvae to air (death of fish larvae).	Changes in fitness of fish through displacement into areas of lower quality. Decrease in population trends for commercially important fish species, change in ecosystem balance, diffuse food web effects, change in food availability for predators (seabirds)	Coastal monitoring program in essential habitats for fish & seabird species.
Wake wash disruption of shorelines	06	MED	YES		Vessel traffic in near shore areas disrupt shoreline environment.	Relatively fragile flora in Arctic	Transiting near shorelines introduces additional wash from ship wake to sensitive shorelines.	N/A	Review proximity of Churchill routes to shorelines.	None	Low. Open water season only.	Shoreline erosion	Unknown	Transits at distance from shore (couples with avoiding habitat)
Disruption of airspace	07	MED	YES		Vessels transiting near sensitive avian habitats.	Unknown	Transit of waters adjacent to avian colonies	Poor understanding of preservation requirements, Hudson Strait narrows near Western extremity, which is also where many sensitive regions are located.	Both	None officially - a guideline from Environment Canada's Canadian Wildlife Services propose some mitigation measures.	Seasonal (lower risk during winter)	Change in behaviour and distribution of seabirds through the habitat.	habituation of seabirds to increased ship traffic, change in distribution of seabirds (avoidance of major shipping zones), increased flushing distance (distance travelled to go hunting for prey)	Maintain a minimum distance of at least 300m from all areas occupied by seabirds (and colonies), travel parallel to the shore at a steady speed.
Noise Disruptions (sailing)	08	MED	YES		Noise from transiting vessels, and increase in vessel traffic and range rapidly increases sonic inputs to environment.	N/A	Transit of waters used by species dependent on underwater sound transmission	Inadequate data on likely locations and seasonal habits of cetaceans available to mariners. Lack of data on noise outputs from ships.	Both	None	Continuous	Hearing injury (may be lethal), disorientation amongst underwater wildlife, leading to disorientation, communication, navigation issues. Increased risk of collisions	Lasting negative impact on animal populations already at risk	Data collection to establish delineation of sensitive areas for shippers, and avoidance of sensitive areas

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
Noise Disruptions (icebreaking)	09	LOW	YES		Noise from icebreaking activities and an increase in icebreaking activities causes moderate increase to sonic inputs to environment.	Arctic sailing outside of short summer season requires icebreaking	Icebreaking activity in waters used by species dependent on underwater sound transmission	Inadequate data on likely locations and seasonal habits of cetaceans available to mariners. Lack of data on noise outputs from ships.	Both	None	High (seasonal)	Hearing injury (may be lethal), disorientation amongst underwater wildlife, leading to disorientation, communication, navigation issues. Increased risk of collisions	Lasting negative impact on animal populations already at risk. Potential socio-economic impact to communities via displacement of sustenance and/or culturally significant wildlife.	Data collection to establish delineation of sensitive areas for shippers, and avoidance of sensitive areas
Noise Disruptions (surveys)	10	LOW	YES		Noise from seismic surveys causes moderate increase in acute sonic inputs to environment.	Appetite for O&G surveys in the area?	Surveys in waters used by species dependent on underwater sound transmission	Lack of data on noise outputs from ships and effect on various levels of ecosystem.	Destination (survey ships) only.	None	Low	Hearing injury (may be lethal), disorientation amongst underwater wildlife, leading to disorientation, communication, navigation issues. Increased risk of collisions. Potential kill-off of sensitive lower species.	Lasting negative impact on animal populations already at risk and/or food chains. Potential socio-economic impact to communities via displacement of sustenance and/or culturally significant wildlife.	Data collection to establish delineation of sensitive areas for shippers, and avoidance of sensitive areas
Air Emissions (operational)	11	MED	YES		Vessel emissions negatively impact air quality in sensitive environment	Arctic is excluded from ECA zone for North America.	Burning of regular diesel or HFO	No regulations for air emissions in the Arctic, no incentives for operators to switch to low sulphur fuel (fuel cost) or alternate fuel type (retrofit cost)	Both	None	Continuous	Health issues amongst sensitive avian populations	Lasting negative impact on animal populations already at risk	Adhere to ECA rules (no HFO use)
Pollutant Discharge (Operational)	12	MED	YES		Vessel emissions as a result of regular operations negatively impact water quality in sensitive environment	Vessel may not dump grey water, but may dump sewage.	Poor regulations	Inadequate regulations prohibiting discharge of sewage.	Both	Restrictions on grey water discharge	Low	Potential local impact on sea populations, negative impact on community shorelines, sustenance fisheries.	Negative impact on animal populations already at risk. Potential socio-economic impact to communities via displacement of sustenance and/or culturally significant wildlife.	0 Discharge policy, subsidy for treatment facilities where feasible, onboard treatment and hold.

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
Harmful Substance Discharge (Operational)	13	LOW	YES		The introduction of harmful substances through regular operations (such as anti-fouling agents, coatings, etc.) negatively impacts water quality in sensitive environment	navigation in ice may cause abrasion of coatings and agents	Use of common chemicals as part of normal operational practices	Lack of data of effect (and magnitude of impact) of common agents used on Arctic environment.	Both	Some regulatory incentives for low-VOC coatings	Continuous	Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries.	Lasting negative impact on animal populations already at risk. Potential socio-economic impact to communities via displacement of sustenance and/or culturally significant wildlife.	Study of effects of coatings, etc.
Introduction of invasive species	14	MED		YES	Ballast water discharge in Arctic ports releases new species into local ecosystem	Sensitive area with no prior exposure to invasive species	Risk of introduction of invasive species is inherent in any shipping operation.	No inspection regime for remote arctic ports.	Destination	IMO and TC ballast water regulations	Low	Competition for at risk or endangered species, disruption of low-diversity Arctic food chain	Negative impact on sustenance food sourcing though fishing, potential ecosystem-wide impact if key species is affected.	0 discharge of untreated ballast
Socio-Economic disruption	15	LOW	YES		Rapid growth in tourism traffic in excess of local population centre's capacities	Small population centres with limited infrastructure and social resources can only support limited growth in visitor traffic	Rapid growth in tourist traffic exceeds the handling capacity of local marine and shore-side infrastructure	Poor planning for sustainable growth in industry.	Destination	Regulatory, required permits constrain growth. developments typically require community impact assessments	High	Risk of overwhelming limited local resources (hygiene, marine support, fuel supply, etc.) leaving insufficient resources for local community	Potential for long-term negative impact on communities if growth is not sustainable and tourism traffic drops. Potential for local health issues, resource shortages.	Advocacy for sustainable growth of tourism trade.
	Shipping and Operational Incidents													

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
Shipping incidents	16	MED		YES	Ship capsizing releases pollutants	Extreme icing conditions change stability characteristics of ship	Vessel stability changes under large ice loads, which may not have been accounted for at design time, particularly for foreign flagged vessels sailing in the Arctic for the first time.	Ice navigation and safe practices (as well as ship capabilities) are never truly predictable, even for the most experienced operators). Adding an increase in traffic, some of which is from relatively inexperienced operators with less capable ships, increases the risk of an accident occurring.	Both	Ice regime systems, zone-date systems, ice navigator requirements, vessel class requirements	Low	Risk of injury or loss of life to crew and passengers. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances.	Potential for injury or loss of life if SAR feasibility is limited due to remoteness and harsh conditions. Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for creation of hazard to navigation if vessel is lost and not salvageable.	
	17	MED		YES	Impact event between ship and ice breaches vessel and allows release of pollutants	Unpredictability of ice conditions	Risk is inherent in ice infested waters	Ice navigation and safe practices (as well as ship capabilities) are never truly predictable, even for the most experienced operators). Adding an increase in traffic, some of which is from relatively inexperienced operators with less capable ships, increases the risk of an accident occurring.	Both	Ice regime systems, zone-date systems, ice navigator requirements, vessel class requirements	Low-Med	Risk of injury or loss of life to crew and passengers. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances.	Potential for injury or loss of life if event is severe and SAR feasibility is limited due to remoteness and harsh conditions. Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for creation of hazard to navigation if vessel is lost and not salvageable.	

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
	18	MED		YES	Vessel beset by ice	Unpredictability of ice conditions	Risk is inherent in ice infested waters	Ice navigation and safe practices (as well as ship capabilities) are never truly predictable, even for the most experienced operators). Adding an increase in traffic, some of which is from relatively inexperienced operators with less capable ships, increases the risk of an accident occurring.	Both	Ice regime systems, zone-date systems, ice navigator requirements, vessel class requirements	Low-Med	Potential for harm to crew if stranded for extended period of time. Potential for damage or loss of ship and release of harmful pollutants if ice pressures breach hull.	Potential for injury or loss of life if event is severe and SAR feasibility is limited due to remoteness and harsh conditions. Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for creation of hazard to navigation if vessel is lost and not salvageable.	Escorts for less capable and larger ships. Sailing with support, provision of support from salvage tug or equivalent closer to shipping routes.
	19	LOW		YES	Impact event between ship and other vessel damages ship and allows release of pollutant	Few navigational aids an well-understood navigation lanes (particularly for new operators)	Risk is inherent to operations in remote/low utilization regions, extreme cold can lower strength of steel and other structural components such as tank walls. Escort activities involve multiple ships operating very close together in unpredictable conditions.	Difficult navigation conditions at times (fog, wind, ice) could force small amount of traffic into localized areas trying to make progress. Escort activities necessarily require icebreakers to sail in close proximity to less capable ships.	Both	General seafaring practices, ice escort practices	Low	Risk of injury or loss of life to crew and passengers. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances.	Potential for injury or loss of life if event is severe and SAR feasibility is limited due to remoteness and harsh conditions. Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for creation of hazard to navigation if vessel is lost and not salvageable.	

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
	20	MED		YES	Grounding of vessel allows release of pollutant	Low use in region, less than complete bathymetry and charts.	Charts and bathymetric surveys of the region are not as developed as more southern regions. Extreme cold can lower strength of steel and other structural components such as tank walls.	Low use of the Arctic to date (compared to other regions) means that supporting navigation aids and charts will need to play "catch up" quickly should traffic begin to increase quickly.	Both	Sonar, repeatable navigation routes.	Low-Med	Risk of injury or loss of life to crew and passengers. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances.	Potential for injury or loss of life if SAR is required and feasibility is limited due to remoteness and harsh conditions. Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for creation of hazard to navigation if vessel is lost and not salvageable.	
	21	LOW		YES	Failure of vessel equipment allows release of pollutant	Extreme cold temperatures, icing, ice clogging	The requirements for operating in the Arctic, particularly in ice, and also particularly on very cold days/seasons exceed the design capabilities of ship's systems, causing freezing, overloading, or other failure of ship's systems enabling release of pollutants.	Harsh conditions in the Arctic may not be fully appreciated by less experienced operators, and like ice, are not 100% predictable by new and experienced operators alike.	Both	Class requirements, ice regime, zone date system.	Low-Med	Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries.	Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up.	

Risk	ID	Level	Oper. Risk	Event Risk	Description or Cause	Influence of Arctic	Immediate Cause	Underlying Cause	Transit vs Destination Traffic.	Current Mitigation	Probability or Frequency	Immediate Consequences or Effects	Potential Consequences or Effects	Potential Mitigation
	22			YES	A loss of ship control leaves the ship vulnerable to impact with rocks, shoals, or ice.	Conditions in the Hudson Strait (winds, currents, dynamic ice) may lead to rapid escalation of situation. Remoteness of region will lead to delays in support or salvage.	Fire, power loss due to equipment malfunction or mechanical failure, operator error, damage to external propulsion components.	Risk of loss of control is inherent with ship operations.	Both	None	Low-Med	Risk of injury or loss of life to crew and passengers. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances.	Consequences could escalate to similar to grounding/capsize events due to harsh conditions, coupled with no towing resources in the area. Closest support would need to steam from Churchill (at least 2-3 days) to arrive and tow. An escalated incident could have long term impact on environment, hazard to navigation if vessel is not salvageable.	Escorts for less capable and larger ships. Requirements for redundancy on ships. Sailing with support, provision of support from salvage tug or equivalent closer to shipping routes.
Sealift/resupply incidents	23	MED		YES	A failure of the systems used to supply shore facilities from a vessel via floating hose fails.	Challenging sealift/supply conditions. Demand for sealift services currently outpaces supply, leading to extension of the season into shoulder seasons. Limited or inadequate sealift infrastructure	Failure of hose, connections between hose and supply or reception facility, ice damage to equipment.	Lack of modern (even basic) infrastructure in many Arctic communities.	Destination	No deployment of floating hoses in ice infested waters (operational or regulatory?)	Low	Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries.	Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up.	Advocacy and lobbying for infrastructure investment for communities.
	24	LOW		YES	A failure of the systems used to supply shore facilities from a vessel via cranes and barges fails.	Challenging sealift/supply conditions. Demand for sealift services currently outpaces supply, leading to extension of the season into shoulder seasons. Limited or inadequate sealift infrastructure	Barge or crane systems fail, due to stability problems, poorly graded landing areas, human error, etc.	Lack of modern (even basic) infrastructure in many Arctic communities.	Destination	Best practices for loading equipment to barges	Med	Risk of injury or loss of life to crew performing operations. Potential severe impact on sea populations, negative impact on community shorelines, sustenance fisheries due to release of pollutants or harmful substances if barged cargo is released.	Potential for lasting negative impact on animal populations already at risk, as well as local communities due to logistical challenges of staging adequate environmental response and clean-up. Potential for negative socio-economic impact on communities if event drives sealift supply down.	Advocacy and lobbying for infrastructure investment for communities.

4.2.2 Key Risk Analyses

The risk inventory and assessment presented in Section 3.1 is presented somewhat differently in the overall risk evaluation matrix shown in Figure 4.1. Here the risk levels of "High", "Medium" and "Low" are differentiated more clearly against the probability and consequence levels associated with each. The following figure maps the contents of the risk inventory to the risk evaluation matrix, using the risk ID numbers from Table 4.3: Risk Inventory and Assessment Table.

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of Occurrence	**Near Certainty**		11, **8**			
	Highly Likely		12			
	Likely	9, 13, 19	6, 7	**1, 18**		
	Unlikely		5, 10, 15, 24	2, 3	**20**, 22, **23**	**16**
	Remote		4	21	14, 17	

Figure 4.2: Overall Risk Evaluation Matrix

A set of the most significant risks has been identified for additional description and discussion below. This covers all "High" risks, and a number of risks that are assessed as "Medium" but which are close to the boundary.

These are as follows:

a. Shipping incident: Ship beset by ice (risk ID = 18)

b. Shipping incident: Grounding (risk ID = 20)

c. Shipping incident: Capsize (risk ID = 16)

d. Shipping incident: Failure during sealift operations (risk ID = 23)

e. Cetacean strikes: Ice and ice-free seasons (risk ID = 01)

f. Noise from operations: Ice and ice-free seasons (risk ID = 08)

Although it is often the focus of most attention in discussions of Arctic shipping risk, the case of ice impact damage is considered to be of lower risk than these top items. Recent experience in the Canadian Arctic suggests that the current regulatory regime, including access limits based on ice class and crew qualifications when operating in ice has reduced the number of damages to a relatively small number with marginal to significant consequences. This is not to say that the risk could not increase in future. It may be that increases in traffic, the dilution of experience that may result from this, and the "internationalization" of certain requirements under the Polar Code will increase the probability of incidents.

4.2.2.1 Shipping Incident: Ship Beset by Ice

As listed in the risk matrix, there is a risk that vessels operating in the Hudson Strait during colder seasons could be best by ice. This could lead to consequences ranging from delays in operations, to poor conditions for crew. Incidents could escalate in the event that ice pressures overstress the hull, or ice draft carries the vessel aground. In these cases, there could be release of pollutants, a need to abandon ship, and total ship loss. However, these are much lower probability events. The following figure shows the assessment of the risk:

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of occurance	Near Certainty					
	Highly Likely					
	Likely			**MEDIUM**		
	Unlikely					
	Remote					

Figure 4.3: Risk Evaluation: Ship Beset by Ice

Note that the risk is deemed relatively high primarily due to the high likelihood of occurrence (as evidenced by numerous reports of vessels becoming trapped, at least temporarily, in the ice) rather than the outcome severity, which is often tempered due to the presence of ice breaking escorts of the use of capable, ice class reinforced vessels. Should traffic in the Hudson Strait increase and begin to include less capable or more un-escorted "new" vessels, the risk level may increase as regards both probability and potential consequences.

This risk is currently mitigated by a variety of regulatory requirements from Transport Canada. The forthcoming IMO Polar Code in principle requires operators to take account of a wide range of hazards when planning for and conducting voyages. Newer operators without a record of Arctic experience may however incur additional risk if they do not have access to ice navigators, experience with Canadian Arctic ice conditions, or sound operating practices.

4.2.2.2 Shipping Incident: Grounding

There are a number of risk scenarios through which a vessel could be damaged or lost through grounding on the coasts of the Hudson Strait or the many islands along its length. Poor hydrographic information is a risk factor for a number of current and potential operations. The potential consequences of such an event include harm to crew, release of pollutants, damage to the ship or even loss of the ship. Additionally, an unsalvageable vessel could create a hazard to navigation, and any serious incident could cause significant harm to the operator's reputation and ability to do business in the region. Due to the remoteness and lack of SAR and environmental response infrastructure in the region, the consequences to both crew and the environment are amplified should an incident occur. The following figure shows the assessment of the risk:

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of occurrence	Near Certainty					
	Highly Likely					
	Likely					
	Unlikely				**MEDIUM**	
	Remote					

Figure 4.4: Risk Evaluation: Grounding

Note that the consequences are considered to be critical (rather than catastrophic) due to the fact that all of the recent recorded grounding incidents for the Canadian Arctic were resolved without loss of life or major pollutant releases, which suggests that while a serious spill or human impact is possible, in the majority of cases it is not the end consequence.

This risk is currently mitigated by a variety of regulatory requirements from Transport Canada and other regulatory agencies. Newer operators without a record of Arctic experience may however incur additional risk if they do not have access to ice navigators, experience with Canadian Arctic ice conditions, or extensive contacts within the Canadian regulatory system.

4.2.2.3 Shipping Incident: Capsize

There is an enhanced risk of capsize in the Arctic, due to issues of icing on deck, as well as ship handing issues in extreme cold. This is a higher risk for smaller vessels such as fishing vessels, small workboats and passenger vessels, and other small craft. The consequences of such an event would almost certainly include harm to crew, release of pollutants, and potentially loss of the ship. Additionally, an unsalvageable vessel could create a hazard to navigation, and any serious incident could cause significant harm to the operator's reputation and ability to do business in the region. Due to the remoteness and lack of SAR and environmental response infrastructure in the region, the consequences to both crew and the environment are amplified should an incident occur. The following figure shows the preliminary assessment of the risk:

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of occurrence	Near Certainty					
	Highly Likely					
	Likely					
	Unlikely					**MEDIUM**
	Remote					

Figure 4.5: Risk Evaluation: Capsize

Capsize events very often end in loss of life, and are also likely to lead to some level of pollutant release after the loss of the ship.

This risk is currently mitigated by a variety of regulatory (stability) requirements from Transport Canada, and SOLAS. The increasing volumes of small craft traffic in Hudson Strait, and more adverse environmental conditions due to climate change may be increasing this risk.

4.2.2.4 Shipping Incident: Failure during Sealift Operations

Sealift operations in the region are extremely challenging, due to the lack of ports and berths for vessels at most locations, coupled with often harsh environmental conditions. Most communities resupply from ships using cranes and barges for containerized cargo, and floating hoses for fuel supply. Both these methods are subject to a risk of spill or cargo loss given a variety of factors. Release of pollutants or loss of cargo would result in environmental damage, an adverse impact on the community depending on the delivery, and potentially damage to the operator's reputation and ability to do business in the area.

The following figure shows the assessment of the risk:

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of occurrence	Near Certainty					
	Highly Likely					
	Likely					
	Unlikely				**MEDIUM**	
	Remote					

Figure 4.6: Risk Evaluation: Sealift Failure

Note that the delicate nature of the systems used coupled with difficult conditions is a primary reason for the high level of risk.

There is limited formal risk mitigation through regulation for many of these operations, which rely on experience and the application of best practices. For example, operators currently claim to follow the best practice of not attempting sealift operations in the presence of ice that is likely to interfere with the activity, particularly for fuel transfers. As the demand for sealift is likely to rapidly outpace the availability of supply in the next few years due to both the cost of acquiring or chartering new ships and the short season in which they operate, operators may choose to attempt to extend the season into less predictable conditions to meet demand.

4.2.2.5 Cetacean Strikes

Several species of cetaceans remain in the Hudson Strait throughout the year, including the winter season. While a risk of cetacean strike (or other marine mammal strike) exists year-round, the winter season and the formation of polynas presents a unique and important set of circumstances with dramatically increase the risk of strike. The following figure shows the assessment of the risk:

		Scope of consequences				
		Minimal or none	**Marginal**	**Significant**	**Critical**	**Catastrophic**
Probability of occurrence	Near Certainty					
	Highly Likely					
	Likely			**MEDIUM**		
	Unlikely					
	Remote					

Figure 4.7: Risk Evaluation: Cetacean Strike

During the winter season, several species remain almost exclusively in the polynas which form in predictable locations each year, as they are their main access to the surface, and serve as feeding and wintering grounds. Icebreaking vessels also naturally take advantage of these regions of open water during operations, leading to an inevitable intersection between vessel operations and population centres of cetacean species during the winter season.

Note that while the nature of icebreaking operations may lead to more interactions between cetaceans and ships, the slower speeds involved with icebreaking operations act as a mitigation against strikes.

The following figure presents an overview of regularly occurring polynas throughout the Canadian Arctic[79]:

[79] Hannah, Dupont, Dunphy, Arctic Review, 14 April 2008. Polynas and Tidal Currents in the Canadian Arctic Archipelago. 13p.

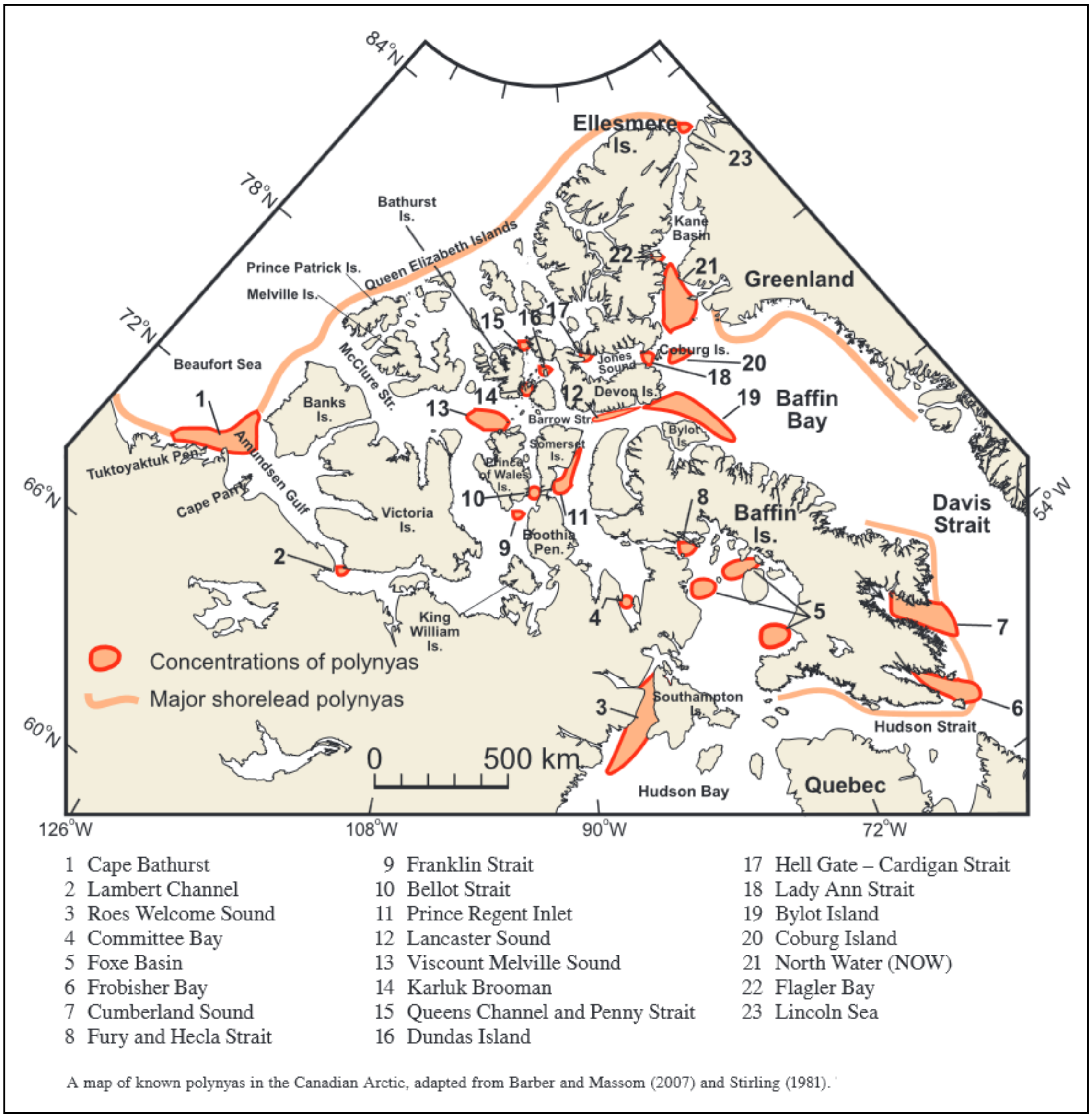

Figure 4.8: Polynas in the Canadian Arctic (Hannah et al. 2007)

The following map shows the areas where polynas are known to develop in the Hudson Strait, overlaid with vessel traffic for the season:

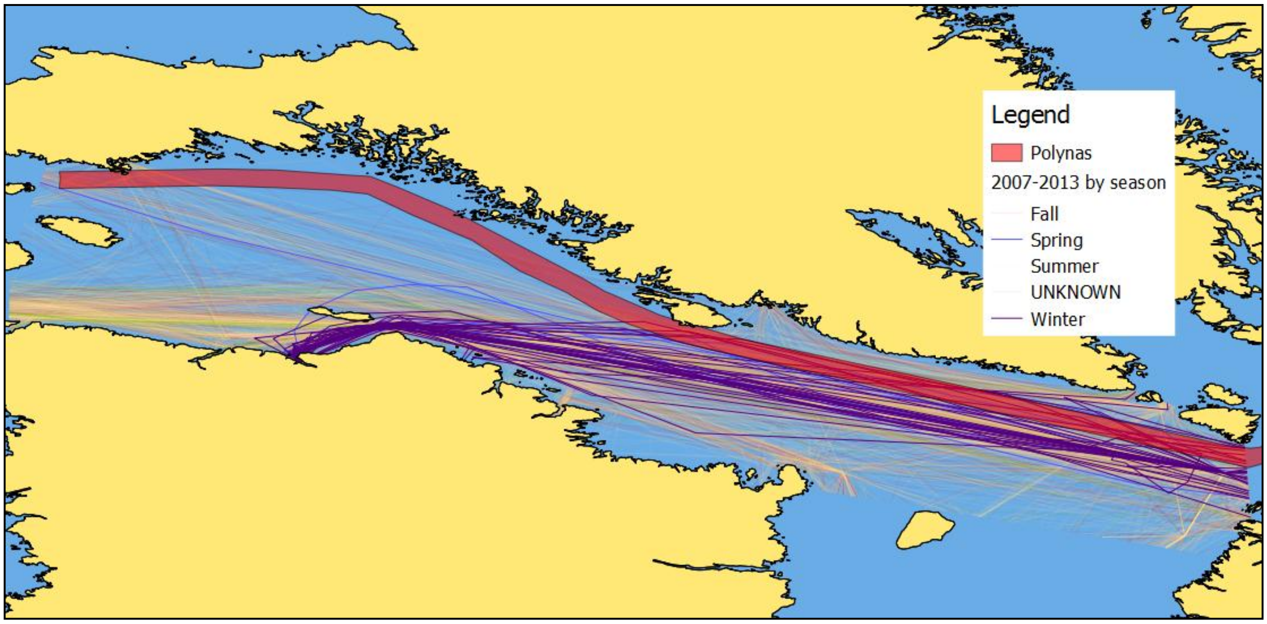

Figure 4.9: Polynas in the Canadian Arctic and Winter/Spring Traffic

As the figure shows, most of the traffic currently intersecting with regions featuring recurring polynas is moving in and out of Deception Bay. This is however due to the fact that traffic in and out of Deception Bay is currently the only fleet other than the Canadian Coast Guard with sufficient capability to operate safely in the Hudson Strait year-round.

Any increase in ice breaking vessel traffic in support of mining or other operations could increase the overall level of risk and extend it to other areas of Hudson Strait.[80]

Occasional strikes may injure or kill a single animal, which can have significant consequences from a social licence standpoint. Repeated impacts may have greater consequences, including impacts on the behaviour of local populations of the affected species. Figure 4.10: Animal Strike Consequence Relationships Shows some of the effects and transfers for cetacean strikes.

[80] There is anthropological evidence to suggest that some Arctic communities were settled in part due to their proximity to recurring polynas.

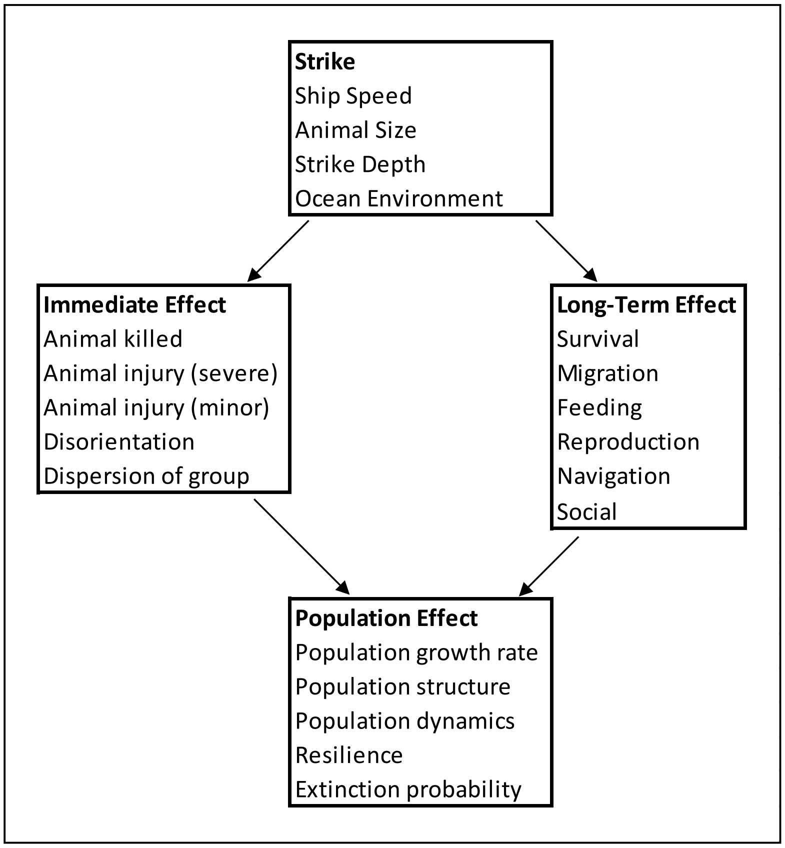

Figure 4.10: Animal Strike Consequence Relationships

Figure 4.12 in Section 4.2.2.6 shows a historical distribution of several data sets for cetacean sightings in the Hudson Strait. Note that the sightings in open water are often in the middle of the Strait where most shipping activity occurs, as well as in Deception Bay and the islands at the West border of the Strait, where a non-trivial concentration of vessel traffic is also present.

Currently this risk is mitigated for both open water and ice only by the practices of the operators involved.

4.2.2.6 Noise from Operations

The noise emitted from engines and vibrations from vessels can travel significant distances under water. Other operational noise sources such as sonars and seismic survey equipment can generate exceptionally high amplitude sounds. Cetaceans and other animals depend on transmission of sound for social interactions, navigation, feeding, etc. Increases in vessel traffic through habitats presents a variety of risks ranging from temporary disruptions to permanent hearing loss, which would likely lead to the death of the affected animal. The following figure shows the preliminary assessment of the risk:

		Scope of consequences				
		Minimal or none	Marginal	Significant	Critical	Catastrophic
Probability of occurance	Near Certainty		MEDIUM			
	Highly Likely					
	Likely					
	Unlikely					
	Remote					

Figure 4.11: Risk Evaluation: Ship Noise

Note that the lack of understanding of the true effects of noise coupled with a lack of data on the frequency of cetacean encounters with vessels is the main reason for assigning a medium, rather than a high level to the risk despite the risk's continuous mode.

Local noise emissions from ships have been measured at almost 200 dB underwater, and icebreaking operations will necessarily increase the noise output. Event based noise from equipment has been measured at higher still sound pressures across a range of frequencies. The following table characterizes sound levels for common commercial vessel activities:

Table 4.4: Sound Characteristics of Various Marine Sound Sources (Hildebrand 2005)[81]

Source	Frequency Range	Sound Pressure	Total Energy
Commercial Shipping	5-100 Hz	150-195 dB*	3.7 x 10^12
Seismic Airguns	5-150 Hz	< 259 dB	3.9 x 10^13
Naval Sonars (LF)	100-500 Hz	235 dB	2.6 x 10^13
Naval Sonars (MF)	2-10 kHz	235 dB	2.6 x 10^13
Fisheries Sonars	10-200 kHz	150-210 dB	Unknown
Research Sonars	3-100 kHz	< 235 dB	Unknown
Acoustic Deterrents	5-16 kHz	130-195 dB	Unknown

The main challenges with assessing and mitigating this type of risk stem from three main factors:

1. Uncertainty regarding the risk to marine mammals (and the marine ecosystem) from ship noise. Noise undoubtedly has a negative impact on the former, however a sound and verified baseline does not yet exist for accurately assessing level of exposure, characterization of the effect of different sound frequencies and amplitudes, as well as the cumulative effects of exposure, and the combination effects of exposure and other risk factors.
2. Inadequate monitoring and risk mitigation. There are few noise monitoring programs in place to collect useful data on the noise output of vessels and the exposure of

[81] Table 1 (Hildebrand 2005) Marine Mammal Commission, Marine Mammals and Noise, March 2007, pp6

marine mammal populations. There are also few established mitigation procedures in place which could be assessed for effectiveness should adequate data become available.

3. Lack of regulation. There are currently no regulations in Canadian waters concerned with management of noise output levels for commercial vessels.

The following map shows the intersection of traffic in the Hudson Strait between 2007 and 2013 with known movements and ranges of a variety of marine mammals known to be susceptible to noise emissions.

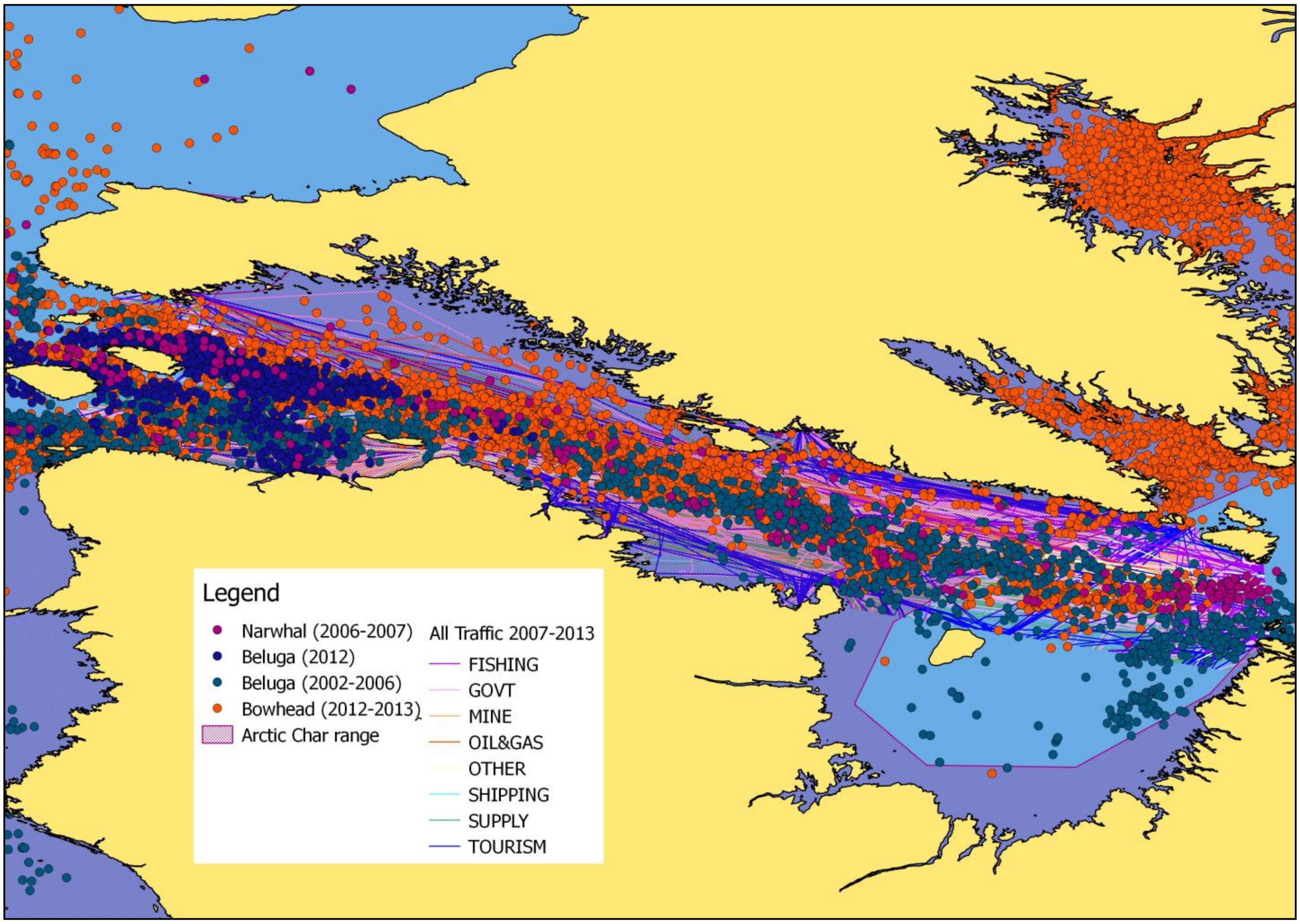

Figure 4.12: Sightings of various cetacean and historical vessel traffic in the Hudson Strait

The consequences of noise exposure in marine mammals are well documented, however their probability of occurring is not well understood, primarily due to a lack of supporting data on exposure, combined effects, and cumulative effects. The following figure shows the various levels of consequences associated with the risk of exposing marine mammals to marine noise sources:

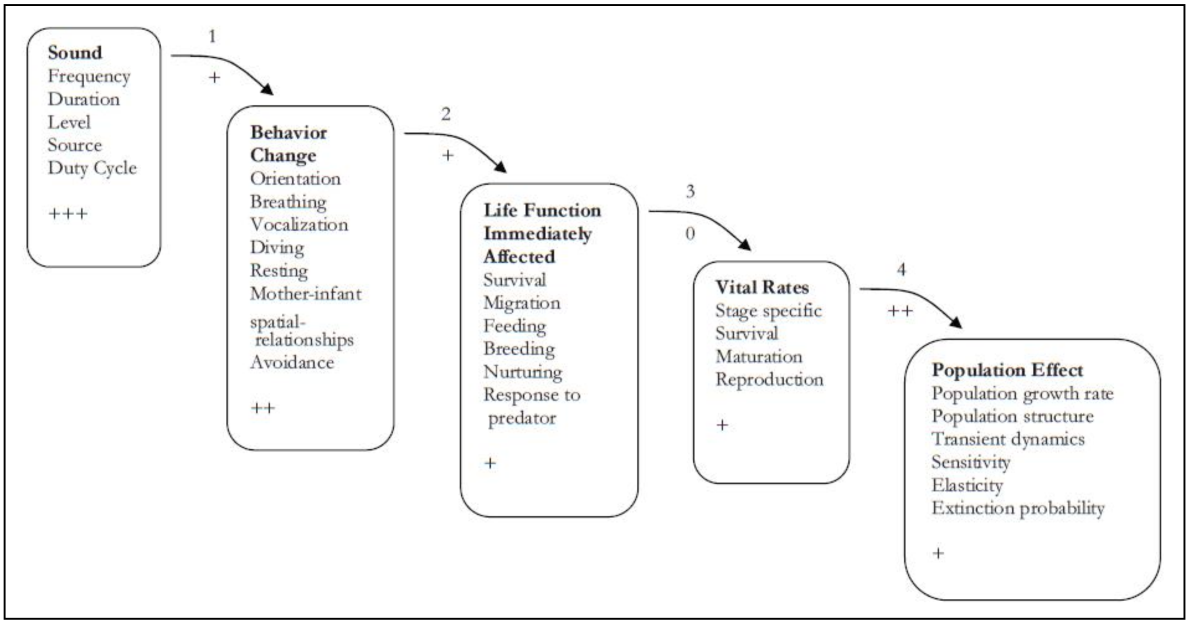

Figure 4.13: Consequences and Transfer of Exposure to Noise (National Research Council 2005)[82]

In the above figure, the "+" and "0" symbols represent the extent to which the consequence (or the transfer function which moves the risk from one level to the next) is understood, with "0" meaning poor or not at all, and "+++" meaning well understood with accepted baseline data.

[82] Figure 3 (National Research Council 2005) Marine Mammal Commission, Marine Mammals and Noise, March 2007, pp16

5 TASK 4: GAP ANALYSIS

The fourth Task of the project presents a gap analysis of the data sources catalogued in Tasks 1 and 2 of the project – shipping activity and environmental, ecological, and socio-economic data respectively. Specifically, it identifies, classifies and addresses gaps between the state of the data collected by the project, and the actual state of data required for an ideal analysis of the various socio-economic, cultural, and ecological impacts of vessel activities in the Hudson Strait.

The data collected in Tasks 1 and 2 of the project was used as an input to the risk assessment produced as Task 3. Gaps in this data can have a number of effects, including lowering the confidence in risk assessment results, or requiring additional assumptions as part of the risk assessment process. The gap analysis evaluates all the data collected in Tasks 1 and 2, and provides a list of gaps which have an impact either on Task 3 directly, or potentially on any future assessments or analyses which could follow on from this project. The gap analysis also ranks the gaps, and identifies those which are considered particularly desirable for closing due to an optimal combination of benefit due to closing and being able to be closed with a relatively modest amount of effort. The results are described in the remainder of this report.

5.1 OVERVIEW OF APPROACH

This report identifies and catalogues a number of gaps between current and desired data sets for the assessment of the impacts and risks of shipping traffic in the Hudson Strait. The current state of knowledge of both ship traffic and the environments of the Hudson Strait has been collected and described in Tasks 1 and 2 of this project. In some cases, the gaps are in areas where an insufficient data quantity and/or quality is relatively common throughout the shipping industry. Other gaps exist due to the unique local environmental or socio-economic situation.

A starting point for gap analysis is to establish a reasonable baseline for what a desirable data set should include. It is important to constrain expectations within the limits of the types and quality of data which are needed for an overall risk assessment, or environmental impact assessment for the Hudson Strait. For example, a better understanding of underwater ship noise propagation would be useful, and is achievable though monitoring and sampling programs. Conversely, a comprehensive study of all local cetacean populations is both logistically challenging, and may not offer enough additional insight to the environment of the Hudson Strait to merit the capital input required for its achievement.

Gap analysis typically follows 4 general steps:

a. Evaluation of all currently held assets (in this case, data sets from Tasks 1 and 2) which must include metrics for the quantity of data, the type of data, and the quality of data;

b. Clear explanation of the data needed for an "ideal" analysis which, like (a), must include metrics for the quantity of data, the type of data, and the quality of data;

c. An evaluation of the "gap" between the current state of each item per (a) and the ideal state of each item per (b);

d. Approaches to close the gaps identified in (c).

Table 4.3 collects the full set of gaps identified under this task. At the highest level, these gaps can be categorized as having a large, medium, or small effort to close, and a high, medium, or low level of criticality.

Effort to Close: This is intended to describe the level of effort to "close" the gap between the baseline data available to the project at the time of writing, and the idea data state.

A large gap could be described as requiring for closure the completion of significant new data collection and/or extensive analysis of existing data which has not yet been undertaken. A small gap could be described as requiring little effort to close, through activities such as additional stakeholder consultation, additional detailed analysis of available data, and/or new yet simple studies and data collection efforts. A medium gap size falls between these two extremes.

Gap criticality: This describes the relative importance of the data gap to the Hudson Strait Shipping Study, and accounts for the project's scope as well as the significance of the data to the types of risk assessments and analysis work the project is intended to support in the future.

A gap with high criticality will provide either a significant improvement to confidence in risk assessment or analysis activities based on the project. A gap with low criticality may improve understanding of the socio-economic, ecological, or oceanographic climate in the Hudson Strait, but will add little if any value to risk assessment or analytical work based on the project. This may be due to a lack of general relevance to the project's scope, or may be due to such data representing high resolution detail where only general details are necessary.

5.2 Gap Analysis

5.2.1 Gap Analysis Process

The gap analysis is presented as a table. Each identified gap is evaluated using a simple matrix. The evaluation identifies the optimal gaps for immediate consideration in terms of their combination of impact on the project's data quality and level of effort required for closure. The most desirable gaps to address are highlighted in red. The matrix used is shown in the following figure:

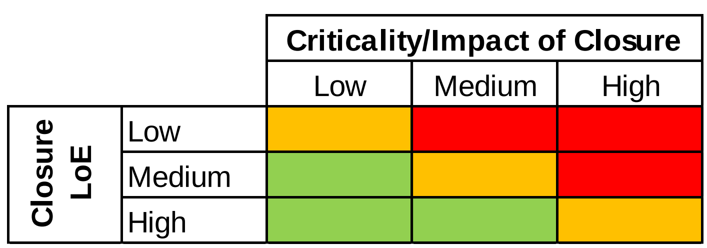

Figure 5.1: Gap Evaluation Matrix

The following tables describe the definitions used to evaluate gaps:

Table 5.1: Gap Analysis – Closure Level of Effort Definitions

Closure LoE	Details
High	Significant effort required, including new, long-term or large-scale studies or data collection efforts, or high-cost data acquisition.
Medium	Moderate effort required, including extension of existing studies, commissioning of new, small-scale studies, or moderate data collection efforts outside scope of planned operations.
Low	Minimal time or cost required, such as data collection as a part of regular operations (e.g. recording additional data with existing or basic additions to ship's equipment) or requesting additional data from stakeholders.

Table 5.2: Gap Analysis – Gap Criticality Definitions

Criticality	Details
High	Closure will dramatically increase confidence in findings of the report, or will dramatically reduce risk of implementing recommendations based on these findings.
Medium	Closure should increase confidence in findings of the report or reduce the risk of implementing recommendations based on these findings.
Low	Closure is unlikely to increase confidence in findings of the report or reduce the risk of implementing recommendations based on these findings.

Using the above evaluation approach, gaps are classified as high (red), medium (yellow), or low (green) priority:

1. High priority gaps represent high benefit and low risk/cost to close. Typically this type of gap should be used to help guide the development of recommendations for future studies or action.
2. Medium priority gaps typically represent a combination of non-trivial benefit and low to marginal risk/cost to close. A selection of these gaps may merit additional discussion in context of the gap analysis, but will not necessarily be used to guide work beyond the current scope.
3. Low priority gaps typically represent items with low benefit, or items with marginal benefits but a high risk/cost of closing – generally these are areas where the baseline information has been useful within the scope of the report, but further refinement will not be recommended for reasons of data resolution, practicality of gap closure, or relevance of data to the project's scope. These gaps will generally be noted but not addressed in further work.

5.2.2 Gap Inventory

The gaps in the table have been evaluated in accordance with the process described in Section 5.2.1. Note that the “priority” levels assigned to the gaps are an evaluation of the relative priority of the gaps. The measures identified to fill gaps are not intended at this stage to be recommendations for future actions, at any priority level. The headings used in the table are defined as follows:

Table 5.3: Gap Table Glossary

Heading	Description
Data	Short description of data.
Priority	Relative priority of gap for closure (High, Medium, or Low)
Criticality	Potential benefit of closing gap (High, Medium, or Low)
Effort/Cost to Close	Potential cost of closing gap (High, Medium, or Low)
State of Data	Baseline state of data as incorporated into report
Desired State of Data	Ideal state of data per scope of report
Gap	Description of the delta between baseline and desired states of data
Effect of Gap	Description of the effect of the gap on the output of the report or the confidence in findings as documented in the report
How Report Addresses Gap	How the existing gap in data has been mitigated or accounted for in the report.
Additional Measures	Potential options for closing gap

Some gaps may not have an entry for “Additional Measures”. In these cases, the associated gap may be addressable by further studies (but no specific approaches have been identified).

The gaps have been aligned as far as possible with the risk categories utilized in the Task 3 report, to facilitate identification of any measures that can reduce the more critical risks. Similarly, the priorities indicated in the Table are informed by the Task 3 risk assessment work.

Table 5.4: Gap Analysis Results Table

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Gaps in Shipping and Vessel Activity/Impact Data										
Accurate/detailed ship transit records (geolocation)	01	HIGH	HIGH	LOW	Ship records are currently compiled from NORDREG data and incorporate a number of assumptions and automated processes for the creation of their transit histories. A key assumption is that where possible, the vessel will travel in a straight course between reported AIS waypoints. These histories do not necessarily account for a) Courses set based on ice conditions b) Courses set based on weather, navigational, or routing preferences. c) Other operational or logistical factors which dictate the course taken by a ship.	Sufficiently dependable information to allow for isolation of spatial and temporal trends for comparing vessel traffic to sensitive regions, while accounting for time of year.	Uncertainty of the precise location of ships for certain cases. Also, a lack of data on manoeuvering tracks and speeds for access and egress to Deception Bay.	The gaps represents an inability to plot the exact historical movements of ships in the Hudson Strait, and overlay them with ranges for habitats and other sensitive areas.	The defined regions for sensitive areas are relatively broad, and the vessel records available provide an adequate representation of traffic for preliminary risk assessment. Future, more detailed work will need to address this gap, while current early work does not.	Acquisition of detailed AIS tracking data from individual vessel operators. Acquisition (for cost) of regional detailed AIS data form 3rd party provider such as ExactEarth.
Accurate/detailed ship transit records (fidelity)	02	HIGH	HIGH	LOW	As above, addressing the additional problem of the reliability of NORDREG AIS data giving a true location for a vessel. Some vessels will "report to NORDREG" upon entering the Arctic, a process which always assigns the same LAT/LONG position regardless of the vessel's true location at the time of the report.	Sufficiently dependable information to allow for isolation of spatial and temporal trends for comparing vessel traffic to sensitive regions, while accounting for time of year.	Uncertainty of the precise location of ships for lower reporting frequencies. Particularly relevant for vessels transiting through the Hudson Strait to Churchill which must navigate past islands at Western-most end of the Strait.	The gaps represents an inability to plot the exact historical movements of ships in the Hudson Strait, and overlay them with ranges for habitats and other sensitive areas.	The defined regions for sensitive areas are relatively broad, and the vessel records available provide an adequate representation of traffic for preliminary risk assessment. Future, more detailed work will need to address this gap, while current early work does not.	Acquisition of detailed AIS tracking data from individual vessel operators. Acquisition (for cost) of regional detailed AIS data form 3rd party provider such as ExactEarth.
Foreign vessel operator information	03	LOW	LOW	MEDIUM	While the nature and qualifications of most domestic traffic is well understood, the performance of both vessels and master for foreign incoming/through traffic is less clearly understood.	Sufficiently detailed information on incoming vessels (i.e., outside the Canadian fleet of regular visitors to the area) to allow for estimates of risk of ice navigation, as well as emissions profiles other ship particulars.	Frequent lack of detail on current state of vessel (i.e., installed power, true dwt, fuel used, etc.)	The gap means that assessments of the likely environmental inputs (emissions, discharge, etc.) as well as risk (cargo loss, vessel damage) of foreign-trading vessels such as bulk carriers in and out of Churchill will have lower confidence.	The majority of vessels where little data is available fall into the category of bulk carriers trading with Churchill. They pose little impact to the confidence of the overall shipping dataset due to the predictability of their routes, the fact that they (currently) trade exclusively during entirely ice-free seasons, and are generally uncomplicated designs which are well understood.	The implementation of the IMO Polar Code should mean that more information on ships entering HS and other Arctic waters is readily available for analysis; measures to collect and collate would be required.

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Vessel cargo specifics	04	MEDIUM	MEDIUM	MEDIUM	Records of cargo carried by vessels were not available at the time of the report's writing, as most operators do not report the details of their cargo manifest. Estimates were generated based on approximate vessel capacities. Due to its nature, modular cargo being delivered as part of sealift operations is almost impossible to quantify with any level of confidence, making estimating the types and quantities of cargo being delivered to communities by sealift impossible	Detailed cargo manifests for vessels carrying bulk, general, liquid, containerized cargo to allow for more complete risk assessment of potential cargo loss.	Almost no data available to general public on cargo.	The gap means that assessments of the likely risk (cargo loss) will have lower confidence.	Vessels which carry cargo with the highest environmental impact in the event of cargo loss (tankers, bulk carriers) have their cargo type and quantity estimated based on simple assumptions; 1. Bulk carriers will typically sail at capacity by dwt 2. Tankers will enter the Arctic at or near capacity in m^3, and most of the latter entering the Hudson Strait from the East will be considered to be beginning their voyage and therefore fully laden.	Measures could be implemented by federal or provincial/territorial governments to collect better information on cargo operations, and these measures can be implemented starting with regions outside the Arctic Successful measures will require regulatory enforcement.
Vessel acoustic properties	05	MEDIUM	HIGH	HIGH	The acoustic properties of vessels operating in the Hudson Strait are unknown, both for steaming, manoeuvering, docking, and icebreaking.	Data for transmitted sound from ships during common activities in the area of interest. Specifically, sound levels for different types of vessels during steaming, manoeuvering, ice breaking.	No data exists other than coarse estimates for peak dB values for containerships transiting in non-arctic waters.	It is currently impossible to accurately determine the exposure of various species to acoustic energy for a variety of reasons, including this gap.	The study flags this as an issue where future studies are critical to understanding and mitigating the risk posed.	Scientific evaluation of ship noise in a number of contexts will be crucial to any future work as it is significant, and poorly understood.
Vessel discharges	06	MEDIUM	MED	MED	The quantity of black water discharged by vessels in the Hudson Strait is unknown.	Metrics for the average amount of black water discharged for common ship and voyage type combinations in the area of interest.	No data is currently available.	It is currently not possible to determine the actual amount of black water discharged to the Hudson Strait by vessels.	Assumptions can be made based on vessel size and crew complement, however without details on holding tanks and operator's policies they are low confidence.	The implementation of the Polar Code may lead to changes in discharge regime and the introduction of procedures that could assist in data collection.
Vessel inputs (coatings, anti-fouling agents, etc.)	07	LOW	LOW	LOW	The characteristics and quantities of potentially harmful agents introduced to the environment by shipping activity (coatings, anti-fouling agents, etc.) both through regular operations and mechanical means (scraping during ice operations) are unknown.	Information on the typical type of coatings and anti-fouling agents used by ships in the area of interest, and estimates of the quantities lost to abrasion as well as regular dispersion to salt water over time.	Minimal data is available for both the types of products used, and the rates at which they may enter the environment though Arctic operations.	It is currently not possible to determine the actual amount of these products introduced to the Hudson Strait by vessels.	The study flags this as an issue worthy of future consideration and evaluation.	Data collection on ice-going vessels could help characterize wear rates and abrasion products

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Invasive species	08	MEDIUM	MEDIUM	HIGH	Models and estimates for invasive species introduction vectors and rates are widely available, but are limited for the environment of the Hudson Strait. Ships can discharge large volumes of ballast waters as they pass through the HS. An important concern with this practice is the potential to introduce non-indigenous species into the marine environment. Invasive species in aquatic habitats are well documented in Canada, but less for the Arctic. One study exists to document the data in the one port of the HS (by Archambault), which shows high risk of having invasive species in HS ports. The ecological consequences of invasive species are unknown.	A global assessment of native species (and proportions of invasive species) for a greater area of the HS, and information on the ecological consequences of invasive species in the HS, including: disease transmission, changes in the genetic structure of native populations, changes in species diversity, alterations of the physical/chemical habitat, cumulative effects.	Uncertainty on how important are the potential of an increase of invasive species and their potential effects on the HS ecosystem.	Risk of underestimating important ecosystem changes and effects on all species of the foodweb.	The study flags this as an issue worthy of future consideration and evaluation.	Refer to the Ballast Water Control and Management Regulations administered by Transport Canada under the Canada Shipping Act. More work could be done to provide baseline data on HS biota to allow monitoring of any changes due to invasive species (and other effects)
Impact of ship traffic on water and sediment quality	09	LOW	LOW	MED	No information was available to the project on the quality of water and sediment in the area of interest. Ship operations can alter the quality of the sediment and water (increase total suspended solids, nutrient mixing, hydrocarbons and metal concentrations). Effects on species or preferential habitat measures are relatively well known already.	Reliable baseline assessment of the water and sediment quality and monitoring of how it changes in time with the increase of ship traffic. Information on ballast water discharge, ship loading, and wastewater management for all ships passing through the HS.	Uncertainty on the actual level of pollution in water and sediments of the HS and lack of power to document the potential changes when ship traffic increase.	These impacts are somehow limited compared to terrestrial activities affecting water, such as construction of docks, vegetation clearing, excavation, drainage, etc.	The study flags this as an issue worthy of future consideration and evaluation.	Refer to the Canadian Council of Minister of the Environment (CCME) water quality guidelines for the protection of marine aquatic life (guidelines for pH, nitrate, arsenic, cadmium, chromium, mercury, total suspended solids, turbidity, and salinity).
Impact of Spills, Accidents and Malfunctions releasing pollutants in an Arctic environment	10	LOW	MED	HIGH	The environmental impacts of Introduction of contaminants through spills, accidents, and malfunctions are documented elsewhere, but are not well understood for the Canadian Arctic.	Sufficiently dependable information/statistics on pollutant release incidents in similar ecosystems.	No data is currently available.	This gap represents a potential underestimate of the impact of ship traffic on wildlife and ecosystem function in the Hudson Strait.	The report identifies the risk associated with pollutant release as a key risk for mitigation measures.	Not applicable at this time - quantitative data would require studying past incidents which have not occurred on a significant scale in the area of interest to date. Additional research will need to take place via modelling and simulation.
Gaps in Ecological Data										
Effect of physical disturbance on marine mammal populations	11	MEDIUM	MED	HIGH	Limited data on the effects of vessel traffic on the behaviour of cetacean species. Interaction with ship traffic can alter the breathing and social behaviours of cetaceans.	Habitat use by cetaceans in link with ship traffic.	Uncertainty on the true effect of ship traffic on marine mammals' behavior and survival, as well as limited metrics for ship/animal interactions.	This gap represents a risk of inaccurately assessing the potential direct effects of ship traffic on cetaceans.	The study flags this as an issue worthy of future consideration and evaluation.	Similar to cetacean strikes, Implement a system of data collection for observations of marine mammals in the HS via an easy interface for ships could use to build a database on marine mammal interactions in the area over time.

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Metrics for animal strikes	12	MEDIUM	MED	HIGH	No information available for quantifying the number of collisions occurring in the Hudson Strait.	Annual statistics on marine mammal encounters and collisions per type of ship for the Hudson Strait	No data is currently available.	Assessments of collision frequency are based entirely on estimates, which results in lower confidence results.	The study flags this as an issue worthy of future consideration and evaluation.	Implement a system of data collection for observations of marine mammals in the HS to build a database on marine mammal interactions in the area over time.
Effects of collisions on cetaceans	13	HIGH	HIGH	LOW	Good data is available documenting the potential effects of vessel/cetacean collisions. Marine mammals in the HS can experience direct injury of mortality from collisions with vessels. Baleen whales (Bowhead) are known to be more vulnerable to collisions. Ship impacts can also adversely impact the biological activities of cetaceans: disturbing their breathing, diet, rest and socialisation, and affecting their ability to care for juveniles.	A global model considering many parameters interacting to increase the risk of collisions: weather, ship speed, whale species & population structure, ambient noise, linked to whale distribution and ship traffic.	Lack of integration between useable data sets for cetacean activities and shipping.	There is no current way of addressing and/or describing the areas of higher risk, or proposing potential solutions to reduce these risks.	Marine mammal distribution maps are overlapped with ship traffic maps and the highly overlapping areas are considered as greater risk area.	Data is available for most parameters, and it would be a matter of integrating that into a holistic approach/model to have the best overview of ship collision risks in the HS. This may lead to mitigation measures such as whale-detection technology (ex. RepCet), station a trained observer on ships passing through the HS, or best practices (using such as "A Mariner's Guide to Whales in the North Atlantic")
Effect of noise on higher species	14	MEDIUM	HIGH	HIGH	Limited information on the response to noise from cetacean species is available, however no information on noise levels or trends on the area of interest was available to the project. Low-frequency noise from large ships (20–200 Hz) overlaps acoustic signals used by whales, and increased levels of underwater noise have been documented in areas with high shipping traffic. Reported responses of whales to increased noise include: habitat displacement, behavioural changes and alterations in the intensity, frequency and intervals of calls, hearing impairment. However, it is unclear whether exposure to noise results in physiological responses that may lead to significant consequences for individuals or populations.	Local estimates of noise levels and effects on different species of marine mammals (mainly cetaceans - whales, narwhals, and belugas, and pinnipeds - seals and walrus)	Uncertainty on the level of noise in the HS and therefore the potential impacts on marine mammal species, specifically for this area.	Less confidence in impact effects on marine mammals if no noise levels are recorded for the HS area.	The study flags this as an issue worthy of future consideration and evaluation.	Conduct specific studies on hearing abilities, behaviour and potential impacts of noise on different species of marine mammals in the Hudson Strait. Support research on acoustic modelling (ice breaking) and monitoring in the HS.

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Effect of noise on commercially important species	15	LOW	LOW	MEDIUM	Limited data is currently available on the effects of intermittent noise on species such as Arctic Char. Intermittent noise disturbance due to vessel operations and loading activities can create avoidance of certain areas by fish species. Response to vessel noise seems to vary with distance, water depth, and natural light levels (Vabø et al. 2002). Noise can also alter communication in fish (for protection of territory, defence and reproduction).	Knowledge of noise tolerance for commercially important species (Arctic Char, Greenland halibut, Wolffish, shrimp), avoidance behavior per species, and estimation of noise in different areas of the HS due to ship traffic.	Limited data is currently available for noise response from certain species, however no overall models for populations is available.	This gap represents a potential loss of information on how species distribution is going to change according to the level of noise generated by ships. Distribution maps that are provided in this study don't take into account the potential avoidance scenarios.	Species distribution are mapped over ship traffic and the overlapping areas are assumed to be high risk of species disturbance.	Develop algorithms coupling ship distance, water depth and luminosity (all data that we have) with fish distribution to represent the potential avoidance risk
Effect of noise on lower trophic levels	16	LOW	LOW	HIGH	The effects of noise on lower trophic levels in the HS is unknown	Information on the overall effects of noise on benthic productivity, biodiversity, species distribution.	No data is currently available.	It is currently not possible to determine the details effects of noise on benthic communities.	The study flags this as an issue worthy of future consideration and evaluation.	The issue is beginning to be recognized by ecologists in other areas of the world, and the Hudson Strait could be a candidate for future studies.
Spatial-temporal distribution of cetaceans	17	HIGH	HIGH	MEDIUM	Relatively good information is available for Bowhead whale, and beluga (satellite tagging), and a little less for narwhal (survey from 2010) in terms of distribution. No data covers all seasons.	Satellite tracking data for all cetacean species passing through the HS, and seasonal information as well.	Uncertainty on the presence of cetaceans in the HS at different time of the year. Since this is an important migration passage but also an important living habitat, not having seasonal data to link with ship traffic could under- or overestimate the impact of ships on cetacean populations (assuming they may or may not be there at the same time).	Risk of under- or overestimating the impact of ship traffic on cetaceans.	Best estimates of cetacean distribution and seasons covered are reported in this study. Time periods where no data is available are highlighted as potentially critical.	Combine satellite tracking data or other type of survey data into a single dataset. Also, make publicly available and integrate the results from the series of 3 acoustic data recorders which were deployed in the HS by DFO.
Spatial-temporal distribution of pinnipeds	18	MEDIUM	MED	MEDIUM	Poor distribution data for seals (from an aerial survey that was not done to census seals), and summer and winter grounds available for walrus (along with some traditional ecological knowledge).	Comprehensive survey of seal and walrus distribution in the HS per month.	Uncertainty on the presence and habitat use of pinnipeds in the HS at different time of the year.	Risk of under- or overestimating the impact of ship traffic on seals in walrus.	Best estimates of seals and walrus distribution for winter and summer. Time periods where no data is available are highlighted as potentially critical.	A walrus survey will be done in October 2014 by a DFO team (J-F Gosselin), this should be considered for further studies.
Spatial-temporal distribution of other species	19	LOW	MED	HIGH	Some quantitative data on fish & other commercially important species distribution in the HS. Shrimp, wolffish, Iceland scallop and Greenland halibut are covered by stock assessments, but distribution is not detailed temporally.	Spatial-temporal distribution of commercially important species in the HS, with critical habitat (ex. for reproduction), main fishing grounds.	Uncertainty on the overlap of commercially important species with ship traffic.	Risk of under- or overestimating the impact of ship traffic on commercially important species.	Data are assumed to represent annual average/distribution. Whenever it's overlapping with ship traffic, it was considered as an important risk to commercially important species.	

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Ecosystem change - Sea Ice	20	MEDIUM	HIGH	HIGH	No empirical data is currently available documenting the effects of changing surface ice conditions. The distribution of sea ice and its relationship to open water plays an important role in determining the distribution, movement patterns and abundance of all marine species (from microalgae and associated primary production through the whole food web). It provides resting surface, represents a temporary barrier to migration, a navigational aid to migrating species, a predation escape system, a source of food, and a hunting area for Inuit.	Sufficiently precise information on how much polynas and pack ice will be perturbed by ship traffic. Sufficiently precise information on how species are depending & affected by ice in the Hudson Strait.	No quantitative data exist describing the effects of icebreaking on pack ice. Uncertainty on how ice will change in link with ship traffic, and how ice habitat change precisely affects population parameters for populations depending on it.	This gap represents the potential impact on the whole ecosystem, with potential cumulative effects through foodweb on all species of the Hudson Strait (from primary production to endangered marine mammal species).	Species distribution are linked with ice predictions models and thus are likely to represent the areas where species depend more on ice.	Development of models of ice disruption, and quantitative data on the effects of icebreaking on pack ice. Specific research projects for each species and their unique relationship to the ice. Interviews and consultation with local communities.
Pinniped habitat change resulting from ice-breaking	21	LOW	MED	MED	Little information is available about walrus breeding and calving in Canadian waters. Pinnipeds depend on ice for breathing, for breeding, and nursing their pups for their first 38-44 days. The timing and route of Walrus migration closely depends on ice, and so is the life cycle that rely on it.	Reliable information of ice conditions (natural plus changes due to ship traffic) in the Hudson Strait	Uncertainty on the survival rates of seals and migration efficiency of Walrus	The gap means that the potential impact of ship traffic on pinnipeds and thus on Inuit harvesting will be underestimated.	The study flags this as an issue worthy of future consideration and evaluation.	
Habitat change for Arctic Char (health & water quality)	22	LOW	MED	HIGH	Adequate information currently available on the biology of this species and its habitat due to value as cultural, subsistence, and commercial resource. Limited data on physical habitat alteration due to ship traffic and waves generation in the coastal habitats.	Reliable assessment of how ship traffic and waves are likely to alter the coasts and habitats of Arctic Char, consequent effects on the survival rate of this species.	Uncertainty on the effect of ship traffic on coastal habitat alteration.	This gap represents a risk of inaccurately assessing the productivity of Arctic Char populations and consequently on Inuit harvest on this stock.	The study flags this as an issue worthy of future consideration and evaluation.	
Impacts of habitat change (sea ice) for seabirds	23	LOW	MED	HIGH	Seabird migration and nesting is known to be linked to ice. No information was available to the project.	Sufficiently precise information on how sea ice affects the biology and survival of seabirds in the HS.	No data is currently available.	This gap represents a potential lack of assessing the true impact of marine traffic on seabird populations in the Arctic.	The study flags this as an issue worthy of future consideration and evaluation.	
General impact on seabirds	24	MEDIUM	MED	HIGH	It is known that ship traffic, and ship emissions in particular, can have an effect on the distribution and behaviour of seabirds. No information was available to the project.	An overview of seabird distributions correlated to ship traffic patterns, including the distance between typical vessel routes and sensitive seabird habitats. Additional research into behaviour of seabirds towards ships in these areas.	No data is currently available.	Underestimation of the effects of ship traffic on seabirds because nothing is considered.	The study flags this as an issue worthy of future consideration and evaluation.	

Data	ID	Priority	Gap Criticality	Effort to Close	State of Data	Ideal/Desired State of Data	Gap	Effect of Gap	How is gap addressed in report	Additional measures
Ecosystem changes - Cumulative effects	25	N/A	N/A	N/A	No information is currently available documenting any assessments of the cumulative effects of ecosystems changes in the Hudson Strait. Marine ecosystems are complex and it is now more documented that in addition to all sources of perturbations potentially impacting the species and ecosystem functions, the cumulative effects are even greater than the sum of these perturbations taken independently. This phenomenon is known and has been studied for other ecosystems, but nothing has been done yet in the Arctic (where other impacts, including climate change, are important)	Better information on how cumulative effects are affecting the HS ecosystem and the species that depend on it.	No data is currently available.	Not assessing cumulative effects presents a risk of under-estimating the overall level of risk posed to the Hudson Strait from shipping activities.	Cumulative effects of various aspects of shipping activities are not considered in the report. The complete lack of information on the topic does not allow assessment with any level of confidence.	Development of a framework for assessing cumulative risk which is acceptable to the involved parties will be required for any additional work.

5.2.3 Gap Analysis Commentary

The gaps identified above can be considered to fall into two main categories:

i. Those for which there is a global lack of data or knowledge, such as the noise signatures of vessels and the effects on animal behaviour;

ii. Those for which there is a local lack of data or knowledge, such as distributions of various species in the Hudson Strait or a lack of detailed information on cargo types and volumes.

Gaps in category (ii) can only be filled by local actions. Those in category (i) are, in general, the subject of more wide ranging ongoing research. However, there could be a case for giving the Hudson Strait and other less-travelled routes more focused attention, as these are areas in which “natural” behaviours have not yet been affected significantly by human interactions. As such, they may offer particularly valuable insights into some aspects of the impacts of marine traffic.

Some of the gaps suggested as having the highest priorities for further work are in the following areas:

Vessel noise: The noise issue is gaining more public visibility, and data collection efforts which could usefully feed into studies would require only minimal time and equipment and would take place entirely during regular operations. Addressing these gaps would also benefit other studies concerned with regions outside the Hudson Strait.

Cetacean interactions: Numerous studies surrounding cetacean behaviour are already in place, and given a sufficiently simple system for logging interactions, could easily and effectively be supplemented by real observational data at a minimal cost. Addressing these gaps would also benefit other studies concerned with regions outside the Hudson Strait.

Vessel traffic and manifest data: Accurate vessel location and performance data, coupled with information on cargo, fuel, and other operational parameters, would have an immense benefit to the quality of any assessments and analyses stemming from this project. The data is, at least for domestic operators, already collected and held internally.

All of these are gaps that have significant influences both on the severity of risks and on the uncertainties surrounding these. They are also amendable to data collection activities that are, in general, relatively easy and low or medium cost to address.

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ANNEX A
TABLES OF DATA SOURCES

The following tables list the collected data sources for the socio-economic, cultural, oceanographic and ecological aspects of the Hudson Strait.

The references cited are detailed in the last section of this report. Availability refers to the format in which the data is provided. Spatial and seasonal distributions are indicated for each data source, if/when existing. The data quality column refers to the overall pedigree of each data source, ranging 1 (general knowledge, guesstimate) to 10 (Field-based, local, recent and quantitative data).

Table A.1: Ecological Data Sources

Species	Reference	Availability	Spatial Distribution	Seasonal Data	Data Quality
Ecosystem	CSAS 2011	PDF	YES	NO	7
Bowhead whale	Wheeler *et al.* 2012	PDF	YES Extract from published map (contacted author to get the shapefile)	YES	9
Bowhead whale	Pomerleau *et al.* 2011	PDF	YES Extract from published map	YES	6
Bowhead whale	Hide-Jorgensen *et al.* 2011	PDF	YES Extract from published map (contacted author to get the shapefile)	YES	8
Bowhead whale	Hide-Jorgensen *et al.* 2006	PDF	YES Extract from published map (contacted author to get the shapefile)	YES	8
Bowhead whale	NWMB 2000	PDF	YES (maps are not in the PDF, I asked for them)	NO	6
Bowhead whale	Dueck *et al.* 2006	PDF	YES Extract from published map	YES	8
Bowhead whale	CSAS 2008	PDF	YES	NO	7
Bowhead whale	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Beluga	Hammill & Lesage 2009	PDF	NO	YES	5
Beluga	Bailleul *et al.* 2012	PDF	YES Extract from published map	YES	5
Beluga	Lewis *et al.* 2009	PDF	YES Extract from published map	NO	8
Beluga	Smith *et al.* 2005	PDF	YES Extract from published map	YES	8
Beluga	Pew	WEB	YES	YES	8

Species	Reference	Availability	Spatial Distribution	Seasonal Data	Data Quality
Beluga	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Narwal	Westdal *et al.* 2010	PDF	YES Extract from published map	YES	8
Narwal	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Walrus	Reeves 1995	PDF	YES Extract from published map	YES	4
Walrus	Mallory and Fontaine 2004	PDF	YES	YES	3
Walrus	COSEPAC 2006	PDF	YES	NO	5
Walrus	Born *et al.* 1995	PDF	YES	YES	5
Walrus	Stewart 2008	PDF	YES	YES	7
Walrus	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Killer whale	Higdon *et al.* 2013	PDF	YES	NO	5
Seals	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Polar Bear	Kurvits *et al.* 2010	PDF + Shapefiles	SHAPEFILES	NO	9
Polar Bear	CAFF 2001	PDF	YES Extract from published map	NO	5
Polar Bear	Elliott *et al.* 2013	PDF	YES	YES (Spring)	9
Eiders	Mallory and Fontaine 2004	PDF	YES	NO	3
Eiders	Mallory and Fontaine 2004	PDF	YES	YES	3
Murres	Kurvits *et al.* 2010	PDF + Shapefiles	SHAPEFILES	NO	9
Seabirds	Mallory and Fontaine 2004	PDF	YES	YES	3
Seabirds	Mallory and Fontaine 2004	PDF	YES	YES	3
Seabirds	Mallory and Fontaine 2004	PDF	YES	YES	3
Seabirds	Mallory and Fontaine 2004	PDF	YES	YES	3
Arctic Char	Kurvits *et al.* 2010	PDF + Shapefiles	SHAPEFILES	NO	9
Greenland halibut	Alton *et al.* 1988	PDF	YES	NO	3
Wolffishes	CSAS 2013	PDF	YES	NO	8
Iceland Scallop	Lambert and Préfontaine 1995	PDF	YES	NO	6
Shrimp fishery	CSAS 2010	PDF	YES	YES	8
Corals & Sponges	Kenchington *et al.* 2011	PDF	YES	NO	7

Species	Reference	Availability	Spatial Distribution	Seasonal Data	Data Quality
Invasive species	Goldsmith *et al.* 2014	PDF	YES	NO	7

Table A.2: Oceanographic, Socio-Economic, and Cultural Data Sources

Data Type	Reference	Availability	Spatial Data	Seasonal Data	Data Quality
Geospatial	Arctic Voyage Planning Guide (Airports)	WEB	YES (manual compilation)	N/A	10
Geospatial	Arctic Voyage Planning Guide (Navigation Aids)	WEB	YES (manual compilation)	N/A	10
Geospatial	GEBCO_08 Bathymetric Grid	WEB	YES	N/A	10
Seasonal	CCG Ice Navigation Ch3	WEB	NO	YES	10
Geospatial	CIS Ice Charts	WEB	YES	YES	10
Models	Chandler, Covill 1985	PDF	YES (manual compilation)	N/A	6
Models	Drinkwater 1983	PDF	YES (manual compilation)		6
Models	Fiammetta & Straneo & Saucier 2008	PDF	YES (manual compilation)		6
Various	GRID Arendal Arctic Atlas	WEB	YES (manual compilation)		7
Geospatial	NOAA Mean SST	WEB	YES	YES	10
Geospatial	NOAA Historical Weather Data	WEB	YES	YES	10
Geospatial	NOAA MASIE Ice Extent	WEB	YES	YES	10
Geospatial	NOAA MASIE Ice Index	WEB	YES	YES	10
Social	Nunavut Planning Commission 2013	PDF	N/A	N/A	5
Various	Thomas, Kendrick VARD 2014	VARD	YES	YES	5-10
Geospatial	XTide 2014	WEB	YES	YES	10

ANNEX B
RISK EVALUATION DETAILS

The following table provides an alternate view of the risk evaluations for the risk items identified in Table 4.3: Risk Inventory and Assessment Table.

Table B.1: Risk Item Evaluations

ID	Risk	Probability or Frequency	Consequence Severity	Risk Level
1	Cetacean strike	3	3	Med
2	Other species strikes	2	3	Med
3	Disruption of fish stocks	2	3	Med
4	Icebreaking - ice environment change	1	2	Low
5	Wake wash disruptions (general)	2	2	Low
6	Wake wash disruption of shorelines	3	2	Med
7	Disruption of airspace	3	2	Med
8	Noise Disruptions (sailing)	5	2	Med
9	Noise Disruptions (icebreaking)	3	1	Low
10	Noise Disruptions (surveys)	2	2	Low
11	Air Emissions (operational)	5	2	Med
12	Pollutant Discharge (Operational)	4	2	Med
13	Harmful Substance Discharge (Operational)	3	1	Low
14	Introduction of invasive species	1	4	Med
15	Socio-Economic disruption	2	2	Low
16	Capsize	2	5	Med
17	Ice Impact	5	2	Med
18	Beset in ice	4	3	Med
19	Ship impact	3	1	Low
20	Grounding	2	4	Med
21	Equipment failure/pollution release	1	3	Low
22	Loss of control	2	4	Med
23	Sealift spill	2	4	Med
24	Sealift cargo loss	2	2	Low