Arctic Marine Shipping Assessment

Background Research Report on Potential Environmental Impacts from Shipping in the Arctic

Draft Version April 24, 2009

Lead Author:

Hein Rune Skjoldal

Supporting Authors:

Donald Cobb, James Corbett, Maya Gold, Susie Harder, Loh Lee Low, Rebecca Noblin, Gregory Robertson, Amy R. Scholik-Schlomer, Whit Sheard, Greb Silber, Brandon Southall, Chris Wiley, Bill Wilson, James Winebrake

Table of Contents

1. Introduction

Marine shipping, if not properly managed, poses a threat to natural ecosystems. This is especially true for the Arctic. Whether it is the release of substances through emissions to air or discharges to water, accidental releases of oil or hazardous cargo, disturbances of wildlife through broken ice, sound, sight, collisions or the introduction of invasive alien species, the Arctic marine environment is especially vulnerable to potential impacts from marine activity.

Extreme cold temperatures, ice and strong seasonal variability characterize the Arctic. These extremes have resulted in a range of adaptations among Arctic animals including the ability to store energy when food is plentiful and fast when it is not; highly insulating outer layers such as feather, fur or blubber to keep warm; and a high degree of seasonal migration to and from the region, especially among marine mammals and birds.

Disruption of the Arctic region's short feeding seasons could result in some animals not getting enough food to cover the energy needed for the long migration and for breeding. Adaptation to the extreme cold climate has resulted in many Arctic species reliant on feathers and fur to insulate against the cold and can quickly die from exposure if that defense is compromised. These characteristics make Arctic species more vulnerable to oil spills and disturbances during critical periods.

The extensive seasonal migrations of marine mammals and birds into and out of the Arctic are key features that, to a large extent, determine the vulnerability of Arctic ecosystems. Seabirds, shorebirds and waterfowl move north to breed and feed during the short Arctic summer. Whales and seals have similar migrations to northern feeding areas. During their migration and stay in the Arctic, many species aggregate throughout the circumpolar north in very large numbers to feed, mate, give birth, nurture their young and undergo certain processes such as molting. Where and when these aggregations occur, animals are particularly vulnerable to potential environmental impacts.

Arctic marine mammals such as bowhead, beluga, narwhal, walrus and several species of seals migrate south in fall to spend the winter in the southern areas of multi-year ice. In spring, they move north again, using systems of polynyas and leads, often before the break-up of the ice. At this time, these mammals reproduce and give birth to their young. Important wintering areas for marine mammals are in the broken pack ice in the northern Bering Sea, Hudson Strait, Davis Strait and southeastern Barents Sea. From these areas, the mammals follow leads and openings north through the Bering Strait and the Chukchi Sea; north through Baffin Bay into Lancaster Sound, into Hudson Bay and Foxe Basin; and north and east into the Kara and Laptev seas. The leads and openings in the ice are also used by seabirds, eiders and other marine birds on their spring migration to the northern breeding areas.

The migration corridors used by marine mammals and birds correspond broadly with the main shipping routes into and out of the Arctic. However, the shipping activity usually occurs later in the season when the ice has receded, compared to the spring use by mammals and birds. This lowers the conflict and threats from shipping with the current seasonal activity patterns. The spring migration corridors are particularly sensitive and vulnerable areas to oil spills, ship strikes and disturbances, and could be a time of vulnerability for marine mammals and birds if Arctic marine shipping expands into this time frame.

The area for this assessment spans a wide range of environmental conditions, from pack ice in the Arctic Ocean to open subarctic waters in the Bering Sea and the Nordic seas in the northeastern Atlantic. The volume of current shipping traffic varies considerably within the Arctic. Currently, there is year-round traffic out of the Yenisei River and Pechora Sea to the port of Murmansk in northern Russia and along the coast of Norway, a moderate amount of seasonal shipping to and from destinations in the North American Arctic and no established trans-Arctic traffic. In contrast, the North Pacific's Great Circle Route between western North America and eastern Asia is a high volume shipping lane that swings through the Aleutian chain near large aggregations of animals. This is the case in Unimak Pass in the eastern Aleutians, which is in close proximity to important haul-outs, rookeries and nesting sites of marine mammals and seabirds and close to active commercial fishing grounds and one of the largest protected essential fish habitats in the world.

2. Potential Environmental Impacts from Ships

***Missing Introductory Text

Ship Category	Ship Sub-category/ Use	Ship Type–Specific Pollution Sources
Government Vessels and Icebreakers	Coast guard vessels, research icebreakers, private icebreakers, government icebreakers, other research vessels	Accident/incident recovery-produced contaminants, emergency dumping oil/fuel, nuclear icebreaker radiation contamination, explosives/munitions, impacts due to icebreaking activity (disruption of ice formation, marine mammals, etc).
Container Ships	Cargo transport	Hazardous goods in transit, convoy collision hazard, grounding hazard (uncharted waters, lack of experienced ice navigation).
General Cargo	Community re-supply vessels, roll on/roll off cargo	Hazardous goods in transit, accidental cargo release, contaminated cargo.
Bulk Carriers	Timber, merchant, oil, ore, automobile carriers	Release of metal contaminants, radiation contamination from cargo, hazardous goods in transit.
Tanker Ships	Oil tankers, natural gas tankers, chemical tankers	Liquid Nitrogen Gas contamination, chemicals and hazardous goods in transit, spills from oil transfer.
Passenger Ships	Cruise ships, ocean liners, ferries	Large volumes of black and grey water release, garbage disposal, cleaning contaminants, disturbance of wildlife through viewing activities, automotive contaminants w/ vehicles ferries .
Tug / Barge	Re-supply vessels Bulk cargo transport	Increased accident hazard (non-propelled), hazardous goods in transit, spills during oil transfer, heavy emitters of air contaminants (black carbon).
Fishing Vessels	Small fishing boats, trawlers, whaling boats, fish processing boats	Increased fire hazard, introduction of pathogens and other contaminants from released fish offal, accidental release of invasive species/related biological contaminants, release of plastics, ghost nets and other fishing debris, seafloor damage from bottom trawlers, depletion of marine species (if not managed), accidental release of refrigerant contaminants.
Oil and Gas Exploration/Exploitation Vessels	Seismic exploratory vessels, oceanic and hydrographic survey vessels, oil drilling vessels, oil and gas storage vessels, offshore re-supply, portable oil platform vessels, other oil and gas support vessels	Hazardous cargo, explosives, acoustic impacts from seismic activities, oil/hydrocarbon contamination, contamination from extraction chemicals, accidental loading/offloading spillage, fire hazards.

Table 8.1 A range of potential environmental impacts linked to ship types operating in the Arctic. *Note: All ships will have certain impacts linked to the release of grey water, sewage, ballast and bilge water; air emissions; regular and accidental discharge of fuel/oil; introduction of noise and other acoustics such as sonar; and possible strikes on animals. Those listed above are in addition to these and specific to the vessel type.* Source: AMSA

2.2 Emissions to Air

2.2.1 Background

Studies assessing the potential impacts of international shipping on climate and air pollution demonstrate that ships contribute significantly to global climate change and health impacts through emission of GHGs (e.g., carbon dioxide [CO_2], methane [CH_4], or chlorofluorocarbons [CFC]), aerosols, nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), and particulate matter (PM) [1-5]. Ships are very minor sources of methane emissions, except for potential evaporative emissions from petroleum cargoes and fuel storage, not assessed here [6]. This has raised the potential for disproportionate impacts from shipping in the Arctic. We present an inventory of emissions of CO_2, BC, NO_x, SO_x, PM, and CO for Arctic shipping. This background section summarizes the emissions and impacts of general concern with regard to shipping.

2.2.2 Brief Summary of Climate-Forcing Emissions and Impacts from Ships

Direct Impacts

Carbon dioxide (CO_2)

Carbon dioxide is produced from marine vessels as a by-product of the oxidation of carbon in diesel fuel. International shipping emitted approximately 800 million metric tons (MMT) of CO_2 in 2000, contributing about 2.7% of global CO_2 emissions that year [7]. Current estimates (2007) report that ships emit about 1,000 $MMTCO_2$/yr, with the increases attributed to growth in international trade [8].

Black carbon (BC)

Black carbon is a component of particulate matter (PM) and is produced by marine vessels through the incomplete oxidation of diesel fuel. Black carbon has a positive climate-forcing effect since it absorbs sunlight [9, 10]; this effect is likely greater in the Arctic region and other snow- and ice-covered regions, because black carbon can reduce the snow's reflectivity and accelerate the melting process when deposited on snow or ice. International shipping emits between 71,000 and 160,000 metric tons of BC annually, representing about 15% of total PM from ships and about ~2% of global BC from all sources [11, 12]. The total warming impact of global BC emissions from global sources has been estimated to range between 18% and 55% of "CO_2 forcing and is larger than the forcing due to the other GHGs such as CH_4, CFCs, N2O or tropospheric ozone," with a best estimate of ~40% [13]; total impacts attributable to BC from ships have not been estimated independent of other PM impacts [13-16], but shipping could be a source of BC closer to Arctic regions than land-based emissions contributing transcontinental impacts. More research is needed to determine how mitigation benefits may be associated with BC reductions from ships in sensitive regions.

Indirect Impacts

Nitrogen Oxides (NO_x).

Nitrogen oxides are produced in high temperature combustion in ship engines and act as precursors to tropospheric ozone (O_3), a potent GHG [14]. In 2000, ships emitted approximately 5 MMT of NO_x (as N), with registered fleet NO_x estimated in 2000 to range between 15% to 30% of global anthropogenic NO_x emissions [7, 11]. Recent estimates are on the order of 7.8 MMT of NOx (as N) in 2007 [17]. Radiative forcing estimates for tropospheric O_3 due to shipping are in the range of 40% of annual CO_2 forcing from ships, although this does not consider the cumulative effects of CO_2 during its longer residence time in the atmosphere [15, 16]. NO_x emissions also can lead to increased nitrates in the atmosphere and methane (CH_4) scavenging, so overall climate forcing impacts may ultimately be neutral.

Carbon Monoxide (CO)

Carbon monoxide is a precursor to tropospheric O_3 and CH_4, two potent GHGs, and is released during fuel combustion. In 2002, ocean-going ships emitted approximately 1.1 MMT of CO [11], or 0.1% of emissions from all fossil fuel sources [18].

2.2.3 Methodology- Overview

Historically, inventories of air pollution from ships focused on local and regional pollutants, such as sulfur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM) [19-22]. These inventories were critical in evaluating proposed policies designed to reduce the regional environmental and health impacts of such pollutants [23-25]. In developing these inventories, researchers applied activity-based and fuel-based methodologies, and these methodologies were subsequently used to also generate estimates of GHG emissions from ships [26-31]. These benchmarking studies gained greater policy importance in recognition of the significant rates of growth in international goods movement [32-36].

Consistent with this literature, we apply here an activity-based emissions model to conduct our analysis. In this work, we estimate emissions for a particular "vessel-trip" or "voyage" based on Arctic shipping data collected by the Arctic Marine Shipping Assessment for 2004. Aggregating all vessel-trips in a region, such as the Arctic region, allows us to create an inventory for the region and to begin to estimate emissions impacts. This section discusses the methodology for our analysis, and provides emissions inventory estimates for the Arctic shipping region.

Data

Data were collected as part of the AMSA project, a summary of which is included in chapter 3 of this report. The data consisted of individual vessel-trips or voyage days in the Arctic region as reported by all Arctic states for the year 2004. The data included: (1) vessel characteristics (IMO number, vessel size, vessel type, main engine power, design speed, country); (2) trip data (duration, distance, origin port, destination port); and (3) geospatial information (latitude and longitude values for ship movements, where available). Norway provided data in a separate format, using AIS reports to delineate unique vessel trips. It is very important to note that vessel counts and trips reported by a nation include vessels registered outside the reporting nation; in fact, most ships reported by nations for open-ocean (high-seas) routes may be registered in major flag States other than nations reporting to AMSA. This is obviously the case for nations like the United States reporting the portion of the Great Circle trade route within the AMSA domain, where few of these ship trips would be US-flag vessels.

Although the data may have gaps and inconsistencies in reporting detail between reporting states, this dataset is the first of its kind to warehouse multination Arctic voyage information into one location, and is considered the best available data on Arctic shipping to date. Data existed for the classes of vessels shown in Table 2.1. This table shows specific vessel types in the first column and the numbers of trips reported in the second column. For fishing vessels, we drew from the data the number of days operating underway associated with large marine ecosystem (LME), instead of number of trips.

Table 2.1 List of vessel classes and voyage counts by class assessed in the AMSA report.

Reporting Category	Trips
Bulk Carrier	1,052
Container Ship	2,096
Fishing Vessel	NA
General Cargo Ship	1,403
Government Vessels/Icebreakers	273
Passenger Vessels	6,972
Special Purpose Vessel	58
Tanker	2,827
Tug and Barge	317
Grand Total	14,998

In many cases data gaps existed that had to be filled using best estimates and assumptions. For example, some of the major data gaps and how they were filled included:

Vessel design speed. When unknown, a "class average" of design speed for vessels of similar class was used; for fishing vessels we assumed a typical service speed of ~6 knots.

Vessel main engine power. When unknown, a "class average" of engine power for vessels of similar class was used; for fishing vessels we assumed the engine power used would follow the propeller law proportionality with average speed.

Trip duration. When data on departure day and/or arrival day were not reported, we apply multi-nation averages by vessel type; this allows us to use all available data in a first-order estimate with a similarity assumption for vessel type undifferentiated by reporting nation.

Analysis

The activity-basedmodel that we applied follows the general structure:

$$E_{ijk} = EF_{ij} \times LF_{ij} \times \frac{KW_j}{\eta_j} \times T_{jk}$$

where, E_{ijk} are emissions of type i from vessel j on route k in grams (g); EF_{ij} is the emissions factor for emissions of type i on vessel j in grams per kWh (g/kwh); LF_{ij} is the average engine load factor for vessel i on route j and takes into account periods of maneuvering, slow cruise, and full cruise operations; KW_j is the rated main engine power for vessel j; η_j is the engine efficiency; and T_{jk} is the duration of the trip for vessel j on route k in hours (h).

The emissions factors used are based on emissions rates used in the 2009 IMO Study of Greenhouse Gases from Ships. These are generally consistent with other literature, including the TEAMS model [37, 38], and with recent studies of particle emissions including BC [12]. Emissions factors in TEAMS were derived for comparison in grams/MBtu, but were converted to g/kwh under the assumption that vessels were using heavy fuel oil with energy content of ~146,000 BTU/gallon and density of ~3,800 grams/gallon. It was also assumed that this fuel had a carbon content of 86.8% and a sulfur content of 2.6% (representative of international marine residual fuels); the sulfur content assumption for fishing vessels was reduced to 0.5% (consistent with lower-sulfur distillate fuels).The emissions factors used for the analysis are shown in Table 2.2.

It was assumed in the analysis that main engines for all vessels except fishing vessels operated at 65% load on average, and that at-sea speeds correspond to that power (~87% of design speed); while this number is lower than at-sea cruising speeds, it represents a trip-weighted average that includes maneuvering and slow-speed operations, and this value is similar to the voyage-weighted average derived from AIS data used in the 2008 Updated IMO GHG Study for Ships

[39]. For fishing vessels, it was assumed that main engines operated at 10% load on average, with corresponding speeds that represent trawling speeds during much of the fleet operation. In addition, because only engine data for main engines was available, it was assumed auxiliary engines contribute 3% to total emissions. This is generally representative of average AE:ME power ratios in previous studies that explored emissions from main and auxiliary engines using an activity-based approach [37, 38]; this serves as a first-order parameter where future analysis may show that greater or lesser AE power is typical for Arctic service.

Table 2.2. Emissions factors used in our analysis (representing 2004 typical values).

Emission		Emissions factor (kg emitted/tonne fuel)
CO		7.4
CO_2	*Transport Vessels*	3206
	Fishing Vessels	3114
SO_2	*Transport Vessels*	54
	Fishing Vessels	10
NO_x	*Transport Vessels*	85
	Fishing Vessels	56
PM_{10}	*Transport Vessels*	6.7
	Fishing Vessels	1.1
BC		0.35

Emission rates were converted into emissions per km traveled and to emissions per day at sea, for vessel trips made by transport ships and for at-sea days by fishing vessels. This allows for a caclulation within GIS that combined the emissions rate per km, the route distance in km, and the number of trips for transport vessels; similarly the calculation within GIS for fishing vessels combined the emissions rate per day of at-sea fishing, and the number of days at-sea by LME.

Results

Emissions were calculated for each and every vessel-trip for which data were available. The total emisssions calculated for each vessel category for the Arctic region are shown in Table 2.3. The inventory is based on vessel voyage data from 2004 obtained by the AMSA team. The ~15,000 trips analyzed represent about 14.2 million km of distance traveled (or ~7.7 million nautical miles) by transport vessels; fishing vessels represents over 515,000 fishing days for 2004. Some results could be an underestimation of current emissions, given potential underreporting bias and anecdotal reports of recent growth in international shipping and trade through the Arctic. Researchers at DNV recently completed a similar activity based emissions inventory for Norwegian waters (*Operational emissions to air and sea from shipping activities in Norwegian sea areas.* DNV Report No. 2007-2030) A review and comparison of the DNV results with the Norwegian portion of the AMSA results showed good agreement for all vessel types, except for general cargo and fishing vessel estimates. The AMSA results for Norway were sometimes greater than, and sometime less than, the DNV results, generally falling within 10% to 30% confidence.

2.3. Total annual emissions in the Arctic region by vessel category; all values reported in tonnes per year (t/y). ***Emission amounts were calculated using the AMSA marine activity database, which is based on information reported by Arctic Council member states. Baseline information was provided in different formats and to different degrees of detail between states***

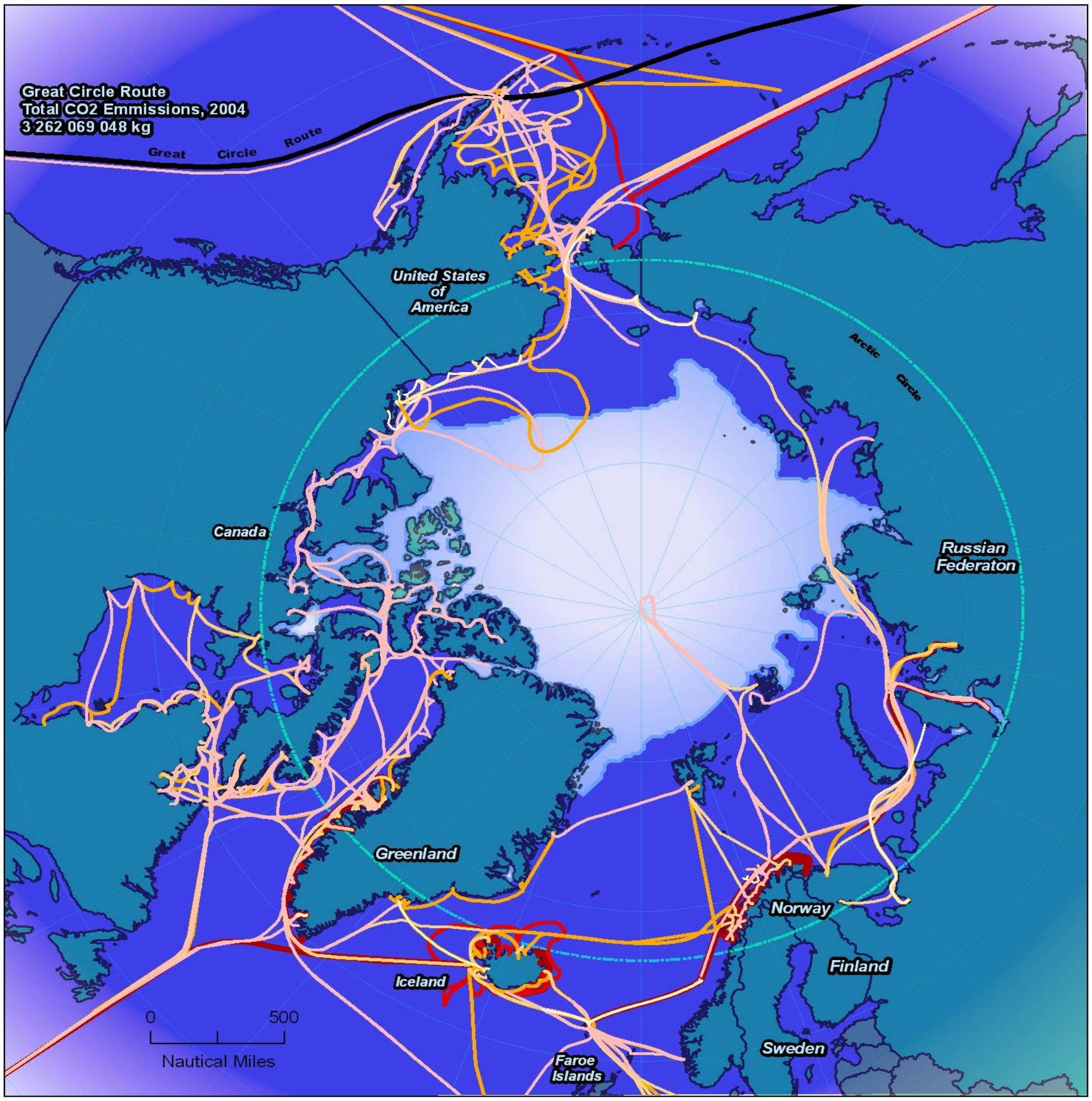
Vessel Category	Fuel Use (kt/y)	CO2 (kt/y)	BC (t/y)	NOx (kt/y)	PM (kt/y)	SOx (kt/y)	CO (kt/y)
Bulk	354	1,120	122	26.9	18.0	18.6	2.57
Container	689	2,170	239	52.5	35.0	36.2	5.01
General Cargo	590	1,860	202	44.9	29.9	31.0	4.29
Government Vessel	117	368	40.1	8.89	5.92	6.13	0.85
Other Service Vessel	3	11	1.19	0.26	0.18	0.18	0.03
Passenger Vessel	349	1,100	120	26.6	17.7	18.3	2.54
Tanker	269	848	92.5	20.5	13.7	14.1	1.96
Tug and Barge	17	54	3.38	1.32	0.88	0.91	0.13
Fishing	1,020	3,230	363	78.0	52.0	53.8	7.4
Total	**3,410**	**10,800**	**1,180**	**260**	**173**	**179**	**25**

Note: Columns may not total due to rounding.

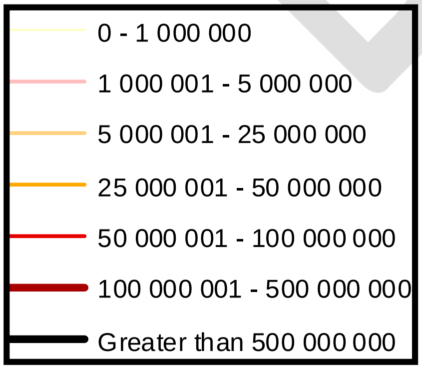
The Arctic Marine Shipping Assessment has developed the first activity-based estimate of Arctic marine shipping emissions using empirical data for shipping reported by all nations with Arctic service.

As part of the AMSA emissions inventory, the amounts of carbon dioxide and black carbon emitted were mapped using the GIS database of shipping routes activity reported by Arctic states (See Map2.1).

Map 2.1: Estimated CO2 Emissions for the Arctic region shown with September 2004 sea ice extent ***Emission amounts were calculated using the AMSA marine activity database, which is based on information reported by Arctic Council member states. Baseline information was provided in different formats and to different***



Carbon Dioxide (CO2) kg per Route



The CO2 emitted by all vessels was mapped according to the location of activity; emissions from transport vessels (non-fishing vessels) were assigned to reported routes. Map 2.1 shows that the heaviest CO2 emissions were found in the Bering Sea region, along the Norwegian coast and in the Barents Sea. There are also moderate emissions along the western coast of Greenland.

2.2.5 Primary findings with regard to emissions from shipping in the AMSA study area

In 2004, fishing vessels was the highest single type of shipping in terms of emissions, contributing 30% of total estimates. With fishing, the top three transport vessel types, containerships, general cargo, bulk carrier, and passenger vessels, account for nearly 80% of remaining emissions; including passenger vessels, these five categories account for nearly 90% of the total.

Importantly, the porting of the Great Circle route in the AMSA study domain and reported byt the United States accounted for about 30% of total emissions. Combined, the Great Circle route and the top three nations reporting transport-ship Arctic activity, Norway, Iceland, and Faroes Islands, account for more than 80% of total emissions in the AMSA study region.

Results show CO_2 emissions from international shipping in the Arctic region defined for the AMSA study domain to be approximately 10.8 $MMTCO_2$/yr. Given that total CO_2 emissions from international shipping globally are about 1000 $MMTCO_2$/yr, Arctic contributions would amount to about 1% of total ship emissions.

Similarly, *on a mass-basis alone* BC emissions from Arctic shipping (estimated here to be ~1,180 tonnes/year) may have independent impact on global climate change compared to other sources, and could have significant regional impacts.

More concerning may be micro-scale emissions which could affect local air pollution or ecosystems, depending on regional conditions. Pollutants with regional air quality impact include NO_x, SO_x, CO, and PM. For these pollutants Arctic shipping emissions are small contributors to global inventories *on a mass basis*. For example, Arctic shipping is responsible for about 260 tonnes/year of NO_x pollution in the Arctic region, about 1% of 25.6 MMT of NO_x (as NO_2, or 7.8 MMT as N in 2007) global ship NO_x emissions, estimated to range between 15% to 30% of global anthropogenic NO_x emissions [7, 11].

Future trends toward increased international shipping in the Arctic will increase these numbers proportional to the increased traffic, although future research is needed to determine whether the increased climate-scale impacts would be proportional to Arctic shipping activity. Previous research [40] indicated that future growth in Arctic shipping could account for additional emissions of Nitrogen between 0.65 to 1.3 million MMT(2.5 MMT to 4.9 MMT NO_x as $NO_{2)}$. This corresponds to an annually compounding growth rate in NOx of ~5% to ~6.5%. At these growth rates, there would be between 40 and 70 times more Nox emitted from Arctic shipping activity in 2050 than there was in 2004. Given the expected reductions in Nox emissions under the new IMO MARPOL Annex VI rules, in order for a ~5% to ~6.5% growth in NOx to, in fact, occur, overall shipping activity and fuel consumption and resulting CO2 and other non-regulated emissions, would have to grow between 6% and 7.5% annually.. If these growth rates occur within the AMSA domain, not on Great Circle routes, then this future ship activity will likely be located in very sensitive environmental regions.

2.2.6 Future research needs

More analysis is needed using economic scenarios that integrate Arctic shipping growth drivers (economic demand, fleet efficiency, and energy sources) to determine if this growth would be reasonable to expect for the Arctic marine study area. Nonetheless, shipping activity in most global regions is projected to grow proportional to growth in the global economy. Global average growth rates for international shipping are in the range of ~4% per year, with regional growth in heavily traveled trade routes similar to or greater than implied for the Arctic by Granier et al [40]. While possible, this kind of regional growth could involve significant population shifts to create Arctic demand for finished goods similar to other major ports in addition to potential demand for Arctic resource extraction. To the degree that growth along the Great Circle routes bordering the Arctic grow (along with corresponding growht on the portion of the Great Circle route included in the AMSA study domain), these emissions may also contitribute substantially to future Arctic impacts.

Significant increase in Arctic shipping activity will increase regional emissions that may have localized impacts. These impacts are not limited to air emissions from ships (as other impacts from shipping are discussed elsewhere in this chapter), but will include emissions contributions to air quality pollution, haze and visibility, possible deposition of aerosols, and regional climate impacts. More complete regional modeling of Arctic shipping is needed to investigate the current and potential impacts from these emissions along major routes and near key port regions.

One finding of this analysis is that increased shipping activity in the Arctic that may arise from changing navigable conditions due to climate change may increase emissions from shipping. However, non-permanent ice cover may not provide all necessary conditions for open navigation on potentially shorter, deepwater transit routes. For example, navigation seasonally may be accompanied by floating ice and other conditions that prevent full-speed transit. More analysis is needed to determine how much shipping may actually grow within the AMSA region and what this growth implies for future emissions trends.

Finally, there are additional emissions from ships that may affect the AMSA region but are not accounted for in this study because these ships operate outside the study area. For example oceangoing ship activity along northern trade routes outside the AMSA region may contribute a significant share of emissions (and therefore, impacts) within the area. More research involving atmospheric transport modeling and better data on ship activity patterns are needed to determine whether this is the case, and how growth in northern trade routes outside of the AMSA study area might affect the region.

Ship Stack Emissions- NOx, SOx, Black Carbon and Ozone:

A Wildcard Issue for the Arctic Region

Ships are powered by engines and fuels that, like other transportation modes, emit CO2 and water vapour, nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO) and Particulate Matter (PM-includes black carbon). Most oceangoing ships burn low-quality residual fuels that tend to contain high amounts of particulates from soot (black carbon), sulfur aerosols, ash, and heavy metals. These are pollutants specifically quantified in the inventory of emissions from Arctic shipping in this assessment. Based on a brief review and comparison with recent DNV data, general fuel quality assumptions in this first assessment are based on global averages by vessel type and may under-represent the potential portion of Arctic vessels running on distillate fuel (MDO and MGO).

Each of these pollutants are linked with specific environmental effects, and interaction between these substances, the atmosphere and local and global climate is complex. For example, NOx is a gaseous contributor to tropospheric ozone formation, SOx gases form particles that contribute to acid rain and cloud effects on regional climate, and other fine particles like black carbon impact air quality, visibility, and climate change. Shipping's contribution to regional and global impacts for emissions such as CO2, NOx, and SO2 have been evaluated by scientists and shown to be significant enough to motivate policy action.[1] However, environmental and climate effects of NOx and ozone, sulfur aerosols and clouds, and black carbon particles in the Arctic, are only beginning to be understood.[2] Black Carbon has been proven to have significant climate forcing effects, in addition to its effects on snow and ice albedo, accelerating the retreat of Arctic sea

---

[1] Buhaug, Ø.; Corbett, J. J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D. S.; Lee, D.; Lindstad, H.; Mjelde, A.; Pålsson, C.; Wanquing, W.; Winebrake, J. J.; Yoshida, K. *Study of Greenhouse Gas Emissions from Ships*; International Maritime Organization: London, 2 February 2009; p 174.

[2] M.G. Flanner et al, *Springtime warming and reduced snow cover from carbonaceous particles*, Atmos.Chem. Phys.Discuss., 2008; C.Granier et al, *Ozone pollution from future ship traffic in the Arctic northern passages*, Geo. Phys Res Letters, Vol 33 2006 American Geophysical Union; D. Lack et al, *Particulate emissions from commercial shipping; chemical, physical, and optical properties*, Geo. Phys Res Letters, (pre –publication – due to be released 2009) American Geophysical Union; V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, Nature Geoscience, April 2008

ice.[3] Background levels of NOx, the precursor to ozone, are very low in the Arctic and recent studies have found that seasonal increases in ozone are closely linked to seasonal increases in shipping activity.[4] Surface ozone is known to have harmful effects on plant growth and human health and is the basis for photochemical smog. Ship stack emissions in and near the Arctic will increase along with growth in shipping activity, except where regulations like MARPOL Annex VI require steep reductions in sulfur emissions through fuel sulfur limits or pollution reductions in specially designated regions. The specific benefits of reducing impacts in the Arctic through control of ship emissions need to be further studied, and the AMSA inventory for 2004 provides a good baseline inventory to evaluate scenarios that may achieve these benefits.

Based on key findings in this AMSA study, the report recommends continued study of ship-based emissions and trends.

Climate change policy is currently focused on CO2 from ships, and the potential climate response to lower ship sulfur emissions is becoming recognized. NOx emission controls may mitigate some of the Arctic regional ozone impacts suggested by one international study, and the AMSA inventory provides an opportunity to update previous research findings. More recently, scientists are recognizing that Black Carbon particles have potentially significant impacts on the vulnerable Arctic environment and climate that need to be quantified. The AMSA contribution to further research may be very important, given that recent studies suggest that reduction of the positive climate forcing due to BC would decrease both global warming and retreat of the sea ice and glaciers and would therefore provide an opportunity to for effective short term mitigation of global warming.[5]

---

[3] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, Nature Geoscience, April 2008; Flanner, Mark G, Charles Zender, James Randerson and Phillip Rasch (2007), *Present day climate forcing and response from black carbon in snow, Journal of Geophysical Research*, Vol 112, D11202 American Geophysical Union

[4] C.Granier et al, *Ozone pollution from future ship traffic in the Arctic northern passages*, Geo. Phys Res Letters, Vol 33 2006 American Geophysical Union

[5] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, Nature Geoscience, April 2008

2.3 Discharges to water of all types

2.3.1 Overview

Discharges to water from a ship can occur both through routine ship operations or one-time incidents and accidents. Different types of discharges include oil, oily water, sewage, garbage, grey water, and cargo (liquid or dry).

Discharges can have a range of impacts on the environment. Oil discharges to water can be toxic to marine life, are very difficult to clean up and can last for years in ocean sediment and the marine environment. Marine species constantly exposed to oil and its components can exhibit developmental problems, susceptibility to disease, and abnormal reproductive cycles. Other types of liquid discharges can contain potentially toxic chemicals, which adhere to tiny particles that are then taken up by plankton and bottom feeding animals, concentrating the substance upward within ocean food chains.

The presence of garbage, dry cargo and other debris in waters as a result of accidental or intentional release results in a number of environmental impacts. These range from damage to marine habitat, entanglement of wildlife, ingestion of plastics and other unsuitable items by marine mammals and birds, as well as creating the potential for vessel damage through collisions and creating a navigational hazard.

2.3.2 Accidental Discharge

A potential accidental release of cargo or pollutants such as oil or chemicals can be considered one of the most serious threats to the Arctic environment and ecosystems that could result from shipping. Accidental releases can range from minor ones that occur through human error in routine operations to major ones such as the Exxon Valdez spill in Alaska.

Main point: chances of this happening are high as shipping increases. Arctic is extreme environment with range of weather, light, and hazards, little infrastructure. Response is likely to be delayed and efforts impaired due to remote locations. All this points to strong prevention measures as opposed to response, which would be both unreliable and untested.

Increase in Toxicity levels in marine environment, oiling of fish/sea birds/marine mammals, nutrient enrichment of the water, introduction of disease agents, entanglement of animals and fish(discarded nets or other garbage), lowered esthetic value of “pristine” arctic environment(tourism)

The accidental release of oil or toxic chemicals can be considered one of the most serious threats to Arctic ecosystems as a result of shipping. The release of oil into the Arctic environment could have immediate and long term consequences. Some Arctic animals are particularly sensitive to oil because it reduces the insulating properties of feathers and fur and they can quickly die from hypothermia if affected. Crude and refined oils including fuel oils used by ships vary much in their physical and chemical properties. This, in addition to other factors, such as, temperature, light, waves, and ice plays a major role for the behavior of oil in the environment and the extent of biological effects.

Other potential problems from released oil include the transfer of oil to nests by sea birds landing on oil slicks and the ingestion of oil by animals while preening. This can lead to death or other biological effects both in the short and long term. Experience tells us that even small spills can have large consequences if they occur where marine birds are concentrated.

Chronic seepage of residual oil after a spill can affect the entire food chain in an area because hydrocarbons are taken up by bottom feeding invertebrates, which then end up as prey for sea birds and other animals, causing effects higher up the food web. Arctic animals are also particularly vulnerable to spills in certain areas and at certain times of the year when animals aggregate in large numbers to breed, nest, bear young and molt.

The Arctic is an extreme environment with a range of weather, light, and hazards, and with little human infrastructure. Responding to oil spills in these conditions is a major challenge, especially where ice is present. There are currently no effective ways of recovering spilled oil after the fact in an ice-covered environment. What is spilled will persist in the environment, or be burned in-situ. Consequently, strong prevention measures must be of primary concern, while response measures, being both unreliable and untested, should be secondary. Although there has been no major spill in the Arctic to date, the risk of accidental or illegal release of oil and other contaminants increases with any increase in shipping activity which involves the use or transportation of oil or other chemicals.

> *Arctic Oil and Gas 2007-Sidebar to accompany accidental discharge section*
>
> A comprehensive assessment of the oil and gas activities in the Arctic has been carried out by the Arctic Council under the leadership of the AMAP (Arctic Monitoring and Assessment) Working group. This assessment report summarized information on the history, current and projected oil and gas activities in the Arctic, and examined socio-economic and environmental effects associated with these activities. The assessment included a detailed description of the main features and species of the Arctic ecosystems and their vulnerability to oil spills and disturbances from oil and gas activities. An illustrative circumpolar map of vulnerable areas based on aggregations of mammals, birds, and fish was produced as an outcome of the assessment.

Regular Discharges to Water

As a part of normal operations, ships produce a range of substances which must eventually be eliminated from the ship through discharging into the ocean, incineration or transfer to port based reception facilities. Referred to as "regular discharges" these include oil, ballast water, bilge water, tank washings (oily water), oily sludge, sewage (black water), garbage, and grey water. Regular ship discharges are regulated through the International Maritime Organization's

(IMO) International Convention on the Prevention of Pollution from Ships (MARPOL 73/78), and other IMO conventions as well as through domestic regulation by coastal states. MARPOL has effectively reduced pollution in the marine environment through regulating the release of regular discharges. However, it has not eliminated discharges into the world's oceans altogether.

Oil is released with bilge water with a maximum allowed concentration of 15 ppm (15 mg per m^3) after treatment with oil separator. Oil is also released with water used for tank washings after required treatment and with restrictions on amount and rate of release to avoid formation of oil film at the surface (blue shine). Oily sludge consisting of high molecular hydrocarbon substances accumulates in fuel tanks in fairly large amounts, constituting typically 1-5 % of the amount of fuel consumed. Oily sludge must not be released but stored on board and brought to reception facilities in ports. The amount of oily sludge is large and represents potentially a significant source of pollution if it is illegally discharged.

A recent study in Norway of ship discharges in the Norwegian Sea and Barents Sea provides an example of the level of discharge from the relatively high number of ship operations in this area compared to some of the other Arctic regions. It was estimated that the total amount of oil released via bilge water and tank washings at the MARPOL allowed 15 parts per million totaled about 2 tons of oil per year, which is a rather insignificant amount. However, it was found that the ship operations in this area annually might generate a fairly large amount of oily sludge of nearly 40,000 metric tons. The total grey water discharge from shipping in the area totaled about 3 million cubic meters per year, while almost 0.7 million cubic meters of black water sewage was produced.

The estimated amounts of waste generated and oil discharged to water in the Norwegian sectors of the Norwegian and Barents Seas can serve as an illustration of the amounts generated and released also for other areas of the Arctic, scaled roughly in proportion to the level of shipping activities in the various areas.

The amount of oil discharged under MARPOL in the Norwegian study indicates that current amounts of legally discharged oil should not pose a significant threat to the local ecosystem. The large volumes of sewage and oily sludge produced, is required under MARPOL to be treated or transferred to port based reception facilities. However, there appears to be a risk for ships to discharge such substances illegally to avoid the associated costs.

Illegal release of oil and other regular discharges can cause oiling, be toxic to marine life, and difficult to clean up. Contamination can last for years in ocean sediment and other compartments of the marine environment, sometimes concentrating upward within marine and coastal food chains. The presence of significant amounts of garbage, dry cargo and other debris in the ocean can also result in a number of environmental impacts. These range from damage to marine habitat, entanglement of wildlife, ingestion of plastics and other unsuitable items by marine mammals and birds, as well as creating the potential for vessel damage through collisions.

Types of Accidental Discharges

Oil spills, cargo containers overboard, hazardous cargo, radioactive substances (nuclear fuel etc), releases associated with ships sinking or going aground (invasive species to land etc.)

Potential impacts of those accidental releases on the Arctic environment

Bird/fish/marine mammal oiling, habitat destruction, considering the effects and response to an oil spill on ice, impacts associated with introduction of invasive species due to ship wrecks etc.

Lack of infrastructure and effective or appropriate response?

2.3.2 Regular Discharges

Types of Regular Discharges

Source	Reason	IMO Restrictions
Oily Bilge water	Water leakage into vessel through shaft seals etc, oil and other liquids from machinery.	Annex 1 Oil separators required Allowable discharge of oil in water at 15 parts per million
Oily sludge	Residue left in oil/fuel storage tanks, (oil, sand, rust)	Annex 1 Sludge must be stored on board and transferred to port reception facility
Tank washings	Water used to rinse tanker compartments withresidual amounts of oil in it (sourced only from tankers).	Annex 1 All vessels must separate out oil and treat washing water prior to release. Allowable discharge of oil in water at 1/30 000 of total cargo
Sewage (black	Treated or untreated waste generated from toilets, hospital	Annex IV Limited rate of discharge, must be X nautical

water)	facilities, etc	mile from shore Guidelines for onboard sewage treatment No restrictions beyond coastal zones
Garbage	Food, operational and domestic waste generated during normal operations	Annex V Onboard incineration mandatory for ships < xxx? No discharge in coastal zones, designated “special areas”, No restrictions outside coastal zones, No discharge of plastics under any circumstance
Grey water	Water used for laundry, showers, baths, washbasins, dishwashers etc.	No restrictions
Ballast water	Ballast tanks	The Ballast water convention Ballast water exchange and treatment may be mandatory by 2016, if ratified by necessary 30 states

Bilge water

Bilge water is comprised mainly of water leakage into the vessel through shaft seals and pump glands, as well as other liquids which may drain into bilge wells from working spaces such as fuel oil, lube oil, cleaning chemicals. (German and Milne Report 1990) Annex 1 of MARPOL, The International Maritime Organizations (IMO) pollution prevention regulation, sets specific discharge levels for water containing oil and requires ships to have oily water separators installed. Though this regulation limits oil contamination levels of bilge water discharged from ships to 15 parts per million, it does not eliminate oil discharge altogether in international waters.

Tank washings

Discharge of tank washings is an issue generally associated only with Tanker vessels. In the past, after unloading a shipment, tanker would rinse out the tanks with water pumped in from the ocean and simply release it back when done. This was discovered to be a significant source of oil contamination in the oceans and tank washings are now controlled under MARPOL, which now requires that all vessels separate out oil and treat tank washings prior to releasing water with an oil content of 15 parts per million concentration of oil, which is allowed in areas not designated as special control zones by the IMO. (check this- reference?)

Grey water

Grey water discharge includes water used in laundry, drainage from showers, baths, washbasins, dishwashers etc. The main proponent of grey water discharge is cruise vessels, although all ships produce certain amounts. While grey water is generally viewed as of relatively little concern as a contaminant, it can contain substances such as chlorine and detergent residues that could become problematic under certain circumstances. (ASIA report 2008) It should be noted that many vessels treat their grey water with their sewage in onboard treatment plants, however, direct release of grey water is not prohibited under MARPOL.

Black water (sewage)

Black water discharge from ships refers to treated or untreated waste generated onboard a ship from toilets, hospital facilities and other sources. Black water release is regulated through annex 4 of MARPOL, which sets out rules governing the rate of discharge of sewage and distance from shore as well as setting out the requirements for the fitting of onboard sewage treatment and sewage reception facilities.(ASIA 2008) The release of sewage, treated or untreated can cause a health hazard. Although governed by MARPOL, there are certain circumstances such as the high seas zones, where the release of sewage is unregulated. (check this-IMO?)

Garbage/debris

Garbage is defined by the IMO as all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of a ship. (http://www.imo.org) The release of garbage by ships is governed by annex V of MARPOL, which sets out how ships should dispose of garbage, requires onboard incinerators for ships of a certain size, and bans the disposal of any plastics overboard (check this-what else?). Under MARPOL, garbage disposal is strictly restricted in coastal zones and "Special Areas" that have been designated by the IMO. The special areas established under Annex V are: *the Mediterranean Sea, the Baltic Sea Area, the Black Sea area, the Red Sea Area, the Gulfs area, the North Sea, the Wider Caribbean Region and Antarctic Area. (www.imo.org)*

Despite regulation of garbage disposal by the IMO and international community, it is inevitable that a certain amount of garbage or debris makes its way overboard. Certain types of garbage are more problematic than others. Of particular concern to seabirds and marine life is plastics and lost fishing materials.

Info Box Garbage (plastics)

Ingestion of plastics has been noted in seabirds across all the world oceans (Laist 1997). Species which forage at the ocean surface appear to be the most vulnerable to consuming bits of plastic, and may mistake these particles for food. Northern Fulmars, a wide-ranging medium sized seabird of the northern hemisphere, appears to pick up plastics with high frequencies (van Franeker 1995, Robards et al. 1995). In general fewer fulmars contained ingested plastics at higher latitudes (Robards et al. 1997), but even over one third of fulmars nesting in the Canadian High Arctic had bits of plastic in their guts (Mallory 2008). It is not clear whether these ingested plastics hurt birds, but when consumed in high numbers the sheer volume of indigestible material in gut will hamper proper digestion of food.

Recommendation:

Vessels should enhance efforts to ensure plastics do not enter the Arctic marine environment.

Ballast water

Ships traveling without cargo take on ballast water to add weight to the ship and thereby achieve safe operating conditions. This includes keeping the ship deep enough in the water to ensure efficient propeller and rudder operation and to avoid the bow emerging from the water, especially in heavy seas. More ballast is necessary for ships to sit lower in the water during stormy weather, or to allow for passage under a bridge. Ballast water is also used to balance the ship as it uses up fuel during a long voyage, or during loading and unloading operations. When a ship is no longer in need of the ballast function it will release the water back to the ocean. Release of ballast water has been linked to the introduction of invasive species throughout the world. The implications of ballast water release in the Arctic will be explored further in Section 2.6 of this chapter.

2.3.3 Regular Discharges and Seabirds

Where major shipping routes reach coastal waters and overlap with large congregations of birds, issues around chronic oil pollution and the accompanying dead oiled beached birds invariably emerge. Probably the best documentation of chronic oil pollution issues are from the North Sea (Heubeck 1995, Camphuysen 1998) and the Grand Banks (Wiese and Ryan 2003, see Box A). Hydrocarbons of any sort pose risks to birds, but pure or mixed products containing heavy fuel oils and crudes generally pose the greatest risk.

Marine birds are especially vulnerable to hydrocarbon contamination for a variety of reasons. The first is simply that the chance of encounter is high because birds and oils both occur at the water surface. The relative vulnerability of marine bird species depends a lot on how much time birds spend at the water surface. In general, diving birds, such as the auks, are more vulnerable to oil than the aerial species, such as gulls (Camphuysen 1998).

Birds that are heavily oiled die quickly from drowning and suffocation, but even lightly oiled birds can die. Birds are protected from the water by their feathers, which form a watertight barrier. When feathers are oiled, they become matted and their structure breaks down, and water is able to contact the skin. In cold water, the high conductivity of water results in rapid cooling of the bird and eventually hypothermia and death. Oils are also toxic when ingested, notably the PAHs (polycyclic aromatic hydrocarbons) and can cause a variety of physiological problems for birds. Anaemia, the destruction of red blood cells, is often found in oiled birds. Eggs and young birds are highly susceptible, tiny amounts of hydrocarbons placed on developing eggs can lead to embryo deformity or death (Leighton 1993).

In the Arctic, oil pollution of any kind arguably poses a greater risk to marine birds than anywhere else in the globe for 2 main reasons. First, many of the marine bird species that inhabit Arctic waters are the most vulnerable to oiling, such as the auks and sea ducks (Camphuysen 1998). Second, the water is always cold, and oiled birds will quickly become hypothermic and die.

Finding:

The discharge of oil and other substances through routine operation of vessels on heavily trafficked shipping routes has the potential to be severely damaging to Arctic Seabird populations.

2.4 Disturbances

2.4.1 Overview

Vessel and associated activities may create numerous disturbances in the marine environment for its inhabitants, ranging from direct injury or death to more subtle behavioral changes. These activities can also impact a wide range of marine species, including marine mammals, fish, reptiles and seabirds.

2.4.2 Noise Disturbances[6]

The underwater acoustic environment is inherently complex and sometimes relatively noisy due to a myriad of natural and anthropogenic sound sources. Some natural sounds are biological (*e.g.*, fish, marine mammals, some invertebrates), whereas others are environmental (*e.g.*, waves, earthquakes). Anthropogenic sources produce sound either as a by-product of their normal operations (*e.g.*, shipping) or intentionally (*e.g.*, hydroacoustic devices and airguns). Substantial measurements of many of these sources and their relative occurrence in the marine environment occur, although there is considerable uncertainty, particularly regarding the nature and

[6] Note all decibel (dB) levels associated with underwater sound sources, in this section, are presented as root-mean-square (rms) pressure levels referenced to 1 microPascal (µPa), unless otherwise indicated. Also note that when a sound level is presented as a source level, this indicates that this is the level measured 1 meter from the sound source (i.e., opposed to a received level, which is the level at the organism of interest).

magnitude of disturbance and other impacts to marine species. However, it is clear that under certain circumstances noise from a host of anthropogenic sources, including vessels, can have various adverse effects on marine life.

For most marine vertebrates, making, hearing, and processing sounds serve critical biological functions, including communication, foraging, navigation, and predator-avoidance (*e.g.*, Richardson *et al.*, 1995a; Tyack, 1998; Wartzok & Ketten, 1999; NRC 2003; 2005; Southall *et al.*, 2007). Specifically, toothed whales have developed sophisticated biosonar capabilities to feed and navigate (see Au, 1993), baleen whales have developed long-range communication systems using sound in reproductive and social interaction (*e.g.*, Clark, 1990; Popper and Edds-Walton, 1997), pinnipeds make and listen to sounds for critical communicative functions (Schusterman, 1981; Schusterman *et al*., 2000), and many fish utilize sounds in mating and other social interactions (Kaatz, 2002). More is known for some species within these groups than others and for many taxa, such as sea otters, sea turtles, and some invertebrates, very little is known about potential acoustic impacts. Most seabird species spend very little time underwater, so exposure to underwater noise is assumed to be a lesser concern.

Environmental noise can be neutral background clutter or it can adversely affect the ability of marine life to use biologically-important sounds (or ”signals”); potential adverse effects include the: alteration of behavior; reduction of communication ranges for social interactions, foraging, and predator avoidance; temporary or permanent compromise of the auditory or other systems; induction of generalized stress responses; and/or, in extreme cases, habitat avoidance or even mortality (*e.g.*, Richardson *et al*., 1995a; NRC 2003, 2005; Clark and Ellison, 2004; Nowacek *et al*., 2007; Southall *et al*., 2007). Additionally, the impacts of noise may be additive or synergistic to those of other human stressors (*e.g.*, Evans, 2002). However, determining when noise exposure, from any source, begins to cause biologically significant effects within a population, ecosystem, or entire species is exceedingly challenging, especially regarding behavioral responses; additional research is clearly needed in these areas (NRC, 2005; see: Southall *et al.*, 2007, Chapter 5).

Spatial and frequency (”pitch”) overlap between acoustic sources and the sounds used by marine life increases the probability of interference with important biological functions. Many impacts, particularly relating to hearing and the process of “masking” (or noise interference) can depend critically on the relative frequency relationship between the sounds an animal makes and/or listens to and the noise source. As seen below (Figure 6-1), the predominately low frequency sounds of large vessels are more similar to the general hearing bandwidths of large whales and many fish species, whereas those of many hydroacoustic devices overlap with the hearing of dolphins and porpoises; pinniped hearing tends to overlapped both types of sounds.

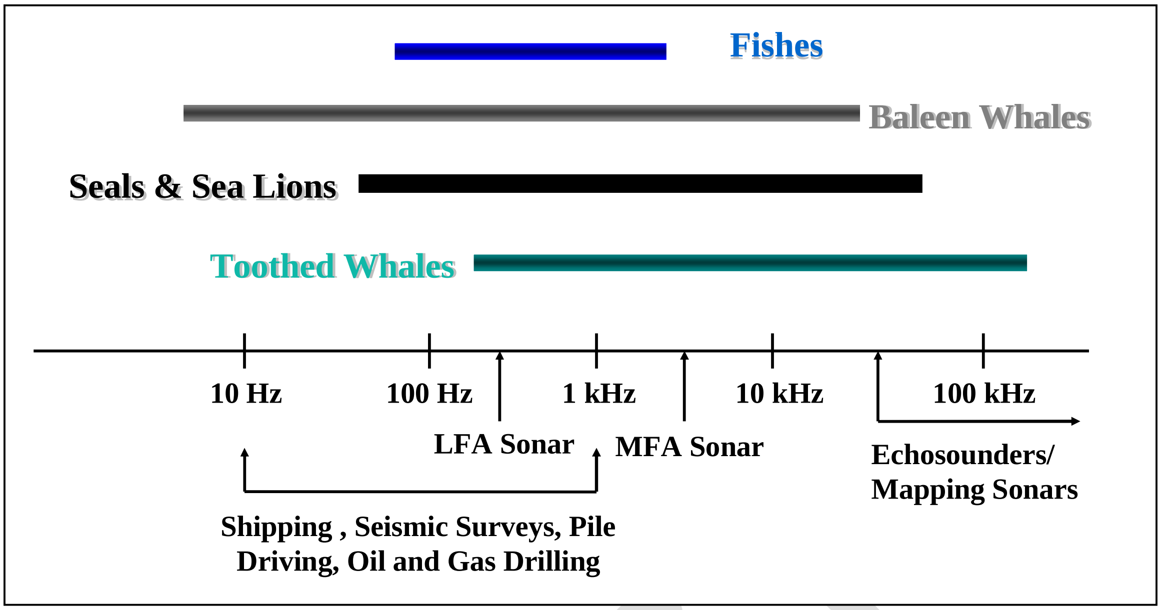


Figure 2.4-1: Frequency relationship between marine animal underwater hearing and human sources of noise (courtesy B. L. Southall, National Oceanic and Atmospheric Administration).

Arctic Ambient Acoustic Environment

The Arctic ambient (background) noise environment is more complex and variable than most other ocean regions due to the seasonal variability in ice cover. Much of the ambient noise levels in the Arctic can be attributed to the movement or cracking of ice, with higher frequency (~1 kilohertz [kHz]) sounds being attributed to the cracking of ice (Milne and Ganton, 1964; Lewis and Denner, 1988). Ambient noise levels under ice-covered areas are typically lower compared to those near the ice margins (*i.e.*, ice-water boundary), which are typically higher than open ocean levels due to wave and swell interactions (Diachok and Winokur, 1974). The size and spacing of the ice flows, as well as the sea state, near the ice margins, determine the amount of ambient noise (Uscinski and Wadhams, 1999). Many Arctic marine species also vocalize and contribute to background levels (*e.g.*, Stirling *et al.*, 1983; Moore *et al.*, 2006). Sound propagation loss (*i.e.*, a loss in amplitude) in the Arctic has been shown to correlate with ice thickness (Gavrilov and Mikhalevskya, 2006). Since ice plays such a critical role in controlling the ambient acoustic environment at some frequencies, it is expected that future changes in ice cover will affect background sound levels in a number of ways.

For instance, with less ice in the Arctic, the prediction is that water this region will be exposed to susceptible to surface winds resulting in abiotic increases in ambient noise levels (*i.e.*, making them more similar to more temperate regions; USARC, 2001). Additionally, and perhaps more worrisome, with declines in the amount of sea ice in the Arctic (*i.e.*, more ice-free zones and longer ice-free seasons), increases in commercial traffic and other types of industrialization in the region are expected. While the timing and magnitude of these changes are uncertain, the concomitant vessel traffic and associated activity (*e.g.*, seismic operation, hydroacoustic device usage) brings potential increases in noise in the marine environment and subsequent impacts to marine life, both acute from discrete, loud exposure and chronic from sustained presence of certain sound sources.

Vessel Operations

In addition to natural sources, anthropogenic sources, like vessel traffic, can also have a profound impact on the ambient levels. Throughout the northern hemisphere, shipping noise is the dominant source of underwater noise below 300 hertz (Hz) (Ross, 1987; 1993). Additionally, small vessels and boats can contribute significant sound energy across a wider frequency band over small to moderate spatial scales (*e.g.*, Kipple and Gabriel, 2003). For some coastal regions that have been better studied, low-frequency ambient noise levels have increased over time, very likely as a result of increased vessel operations (Curtis *et al.*, 1999; Andrew *et al.*, 2002; McDonald *et al.*, 2006).

All vessels produce sound as a by-product of their operation. Typically, vessels produce low frequency sound (*i.e.*, below 1 kHz) from the operation of machinery onboard, hydrodynamic flow noise around the hull, and from propeller cavitation, which is typically the dominant source of noise (Ross, 1987; 1993). Most sounds associated with vessels are broadband (*i.e.*, contain a broad range of frequencies), though, tones are also associated with the harmonics of the propeller blades (Ross, 1987; 1993). The sound a vessel produces typically relates to many factors, including size, speed, load, condition, age, and engine type (Richardson *et al*., 1995a; Arvenson and Vendittis 2000; NRC 2003). Usually, the larger the vessel or the faster it is moving results in more noise being produced (Richardson *et al.*, 1995a). Depending on the vessel, source levels can range from less than 150 decibels (dB) to over 190 dB (Richardson *et al.* 1995a; Arvenson and Vendittis 2000).

Increased vessel operations can have a variety of impacts on the Arctic marine inhabitants. Behavioral reactions, such as avoidance, are some of the most common reactions to vessel noise (*e.g.*, Blane and Jaakson, 1994). Behavioral responses to noise can be complex to interpret and often depend on a variety of factors, including context, the age of the individuals involved, behavioral state, prior experience with the sound sources, distance from the sound source, and characteristics of the sound source, including movement (NRC 2003, 2005; Southall *et al.* 2007). For example, beluga whales (*Delphinapterus leucas*) in different geographical areas can exhibit an extremely wide variety of behaviors when exposed to vessel noise ranging from tolerance to fleeing an area, based apparently on the relative frequency and context of the exposure (see Wartzok *et al.*, 2004). Often, behavioral responses, associated with vessel noise, are considered transient. Nevertheless, it is unknown how repeated short-term behavioral responses translate to cumulative or population-level impacts (Bejder *et al.*, 2006; Stockin *et al.*, 2008).

In addition to inducing behavioral reactions, recent data for blue whales (*Balaenoptera musculus*), North Atlantic right whales (*Eubalaena glacialis*), killer whales (*Orcinus orca*), and beluga whales indicate that many species may be adjusting their vocalization (e.g., frequency, call rate, call duration, and loudness) to compensate for masking associated with vessel noise (Lesage *et al.*, 1999; Foote *et al.*, 2004; Schiefele *et al.*, 2005; McDonald *et al.*, 2006; Parks *et al.*, 2007; Holt et al., in press). Additionally a recent studied demonstrated that a Cuvier's beaked whale (*Ziphius cavirostris*) reduced its vocal buzzes during foraging in response to a passing cargo ship (Soto, 2006).

Vessel noise, in addition to potentially impacting marine mammals, produce sounds in the hearing range of fishes (Amoser *et al.*, 2004). Continuous exposure (30 min.) to boat noise has been shown to increase cortisol levels (stress response) in fishes (Wysocki *et al.*, 2006). Hearing impairment (*i.e.*, temporary threshold shifts [TTS]), associated with long-term, continuous exposure (2 h), and masked hearing thresholds have also been recorded for fishes exposed to noise from small boats and ferries (Scholik and Yan, 2001; Vasconcelos *et al.*, 2007). Furthermore, vessels (i.e., trawlers, ferries, small boats) can also alter behavior in fishes (e.g., induce avoidance, alter swimming speed and direction, and alter schooling behavior), similar to marine mammals (Engås *et al.*, 1995; Engås *et al.*, 1998; Sarà *et al.*, 2007).

The Scientific Committee on Antarctic Research (SCAR) recently evaluated the potential impacts of ship noise in Antarctica and concluded this type of noise is most likely to "interfere with communication" (SCAR, 2006a). Indeed, increased ambient noise levels can have the potential significantly decrease the range over which marine mammals, like baleen whales or fishes, communicate, attract mates, or defend territories (Payne and Webb, 1971; Vasconcelos *et al.*, 2007; Simard *et al.*, 2008; Tyack, 2008). Again, implications of these impacts are not completely understood but are an important consideration for the long-term health and sustainability of the Arctic ecosystem and should be investigated further.

Potential environmental impacts from incidentally-radiated noise from large commercial ships as well as possible vessel-quieting technologies to reduce the potential for impacts, have begun to receive increasing interanational attention and consideration. The U.S. National Oceanic and Atmospheric Administration (NOAA) has convened two interanational symposia on these issues, bringing together industry, government, and environmental scientists, managers, and businesspeople (Southall, 2005; Southall and Scholik-Schlomer, in press). A related symposium was also convened by an environmental non-governmental organization (Okeanos – Stiftung für das Meer (Foundation for the Sea); Wright, 2008). These collaborative efforts have initiated an ongoing, interagency, interdisciplinary dialog being sustained and advanced in the form of a formal correspondence group on the subject recently approved by the Marine Environment Protection Committee of the International Maritime Organization. Several dozen member nations and industry and environmental organizations are taking part in the correspondence group, being chaired by the United States, whose goal is to survey the available information and make recommendations for voluntary measures regarding vessel-quieting technologies.

Seismic Operations

As shipping in increasingly open Arctic waters increases and hydrocarbon development becomes more viable, it is likely that seismic surveying will also increase. The oil industry, academic and government groups, and other industries use seismic surveys to map the geological structures beneath the sea floor (NRC, 2003; MMC, 2007).

Seismic surveying involves the use of one or more airguns towed in an array to produce low-frequency bursts of sound at intervals of a few seconds, with peak source levels of 220-255 dB re: 1µPa (Richardson & Wursig, 1997; NRC, 2003; Compton *et al.*, 2008). The dominant frequencies of airgun pulses are below 120 Hz, but higher frequencies up to 20 kHz can also be produced (Engel *et al.*, 2004; Compton *et al.*, 2008). These dominant frequencies overlap with those used by baleen whales and fish, and the higher frequencies overlap with those used by many odontocetes (Compton *et al.*, 2008). Seismic pulses are often detectable more than 100 km from the source and may be heard more than 1000 km away in deep water (Richardson & Wursig, 1997).

The impacts of seismic airguns on marine mammals are still poorly understood. However, there is a growing body of evidence demonstrating a variety of behavioral effects, as well as the potential for physical injury (*e.g.*, Richardson et al., 1995a; Richardson & Wursig, 1997; Gordon et al., 2003). As with other noise sources, airguns may cause physical impacts, such as temporary or permanent hearing loss (over likely small areas surrounding sources); behavioral effects, such as alteration of feeding patterns or changes in dive patterns; perceptual effects, such as masking of communications among animals; and indirect effects, such as loss of prey (see Richardson *et al.*, 1995a; Gordon et al., 2003; NRC, 2003; DFO, 2004; MMC, 2007; Southall *et al.*, 2007).

Demonstrated impacts of seismic airguns include a host of behavioral reactions and signs of stress (*e.g.*, Richardson *et al.*, 1995a; Richardson & Wursig, 1997; Gordon *et al.*, 2003; NRC, 2003; Compton *et al.*, 2008). Reactions to seismic airguns vary widely, among species and even among individuals. For example, Bowles *et al.* (1994) observed changes in sperm whales' vocalizations at a distance of 370 km from seismic sources, with estimated received levels of 112 dB (Bowles *et al.*, 1994), while other studies have shown sperm whales to have very low sensitivity to seismic airguns (Gordon *et al.*, 2003). These variations may be due to a host of variables including age and sex of the individual, the activity in which it is engaged (e.g., feeding animals less likely to change behavior than resting animals), and prior experience of the individual or group (Gordon *et al.*, 2003; NRC, 2003).

Despite huge behavioral variations in response to seismic noise, the generally accepted impacts thresholds are 160 dB for behavioral response and 180 dB and 190 dB for physical injury to cetaceans and pinnipeds, respectively (Richardson & Wursig, 1997; Compton et al, 2008).

Seismic surveys can also affect fish behavior and hearing (*e.g.*, Engas *et al.*, 1996; Gordon *et al.*, 2003; McCauley *et al.*, 2003; NRC, 2003; DFO, 2004; Popper *et al.* 2005; Song *et al.* 2008).

Such impacts may be significant not only to the fish populations themselves, but to the marine mammals that rely on them for food (Gordon *et al.*, 2003; NRC, 2003).

Finally, seismic surveys have the potential to indirectly impact human populations in the Arctic by harming or deflecting the marine mammals on which they rely for subsistence (Gordon *et al.*, 2003; MMS, 2007; Suydam et al., 2007). In the Alaskan Arctic, for example, marine mammals and fish comprise 60 percent of coastal communities' diets, and bowhead whales are integral to both the diet and the culture of these communities (MMS, 2007). If seismic disturbances force subsistence hunters to go further out to sea for food, their risk of injury increases at the same time that their ability to provide food for their families decreases (MMS, 2007).

Several nations, including Canada, Russia and the United States, use standards to minimize the impact of seismic surveys on marine mammals (Compton et al., 2008). Mitigation measures typically include the use of safety zones, soft starts, onboard visual observers, passive acoustic monitoring (PAM), aerial and dedicated research vessel surveys, and temporal and special restrictions for especially sensitive areas (Compton *et al.*, 2008). These mitigation measures are essential tools in reducing stress and harm to marine mammals, but they have shortcomings. For example, visual observers are likely to miss a large number of animals affected by seismic surveys due to bad weather or darkness (Compton *et al.*, 2008). Even in perfect conditions, marine mammals well beyond an observer's field of vision may be impacted (Compton *et al.*, 2008). Furthermore, most marine mammals spend a large proportion of their time under water and thus may be in the project area without ever being seen (Gordon *et al.*, 2003; Compton *et al.*, 2008). Continued investment and research into ways to minimize the impact of seismic testing on marine animals is therefore necessary.

Commercial Hydroacoustic Devices

Vessels and ships typically employ some type of commercial hydroacoustic device (*e.g.*, commercial sonar, like bottom profilers, echosounders, side scan sonar, fish finders, etc.) for navigation, depth finding, seafloor mapping, or to detect biologics (*e.g.*, fish, plankton) as a part of normal operations. These devices produce short pulses (milliseconds in duration) and use frequencies ranging from low to high (few hundred Hz to hundreds of kHz), depending on their utility, with many capable at operating at multiple frequencies (Richardson *et al.*, 1995a; Kremser *et al.*, 2005). The majority of hydroacoustic devices operate at frequencies above 10 kHz, with sub-bottom profilers operating below 10 kHz most frequently (Richardson *et al.*, 1995a; ICES, 2005; SCAR, 2006a; 2006b). Most of the sound produced by these types of hydroacoustic devices is focused downward with a very narrow beam of acoustic energy (though some are forward looking). They are also most often employed when a boat or vessel is in shallow waters (though, some are capable of operating at full ocean depths; ICES, 2005; SCAR, 2006b). Some have rather high source levels exceeding 200 dB, with energy outside the main beam being typically at least 20 dB lower (Richardson *et al.*, 1995a; NRC, 2003; Kremser *et al.*, 2005; SCAR, 2006b).

The majority of commercial hydroacoustic devices produce frequencies too high to be audible by the majority of fish species (NRC 2003), although some clupeid species (specifically those in the subfamily Alosinae) have the ability to detect ultrasonic frequencies (*i.e.*, above up to 180 kHz) and could potentially be impacted by these sources (Mann *et al.*, 2001). Due to the potential broad range of frequencies that can be associated with these types of devices, there are a broad range of species that could potentially be impacted.

A recent assessment evaluated the potential for hydroacoustic devices (*i.e.*, multibeam echosounder and sub-bottom profiler) to induce temporary hearing loss (i.e., TTS) (Kremser *et al.*, 2005). Unless the animal travels within close range of these devices while broadcasting this type of impact was considered very unlikely; mitigation measures (*e.g.*, shut down) designed to detect animals in close proximity the source are a possible way of minimizing this relatively small risk. Although, detection by some means (*i.e.*, visually or acoustically) can often be a challenge. SCAR also evaluated several hydroacoustic devices and concluded the likelihood of auditory injury would be low and minor displacement over short periods (days) may occur in exceptional situations (SCAR 2006b). Watkins *et al*. (1986) reported sudden behavioral reactions from several large whale species only if echosounder was suddenly started near a whale. If the echosounder was already broadcasting, as the vessel approached the whale, it was typically ignored (*i.e.*, whale did not exhibit a negative reaction), which seems to support SCAR's general conclusions. More information exists (see Southall *et al.*, 20007 for a review) on the potential impacts relating to use of military sonar and acoustic harassment or acoustic deterrent devices (AHDs/ADDs), which are similar but not identical to hydroacoustic devices (*e.g.*, tactical sonar often is omnidirectional [that is the sound travels in all directions and is not just directed downward] or forward-looking and source levels are typically higher; AHDs/ADDs are also typically omnidirectional and are designed specifically to repel an animal from a location).

Icebreakers and Noise

Compared to other vessels, icebreakers produce louder and more variable sounds due to the episodic nature of their normal function (*i.e.*, ram forward into the ice and then move in reverse to begin the process again). Though, the act of physically breaking ice does not produce the majority of noise underwater, instead, as with other vessels, propeller cavitation is the main source (Malme *et al*., 1989). Icebreakers are capable of producing sounds with higher frequency (> 5 kHz) components than other vessels and are typically much louder going in reverse compared to moving forward (due to cavitation) or when ramming fails (*i.e*., little forward motion) and the propeller remains turning at full speed (Malme *et al*., 1989; Cosens and Dueck, 1993; Richardson *et al.*, 1995a; Erbe and Farmer, 1998, 2000). Source levels for icebreakers can range from 174 dB to over 200 dB (Malme *et al*., 1989; Richardson *et al*., 1995; Erbe and Farmer, 1998).

Different species have been recorded to behave differently in the presence of icebreakers. For example, beluga whales data indicated (*e.g.*, alarm vocalizations) that they were aware of the icebreaker vessels presence at distances of over 80 kilometers (km) away and exhibited strong avoidance responses at distances 35 to 50 km away, while narwhal whales (*Monodon monoceros*) only displayed subtle response to the same icebreakers (Finley *et al.*, 1990). In another study, Richardson *et al*. (1995b) played bowhead (*Balaena mysticetes*) and beluga whales sounds from an icebreaker during their spring migration. Bowhead whales were tolerant of these sounds until levels were more than 20 dB higher than ambient levels. At that point, it was common for them to divert their migratory course to avoid higher exposure levels. It was predicted that bowhead whales could react in this manner from 10 to 50 km away from an actual icebreaker, which could have biologically significant implications, especially for mothers and calves. For beluga whales, the results were not as dramatic, with only six out of eleven groups altering their migratory path when exposed to these playbacks.

Some icebreakers are also equipped with bubbler systems to aid in clearing ice from the vessel's path that can create an additional noise source (Erbe and Farmer, 1998; 2000). Bubbler system noise is typically dominant at frequencies below 5 kHz, with source levels as high as 194 dB (Erbe and Farmer, 1998; 2000). Bubbler systems and cavitation associated with icebreaker movement has the ability to mask auditory ability and vocalization of Arctic inhabitants (Erbe and Farmer, 1998; 2000). Specifically, for belugas it was determined that zone of masking could extend from 14 to 71 km from the source (Erbe and Farmer, 2000). Erbe and Farmer (2000) estimated the zone of behavioral disturbance for icebreakers for beluga whales could be up to 32 km for bubblers and up 46 km for icebreakers. There is an increased possibility of TTS if animals are exposed to these types of sounds for an extended duration (i.e., animals do not or cannot alter behavior to avoid this type of exposure, which they are expected to do in most situations).

Findings

There is clearly some degree of scientific uncertainty regarding the scope and nature of environmental disturbances arising from vessel operations, seismic surveys, hydroacoustic devices, and other anthropogenic sound sources, but some simple conclusions may be drawn from the fairly substantial (in some areas) information that is currently available.

Sound is of vital biological importance to most, if not all, marine vertebrates and anthropogenic noise can have various adverse effects.

Vessel activities and other sound sources can increase marine ambient noise on both acute and chronic time scales; in some areas there appears to be an ever-louder low-frequency background din associated with increases in commercial shipping.

The wide-scale introduction of commercial and research activities into Arctic areas and concomitant increases in marine ambient noise are very likely to have impacts on both the acoustic environment and the sound-centric animals living there.

Impacts from noise will vary by sound source (*e.g.*, vessel operation, icebreaker operations, seismic, and hydroacoustic devices), as well as by species (*i.e.*, different species hear and use sound differently).

Very few of these effects are expected to include direct physical injuries to hearing or other systems; rather, there is more concern regarding behavioral disturbance and avoidance of key areas, as well as interference masking of acoustic communication.

Cumulative and population- and ecosystem-level impacts of exposure to chronic sources of ambient noise from vessels remain poorly understood but are important considerations.

Finally, there are existing and emerging technologies appropriate to minimizing the directed or incidental sound output of vessels, seismic survey operations, and hydroacoustic devices which, as well as carefully-considered operational measures, could minimize radiated noise. However, the respective economic costs and environmental benefits of these measures remain somewhat uncertain.

2.4.3 Vessel Strikes on Marine Mammals

Vessel collisions, resulting in death or serious injury, are a legitimate threat to marine organisms world wide. Vessel collisions ("ship strikes") occur with large whale species (Best et al., 2001; Knowlton and Kraus, 2001; Laist et al., 2001; Jensen and Silber, 2003; Vanderlaan and Taggart, 2007), small cetaceans (Van Waerebeek and Leaper 2008), marine turtles (Hazel et al., 2007), and sirenians (Calleson and Frolich, 2007; Greenland and Limpus, 2006). Records indicate that nearly all large whale species are vulnerable to ship strikes (Jensen and Silber, 2003; Van Waerebeek and Leaper 2008) including but not limited to sperm (*Physeter catodon*), blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus)*, sei (*Balaenoptera borealis)*, right (*Eubalaena glacialis*), and humpback (*Megaptera novaeangliae*) whales. Van Waerebeek and Leaper (2008) reported that a number of small and mid-sized cetaceans occurring in the Southern Hemisphere are also involved in vessel collisions. Strikes involving sirenians and small water craft are an ongoing problem in locations in which these species occur (U.S. Fish and Wildlife Service 2001, Greenland and Limpus 2006). There is at least one anecdotal record of a large fish, a whale shark, being struck and killed. Pinniped species appear not to be involved in vessel strikes, perhaps owing to their relatively smaller size and higher maneuverability, as are large whales, although we know of no comprehensive data mining for such occurrences.

Vessel collisions with marine mammals can result in massive trauma, hemorrhaging, broken bones and propeller wounds (Knowlton and Kraus, 2001; Campbell-Malone 2007). When large whale species and large vessels are involved, the animal occasionally is found draped across the bow when a ship arrives in port. Propeller wounds can be massive and cause immediate death or, alternatively, result in relatively superficial wounds. Some individuals are seen living with evidence of having survived propeller strikes. However, in one well-documented incident, one entire fluke of a right whale was removed by the propeller when struck by a fast moving 42 foot pleasure craft.

Jensen and Silber (2003) described nearly 300 observations of large whale ship strikes, and Van Waerebeek and Leaper (2008) accounted for over 750 cetacean vessel strike records worldwide. Virtually all motorized vessel types, sizes, and classes are represented in these data bases. The number of records provided in this literature is a minimum, because there are others, perhaps many, which go undetected or unreported. In some cases, carcasses are found but because injuries are internal (e.g., hemorrhaging, broken bones), or due to advanced decomposition, it is not always possible to determine cause of death and when large vessels are involved, the mariner may not be aware a strike has occurred.

There are relatively few known records of Artic or pagophilic cetacean species being involved in ship strikes. For example there are a handful of observations of vessel strikes in bowhead whales (*Balaena mysticetus*) as evidenced by healed propeller wounds, (Philo et al., 1993; Angliss and Outlaw, 2005). The relatively infrequent occurrence is almost certainly a result of relatively lower vessel traffic in high latitudes as compared to major trading routes and human population centers in lower latitudes.

As to large whale species worldwide, in the various databases, fin whales are most commonly represented (Jensen and Silber, 2003, Van Waerebeek and Leaper 2008); but Vanderlaan and Taggart (2007) determined that North Atlantic right whales are the most highly represented species on a per capita basis likely due, in part, to its small population size. This feature is compounded by a distribution in coastal waters near eastern U.S. and Canadian human population centers. However, it is worth noting that right whale natural history is similar to that of the Artic dwelling bowhead whale. Certain features, namely relatively slow swimming speeds, general behavior, group size, and an ecology involving skim, mid-water, or surface feeding and a positive buoyancy (due to high body fat content), also makes the bowhead whale potentially vulnerable to ship strikes, particularly as vessel traffic increases in their waters. For example, there appears to be only small degrees of escape response to avoid a strike (and perhaps only in the closing seconds) in right whales (Laist et al., 2001; Kite-Powell, et al., 2008), but this is little studied. Bowhead whales could be expected to exhibit similar behavior.

Arctic odontocetes (toothed whales), namely narwhals and beluga whales, are probably less vulnerable to ship strikes, given their greater overall maneuverability relative to large whales, echolocation capabilities (and social behavior in which groups tens or hundreds of individuals may enhance ship detection and flight). It should be noted, however, that records of roughly comparable "mid-sized" odontocete cetacean species such as pilot whales (*Globicephala spp.*), killer whales (*Orcinus orca*), and various species of beaked whales also appear in ship strike databases.

A number of steps have been taken to reduce the threat of ship strikes to endangered large whale species. In Canadian waters, shipping lanes have been shifted in the Bay of Fundy to reduce the confluence of ships and North Atlantic right whales in areas of right whale aggregation. Canada has also submitted a proposal to the International Maritime Organization (IMO) to establish a vessel “Area To Be Avoided” (ATBA) in Roseway Basin for the same purpose. The U.S. has recently submitted a similar proposal to the IMO to establish an ATBA in waters off New England. In the U.S., recommended shipping routes have been established outside key U.S. ports and in Cape Cod Bay, (http://www.nmfs.noaa.gov/pr/shipstrike/routes.htm) in North Atlantic right whale aggregation areas. In addition, the U.S. modified a Traffic Separation Scheme (TSS) that services Boston, also to reduce the co-occurrence of vessel traffic and several large whale species.

In a number of locations vessel speed restrictions or advisories have been or are being used to reduce the threat. Vessel speed has been implicated as a key factor in the occurrence and severity of vessel strikes with large species (Vanderlaan and Taggart , 2007). Several independent studies (Vanderlaan and Taggart, 2007; Pace and Silber, 2007) indicate that vessel speeds of 10-14 knots, rather then typical at sea speeds of 15 knots or more increase by one-half or greater the probability that a whale will survive a collision with a ship. Slutsky (2007) determined that the force of an impact experienced by a whale increases linearly with vessel speed. Therefore, vessel speed restrictions are being employed in various settings to reduce the likelihood and severity of ship strikes of large whales. For example, to reduce the threat of vessel strikes of humpback whales in Glacier Bay National Park, the U.S. National Park Service limits the number of cruise ships entering the Park and requires ships travel at 13 knots or less in areas and times when humpback whales are present (National Park Service, 2003). In response to a number of ship strikes of blue whales off the coast Southern California, the Channel Islands National Marine Sanctuary, the National Marine Fisheries Service (NMFS) and the U.S. Coast Guard advised ships to travel at speeds of 10 knots or less in approaches to the ports of Los Angeles and Long Beach (Bettridge and Silber, 2008). And, to reduce the likelihood of ship strikes to North Atlantic right whales, the U.S. NMFS provides vessel speed advisories of 10 knots or less that accompany North Atlantic right whale sightings along the U.S. eastern seaboard; and NMFS has proposed a vessel speed regulation in key port entrances and right whale aggregation locations along the U.S. east coast (71 FR 36299; 26 June 2006). Vessel speed restrictions have been proposed to reduce the likelihood of collisions with fin whales in the Mediterranean Sea (Panigada, et al., 2006).

To the extent that bowhead whales, and lesser extent narwhals and beluga whales and other Arctic marine organisms, are vulnerable to ship strikes in light of expected increased vessel traffic in the Artic, modifications to customary vessel operation in key cetacean aggregation areas or vessel speed restrictions (<12 knots) should be considered. Where feasible, vessel routing measures to avoid known cetacean aggregation areas or vessel speed restrictions (<12 knots) should be considered. As to the authority to do so, the United States has proposed limiting vessel speed on behalf of North Atlantic right whales under the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA), and provides vessel speed advisories on behalf of right and blue whales because these species are listed as endangered on the ESA's List of Endangered and Threatened Wildlife and Plants. The bowhead whale likewise has an "endangered" designation on the U.S. ESA's List. Canada's Species at Risk Act (SARA) provides similar designations for the bowhead whale and certain populations of beluga whales. Both the United States and Canada has established routing measures (modifying a TSS and creating ATBAs, as noted above) in international waters by seeking endorsement through the IMO. Thus far, each has received IMO endorsement, among the first to receive endorsement on behalf of endangered marine organisms.

With regard to endangered North Atlantic right whales occurring in Canadian waters, Elvin and Taggart (2008) argued that Canada has the legal authority to modify vessel operations in Canadian waters under SARA and other statutes, and that Canada should likewise possess the political will to take appropriate action.

2.4.4 Light Disturbances –Effects on Sea Birds

Birds of all species appear to be attracted to lights, putting them at risk of collision with the lighted and/or nearby structure(s). This attraction and resulting risk of collision, varies greatly with weather playing an important role. Birds appear to be at much greater risk of attraction and collision when visibility is poor. Young and naïve birds are much more susceptible to colliding with lighted structures. The fall migration is when most bird attraction and collision issues emerge, as young birds are travelling for this first time, and inclement weather becomes more frequent in the fall.

Specific to the marine environment, young birds in the Procellariforme family, or tube-noses (of which albatrosses are the largest members), especially the smaller nocturnal species are the most vulnerable to light attraction and collision (Montevecchi 2005). Marine birds are not the only species found on vessels at-sea attracted by the lights. Many landbirds migrate over seas and oceans and a wide variety of species have been found on ships and offshore platforms.

For the Arctic, light attraction of marine birds is likely to be less of an issue compared to shipping at more southerly latitudes for a variety of reasons. One is simply that most birds are in the Arctic in the summer months to breed, when there is little or no night. Secondly, and likely a related factor, most Arctic breeding seabirds are diurnal, so these species are less active at night, making light attraction less of an issue. Thirdly, Arctic waters tend not be major migration routes for land birds.

However, there are still risks, especially during the non-breeding period in ice-free waters. A wide-variety of nocturnal species nest in the North Pacific, especially in the Aleutian Islands, such as the large numbers of Leach's Storm-Petrel, Fork-tailed Storm-Petrel, and Cassin's Auklet. The Storm-Petrels, the smallest members of the tube-nose family, appear especially vulnerable in late summer and early fall, just after the juveniles first leave their nesting islands, and 100s can pitch on a vessel during foggy conditions. Many of these birds are simply disorientated and are not injured, but encounter other problems while on the vessel (trapped in closed spaces, oiling or fouling from material on deck). These problems are not unique to the smaller nocturnal species, as one example, common and king eiders (large ducks) were found colliding with large shrimp vessels in west Greenland waters. As these are larger birds that fly quickly, the collision itself caused the injury or death.

Disturbance-Impacts on Seabirds

Vessel traffic has the potential of disturbing marine wildlife in a variety of ways and to varying degrees. Disturbances can range from minor disruptions in behaviour, such as animals stop feeding or flush to the water, to worst case scenarios resulting in a panic of adults and the death of 100s or 1000s of eggs or juveniles. Seabirds are especially vulnerable to certain types of disturbance, mainly because they concentrate in large numbers at colonies or in flocks, so that a single disturbance event could affect thousands of birds. The breeding period is an especially sensitive, and certain cliff nesting species (such as murres) may dislodge their egg or chick from the cliff when panicked. Many marine birds undergo a flightless period after breeding to replace worn flight feathers (termed moult). Shipping disturbance is detrimental at this time, as the birds are unable to fly away from moving vessels and are often already stressed. Marine waterfowl, like sea ducks, congregate in large numbers (1000s) for this moult, making single disturbances disruptive to many birds.

Fortunately disturbance to large numbers of Arctic marine wildlife can be relatively easily mitigated by careful planning of shipping lanes. Large seabird colonies are well known and should be avoided; similarly marine mammal haul-outs are traditionally used and should be avoided. Additionally, many large colonies and haul-outs fall within areas with some form of special protection. Concentrations of moulting sea ducks tend to occur reliably in the same general area in late summer, making it possible to avoid these areas at this time of year.

2.4.5 Cruise ships and disturbance

Cruise ships present a special of case of shipping, as the ships are actively seeking areas of special interest, including superior wildlife viewing opportunities. This creates the potential for cruise ships to have greater impact on concentrations of wildlife, not only from ship transit itself, but other activities related to the tourism package (close approach to haul-outs and colonies, landing of tourists on colonies with small craft, longer times spent near concentrations of animals). Yet, the cruise ship industry has a vested interested in maintaining healthy wildlife populations as part of their tourism package.

Except for gross disturbances (e.g. blowing a ship's horn below a large nesting cliff), the impacts of various disturbances on seabird colonies are still not well known (Chardine and Mendenhall 1998). Additionally, some seabirds are known to habituate to repeated human activity, reducing or even negating the impact over time (Nisbet 2001). Cooperation among cruise ship operators in the Arctic to develop best practices, in partnership with academic and regulatory bodies, could lead to a sustainable eco-tourism in the Arctic.

Recommendation: Numerous calls for Arctic cruise ship operators to form an organization parallel to Antarctic operators (International Association of Antarctica Tour Operators, IAATO) (Chardine and Mendenhall 1998, Arctic paper 2008) have been put forth, and that call is repeated here. Once in place, biologists, operators and regulators should work together to develop overall best practices for wildlife viewing in the Arctic, which would be used in conjunction with any local regulations in place around protected areas. Further research on the impacts of disturbance are also needed to ensure that regulations are effectively protecting wildlife, but also not restricting viewing opportunity unnecessarily.

2.5 Physical impact on the seafloor

Info Box- Dredging in the Port of Churchil Canada- A Case Study by Don Cobb

The combination of market opportunities and increasing length of shipping season, have contributed to an enhanced opportunity for the Port of Churchill, Manitoba, Canada to become a major port for international shipping. Established in 1931 in Churchill Manitoba (58 47N, 94 12W) along the southwest coast of Hudson Bay (fig. 1), the Port has a direct rail line access to western Canada, where a major portion of North America's cereal grains are produced. More recently, other commodities have been shipped or are proposed to be shipped, including ores, fertilizers, and other agricultural crops. Recently there has been reference to a proposal for an "Arctic Bridge" between North America and Russia. However, in order to accommodate ever increasing size of ocean going vessels, it was decided that the Port must be upgraded. The Port was suffering from limited grain handling capacities, shallow water depths in the grain berths and navigation channel, and a narrow range of bulk materials.

In 1998, The Hudson Bay Port Company (HBPC) proposed to enhance the operations at the Port. Post glacial isostatic rebound and sedimentation have contributed to lower water depths at the Port, so a two year project was initiated that would involve dredging up to 1,200,000 m3 of sediment in several locations (insert fig. 2, map of dredging areas) to accommodate modern ocean-going vessels in the range of 50,000 Dead Weight Tonnes. This case study will describe the project, the potential impacts to marine resources and the environmental assessment and monitoring programs that were conducted under the Canadian Environmental Assessment Act (CEAA) to ensure that the project did not result in significant environmental impacts.

The Port of Churchill is influenced by sediment dynamics of the Churchill River estuary, thus over time, a natural build-up of sediment occurs. This accumulation of sediment results in restricted access and loading/unloading operations. Dredging was proposed in the outer channel, inner harbour, grain berths and south berth to ensure the safe and efficient operation of vessels at the Port.

An environmental assessment (EA) was conducted in accordance with the Canadian Environmental Assessment Act (CEAA), and responsible federal authorities were involved to ensure the operation was conducted in accordance with their mandates. This included gathering of baseline data on physical, chemical and biological components of the proposed dredge and disposal sites. This information was used to describe potential environmental effects of the project. Main potential impacts identified in the EA included: decreased water quality from suspension of sediment, and effects on marine mammal use of the vicinity. The EA also identified mitigation measures to address these effects. Following the EA, the proponent was required to prepare an Environmental Monitoring Plan, as well as a plan to compensate for lost fish habitat.

Prior to dredging, the seabed was characterized using a Seabed Imaging and Mapping System (SIMS), while direct sampling of sediment was conducted using a clamshell grab sampler. In total, 71 stations were sampled for grain size, total organic carbon, metals, PAHs and PCBs from the four areas. Fish habitat features were also identified on a gross level. Four hours of video was acquired for each area using the SIMS, and bottom sediment was classified as clay/mud, sand, gravel, stone/rubble, and/or clams. Fish and marine mammals were also observed throughout the field program. All areas sampled comprised primarily coarse grained sediments (medium to coarse sand with small amounts of gravel and fines). The diversity of seabed habitat affected was considered low, however to compensate for lost habitat due to dredging, a compensation plan was developed that would result in increasing productive capacity of exiting habitat in the disposal area suitable for colonization by benthic communities.

Dredging was conducted from August 3 to September 9, 2000. A total of 74,170 cu.m. was dredged from the grain berths and a portion of the turning basin, and 258 trips were made to the disposal site; the remainder of the dredging program was to be completed in 2001.

An environmental monitoring program was conducted to delineate the extent of plumes during dredging and disposal, effects of sediment on fish and beluga, benthic organisms and fish habitat. The monitoring program revealed that only minor sediment plumes were generated during dredging and disposal, and that mean water column turbidity at the stations greater than 100 m down current of the dredge differed by less than 20% from background. Temporal magnitude of the plume was very small with dispersal by strong surface currents during ebb and flood tides. Results of the beluga whale monitoring indicated that noise and increased suspended solids from dredging activities did not affect beluga whales.

2.6 Introduction of Alien and Invasive Species

Species are considered alien if they are not native to a given ecosystem. These species can also be referred to as exotic, non-native, or non-indigenous species. Alien species are considered to be invasive when their introduction causes, or is likely to cause, harm to the environment, the economy, or human health. The introduction and spread of alien invasive species is a serious problem that has ecological, economic, health and environmental impacts, including loss of native biological diversity.

As the world has become smaller through international trade, the introduction of invasive species has come to the forefront as a potential threat to ecosystems throughout the world, having already decimated many.

Although the introduction of invasive species into the Arctic environment has been little studied, it is an issue which deserves further study in the context of a changing climate and increasing shipping, which could make ecosystems more vulnerable to the introduction of species from southerly latitudes considering the potential for a rapid increase in development and ship activity in this region.

2.6.1 Sources of Invasive Species

As with ships operations in non Arctic areas, the threat from invasive species come from four sources; unmanaged ballast water discharge, hulk fouling, invasive species discharge involved with cargo operations and casualties or shipwrecks.

Ballast Water

Ballast is defined as any solid or liquid that is brought on board a vessel to increase the draft, change the trim, and regulate the stability or to maintain stress loads within acceptable limits. With the introduction of steel-hulled vessels and pumping technology, water became the ballast of choice. Ships are designed and built to move through water carrying cargo, such as oil, grains, containers, machinery and people. If the ship is travelling without cargo, or has discharged some cargo in one port and is on route to its next port of call, ballast may be taken on board to achieve the required safe operating conditions. This includes keeping the ship deep enough in the water to ensure efficient propeller and rudder operation and to avoid the bow emerging from the water, especially in heavy seas. There are thousands of aquatic species that may be carried in ships' ballast water, including bacteria and other microbes, micro-algae, and various life stages of aquatic plant and animal species. (TC Ballast Water Website)

Ballast Water discharge from ships in some areas of the world have had a catastrophic effect on the ecosystem and have caused many millions of dollars of damage to infrastructure, fishery stocks and industry. The Zebra Mussel, poster child of a ballast discharge gone badly in the north american great lakes region, is only one of 185 invasive species currently known in that ecosystem, the majority of which have been attributed to ballast water discharge since the opening of the St Lawrence Seaway in 1959. San Francisco Bay is even more heavily invaded. Other ports and ecosystems around the globe have been affected. . To date, the effect of the introduction of invasive species via ballast water discharge or other ship source vectors; current or potential, to ports in the Arctic has been studied to a very limited extent..

However, in the context of the larger picture of climate change and the potential for environmental impacts on the Arctic, non native or invasive species are being studied. Multi national scientific studies such as Tundra 99 in the Canadian Arctic and a similar previous expeditions in the Nordic Countries and the Russian Arctic examined biodiversity in the High arctic as part of a much larger agenda. The National Science Foundation in the United States, Department of Fisheries and Oceans, Natural Resources Canada , Environment Canada in Canada and the Swedish Polar Secretariat are among the various scientific groups currently investigating this area.

With limited baseline data on what species might actually be at risk from ship operations such as ballast water discharge, the precautionary approach and proactive preventative action are recommended.The changingArctic climate may increase the survivability of organisms or species introduced by the above ship source mechanisms

There are a large number of factors, acting individually and in combination, that influence the potential for invasion success. The Canadian Aquatic Invasive Species Network and a number of researchers around the world have examined models to predict the likelihood of survival of organisms. Whether the models will be predictors of success in the unique Arctic environment remains to be seen, but it is likely that the harsh climatic conditions in the Arctic have played some role. Factors such as cold air and water temperatures, limited food sources,, the high (and low) concentrations of marine life in certain areas, the short growing seasons, the seasonality of sunlight, etc. have potentially shielded the Arctic from the effects of species invasions seen in lower latitudes.

Ballast Water Management- International Regimes/IMO

The International Maritime Organization, (IMO) at the request of countries such as Canada, The United States, Australia and New Zealand in the early 90's took on the problem of ballast water discharge in its work program.

From a scientific point of view, the issue desired in ballast water management is the decrease in the number of organisms, that if introduced into a donor environment, might survive. Ballast Exchange attempts to flush coastal organisms from ballast tanks, and replace them with less abundant non coastal organisms, that theoretically will not survive in a coastal port. If that donor or receiving port is a fresh water port, the exchange of fresh water with saline water further reduces the threat, by introducing salinity shock to any freshwater organisms. While there have been a number of scientific papers that have examined the effectiveness of ballast water exchange, until ballast water treatment technologies are available worldwide, it is very much seen as an effective tool to decrease the risk of introduction of invasive species.

The International Convention for the Control and Management of Ships Ballast Water and Sediments was adopted by the International Maritime Organization (IMO) in 2004. This convention incorporates ballast exchange as the existing standard, but requires the fitting of ballast water treatment systems that will treat water to a defined discharge standard starting in 2011 and ramping up the requirement until 2016 when all ships will be required to have a treatment system onboard.

Ballast water treatment has been seen as a total solution to the problem and many political and environmental groups are putting pressure on governments to require shipboard treatment of ballast at a rate in advance of those in the International Ballast Water convention.

The current IMO ballast water treatment standard D2 requires that treatment provide a discharge standard of less than 10 viable organisms per cubic metre greater or equal to 50 micrometres , less that 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometre in minimum dimension and the discharge of indicator microbes shall not exceed certain minimum concentrations.

By the very nature of IMO, this discharge standard was a compromise between the engineering knowledge at the time, the lowest acceptable biological need and political reality. As such, environmental groups continue to call for more stringent standards and the US political system may in fact incorporate them.

From an Arctic Perspective, whether exchange or treatment, the reality is that a small percentage of viable organisms will still be discharged. As of this date the Ballast Water Convention has yet to be ratified by the required 30 states representing not less than 35% of the worlds merchant tonnage.

Regional Regimes - Canada and the United States

From an Arctic perspective – both Canada and the United States have mandatory regulations regarding requiring ballast water exchange for ships entering waters under their jurisdiction. This would include vessels heading to Alaskan ports in the US and any Arctic port in Canada assuming the voyages for the ships in question originated outside the 200 mile exclusive economic zone of either country. Both countries require ships to have a ballast water management plan onboard and to provide each jurisdiction a Ballast Water Reporting form prior to entry, indicating the location of ballast uptake and exchange. The US allows a safety exemption for ships, if the master feels exchange would endanger the vessel. Canada does not allow a safety exemption but has designated alternate ballast water exchange zones if the conditions outside the EEZ are problematic. For the Eastern Arctic, there is an alternate exchange zone for ships heading for Hudson Bay, and one for those heading to Lancaster Sound. No alternate exchange zone is provided for the Western Arctic due to the shallow depth of the Beaufort Sea and the lack of flushing current..

To date no similar legislation is in place requiring ballast management for ships heading to the Northeast Passage from either direction. Norway, Sweden and Finland have expressed concerns and plans to implement Ballast Water management for the Baltic Sea (HELCOM) but other than the ratification of the Ballast Water Convention and compliance with the assigned dates, no separate legislation seems imminent.

Canada and the IMO have collaborated on updating the IMO Globallast Risk Assessment tool. Currently the international standard for risk assessment of ballast water, the Globallast software program was originally based on a risk algorithm produced by Australia and used by the IMO in the first Globallast program. Six ports from six third world countries were evaluated for risk of invasion from ballast water discharge. The program uses a number of inputs to create a picture of risk. Specific species present in the donor and receiving ports, length of voyage, the presence of fresh water vs. salt water all are taken into consideration. However, the predominant input is the similarity of ecosystems. In this model, it is surmised that donor regions that have similar environmental attributes to receiving regions are a higher risk for facilitating successful invasions. From this point of view it would appear that vessels trading from south of 60 degrees and discharging ballast water into the Arctic that was entrained from sub arctic donor ports might be reasonably protective. Shipments between Arctic ports on the other hand could be some cause for concern. The recent agreements to expand trade between Murmansk and Churchill might become an issue from an invasive species / ballast point of view should either one of the voyage legs enter with untreated ballast. The trial voyages to date have fortuitously carried carried both way – an advantage for both the shipowner and the environment.

Examination of current and potential trade into the Arctic should give some indication of potential risk. From a Canadian and US perspective, the current trade is fairly accurately mapped.

Voyages to Arctic Alaska from a US perspective are considered to be of two distinct types when it comes to ballast water. If one considers lower Alaska to be in the Arctic ecosystem, tankers in ballast heading to Valdez to load crude are the biggest potential source of risk. The amounts of ballast are huge and the trip is always a "ballast in, product out" voyage. Vessels coming from outside the 200 mile EEZ are required to exchange their ballast, but US flag vessels that have taken ballast in US waters of the lower 48 states are exempt.

The remainder of voyages in Alaska that involve ballast are predominately supply voyages to the Aleutians or to the North Slope Oil fields. The voyage pattern here is the opposite. Generally these vessels are relatively small (at least in comparison to the crude oil tankers) are loaded with cargo on the upbound trip and have a limited ballast capacity. The majority of ballast taken on is actually entrained in Arctic ports for the trip south.

There are of course exceptions. The bulk carriers that go to take cargos at the Red Dog mine, in the Bering Sea, entrain significant amount of ballast, but are subject to ballast exchange regulations.

The large number of cruise ships that head to Alaska every year are subject to intense scrutiny by both US and Canadian authorities and are subject to both countries ballast water legislation. Many of these cruise ships have been fitted with prototype ballast water treatment systems.

Despite a much larger Arctic coastline, the situation in Canada roughly mirrors the Alaskan experience from a trading pattern perspective. With minimal exploration in comparison to the 80's the Beaufort Sea and Western Arctic are predominately serviced by Northern Transportation Company Limited (NTCL) tug barge operations based in the Mackenzie River. For these relatively small vessels ballast water is minimal. The ports of the Eastern Arctic are served by a much bigger supply train to that of the Western Arctic, but the pattern is similar. For example, an NTCL tug / barge supply route is operated out of Churchill. A much larger sealift operation is run out of Iqaluit with primary cargoes loaded in Montreal by Desgagnes in collaboration with the Nunavut Government. Again the pattern, even with the relatively large ice strengthened geared vessels is of cargo upbound and any ballast taken in the Arctic.

There are a limited number of voyages for tourists both within the Canadian Arctic and through the Northwest passage, mostly by ex Soviet converted icebreakers. These vessels are subject to the Canadian Ballast Water regulations and require exchange prior to entering.

Due to these factors, the current threat the Arctic Environment is likely relatively small.

The past histories of oil and commodity exploration suggest that the Canadian Arctic has the potential for both significant reserves of commodities that can be exported in bulk.

When in production, mines such as Polaris or oil production facilities such as Bent Horn, (both now closed), required a steady supply of relatively large ships coming entering in ballast, discharging that ballast into the Arctic and then loading cargo. Because of both the prevailing and potential weather conditions, the requirement to minimize exposure of non ice strengthened hull sections, and a desire to decrease propeller / ice interactions ballast capacity is often maximized. Currently bulk commodities are still shipped out of the Raglan mine in Deception Bay.

Future potential developments include a mines on Baffin Island with proposed year round shipment. Icebreaking bulk carriers of approx 170,000 Dwt are proposed with the proportionally large ballast capacity.

When and if oil exploration again targets the Beaufort Sea, ballast is likely to be an issue not only with respect to ships but also from drilling rigs / vessels depending upon the type of drilling platform used. Further, should production scenarios involve shipment by tanker rather than by pipeline, there is a risk that, whether treated or exchanged, large quantities of ballast (and some percentage of organisms) would be discharged at the same loading location or port. Dispersion studies are currently ongoing to quantify risk for the IMO standard, but one potential risk reduction scenario would be to require ships heading for ecologically sensitive areas to exchange ballast BEFORE undertaking Ballast Water Treatment. This should even further minimize the threat by providing less viable organisms in the pre-treatment water.

There has been much made of the potential for ships to use the NorthWest Passage in the future. From a ballast perspective, the risk is likely still low, as from a transit perspective, there is no operational need to discharge the ballast while inside the passage.

The Department of Fisheries and Oceans in Canada has examined the appropriateness of using the IMO discharge standard to protect the Great Lakes. Further work would be required but the concept might also be appropriate in an Arctic context. (Sarah)

Hull Fouling

Current scientific research has suggested that fouling of ships hulls, sea inlets and underwater appendages may be as threatening as ballast water discharge for the introductionof invasive species to the receiving environment.

Historically, the combination of wooden hulls, long voyages and often extended periods in warm water facilitated fouling in the days of sail . There are many recorded introductions of invasive species as a result of this vector. Certainly many hundreds of whaling vessels entered the US and Canadian Arctic in the 19^{th} century, with hulls fouled with organisms from southern climates.

With the advent of iron and steel hulls, and faster voyages due to the advent of steam and technical advances in antifouling coatings, the issue became rather minor. Technical advances, such as copper sheathing, antifouling paints and eventually quite complex biocidal coatings ensured that ships hulls remained clean by the end of the 20^{th} century. Unfortunately, the most recent advances in antifouling coating came at a price to the environment that the international community felt was inappropriate. The Antifouling Convention banned the use of Tributyl Tin compounds, the most common (and most effective) antifouling agent. To date, no comparable product has been formulated that has been found to be as effective and as a result, hull fouling has once again risen in importance as a vector of transfer of invasive species.

The relatively limited numbers of vessels, the short season of entry into the Arctic for most vessels and the differential between temperate or warm climate species that might be attached to a hull may serve to protect the Arctic environment and minimize the risk.

Similarly hull coatings that are designed to minimize friction in ice, may be effective antifouling agents, as would be the scouring effects of passage through ice. However the ice itself might become a vector should organisms be scraped off hulls . There is considerable research examining the ability of organisms to remain dormant in sediments only to be revived when conditions are right. Certain organisms may do the same when exposed to cold.

Assuming that in both the Russian and North American Arctic oil exploration may drive much of the shipping in the future, hull fouling of oil rigs transported around the world has been noted as a significant potential source of invasion. Mitigating that is the limited use of rig types more suitable to southern climates such as semi submersible or jack ups. To date, the ability to operate in ice has limited their use in Arctic conditions .

The International Maritime Organization has recognized the issue of hull fouling as a problem and has tasked the Bulk Liquid & Gas Subcommittee of the Marine Environmental Protection Committee to provide recommendations and guidelines for prevention of bio-fouling using the guidelines provided under ballast water (resolution A 868(20)) as the model.

A correspondence working group has been struck, Chaired by New Zealand with instructions to report back in February of 2009. Arctic Countries are represented on the working group.

Cargo Operations

Most international movement of good is regulated by various fumigation and biosecurity provisions to prevent the movement of invasive species in cargo. Various national agencies inspect both ships and goods to ensure a clean bill of health. (Regulations)

For movement of international goods to the Arctic, it must be noted that in many cases the movement is between domestic ports, not international ones. As such the fumigation requirements often do not apply . If one couples that with the reality that much of the sealift and resupply movements into the Arctic are palletized, there is a potential for unwanted organisms to be entrained in the cargo or the stowage materials

While invasive insects such as the “Asian Longhorn Beetle”, the Emerald Ash Borer” , both likely invasive species transported to North America in the cargo spaces of ships are not likely to be a threat above the tree line in the Arctic, similar invaders with a tolerance for cold weather might be hitchhikers.

Casualties and Shipwrecks

History is filled with examples of shipwrecks casing ecological damage to pristine environments, thanks to the creatures on board that survived the shipwreck. Despite advances in navigation, shipbuilding and propulsion technology, casualties and shipwrecks still occur.

From an Arctic perspective, casualties can be related to both the reason that ships entered the Arctic and the ability of the hulls to withstand the conditions present. Whaling in the 19th century provided both much profit and horrific accounts of vessels lost on the Arctic whaling grounds. The depths of Pauline Cove and Pt Barrow are littered with many such wrecks. Early exploration left many ships on the bottom. Indeed the government of Canada has just embarked on a search for the remains of Frankins'ships *Erebus* and *Terror,* Marine Archaeology was well rewarded with the discovery of the *Breadalbane* in 1980 , a vessel sent to find the Franklin expedition s crushed in the ice in 1853. The Hudson's bay vessel *Baychimo* , abandoned in 1933 was reported to be still afloat north of Barrow, stuck in an ice flow as late as the 60's. The remains of the *Baymaude* are still visible in Cambridge Bay.

From an invasive species point of view, the potential to have left more than a wreck on the bottom seems to have had little attention in the high Arctic. Shipwrecks in the Aleutians have caused significant ecological damage. See data on Rat Island

Transport Canada, in the process of examining the way forward on what eventually became the *Guidelines for Ships Operating in Arctic Ice Covered Waters* and the International Association of Classification Societies' *Unified Requirements for Polar Ships* contracted a series of papers examining the casualty statistics in both the Canadian and Russian Arctic in the 1990's. While the data was quite comprehensive, the primary casualty statistic was that hull damages far exceeded damages to machinery.

With the receding of the first year coverage in the Arctic in the past few seasons, the chance of multi year ice being present seems to have increased. The chance for catastrophic damage may have in fact increased.

Rats in Alaska- info Box

Vessels may carry rats and thus pose a potential threat to wildlife on islands and mainland areas along the North Pacific Ocean shipping routes or potential new routes that traverse the Arctic region. Alaska particularly may be vulnerable to rat infestation, since many islands, particularly in the Aleutian Islands chain, are rat free. Rats have eliminated bird species from islands throughout the world. They are voracious predators on eggs, chicks and even adult birds as large as albatrosses. Alaska is particularly vulnerable to rat infestation; the Aleutian Islands provide nesting and foraging habitat for millions of breeding seabirds, and Alaska's coastal seabird habitats are seasonal nesting habitat for about half of all seabirds in North America. Most of these birds nest on islands within the Alaska Maritime National Wildlife Refuge.

One major concern is the accidental release of rats during a shipwreck incident. Vessels that are grounded on shore may release rate to the land. At-sea wreckage may harbor rats aboard debris, transporting them to adjacent islands or mainland areas. Any vessel accident carries with it a concern for a “rat spill” which, to seabird scientists, can be as devastating as an oil spill. Rats multiply rapidly, and a single incident on a rat-free island may devastate seabird populations there.

The Alaska Board of Game has adopted new regulations that went into effect in September 2007. The regulations were designed to protect Alaska's people and wildlife by preventing the spread of rats into the rat-free parts of Alaska and controlling rats where they are already established. These regulations affect boats in Alaskan waters with rats aboard, trucks or any other moving vehicle with rats aboard, harbors or other facilities with rats, or anyone whose garbage is feeding rats or mice.

Norway and roof rats are not native to Alaska or even to North America. Alaska was still part of Russia in 1780 when the first rats are believed to have reached Alaska on a Japanese sailing ship. The ship went aground on what became known as Rat Island. Now, over 200 years later, the seabird colonies that once must have flourished on Rat Island are gone, but the rats remain. Since that fateful beginning, other shipwrecks, the creation of harbors and docks allowing boats to tie up, and especially World War II, brought rats to many of the towns of Southeast Alaska and to more than a dozen inhabited and uninhabited islands of the Aleutians.

Rats have few competitors or predators on many of the infested islands in Alaska, and rats are very adaptable to life in these remote areas. Dense colonies of nesting seabirds, intertidal organisms, insects, spiders, lush vegetation and seeds provide abundant food items for rats. They are capable of killing and stockpiling birds for winter food and switching to alternative food sources when the birds are gone. As many as 20 auklet bodies have been pulled out of one rat den. Rats can kill even very large birds, but the small ground and burrow nesting birds in the treeless Aleutians, Pribilofs and Southwest Alaska are most at risk. Some islands have tremendous seabird colonies of more than a million birds. Should rats become established on a bird-rich island such as Buldir or Bogoslof, millions of birds would be killed. At least 14 seabird species on Audubon’s Alaska Watchlist for declining species nest on islands at risk of rat introductions. Whiskered auklets, red-legged kittiwakes, and McKay’s buntings are just some of these special birds.

Today, the U.S. Fish & Wildlife Service believes that the islands of the Aleutians remain at great risk for further rat introductions through shipwrecks. An average of two shipping mishaps a year occur on or adjacent to the Alaska Maritime National Wildlife Refuge due to its location in the midst of one of the world’s busiest shipping lanes, the North Pacific Great Circle Route. Over 3,000 ships such as large container ships and freighters annually pass through the Aleutian Islands passes. Any increases in this traffic load will only increase the potential threat from accidental rat infestation from incidents such as sinkings, at-sea fires and other sources of vessel debris and wreckage, and vessel groundings on shore.

The U.S. Fish & Wildlife Service has developed a specially trained “rat spill” response team of Service employees and partners, which is the first line of defense against rats fleeing sinking ships. Shipwreck response kits strategically located along the coast are used by the team against rats on or fleeing a sinking ship. The kits contain everything needed to kill rats attempting to go ashore. When ships wreck on rat-free islands, crews put beach defenses in place to protect the native wildlife. Should the rats make it to shore and began reproducing, removal may not be possible or would be extremely expensive and difficult.

Findings- Ballast Water

The risk of introduction of invasive species into the Arctic marine environment in North America from outside the Exclusive Economic Zone of Canada or the United States is relatively low due to mandatory ballast water regulations in force in both countries.

Domestic movement of cargo and is also relatively low risk because of the voyage patterns

However domestic ballast water movements to the Arctic from either country could be high risk as, they are currently exempt from the regulations

Movement of ballast into areas of the Arctic that is currently unregulated by National Ballast Water legislation is high risk

For cases where large amounts of ballast are known to be discharged in the same geographic location, e.g. Tankers coming to load crude at oil production facilities within the Arctic, extra cautions should be taken with ballast discharge.

Findings: Historically the Arctic has been the source of many ship casualties and wrecks. In some cases the invasive results of those ships wrecks are well documents. Recent history and the inclusion of multi year ice in the shipping channels has potentially increased that potential

Findings- Hull Fouling

In sub Arctic waters, transfer of aquatic invasive species on the hulls of ships has become a serious threat to the environment, rivalling ballast water discharge. Because of the unique nature of both the trade and the environment, hull fouling may be a potential threat in the Arctic but there is insufficient research to show a cause and effect.

The International Maritime Organization currently is dealing with the issue and the Arctic needs to be considered in their deliberations

3. Impacts by regions

Missing text

3.1 Barents Sea and Kara Sea LMEs

****Note Section 3.1 not yet complete

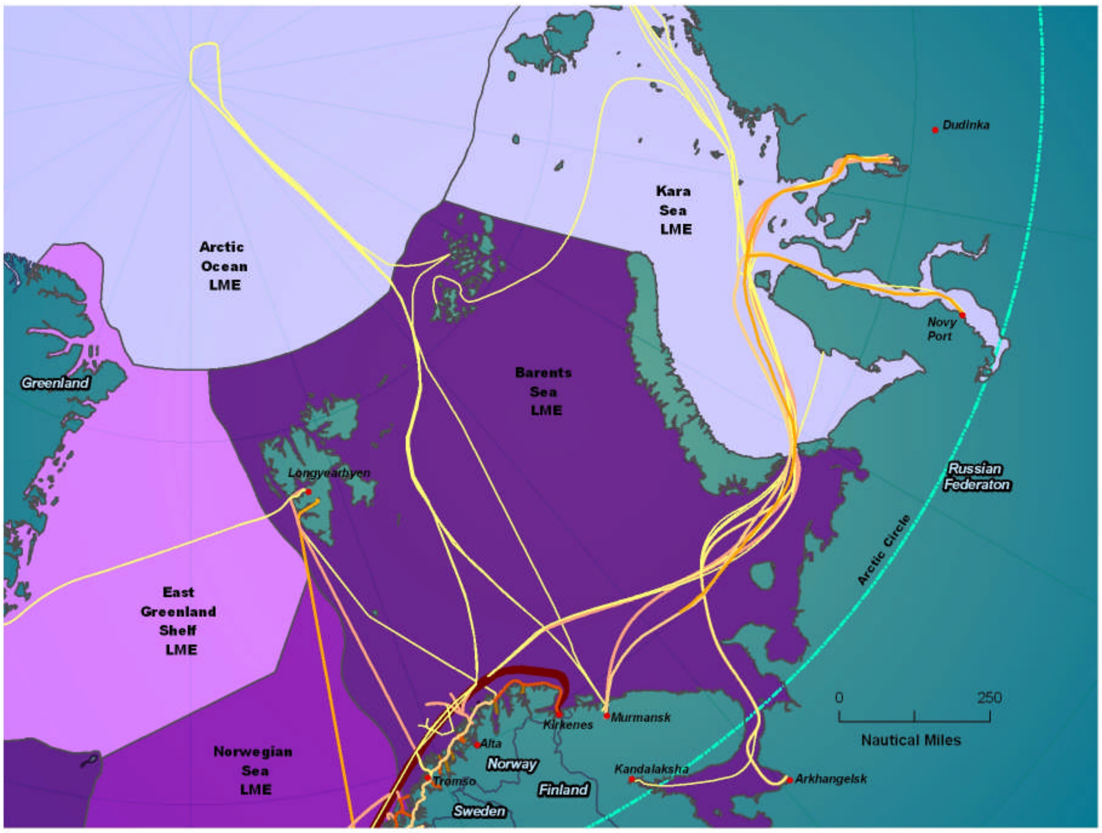
There is a large volume of shipping in the Barents Sea, while the shipping activity is considerably less in the Kara Sea. The main shipping route into the area is along the coast of Norway. A main shipping lane goes through inshore waters, and much of the traffic to and from ports in northern Norway follows this route. Traffic to and from Russia follows an offshore route in the open sea to ports in Murmansk, the White Sea and other areas. Transport of oil from Russia is from ports in the White Sea, Murmansk, Pechora Sea (i.e., Kolguev, Varandey), and Ob' and Yenisei estuaries in the Kara Sea. There is also year-round shipping of nickel ore by Norilsk Nickel from a port in the Yenisei estuary. In the western Barents Sea, there is a shipping route to Svalbard with seasonal traffic of cargo ships supplying the communities, bulk carriers transporting coal and cruise ships. There is also a substantial number of fishing vessels that operate year round in the ice-free part of the southern and central Barents Sea, while there is little fishing activity in the Kara Sea.

Norway adopted in 2006 an integrated management plan for the Norwegian part of the Barents Sea and adjacent waters off the Lofoten Islands. In the preparatory work for this plan, an assessment of environmental impacts from shipping was carried out and valuable and vulnerable areas were identified. The plan established a forum on environmental risk management headed by the Norwegian Coastal Administration, that is tasked with providing better information on risk trends in the area, especially as regards acute oil pollution from ships and other sources. In July 2007, the IMO established regulations that require larger cargo vessels and tankers transiting the Norwegian coast of the Barents Sea to operate further away from the coast than in the past. This requirement is intended to allow a longer response time in case of accidents that could impact the Norwegian coastal environment and resources.

Vulnerable areas in the Barents and Kara seas have been identified in relation to oil and gas activities, based on where there are aggregations of animals that could potentially be impacted by oil spills or disturbances from activities. The Barents Sea holds more than seven million pairs of breeding seabirds, with major colonies on Svalbard, the western section of Novaya Zemlya off the coast of northern Russia and along the coast of northern Norway. The oceanographic polar front and the ice edge in the western and central Barents Sea is a concentrated zone of life in spring and summer with aggregations of seabirds and seals. The polar front area is also the wintering area for the large Barents Sea capelin stock and for seabirds such as thick-billed murre. Svalbard and Frantz Josef Land in the northern Barents Sea are important breeding and feeding areas for seabirds, walrus and seals, and denning areas for polar bear. The southern and eastern Barents Sea is a wintering area for many seabirds and sea ducks that breed further east in the

Russian Arctic. The Pechora Sea area and the southern Kara Sea lie adjacent to tundra and wetlands that are important breeding grounds for geese, ducks and shorebirds. Many of these use coastal habitats for staging during spring migration and after breeding when they prepare for the fall migration out of the Arctic.

Map of 2004 Vessel Activity for the Barents and Kara Sea Region



The southern Barents Sea is a rich fisheries area with large stocks of cod, haddock, capelin, juvenile herring and shrimp. A major stock of polar cod spawns under ice in the Pechora Sea region, and this region is also the main wintering area for white whales of the Karskaya population that is migratory between the Barents, Kara and Laptev seas. The smaller White Sea beluga population has its wintering area in the Voronka and Gorlo area at the entrance to the White Sea. The Barents Sea harp seal population has its whelping and molting areas on the ice also at the entrance to the White Sea. The Novaya Zemlya population of Atlantic walrus has its wintering area in the pack ice in the Pechora Sea region. White whales and walrus migrate north in spring following lead systems west of Novaya Zemlya, and the white whales continue east through the northern Kara Sea and into the western Laptev Sea in early summer. There are two subpopulations of polar bears in the Barents and Kara seas with seasonal migrations following the ice.

There are no documented negative impacts on animals in this area from shipping activities. Accidental oil spills have occurred and have been associated with high local mortality of seabirds. However, these incidents have not had material impacts at the population level for the affected species. Ship strike of whales could occur in some areas but there are no reports to suggest that the level of impact is significant. The greatest concern is the threat from accidental oil spills that could have a large impact on seabirds and other marine birds, and also on marine mammals such as polar bear and on spawning polar cod. Disturbance of wintering white whales and walrus and ship strike of whales are also concerns as the shipping activities are likely to increase in the future.

3.2 Baffin Bay-Canadian Arctic Archipelago and Hudson Bay LME's

Note- Not complete yet

3.2.1 Description of LME's and Region

The Canadian Arctic, as with other polar regions, is currently experiencing unprecedented and rapid change, ahead of other parts of the planet as a result of global climate change. In the context of this, and in some cases due to these changes interest in the potential wealth of natural resources and new shipping opportunities has increased significantly as of late. There is the potential for a large increase in shipping activity in the Canadian Arctic is due to the relatively low amount of shipping previously occurring and the large number of new resource development activities on the horizon for this region. For the AMSA, it is valuable to examine this region in more detail, as there are a number of unique environmental and development issues currently being faced in the Canadian Arctic that should be of consideration in the circumpolar context.

The Canadian Arctic is home to rich diversity of wildlife that thrives in a variety of ecosystems varying from the east to the west. Canada, through its membership in the Arctic Council has recently adopted the Large Marine Ecosystem (LME) approach. Seventeen LME's have been identified in the Arctic region, some of which transect political boundaries. Four of these LME's occur in Canadian waters, including the Hudson Bay, Baffin Bay/Davis Strait, Arctic Archipelago, and Beaufort Sea. The geographic and biological factors which define the Canadian LME's will be described below.

3.2.1.1 Hudson Bay LME

The Hudson Bay large marine ecosystem (LME) geographically encompasses Hudson Bay, James Bay, Foxe Basin, Hudson Straight and Ungava Bay. These are areas of relatively high primary productivity, especially in coastal zones. (Sherman et al 2008) The Hudson Bay LME is a highly enclosed area characterized by large amounts of fresh water influx. The Hudson Bay receives an input of freshwater concentrated to a 6 months period (May-October) that is annually about 700 km^3 (Prinsenberg 1986c). This is more than the discharge by the largest Siberian river (Yenitseyi, about 620 km^3) and about twice that of the Mackenzie River (about 330 km^3). (O and G)

Hudson Bay is fully ice covered from December to April, with ice starting to form in the northern areas in late October and rapidly increasing in extent and thickness during November and December (Prinsenberg 1986c). The Foxe Basin has a longer ice season, and only during September is the basin normally ice free, with some remnants of the ice concentrating in the southwestern corner off the northeast coast of the Southampton Island (Prinsenberg 1986b). Seasonal production in areas of this LME that have been studied include both ice algae and phytoplankton (Roff and Legendre 1986). The fish communities in this LME are generally low in species numbers but which occur in a diversity of habitats spanning freshwater to brackish water.

Hudson Bay LME supports a large number of marine bird populations. The true seabirds and many other species migrate to the region in spring and fall through the Hudson Strait, resulting in large concentrations of birds along the ice edge as it melts out in spring. Sea ducks, notably common eiders, are abundant along Hudson Strait and Ungava Bay and the endemic Hudson Bay subspecies of common eiders spends the entire year in Hudson Bay, wintering in open waters areas, notably the Belcher Islands (Freeman 1970, Gilchrist and Robertson 2000). Large seabird colonies (mostly thick-billed murres) occur at the central part of the LME, at Akpatok, Digges and Coats Island (Gaston et al. 1985, Gaston 1991, 2002). Due to the shallow depths and extensive nearshore habitat, Foxe Basin is home to more coastal and estuarine species of birds, large and sometimes globally significant populations of shorebirds (notably red phalaropes), brant, Sabine’s gull and other species are present (Mallory and Fontaine 2004).

A small population of about 350 bowhead whales inhabits Hudson Bay and Foxe Basin, and is listed as endangered (CAFF 2001). The location of the Roes Welcome Sound polynya is an important summer feeding area for bowheads where they reside from mid May to mid September (Stirling et al. 1981). Narwhals have a similar occurrence in this area.

The northern Foxe Basin is an important area for walrus which occupy the area year-round, wintering in the leads and polynya. Walrus is also abundant in the northwestern part of the Hudson Bay where they concentrate to winter in the Roes Welcome Sound polynya. Many walrus migrate into and out of the Hudson Strait, following the southern coast on their westwards migration in early summer and returning along the northern shore in fall. The Foxe Basin is also an important summer feeding area for bowheads and narwhals, as well as for beluga whales. (Stirling et al. 1981).

3.2.1.2 Baffin Bay/Davis Strait LME

The Baffin Bay/Davis Straight LME geographically encompasses an area which extends from the entrance to Ungava Bay, north along the Davis strait along the eastern edge of Baffin Island to the southern edge of Ellesmere Island, and is bordered on the east side by the continental shelf line, beyond which the deep shore waters begin. This LME is characterized by seasonal ice cover in the winter and is under the influence of fresh water influx and tides. Primary production in this LME is relatively high, in the form of Phytoplankton and Zooplankton, occurring mainly in the coastal areas of Baffin Island. This supports numerous populations of shrimp, groundfish, marine mammals and sea birds (Sherman et al).

Sea ice is an important part of the physical and ecological conditions in this LME. Most of the Baffin Bay and the western areas south of the Davies Strait are covered by ice in winter. Sea ice starts to form in late autumn and develops into a thick pack-ice in Baffin Bay. Due to currents and winds there is much movement in the ice with cracks, leads and ridges forming as a result. The pack ice remains in motion all winter in northern Baffin Bay and extending into the Lancaster Sound, along western Greenland, and in the Davis Strait region. Off central Baffin Island, the pack ice becomes consolidated and remains landfast well into summer (Brown and Nettleship 1981). The northern end of Baffin Bay is home to the North Waters Polynya, on of the largest and most northerly, which provides important habitat for sea birds and marine mammals overwintering or for migration. (Mills, 1986)

Many fish and shellfish species thrive in this LME, some of which are commercially exploited, including the capelin, polar cod, greenland and atlantic halibut, atlantic cod, northern shrimp, and snow crab (O and G 2008). In addition to their commercial value these species are also an important food sources for the 16 species of marine mammals and many large colonies of sea birds which thrive in this region.

Many whale species are summer visitors including sperm whales (*Physeter catodon*), bottlenosed whales (*Hyperoodon ampullatus*) and pilot whales (*Globicephala maelaena*) (Stirling et al. 1981). Minke (*Balaenoptera acutorostrata*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*) and occasional blue whales (*B. musculus*) are also common in the coastal waters in summer. (Teilmann and Dietz 1998). Populations of beluga and narwhal winter in areas in Baffin Bay.

In addition to whales, this LME supports a range of seal populations, including the most widespread and numerous species, the resident ringed seal (*Phoca hispida*), which occur almost everywhere in the region. (Stirling et al. 1981). Ringed and bearded seals are abundant in the northern Baffin Bay area and these seals support a population of polar bears in that area (Lunn *et al.* 2002). The harp seal (*Phoca groenlandica*) and hooded seal (*Cystophora groenlandica*), are also seasonally present and whelp in high concentrations in areas on the drift in the central Davis Strait (Sergeant 1974, Bowen *et al*. 1987).

The Baffin Bay - Davis Strait LME supports a significant portion of the seabird populations of the Arctic and the majority of the seabird species present are colonial breeders. Impressive colonies, some supporting >100,000 birds, often occurring on steep rocky coasts, of thick-billed murres, northern fulmars and black-legged kittiwakes occur in the LME (Mallory and Fontaine 2004). The Thule district of Greenland is included in this LME, and hosts colonies of millions of dovekies (Boertmann and Mosbech 1998. Egevang et al. 2003), along with large numbers of murres, fulmars and kittiwakes (Boertmann et al. 1996). Birds at colonies in the northern part of the LME make extensive use the North Water Polynya. In spring, recurrent ice edges, shear zones and polynya are important feeding and staging grounds for seabirds migrating towards the breeding grounds and during pre-breeding. In fall, birds breeding in this LME, along with many birds from the western portions of Arctic Archipelago and West Greenland Shelf migrate south through these waters.

3.2.1.3 Arctic Archipelago LME

The Arctic Archipelago LME geographically encompasses the marine area in and around the Arctic Islands, extending west from Baffin Bay to the waters just beyond Banks Island and the Amundsen Gulf and North to continental shelf beyond the northern tip of Ellesmere Island. This region is highly enclosed and is characterized by narrow straits and relatively shallow waters (Sherman et al.). The entire archipelago in past years have been covered by ice during winter. Most of this is landfast ice between the islands, while moving pack ice occurs north of the archipelago and in the Lancaster Sound. Much of the archipelago remains ice-covered during summer, although the ice may break up and become mobile and the ice-cover is only partial. It should be noted, however, that in the context of recent changes in this region that seasonal patterns may no longer apply.(Oand G)

The presence of year round ice cover has resulted in this region being fairly low in primary productivity. (Sherman et al) One of the criteria for defining an LME is the presence of trophically coupled populations. In this respect the archipelago is an ill-defined LME as there appears not to be distinct populations of fish or mammals that reside here. Rather, the area is a transition zone and one into which populations extend during seasonal feeding migrations. (O and G) As an example, most major seabird colonies in this LME are concentrated along Lancaster and Jones Sounds, and birds from these colonies use the waters of the Baffin Bay/Davis Strait LME, including the North Water Polynya to varying degrees throughout their time in Arctic waters.

The ringed seal (*Phoca hispida*) is distributed widely and is the most common marine mammal in the archipelago. Here as elsewhere they form the main food for the polar bears inhabiting the region, aerial surveys have shown the highest densities of ringed seals to occur in the area of the Barrow Strait, decreasing north and west in the archipelago (Kingsley et al. 1985). Atlantic walrus (*Odobenus rosmarus rosmarus*) occurs in the eastern and central parts of the archipelago. (Stirling et al. 1981).

Beluga whale (*Delphinapterus leucas*), bowhead whale (*Balaena mysticetus*), and narwhal (*Monodon monoceros*) are regular visitors to the archipelago in summer. The population of belugas in the Beaufort Sea extends into the western part of the archipelago during summer as does the western Arctic bowhead whale stock which summers in Amundsen Gulf. (deMarch et al. 2002)

As indicated above, true seabird populations in the Arctic Archipelago LME tended to centered around Jones and Lancaster Sound. Prince Leopold Island is the largest seabird colony in the LME. The COSEWIC *Endangered*-listed Ivory Gull, nests throughout the LME from Baffin Island to Ellesmere Island (Gilchrist and Mallory 2005). In the central and western portion of the LME, more coastal species are present, such as waterfowl, gulls and shorebirds. Concentrations of migrating and staging sea ducks have been noted along the coasts of Victoria and Banks Island, as well as the mainland coast (Mallory and Fontaine 2004), on there way to and from non-breeding areas off Alaska and Russia. At the western end of the LME, the only colony of the Pacific subspecies of Thick-billed Murre nests at Cape Parry (Johnson and Ward 1985). Due to the high level of ice coverage, few birds over-winter in this LME.

3.2.1.4 Beaufort Sea

The Beaufort Sea LME geographically encompasses the ocean basin west of the Amundsen Gulf and Banks Island in to the eastern edge of the Chuchki Sea off the Coast of Alaska. The Northern edge of this LME extends to 75 degrees north, which is the average summer min sea ice extent. The Beaufort Sea is completely ice-covered in winter. Melting of ice starts in late spring the ice usually retreats northwards from June onwards to the seasonal minimum extent in September, although there is inter-annual variability. In cold years most of the Beaufort Sea has remained ice-covered during summer, however, in recent years melting has been large and there has been relatively little ice during summer (Macdonald et al. 2003).

The primary production by phytoplankton is largely governed by ice and ice melt. Located between about 70-75^{o}N, there is sufficient light for primary production for a period of more than 6 months, however, the influx of fresh water from the Mackenzie results in stratification of the water column which lowers the availability of nutrients by mixing resulting in moderate to low primary production. (O and G) In the winter months the Cape Bathurst Polynya provides important habitat for many marine mammals and seabirds. (Environmental Handbook 1998)

Several species of fish live in the coastal waters of this area, including Arctic cisco (*Coregonus autumnalis*), broad whitefish (*Coregonus nasus*), least cisco (*Coregonus sardinella*), and Dolly Varden char. Beluga whales (*Delphinapterus leucas*) travel to the Beaufort LME in summer and the population is one of the largest populations in Canadian waters numbering at least 39.000 individuals (NMFS 1999). Bowhead whale (*Balaena mysticetus*) of the western Arctic stock migrate between overwintering areas in the Bering Sea to feeding areas in the Beaufort Sea during summer. A small number of gray whales may also feed in the Beaufort Sea during summer, which has become more common as the eastern North Pacific gray whale population recovers from depletion by commercial whaling (Wade and Perryman 2002).

Ringed seal (*Phoca hispida*) are year-round residents of the Beaufort Sea LME where they are closely associated with the sea ice which provides a platform for resting, feeding, molting, pupping, and nursing (Frost et al. 2004). Bearded seals (*Erignathus barbatus*) also occur in the Beaufort Sea, as do small numbers of spotted seals and an occasional walrus (*Odobenus rosmarus*). Polar bears from the southern and northern Beaufort Sea populations are also present, largely associated with the sea ice, but they also occur along the coast of Alaska during the fall to feed on the carcasses of bowhead whales harvested by the Eskimo communities.(O and G)

Aerial surveys in the Beaufort Sea have documented that birds are widespread in substantial numbers in both nearshore and offshore waters of this area (Fischer, 2001; Fischer, Tiplady, and Larned, 2002; Larned, Platte, and Stehn, 2001; Stehn and Platte, 2000; USDOI, Fish and Wildlife Service, 2002) In this LME most loons, waterfowl, and seabirds are found within 50 km of the coast and bird densities are generally lower in offshore areas. Barrier islands provide important nesting habitat for birds such as common eiders, glaucous gulls, arctic terns, and black guillemots. Lagoons formed by barrier islands, bays, and river deltas of the Mackenzie provide important brood-rearing and staging habitat for waterfowl, particularly molting long-tailed ducks; eiders; other waterfowl species; and plovers, sandpipers, and phalaropes. The use of lagoons and other coastal habitats by migrants peaks in August to late September. From late September to mid-October, a majority of the world Ross' gull population occurs offshore of Point Barrow and eastward to the Plover Islands (Divoky, Hatch, and Haney, 1988).

3.2.2 General Description of Shipping traffic- 2004 baseline

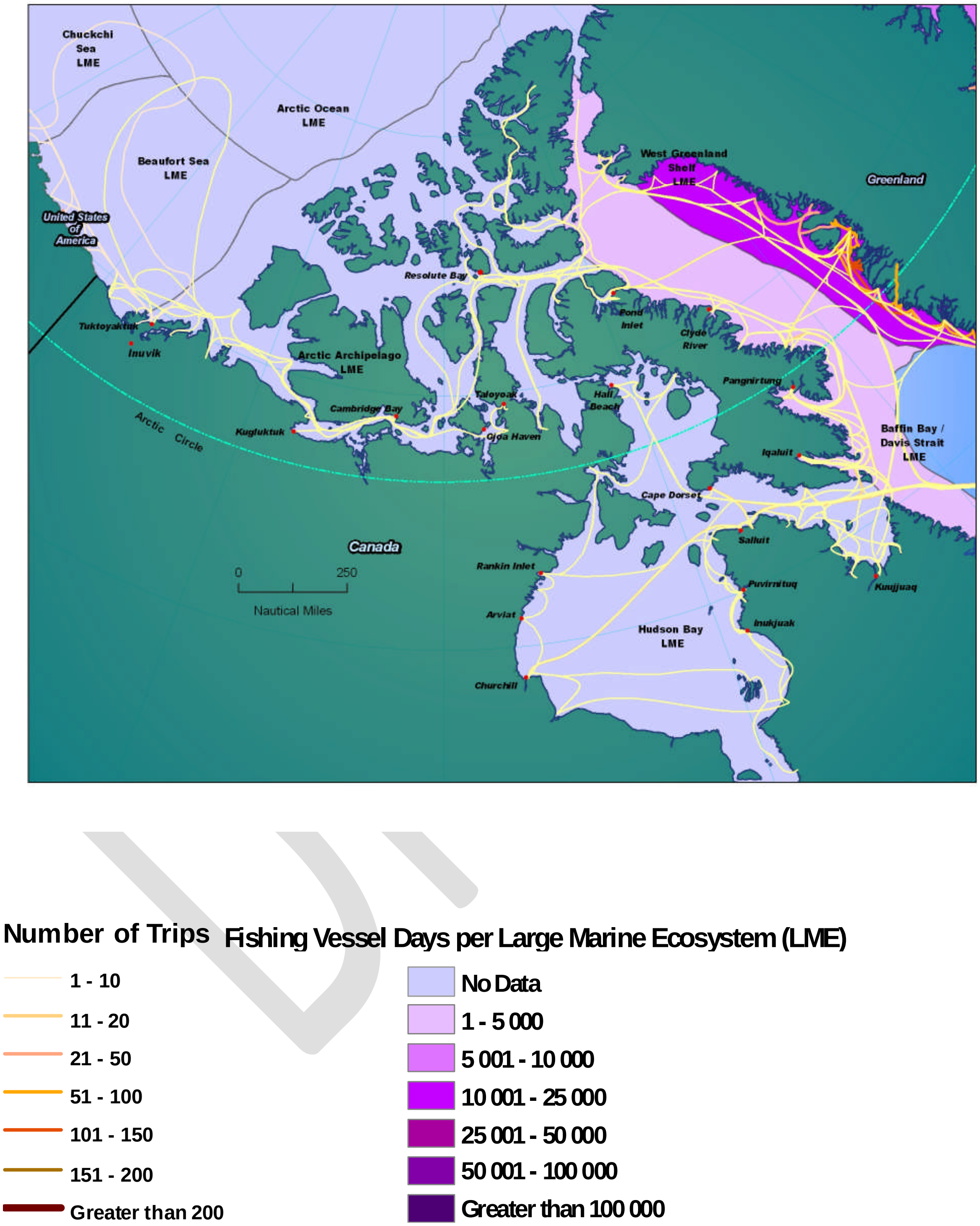
Over 30 000 people live in the Canadian high Arctic and this population is growing, with a very young population and a birth rate higher than elsewhere in the country. (check these #'s with StatsCan). For many years shipping has been the main link to the outside world for remote Arctic communities in Canada it remains so. The yearly sea lifts remain the key source of goods and necessities for many communities and their deliveries have profound impacts on local economies and quality of life, making shipping a very important activity.

Though shipping is a very important part of the northern economy in Canada, the level of activity taking place for 2004, the baseline year of the AMSA report is relatively small. This is apparent when examining the number of ships operating in Canadian Arctic waters in comparison to the level of traffic experienced elsewhere in the Arctic and the world. In 2004 there were 60vessels(not including fishing) which operated in Canadian Arctic waters, while, for examples there were 93 + ships operating in Greenlandic waters, and 1000+ ships operating in Norwegian water, (refer to chapter 3 for further information) (# of ships entering the port of LA?). The differential in shipping activity is due, in part, to the relatively short shipping season in Canadian waters compared to the year round ice free Barents Sea off Norway. While the number of voyages is small relative to voyage numbers elsewhere, the high level of community dependence on each voyage makes ocean transportation to communities critically important.

The types of shipping activity occurring in the Canadian Arctic for 2004 can be generally grouped into the following activities: community re-supply (Tug-Barge, cargo, fuel tankers), Canadian Coast Guard and research activity, cargo and resupply support for resource development operations, cargo shipments in and out of the Port of Churchill and tourism. Depending on a myriad of factors, anywhere from modest to rapid growth is expected in all of these types of activities in the coming future. Where the biggest increase is expected based on known information is in the natural resource exploration and extraction sector (ASIA 2008). This is due to the high level of exploration going on at the moment, with over 100 claims being explored in 2007 in Nunavut alone (INAC Nunavut report 2007) as well as a number of big mine operations due to be coming online within the next 2-5 years. The specific upcoming developments in the Canadian Arctic which are likely to dictate future shipping and associated environmental concerns in this region will be examined in further detail below.

How current shipping activity is distributed in the Canadian Arctic can be seen on the map below. Though much of this activity occurred in the region of the Arctic Archipelago which makes up the Northwest Passage, it should be noted that none of the traffic transited through the passage for this year aside from a few coast guard and research vessels (need to verify this with Susie).

Map of 2004 Shipping Activity in the Canadian Arctic
Region



Shipping in the Canadian Arctic has been occurring in safe and relatively environmentally sustainable way for many years. This has been due to both to the historically low level of activity already described as well as the regulatory restrictions that have been in place to protect the Canadian Arctic Waters from shipping since the 1970's in the form of the Arctic Waters Pollution Prevention Act (AWPPA). The low level of shipping activity and limitation of operations to times of favorable conditions has meant that resulting environmental impacts to date have been light/few.

Due to the low the level of shipping activity in the Canadian Arctic up to and including the baseline year of 2004, there has been little recorded environmental impacts from shippingin this region, however, what this also means is that it will take less of an increase in activity to double or triple current levels. Any increase in activity brings with it a corresponding increase in the risk of damage to the environment both from normal ship operations and accidents or emergencies.

3.2.3 Specific Environmental Concerns

The Canadian Arctic is a vast and relatively pristine region which, in addition to its human population, supports a vast array of terrestrial and marine species, both endemic and migratory. These populations are now all under stress to varying degrees due to the changes now occurring in the Arctic environment as a result of global climate change. (Reference-ACIA?) Ironically, it is those changes which are also behind the possible increase in shipping activity in this region which could result in additional stress on Arctic populations. Any potential impacts from an increase in shipping activity in the Canadian arctic must be considered in this context.

Specific adverse impacts associated with shipping activity that are of the most concern in the Canadian Arctic, as identified in previous studies, include:

The discharge of pollutants in the marine environment as a result of normal operations or accidents.

Adverse impacts on wildlife populations due to disruption of migratory patterns or disturbance.

Adverse impacts on traditional use patterns both as a result of the above or disruption from icebreaking/shipping activity.

(Marine Env Handbook pg 1)

Hunting and traditional foods are of profound importance to the Indigenous people of Canada's north (Marine Env Handbook pg 5). Therefore, the protection of wildlife populations is not just of ecological but also social and cultural importance. At particular risk of adverse impacts from shipping would be marine mammals, sea birds, and some caribou. These impacts can be for a range of reasons including disturbance, introduction of invasive species, mammal strikes, and physiological problems as a result of released pollutants, among others. The range impacts are explored in further detail in previous sections of this chapter.

There are certain environmental issues relating to shipping which are of particular consideration for this region. One of these relates to the potential impacts associated with the opening of channels through ice by icebreaker ships. When an icebreaker makes passage through ice it opens up a water channel that may take some time to freeze over again. This can cause problems for local wildlife and people who may be a caught out on the wrong side of the channel. There is also some consideration of how the open channels may impact the movements of marine mammals, which often seek ice edge opening for breathing.

This particular issue has come to the forefront in consideration of a new mine operation being proposed in Mary River, Nunavut, where the company is planning year round operations with icebreaker bulk carriers, which could potentially be operating daily, meaning that some open water channels may never refreeze. In the early 1980's a study was carried out which examined this same issue but in relation to the ice breaking activities for the lead-zinc mine in Nanisivik on the north end of Baffin Island. At the time the hunters had similar concerns to those today, that the noise from the icebreakers would alter the behavior of the narwhals. Over three summers scientists tracked the responses of both beluga and narwhal whales that were congregated at the ice edge, both as the icebreakers approached, during icebreaking and after they had left they area.

The scientists found that belugas and narwhals in the area were highly sensitive to shipping in the spring, but that the two species responded in different ways. Both whales showed evidence that they were aware of the presence of the ships over 80 km away and that strong avoidance reactions occurred when the ship was between 35-50km away. Belugas showed greater reactions to ship disturbance and returned more slowly than narwhals. There was also evidence that the whales sensitivity to the noise declined over time. It was observed that part of the sensitivity may have had as much to do with the previous lack of exposure to ships as the ship itself. It was evidenced that Narwhals in other areas have become accustomed to noise. (lgl ltd 1986) All of this is to say that ships noise will have impacts, but that depends on many factors, further study is needed in this area.

An issue which has been identified relating to ship traffic has to do with the wake produced by vessels traveling through ice covered waters. Seals make their deans hidden underneath the ice. A ship traveling through a seal whelping area can adversely impact the nearby seals through flooding the den with water or even just by wetting the baby seals that have yet to develop proper insulation. A study carried out in the 1980's demonstrated that the passage of two tanker ships, 8 times would result in a 1% mortality rate of the localized seal population, this would be equivalent in numbers to the total catch for a community such as Resolute. (Smiley, D 1986)

Another issue of particular concern in the Canadian Arctic is a result of the unique geographic nature of it the Archipelago where the famed northwest passage is. The Canadian Archipelago is a series of islands with numerous straits and bays. The straights are narrow and often shallow, and some areas remain uncharted, resulting in very challenging navigation. The current ship traffic in this region is from a handful of operators who have a high level of experience and expertise operating in this region. This level of expertise, combined with compliance with the current Canadian regulatory regime for Arctic waters has meant that accidents have been few and far between.

The geographic nature of the Arctic Archipelago is also favored by many types of marine mammals, which often congregate in shallow bays and migrate through many of the narrow straits. Extra care will need to be taken to ensure that the marine mammals are not adversely impacted due to the potential increase in traffic in this area.

As shipping activity in this region increases, however, what we will potentially see is an influx of new operators with masters and crews without this level of experience. When the challenging navigational conditions are combined with rapidly changing ice and weather conditions and the lack of expertise the risk of accident increases significantly. As with anywhere in the Arctic, the main threat to the environment would be from a potential accident or spill, which could be both disastrous in terms of impacts and response measures. The particular challenges associated with responding to spills and accidents in the Arctic environment have been explored further in both Chapter 7, section… and in Section 2.3 of this chapter.

3.2.4 Areas of Development/Future Shipping

The Canadian Arctic remains one of the last frontiers for natural resources as well as one of the last areas of relatively pristine wilderness on earth. This is a region with virtually no roads, no rail lines, and where air services are both infrequent and very costly. (CASA 2007) This is also a region with a very challenging climate, where there are extremes of both 24 hours of darkness and 24 hours of light as well as extreme cold temperatures for much of the year. The lack of infrastructure and the extreme climate have, until recently, made this region one that was fairly uneconomical for large scale resource development. Rising prices of oil, gas and other commodities coupled with the climate changes now occurring have changed that.

The US Geological Survey recently released an assessment of undiscovered oil and gas reserves north of the Arctic Circle. In this report it was estimated that 17,872.43 million barrels of oil and 117,611.07 billion cubic feet of natural gas might be lying under the surface of the earth or ocean floor in the Canadian Arctic alone. (USGS Fact Sheet 2008) Any type of development in Canada’s north will have implications for how and where shipping traffic will increase in this region and the environmental issues which will subsequently need to addressed to ensure that serious impacts are mitigated. A few specific projects and areas have been identified which will most directly impact future shipping traffic in the Canadian Arctic. These are described below.

Baffinland Mary River Mine

Baffinland mine corporation is proposing an iron ore mine in Mary River, located on north Baffin Island in the Canadian province of Nunavut. No infrastructure or settlements currently exists at Mary River, but it is near to the communities of Pond Inlet, Igloolik Clyde River, Arctic Bay, and Hall Beach.

The Baffinland project will involve the construction, operation, closure, and reclamation of 20 million tonne per annum open pit mine. When operational, high-grade iron ore will be mined and shipped to markets after crushing and screening. A railway will be built to transport the ore from the site 143 km to an all season deep-water port and ship loading facility to be built in Steensby Inlet. The ore will be shipped from this port through Foxe Basin to its primary market, steel mills located in western Europe, via the port of Rotterdam, Germany (Baffinland exec summary).

Baffinland is considering commissioning approximately 12 cape size icebreaking ore carriers with a maximum load capacity of 130 000 tons to service the mine. This dedicated fleet will operate year round with additional shipping occurring during the open water season. In the open water season, non-icebreaking ore carriers and other conventional ships will be used (icetech article). Construction of this mine is predicted to run from 2010 to 2014 and the mine is planned to be in operation for 21 years starting in 2014. During operational period, the mine will require an onsite staff of approximately 670 people.

The Baffinland project is currently being recommended to undergo an environmental review by the minister of Canadian Indian and Northern Affairs. A number of concerns have been raised by the various communities and government departments consulted, including impacts to marine mammals caused by shipping and potential spills along the proposed shipping routes, potential impacts on marine water quality, in particular, the marine water quality in proximity to the sea port, disturbance to waterfowl and seabirds nesting in coastal areas along the proposed shipping route, shoreline erosion as a result of wake effects along the proposed shipping route, and impacts resulting from accidents or malfunctions which may occur during mining operations, rail transportation, and marine shipping. (NIRB- letter to minister)

If this project goes ahead as planned it will have profound impacts on the ship traffic levels in the Canadian Arctic. At the maximum load capacity of the vessels approximately 138 loads will be necessary just to get the ore to market, which could mean a shipment every three days. This would not account for shipments necessary to service and supply the mine. This could increase the ship traffic in the Canadian Arctic by 1/3 just through the operation of this mine. However, until the environmental assessments have been completed the future of this project will remain uncertain.

High Lake Mine

Wolfden Inc are proposing a copper zinc, gold and silver mine in Nunavut near the communities of Kuglugtuk and Cambridge Bay on Baffin Island. Mining will be done through open pit and underground methods and the life of the mine is estimate to be at 14 years, with construction beginning in 2008.At peak the mine is expected to produce 1.4 million tons of ore a year and will have a staff of 335. Wolfden is proposing to ship out all of the ore by a 50 km road to a dock which will be constructed at Gray's bay in the Coronation Gulf. The shipping operation will employ tug barge tandems, fuel tankers, ice class vessels and smaller boats close to the docks.(Wolfden Inc Exec summary) Shipping operations are planned to take place in the ice-free season, but some icebreaking support may be necessary. Wolfden predicts that 4 to 7 ships will be required to haul the concentrates out every year. Based on the environmental assessment carried out by Wolfden, the company has concluded that the project will not cause significant adverse impacts to the surrounding environment. The project is currently under review by the Nunavut Impact Review Board. The public has concern that the potential icebreaking activity could interrupt Caribou migrations and etc…

Bathurst Port and Road

A new port and road project is proposed for the community for Bathurst Inlet in western Nunavut, not far from where the High Lake mine is also proposed. The proponents of this project (Kitikmeot Inuit Corporation directly and indirectly own 62.75% of the project) propose building an all weather road which would lead km inland from Bathurst Inlet to service existing diamond mines in the area far to the north of Yellowknife which have been experiencing difficulty in getting supplies due the unreliability of winter roads. A component of this proposal would be the development of a port and Diesel fuel tank farm. Shipping to the port is planned in the regular shipping season of mid –July to October, with vessels of up to 50, 000 ton delivering 300 000 tons of fuel and cargo for communities and mines. If approved, construction of this project could begin in summer of 2009, with it becoming fully operational by winter 2011. (BIRP- Draft Environmental Assessment Executive Summary 2007)

The shipping route which is proposed would follow the existing sea lift route through Barrow Strait and the Queen Maude Gulf. Some impacts are expected on wildlife populations, the main ones being the seabird colonies which would be close to where the shipping route passes. These impacts are proposed to be mitigated through avoiding sensitive wildlife areas, minimizing sensory disturbance and implementing a no hunting and employee education policy. It is predicted that proposed development of additional mine which will also require the Bathurst Port and Road facilities to import supplies and export product could result in a three fold increase in shipping and truck traffic in coming years. (BIRP- Draft Environmental Assessment Executive Summary 2007)

High Arctic Oil and Gas Reserves

Between 1969 and the late 1980's many wells were drilled in the Canadian high arctic islands and eighteen fields of oil adn gas had been discovered. However, the costs of developing the fields were high relative to the price of oil at the time so this resource has, to date, remained unexploited. The Bent Horn field on Cameron Island was exploited briefly between 1985 and 1990, when an icebreaking oil tanker was employed to bring the oil to market (NRCAN Info Sheet). With the rising price of oil and the prospect of a new pipeline to link the Arctic to southern market, this area has the potential for some significant oil and gas development. In particular, places such as the Drake Field, with known reserves of over 99 billion cubic metres of gas, it seems that development will occur sooner rather than later (NRCAN info sheet). Due to the remote location of these gas fields, shipping will inevitably play a part in any development, both to bring in supplies and construction equipment, and to bring out the oil and gas.

Mackenzie Delta-Oil and Gas

As early as the 1960's exploration for oil and gas in the Mackenzie Delta region of the Canadian western Arctic began. As of 1996 the National Energy Board estimates that up to 1.9 trillion cubic meters hydrocarbons in the Mackenzie Delta and Beaufort Sea regions. (NEB 1998). However, until recently, the market price of oil and gas coupled with expensive extraction and export costs due to Arctic conditions have made development of this resource uneconomical. In 2004 work began on a proposal for a pipeline linking known natural gas reserves in the Mackenzie Delta region to a hub in northern Alberta, known as the Mackenzie Gas Project, backed by a consortium of oil companies and Indigenous groups.

The Mackenzie Gas Project proposes the development of three major natural gas fields and construction of a major pipeline along the valley of the Mackenzie river. If built, the pipeline could ship more than 34 million cubic metres of gas a day. The Mackenzie Gas Project had completed an environmental assessment and is currently making its way through the regulatory approval process. (Mackenziegasproject.com). If it were to go ahead there will be a surge activity, both in construction and new exploration for new oil and gas reserves.

In June 2008, the Government of Canada held auctions for oil and gas exploration leases in the Beaufort Sea. The bids they received were record breaking, BP bid 1.2 billion for the rights to explore an area of 611 000 hectares north of the town of Tuktoyuktuk, 2 other bidders put in another 4.3 million for two additional leases. (CBC Article) What is interesting about these leases, aside from the large amounts spent on them, is that they are in areas not previously expected to have significant oil and gas reserves and are located far offshore, some under 1000m of water. This will mean that any of that activity will most certainly be offshore, requiring ship-based support (ref for this?).

Shipping from Tuktoyaktuk to Fort McMurray Alberta (Oil Sands)

The Northern Transportation Company Ltd (NTCL), a major re-supply and shipping company in operating in the Canadian Arctic, has recently gone into partnership with Mammoet, heavy lifting experts, to move very heavy and large modules to the Fort McMurray area for the Alberta oil sand developments. The new venture proposes shipping the oversize cargo from Tuktoyaktuk in the western Arctic down the Mackenzie River through the Great Slave Lake to Fort Mcmurray. This proposal is still in the planning stages, although a test run was carried out in 2006. (The Link 2008) See Fig XX for route details.

Although still speculative, if this shipping route goes ahead it could see oil sands operators taking advantage of cheaper steel manufacturing in areas such as China and Korea, with shipments coming into port in Tuktoyaktuk via the Pacific and the Bering Strait. This would result in an increase in cargo ship activity from current levels in the Beaufort Sea in the near future.

Source: NTCL Naviaation Ltd.

Port of Churchill

The Port of Churchill is Canada's only deep-water seaport in the Arctic. It is located on the Southwest shore of Hudson Bay, in the province of Manitoba. The closest city is which Churchill is linked to by approximately 1700 kilometres of rail line to the city of Winnipeg. The bulk of the shipping traffic in the Port of Churchill is in grains coming from the Canadian prairies, with the bulk of the rest of the traffic being general cargo destined for Eastern Arctic communities. More recently other commodities such as ores, fertilizers and other crops have been or are being proposed for shippign thoguh this port. Weather and ice conditions had, until recently, limited the operating season to four months of the year. Over the last ten years ice free conditions have lengthened the season at both the beginning and the end and it is anticipated that the shipping season will continue to legthen.

In 2007 a first time shipment of cargo arrived at the Port of Churchill from Murmansk in north western Russia. This route is being termed the "Arctic Bridge", a shipping route which will connect Murmansk in Northern Russia to North America via Churchill. The current connection between Murmansk and mid-continental North America through the St. Lawrence Seaway and Great Lakes to Thunder Bay, Ontario typically takes 17 days. The voyage from Murmansk to Churchill is only 8 days under good conditions, representing a signifigant savings in time and distance travelled. (Krauss, Clifford, 2005) In 2000 a project began at the port of Chruchill which would enhance the operations of the port through dredging and upgrading the port reception facilities. This project was undertaken in the aniticpation that Churchill will begin to see an increasing amount of shipping traffic int the future.

All ships traveling to Churchill must travel through the Hudson strait and south through Hudson Bay, both areas of ecologicl sensitivity. If the "Arctic Bridge" route were to become a trafficked international route ship traffic to and from Chruchill could increase dramatically in the coming years.

Summary

When examining resource development projects on the go or being proposed for the Canadian Arctic a pattern emerges. There appears to be the potential for a significant and possibly rapid increase in activity, which could directly or indirectly impact the shipping traffic in this region. Some areas which may have previously seen only a few coast guard vessels and community re-supply barges every summer could now see bulk cargo vessels coming and going year round, other areas may see much more tanker traffic as oil and gas fields are developed. Whether this increase in activity will have severe or minor impacts on the local environment is yet to be determined. What we do know is that because of the relatively low levels of shipping activity currently occurring in the Canadian Arctic, any increase will be a significant one.

It is in the interests of Canada and the world to protect the unique Arctic ecosystems, already vulnerable from the effects of global climate change. Accurately predicting the potential impacts from these projects would be a difficult task given the large number of unknown factors. Some attempt has been made to do this through the Environmental Impact Assessments already carried out or planned for some of these projects. What will be the unpredictable what the cumulative impacts will be and how these will interact with the stresses being felt due to the rapidly changing Arctic climate.

3.2.4 Vulnerable/sensitive/ecologically significant areas

Section missing text

Hudson Strait – routes to Churchill, and northern Foxe Basin

As the corridor to Hudson Bay and Foxe Basin, Hudson Strait is also heavily used by migratory animals, including marine birds and mammals. The major seabird colonies at Akpatok Island, Digges Sound and Coats Island are especially sensitive areas for shipping disturbance and accidental releases. For waterfowl, notably common eiders, the breeding islands in western Ungava Bay and Markham Bay on Baffin Island are particularly important sites (Mallory and Fontaine 2004).

Once in Hudson Bay, the open water route to Churchill poses less concern to coastal species, of more concern would be the general disruption of sea ice for marine mammals and polar bears, if ice breaking activity were to occur. The area around Churchill itself, including Cape Churchill and the surrounding Wapusk National Park, is a rich coastal ecosystem, and a release of hydrocarbon would severely impact the extensive subtidal and intertidal coastal ecosystem in the region. Shipping traffic in the Churchill River has the potential to disrupt the migration and increase the chance of strikes of beluga whales in the river.

Foxe Basin is a shallower region, more like western Hudson Bay, with extensive low-lying coastal regions. Two Migratory Bird Sanctuaries are in Foxe Basin. East Bay on Southampton Island hosts the largest colony of common eider in the Canadian Arctic, and extensive shallow areas hosting breeding geese, shorebirds and gulls. Dewey Soper, an extensive sanctuary on the western coastal portion of Great Plain of the Koukdjuak, hosts the largest goose colony in the world, and is characterized by an extensive tidal zone. Fortunately both of these sanctuaries are relatively far from any shipping route destined to Steensby Inlet. The islands on the northeastern portion of Foxe Basin have been identified as important areas for breeding and staging birds, including eider and brant (a truly marine goose species, which would be at risk from hydrocarbon discharges).

The Northwest Passage

Normal shipping operations in the open water of Davis Strait and Baffin Bay are likely to cause limited environmental issues. More potential issues arise at the entrance of Lancaster Sound, where large seabird colonies occur on Bylot Island at Cape Graham Moore and Cape Hay (Mallory and Fontaine 2004). Birds from these two colonies, as well as others in the region, congregate at the eastern portions of Lancaster Sound (Mallory and Fontaine 2004). Further west in Lancaster Sound on southern Devon Island, Hobhouse Inlet and Cape Liddon/Radstock Bay, host large seabird colonies and are important sites for marine mammals (Mallory and Fontaine 2004). Prince Leopold Island and its surrounding waters, at the northeastern corner of Somerset Island, hosts a major and diverse seabird colony, with 100 000s of birds in the area in summer (Gaston and Nettleship 1981).

In Prince Regent Inlet, Cresswell Bay stands out as an environmentally sensitive site. Sea ducks stage and moult at this site in the thousands. Shorebirds and other coastal species use the shorelines of this site extensively. A large number of belugas are found in Cresswell Bay (DFO 1999, Mallory and Fontaine 2004).

At the western reaches of the Northwest Passage, Lambert Channel stands out as an critical staging area for sea ducks migrating to their breeding grounds (Mallory and Fontaine 2004).

3.3 Bering Sea LME's (North Pacific Great Circle Route)

Case Study – Shipping Impacts on the Marine Environment on the Great Circle Route - 2004 Scenario

3.3.1 Description of the Great Circle Route and the Large Marine Ecosystems it Traverses

The Great Circle Route (Figure 1) is the most economic pathway for commerce between northern ports of the west coasts of the U.S. and Canada to ports in the eastern Asian countries of South Korea, Japan, the Russian Federation, particularly Vladivostok, and other regional ports. The Great Circle Route is comprised of northern and southern sea lanes. Northern lanes transit the North Pacific Ocean from North American west coast ports, across the North Pacific and western Gulf of Alaska, through the Aleutian Islands and southern Bering Sea, and thence southwest to Japan and other Asian ports. The segment of this route considered in this analysis is that portion that extends from the western Gulf of Alaska, westward offshore from the Alaska Peninsula, and through the Aleutian Islands including the passes at Unimak Pass and the Rat Islands. The route traverses three Large Marine Ecosystems (LME) of the eastern Pacific Ocean: the California Current LME, the Gulf of Alaska LME, the East Bering Sea LME, and the West Bering Sea LME. The latter two LMEs include the Aleutian Islands.

The California Current LME includes the major ports of Los Angeles, San Francisco, Seattle, Portland, and Vancouver. Vessels transiting the North Pacific Ocean from these ports frequently travel the Great Circle Route because it is the shortest distance and vessels may be advantaged by favorable ocean currents. Even vessels from Panama traveling to Vladivostok may travel through the Great Circle Route. The California Current LME is characterized by the southerly flowing California Current, frequent coastal upwelling, and its nature as a transitional marine system between subarctic and subtropical water masses.

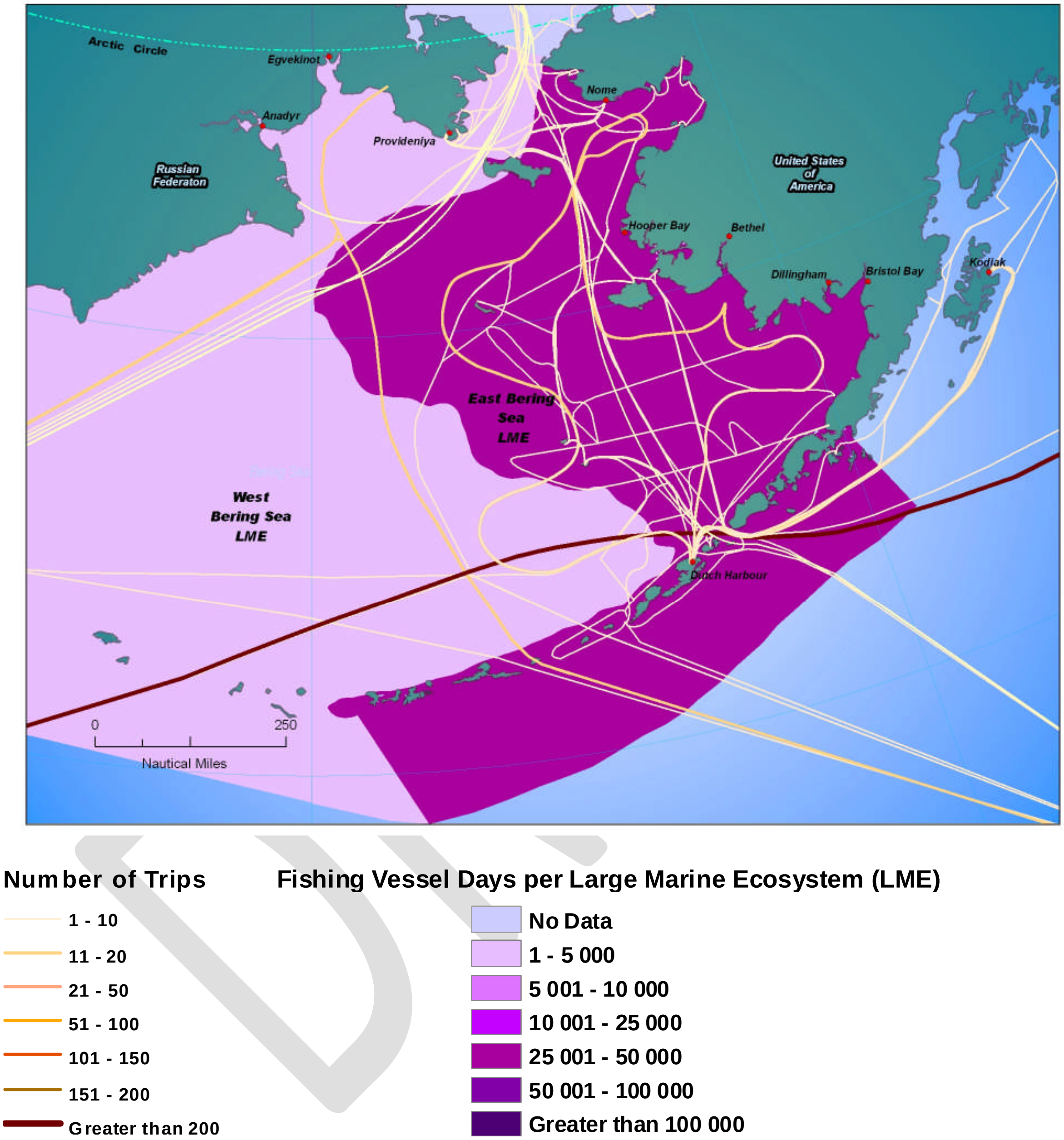
The Gulf of Alaska LME is characterized by the counterclockwise gyre of the North Pacific Ocean with its cold westerly flowing Subarctic Current and the westerly flowing Alaska Current. This region is subarctic, highly productive due to the influx of river and glacial water from the adjacent land masses, and supports rich fisheries and marine mammal and bird populations. Vessels from Alaskan ports enter the Great Circle Route in the North Pacific Ocean and transit the Gulf of Alaska LME enroute to other Alaskan ports or the U.S. or Canadian west coasts.

The East and West Bering Sea LMEs also are characterized by their subarctic climate, and are strongly influenced by a persistent atmospheric low pressure system that produces intense storm activity and strong ocean currents, particularly through Aleutian Island passes. These LMEs have highly productive marine waters over the broad eastern Bering Sea continental shelf and the waters adjacent to the Aleutian Islands. Some of the largest commercial fishery catches occur in these LMEs. The East Bering Sea LME includes waters of the eastern Bering Sea and eastern Aleutian Islands, and the major fishing port of Dutch Harbor. The West Bering Sea LME includes waters off the Russian Federation's eastern coast and the western Bering Sea and western Aleutian Islands and Commander Islands. Few ports are present in this LME. The Alaska Stream ocean current flows westerly through both LMEs, then flows northward in the western Aleutian Islands area as the Aleutian North Slope Current. Currents in the central Bering Sea flow counterclockwise generally along the continental slope around the deep Aleutian Basin. Currents of the West Bering Sea LME along the eastern Kamchatka Peninsula include the south flowing Kamchatka Current which merges with the Oyashio Current along the Kuril Islands, encountering and diverting to join the West Wind Drift. The Kuroshio Current flows northerly east of Japan and also encounters and merges with the West Wind Drift.

Vessel traffic in the North Pacific Ocean transiting the Great Circle Route passes through the highly productive marine ecosystem of the North Pacific Ocean and its western Gulf of Alaska and Bering Sea/Aleutian Islands areas. This route extends offshore from Canada and the U.S. west coasts and continues through the U.S. Exclusive Economic Zone (EEZ) offshore from Alaska. Once departing Canadian or U.S. ports, vessels generally move offshore from the California Current LME into oceanic waters. The route then takes vessel traffic through the productive marine waters of the Alaskan Continental Shelf of the Gulf of Alaska and Alaska Peninsula area of the Gulf of Alaska LME. The route then extends through the Aleutian Islands, principally through Unimak Pass, thence northward into the southern Bering Sea, and back through the Aleutian Islands in the vicinity of the Rat Islands, traversing both the East Bering Sea and the West Bering Sea LMEs. The route continues to Asian ports southeastward from the western portions of the Aleutian Islands.

3.3.2 Vessel Use of the Great Circle Route

Map of 2004 Vessel Activity in the Aleutian Island Chain



Muse (2007)[7] and Nuka and Cape International (2005) have estimated that 2,700 to 3,000 vessel voyages occur through the Great Circle Route annually. This Arctic Marine Shipping Assessment estimates that 2,759 vessels passed along this route in 2004. Vessel use of this

---

[7]http://benmuse.typepad.com/ben_muse/2007/01/the_great_circl.html

region by maritime commerce includes commercial fisheries[8], cargo shipping, recreational or ecotourism vessel voyages, military and U.S. Coast Guard activities including U.S. Homeland Security, oil and gas exploration, and marine research. Of these categories, container ship traffic is the heaviest with nearly 1600 annual transits in 2004. Bulk cargo carriers and general cargo transits in 2004 were approximately 580 and 259, respectively.

3.3.3 Environmental Sensitivity of the Great Circle Route

The marine and coastal environment and resources of this route include the rocky shorelines, fjords, and tidal wetlands along the coasts of Canada, Alaska, and the Russian Federation, which seasonally support populations of shorebirds, nesting seabirds, herring, and other marine resources as well as millions of salmon during their migrations to streams of origin. Benthic habitats provide important habitat for fish and invertebrates that, in turn, support other fish, marine mammals, and seabirds. The North Pacific Ocean is seasonal and year round habitat for marine mammals, seabirds, and fish, many of which are harvested commercially. This route passes through the U.S. Alaska Coastal Maritime Wildlife Refuge which provides nesting and foraging habitat seasonally for millions of seabirds and year round habitat for thousands of marine mammals. The Aleutian Islands ecosystem includes rich coastal and shoreline assemblages of kelp and urchin habitats, embayments with tidal wetlands and extensive eelgrass beds that annually support millions of migrating birds, and steep rocky slopes with cold water coral and sponge communities.

The marine environment of this region is primarily influenced by the Alaska Stream that transports marine waters and nutrients westward. The region also is heavily influenced by the meteorological patterns from a persistent low pressure system termed the Aleutian Low; this prominent feature generates frequently stormy and turbulent weather and sea conditions, creating forcing conditions that enhance marine productivity but also pose periodic risks to shipping. Strong tidal currents in Aleutian Island passes and a net northward transport of waters into the Bering Sea bring nutrients and biota important to the Bering Sea ecosystem (NPFMC 2007). This complex interaction between bathymetric features, tides, weather systems, ocean currents, and nutrient transport results in continuous mixing of surface and deep waters and the infusion of nutrients and plankton production that support one of the most productive ecosystems in the world.

3.3.4 Vulnerable Resources and Environmental Risk

Shipping incidents, including vessel incapacitation and eventual groundings, fire or other damage at sea, contaminant spills, accidental loss of containers or other materials from vessel decks and holds, coastal shipwrecks, collisions, and the noise disturbance or other impacts from vessels presence and movement create opportunities for adverse impacts on the region's

[8] Commercial fishing vessel activities are not considered in this assessment.

resources. Each of these potential incidents carries with it a risk to the region's ecological and human resources.

3.3.5 Resources at Risk

This region is rich in marine life including abundant seabird and marine mammal populations, fish and shellfish that are harvested commercially, coastal and intertidal/subtidal habitats that support mammals, birds, and other marine organisms, and many human communities. Seabirds are particularly abundant, nesting and fledging young along the rocky shores and islands of the Gulf of Alaska and Aleutian Islands; large colonies fledge millions of young annually (Figure 2). Albatrosses, fulmars, shearwaters, petrels, murres, kittiwakes, auklets, puffins, cormorants and gulls are common throughout the region, as are porpoises and whales, and thousands of Steller sea lions and harbor seals occupy haulouts and rookeries along the coast. Northern fur seals migrate through the region in spring and again in fall (Figure 3), while sea otters are present throughout the year (Figure 4).

The populations of several marine species are depressed, declining, or otherwise considered particularly sensitive and in danger of potential extinction, and are listed under the U.S. Endangered Species Act (ESA). Portions of the nearshore region throughout the Gulf of Alaska and Aleutian Islands are kelp-dominated algal forests that support large numbers of sea urchins that in turn support the southwest Alaska stock of northern sea otter which is listed as threatened under the ESA (Table 1). This region also provides habitat for the endangered Steller sea lion (Figure 5) and several species of endangered cetaceans (Table 1). The endangered short-tailed albatross and threatened Steller's eider are present in portions of this region. Short-tailed albatross are present primarily along the outer areas of the Continental Shelf (Figure 6) while the ESA-listed Steller's eider (Figure 7) winters in bays and other sheltered areas in the Aleutian Islands. Threatened spectacled eiders may occur in the southern Bering Sea, but generally occur in more northern waters.

The ESA affords considerable protection for these species in the U.S. Activities that could potentially adversely affect these species or their designated critical habitat would require a process of formal consultation with the Federal agencies responsible for their management (National Marine Fisheries Service or U.S. Fish & Wildlife Service). Human activities found likely to adversely affect any of these species could be required to take action to mitigate, or change operations to minimize, such impacts. ESA-listed species present in the Great Circle Route region are listed in Table 1.

Commercial fisheries in this region provide a very large proportion of the annual landings by the U.S. fishing industry. Salmon, halibut, herring, crab, groundfish, and many other fisheries are prosecuted annually in the region (Table 2). In 2004, Alaska fish landings were 2.43 million mt with an ex-vessel value of $ 1.17 billion, which was a large proportion of the entire U.S. 2004 landings of 4.4 million mt valued at $ 3.7 billion (NMFS 2005). The commercial groundfish catch off Alaska totaled 2.2 million mt in 2004, and was comprised of many species including primarily walleye pollock, Pacific cod, various flatfish and rockfish species including yellowfin sole and Pacific ocean perch, sablefish, and Atka mackerel (Table 3). The ex-vessel value of the catch, excluding the value added by at-sea processing, was $593 million in 2004. The gross value of the 2004 groundfish catch after primary processing was approximately $1.7 billion (F.O.B. Alaska). The groundfish fisheries accounted for the largest share (51%) of the ex-vessel value of all commercial fisheries off Alaska in 2004, while the Pacific salmon (*Oncorhynchus spp.*) fishery was second with $225 million or 19% of the total Alaska ex-vessel value. The value of the Pacific halibut (*Hippoglossus stenolepis*) catch amounted to $169 million or 15% of the total for Alaska; the value of the shellfish fishery was approximately $165 million in 2004 (NPFMC and NMFS 2005).

All but a small part of the commercial groundfish catch off Alaska occurs in the groundfish fisheries managed under the Fishery Management Plans (FMP) for the Gulf of Alaska (GOA) and the Bering Sea/Aleutian Islands area (BSAI) groundfish fisheries. Walleye pollock (*Theragra chalcogramma*) has been the dominant species in the commercial groundfish catch off Alaska. The 2004 pollock catch of 1.54 million mt accounted for 71% of the total groundfish catch of 2.2 million mt. The western part of the Gulf of Alaska and the Aleutian Islands areas are the central fishing areas for groundfish off Alaska (NMFS 2003), and the Great Circle Route passes directly through much of these productive fishing grounds. Salmon and herring fisheries managed by the State of Alaska occur in this region from spring through fall months, generating $ millions in revenues to fishers in hundreds of communities.

Fish harvested in the marine ecosystem is landed aboard catcher/processor vessels, landed aboard catcher vessels that deliver to motherships, or landed ashore by large and small catcher vessels. Fishing activity occurs year round, but primarily from January to October, and geographically is dispersed throughout the Aleutian Islands, western Alaska, and the Gulf of Alaska (NPFMC 2007). Commercial fisheries are important to the economy of Alaska and the U.S. Pacific Northwest, and products are shipped throughout the world, particularly to Japan, South Korea, People's Republic of China, Europe, and other U.S. states.

Trawl, hook and line (including longline and jigs), and pot gear account for virtually all of the catch in the BSAI and GOA groundfish fisheries; most are small vessels < 60 feet Length Over All (Tables 4 and 5). There are catcher vessels and catcher/processor vessels for each of these three gear groups. In the five years leading to 2004, the trawl catch averaged about 90% of the total catch, while the catch with hook and line gear accounted for 8.1%. Most species are harvested predominately by one type of gear, which typically accounts for 90% or more of the catch. The one exception is Pacific cod, where in 2004, 37.4% (101,000 mt) was taken by trawls, 46.7% (126,000 mt) by hook-and-line gear, and 15.9% (43,000 mt) by pots. In each of the years since 2000, catcher vessels took about 49% of the total catch and catcher/processors took the other 51% (NPFMC and NMFS 2005). Coastal fisheries for herring and salmon are largely by smaller vessels using gill nets or purse seines, and some offshore troll (hook and line) gear is used offshore southeastern Alaska for Chinook salmon.

Coastal fisheries in the U.S. and Canada (British Columbia) are managed by Provincial or State fishery regulatory agencies, and salmon fisheries in the southern part of this region are partly managed by adjacent states and also are jointly managed under treaty between the U.S. and Canada. Marine fisheries offshore B.C. are managed by the Canada's Department of Fisheries and Oceans, while offshore fisheries in the U.S. are managed jointly by the Pacific and North Pacific Fishery Management Councils and the National Marine Fisheries Service.

Human communities are present along the coasts of the Great Circle Route; residents depend heavily on marine resources from the region. Communities vary in composition, from the largest community in Alaska, Anchorage, at the head of Cook Inlet, to smaller cities such as Ketchikan, Sitka, Cordova, and Homer that rely upon the marine environment for part of their economy, primarily from marine shipping, commercial fishing, and marine recreational activities. Larger communities heavily dependent on marine commercial fisheries are Kodiak and Dutch Harbor which, in 2004 were the largest and fourth largest U.S. ports in the U.S. in quantity of seafood landed, respectively. Ex-vessel values of seafood products landed at Dutch Harbor and Kodiak in 2004 were $155 and $91 million, second and fourth highest seafood revenues to U.S. ports, respectively. Characteristic of this region are many small, rural communities, most of which are largely Native Alaskan in composition, including Metlakatla, Yakutat, English Bay, Old Harbor, Chignik, Sand Point, Akutan, Atka, and Adak; these villages rely heavily on adjacent marine waters for commercial fishing and subsistence harvest of marine resources such as fish, marine mammals, and birds. Numbers of residents in these communities vary from thousands of people in Kodiak and other larger communities, to a few hundred or fewer in smaller villages.

Six western Alaska Community Development Quota groups, representing 65 rural villages, receive a share of the annual fishery allocation from the North Pacific Fishery Management Council to stimulate economic development in rural Alaska. This program provides hundreds of jobs with wages of $5-8 million annually and revenues to fund acquisition of vessels or to invest in fishery-related businesses and community infrastructure (NMFS 2003).

3.3.6 Potential Risks to Resources

Shipping activities may result in incidents that can have effects on the resources, habitats, and human communities along the Great Circle Route. These include discharge of oily wastes or other contaminants from routing operations, accidental discharge of oil or other contaminants from accidents or groundings, at-sea fires or other incidents that result in debris or vessel groundings on adjacent lands, vessel noise and resultant disturbance to marine mammals, marine mammal and seabird collisions with vessels, and release of ballast water and potential exotics or nuisance biota to the marine environment or adjacent land. Vessel lighting may attract seabirds, resulting in bird strikes with vessel superstructures; this is a particular concern for shearwaters.

Contaminants from vessel incidents can foul seabirds and marine mammals at sea or drift ashore and impact beaches and shorelines and biota inhabiting these areas. Contaminants may affect the forage base for important commercial species or prey for marine mammals or birds. Rats (primarily Norway rats) may be aboard some vessels; incidents that release rats to lands where seabirds nest can result in devastation to seabird colonies.

Shipping incidents can threaten $ millions in revenues to fishers, including vessel owners, captains and crew, as well as processors and affiliated industries that support fisheries (warehousing, cold storage, shipping, container manufacture, fuel distribution, shipyards and repairs, gear manufacture, etc.). Adverse effects from shipping incidents can also affect subsistence and personal use of marine resources by residents of communities in the region and Native people who rely on marine resources for subsistence.

Once vessels have departed western U.S. ports, the Great Circle Route lies relatively far offshore the coasts of the U.S. and Canada, but the route traverses fishing grounds in the Gulf of Alaska and Bering Sea/Aleutian Islands areas, all of which are rich fishing grounds and oceanic nurseries for many species of fish. Particularly prominent are walleye pollock, various species of flatfish, halibut, Pacific cod, king and Tanner crab, sablefish, and Pacific ocean perch. While generally offshore for most of the route, vessels also may pass close to the Aleutian Islands where the impacts from shipping incidents would likely be most pronounced given the proximity to land and the immediacy of impact before opportunity for at-sea dispersal of contaminants. Fisheries in the Aleutians are dominated by Atka mackerel, Pacific cod, and rockfish (NPFMC 2007).

Aleutian Islands communities are dependent on fishing and the use of other marine resources from this region, particularly in smaller villages that partially subsist on these resources. The cities of Dutch Harbor and Kodiak are major seafood ports in the U.S.; impacts on fish resources could significantly affect commerce and the livelihood of residents and the general seafood industry in these communities.

The U.S. National Research Council has recently drafted a design for a comprehensive risk assessment of vessel incidents in the Aleutian Islands (NRC 2008). This study's recommendations include phased preliminary and focused risk assessments, and a quantitative fate and effects analysis to assess potential damages that could accrue to natural resources and socioeconomic systems associated with different hazards, sizes of spills and accident locations. The NRC (2008) study also recommended that the U.S. Coast Guard and the State of Alaskan manage the risk assessment and that it be guided by an advisory panel of experts and stakeholders and reviewed by a peer review panel. The study also recommended interim steps be taken including expansion of a vessel tracking system along the Great Circle Route, study of possible deployment of an Aleutian Rescue Tugboat, design of a vessel traffic information system for the Unimak Pass and Dutch Harbor areas, and consideration of options for tracking and monitoring/managing vessel traffic in congested areas in this region.

3.3.7 Major Ecological Risk Issues of Concern along the Great Circle Route

Whale strikes – The North Pacific right whale is extremely rare and listed as endangered under the ESA. Only 25 have been censused and perhaps up to 100 are thought to exist. Right whales are susceptible to ship strikes because of their tendency to spend time on the water surface and are difficult to observe from vessels, particularly at night. North Atlantic right whales are struck by vessels in the Atlantic Ocean frequently, even with mitigation measures in place to reduce these incidents. Although little information is available on movement patterns, North Pacific right whales likely move into the eastern Bering Sea in spring, spend time feeding through the summer (critical habitat for this species has been designated in the eastern Bering Sea and near Kodiak Island – Figure 8), and return south in the fall/early winter. While no ship strikes of North Pacific right whales have been reported to date, vessels transiting the Great Circle Route may encounter this species in the western Gulf of Alaska and the Unimak Pass area; increased shipping would increase the opportunity for ship strikes, further threatening this rare species.

Spills of toxic materials – Spills or incidents that result in release of toxic materials, particularly petroleum products, may result in contact of toxins with marine organisms; those particularly susceptible include whales, pinnipeds, and seabirds. Fur seals migrate to the Pribilof Islands (and smaller groups migrate to Bogoslov Island) in May, mate and pup, and return to pelagic habitats in the Pacific Ocean in fall (September-November)(Figure 4). Fur seals migrate primarily through the Aleutian Island passes in spring and fall. The population has been in decline for years. Toxic materials contacting fur seals would likely result in some levels of mortality, further exacerbating the decline in this species' population.

Thousands of other marine mammals, such as killer whales, humpback whales, porpoises, gray whales, and Steller sea lions, and millions of seabirds forage in offshore marine waters of this region, especially during spring through fall. Toxic materials could cause mortality to large numbers of seabirds and marine mammals.

The ESA-listed short-tailed albatross feeds at sea year round (Figure 6) and could be affected by contact with toxic materials or ingesting debris or contaminated fish; the ESA-listed Steller's eider is susceptible to contaminants that may drift ashore into bays and inlets where they winter. The endangered Steller sea lion forages partly in offshore waters; its population is stable or slightly declining at present. Shipping incidents that adversely interact with any endangered or threatened species of marine mammals or birds could worsen their already diminished abundance, possibly resulting in consultation with Federal agencies and curtailment of vessel activities or other measures taken against vessels, crew, and owners.

Toxic materials that reach shorelines in this region may injure or kill sea otters, the Southwest Alaska stock of which is listed as threatened (Figure 5). Oil or other contaminants may damage or render unproductive coastal and intertidal habitats used by many species, especially eelgrass beds or tidal estuaries that provide forage for migrating waterfowl or wintering areas for the endangered Steller's eider (Figure 7). Endangered Steller sea lions haul out and occupy rookeries for mating and pupping throughout the western Gulf of Alaska and Aleutian Islands (Figure 3). Northern harbor seals also occupy rookeries and haulouts along this route and are susceptible to contaminants that may drift close to shore. Millions of seabirds forage in coastal waters near nesting areas on Aleutian Islands and Alaska Peninsula coastal cliffs and shorelines (Figure 2).

Spills of toxic materials also may limit geographically or temporally, or entirely stop, commercial fishing; impacts could be severe economically and socially to Alaskan coastal communities and could be felt economically throughout other parts of the U.S. and the world. Particularly susceptible would be coastal herring and salmon fisheries prosecuted from spring through fall, and tainted fish or other marine organisms would transport toxins through the marine food web, with delayed effects on fisheries such as crab or other shellfish.

Introduction of Exotics – Some vessels release ballast water as a consequence of taking on cargo or to aid in vessel trimming. Ballast water may carry exotic organisms from other parts of the world, potentially introducing alien species that could compete or overrun native species in the marine environment, estuarine and shoreline areas, or on lands adjacent to the shipping lanes or in ports. Vessels may accidentally run aground, break up at sea, or accidentally discard debris that washes ashore, carrying with these incidents the threat of rat infestation to lands that currently are rat free. Of particular concern is the Norway rat, *Rattus rattus*, that may feed on seabird eggs, chicks and adults, threatening the millions of seasonal seabird occupants of the Alaska Peninsula and the Aleutian Islands. Rats have decimated the seabirds on many of the Aleutian Islands and many smaller islands in the Alaska Coastal Maritime Wildlife Refuge, which is home to millions of nesting seabirds. Ground nesting birds are vulnerable (Ebbert et al. 2007) such as puffins, auklets and storm petrels; these species also leave their eggs and young for extended periods while foraging and may become prey for rats.

3.3.8 The M/V Selendang Ayu Incident

On 8 December 2004, a cargo ship, the M/V *Selendang Ayu* transiting the Great Circle Route lost power and eventually came ashore near Dutch Harbor in the Aleutian Islands where it broke into two sections, dispersing its cargo of soybeans and quantities of fuel oil and other contaminants. This incident caused loss of life and major economic costs to the shipper, and heightened local and international concern over vessel traffic in the sensitive regions of the North Pacific Ocean, particularly the Aleutian Islands. Since the Great Circle Route passes through the eastern and western Aleutian Islands, and is close to very large populations of marine mammals and birds and rich commercial fisheries, future vessel traffic in this region will be more closely scrutinized and monitored. Operations to rescue the crew from the Selendang Ayu resulted in loss of life for both rescuers and crew, increasing the adverse effects of this incident. Penalties paid by the shipper funded cleanup, salvage, environmental study and monitoring, and future risk assessment efforts, adding to the overall cost of loss of the ship and its cargo.

Here is s brief description of immediate impacts to wildlife in the Selendang Ayu case:

“more than 1,500 birds and five otters have found dead. Several hundred more live oiled birds were spotted, but proved to unreachable because of the remote Bering Sea location. The oiled birds collected, included Common Murres, Crested Auklets, Horned-grebes, Pelagic Cormorants and a Long-tailed Duck.

To study the impact of the spill on shorebirds, the U.S. Fish and Wildlife Service (USFWS) released 162 bird size blocks of wood from the grounding site the second week in January 2005. The blocks helped determine where dead birds might have drifted. Tar balls from the spill were reported far from the spill site and quickly drifted with the currents. They range in sizes of several meters to small droplets that could hardly be visible.

For three weeks the weather proved to be a frustrating waiting game for rescuers on scene. As soon as there's an opening in the storms rescuers would resume work; but it has to be safe enough for the rescue teams to access the impacted areas. The cleanup and search for oiled animals was stalled by strong winds, rough seas and the remoteness of the spill. Adding to concerns: only five hours of daylight in this area of Alaska in winter.

3.3.8 The Contrasting Exxon Valdez Spill Case

The M/V *Selendang Ayu* incident is, by contrast a much less severe event that that of the 24 March 1989 case of the *Exxon Valdez* oil tanker spill that occurred in Prince William Sound in the Gulf of Alaska. It is considered one of the most devastating man-made environmental disaster ever to occur at sea. Prince William Sound's remote location (accessible only by helicopter and boat) made response and recovery efforts exceptionally difficult . The region was a habitat for salmon, sea otters, seals, and seabirds.. The vessel spilled 10.8 million U.S. gallons of crude oil that eventually covered 11,000 square miles of ocean.

The spill hit just as the region stirred with spring life. Zooplankton and phytoplankton beginning to bloom. Salmon fry emerging from gravel beds in freshwater streams, herring returning to spawn. Soon, migratory birds began nesting. It was just before peak pupping for sea otters, seals, and sea lions, and when marine mammals concentrate in coastal waters to eat herring, krill, and salmon. More marine mammals and birds died than in any other oil spill. Some populations, like harbor seal, were already declining so the spill added insult to injury. Only 2 of 26 species studied by the Exxon Valdez Oil Spill Trustee Council have recovered (bald eagle and river otter). The Exxon Valdez spill killed nearly ten times as many birds as any other U.S. or European oil spill. As many as half a million birds died. Over 30,000 carcasses of 90 species of birds were plucked from the beaches, but this is only a fraction of the actual mortality. Harm to birds from chronic effects and decreased reproduction continues to the present. Some fish died but the most serious damage was to their critical spawning and rearing habitats.

Salmon spawn in the intertidal zone, herring in the subtidal zone on kelp, and Dolly varden and cutthroat trout feed in shallow water. Over 100 salmon streams were oiled

Exxon mounted a cleanup effort that exceeded in cost, scope and thoroughness of any previous oil spill cleanups. More than 11,000 Alaska residents, along with Exxon employees, worked throughout the region to try to restore the environment. The cleanup actions themselves can cause further impacts to the LMRs. They can displace and destroy the microbial populations on the shoreline; many of these organisms (e.g.plankton) are the basis of the coastal marine food chain, and others (e.g. certain bacteria and fungi) are capable of facilitating natural biodegradation of oil. At the time, both scientific advice and public pressure was to clean everything, but since then, a much greater understanding of natural and facilitated remediation processes has developed, due somewhat in part to the opportunity presented for study by the *Exxon Valdez* spill.

Both the short- and long-term effects of the oil spill have been the subject of research to this day. However, the effects of the spill continue to be felt today. Overall reductions in population have been seen in various ocean animals, including stunted growth in pink salmon populations. Sea otters and ducks also showed higher death rates in following years, partially because they ingested prey from contaminated soil and from ingestion of oil residues on hair due to grooming.

Debate continues about the long-term impacts of the spill and about recovery. To the naked eye, Prince William Sound may appear "normal." But if one looks beneath the surface, oil continues to contaminate beaches, national parks, and designated wilderness. In fact, the Office of Technology Assessment estimated beach cleanup and oil skinning only recovered 3-4% of the *Exxon Valdez* oil and studies by government scientists estimated that only 14% of the oil was removed during cleanup operations. Almost 15 years after the spill, it was found that the effects are lasting far longer than expected. Some shoreline habitats may take up to 30 years to recover. Exxon Mobil denies any concerns over this, stating that they anticipated a remaining fraction that they assert will not cause any long-term ecological impacts. However, a study from scientists of NOAA concluded that this contamination can produce chronic low-level exposure, discourage subsistence where the contamination is heavy, and decrease the "wilderness character" of the area.

3.3.9 Future Vessel Traffic

Container ship and bulk carrier vessel traffic on the Great Circle Route will likely increase because of increasing worldwide demand for trade between western U.S. and Canadian ports and eastern Asian and the eastern Russian Federation ports. The NRC (2008) recently reported that 4,470 vessel transits occurred through Unimak Pass in the Aleutian Islands in 2006-2007, indicating a considerable increase from the 2004 Great Circle Route reported traffic of fewer than 3,000 vessels. Sakhalin oil field development will generate increased oil tanker traffic on parts of the route. Fishery development in the North Pacific Ocean may be at optimal levels at present, but continued export of fishery products from U.S. and Canadian waters to the west will likely maintain existing levels of transport by cargo vessels. Tourist vessel activity may increase, although costs of fuel may slow the rate of growth. U.S. and Canadian Coast Guard activities will continue, and possibly increase, with continued heightened homeland security issues. Development of petroleum resources in the east Aleutian Basin near Alaska's Bristol Bay could generate natural gas or other petroleum product transport from this region within a decade or more. And production of Alaska's North Slope natural gas reserves via pipeline to either Canada and the central U.S. or coastal Alaska could, depending on the final development scenario, increase LNG vessel activity along the route, probably in a decade or more.

Table 1. The following species and critical habitat occur in U.S. Great Circle Route waters and have been provided protection under the Endangered Species Act of 1973 (16 U.S.C. 1531 *et seq.*):

Listed Species	Stock	Latin Name	Status
Short-tailed albatross		*Phoebastria albatrus*	Endangered
Steller's eider		*Polysticta stelleri*	Threatened
Spectacled eider		*Somateria fischeri*	Threatened
Northern sea otter	Southwest Alaska	*Enhydra lutris kenyoni*	Threatened
Blue whale		*Balaenoptera musculus*	ndangered
Bowhead whale		*Balaena mysticetus*	Endangered
Fin whale		*Balaenoptera physalus*	Endangered
Humpback whale		*Megaptera novaeangliae*	Endangered
Northernright whale		*Eubalaena glacialis*	Endangered
Sei whale		*Balaenoptera borealis*	Endangered
Sperm whale		*Physeter macrocephalus*	Endangered
Steller sea lion	Western population	*Eumetopias jubatus*	ndangered

Steller sea lion	Eastern population	*Eumetopias jubatus*	Threatened
Chinook salmon*	Puget sound	*Oncorhynchus tshawytscha*	Threatened
	Lower Columbia River		Threatened
	Upper Columbia River Spring		Endangered
	Upper Willamette River		Threatened
	SnakeRiver Spring/Summer		Threatened
	Snake River Fall		Threatened
Sockeye salmon*	Snake River	*Oncorhynchus nerka*	Endangered
Steelhead*	Upper Columbia River	*Oncorhynchus mykiss*	Endangered
	Middle Columbia River		Threatened
	Lower Columbia River		Threatened
	Upper Willamette River		Threatened
	Snake River Basin		Threatened
Leatherbacksea urtle		*Dermochelys coriacea*	ndangered

Table 2. Production and gross value of major commercial fisheries off Alaska, excluding groundfish, in 2004. (NPFMC and NMFS 2005)

	Gulf of Alaska		Bering Sea/Aleutian Islands		Alaska Total	
Fishery	Quantity (1000 mt)	Value ($ million)	Quantity (1000 mt)	Value ($ million)	Quantity (1000 mt)	Value ($ million)
Salmon	181.0	524.4	50.1	202.7	231.1	727.1

Halibut	17.8	148.7	3.4	27.8	21.2	176.5
Herring	11.5	19.5	16.9	18.7	28.4	38.2
Crab	4.0	50.1	11.4	158.4	15.4	208.5
Other	3.5	16.8	11.7	16.3	15.1	33.2

Table 3. Harvest (in thousand mt) of major groundfish species off Alaska in 2004. (NPFMC and NMFS 2005)

Species	Gulf of Alaska	Bering Sea/Aleutian Islands	Alaska Total
Pollock	63.9	1481.4	1545.3
Sablefish	16.9	2.0	18.9
Pacific cod	56.7	213.8	270.5
Flatfish	23.0	174.7	197.7
Rockfish	22.1	17.7	39.8
Atka mackerel	0.8	60.5	61.3

Table 4. Number and tonnage of commercial fishing vessels that harvested groundfish off Alaska in 2004. (NPFMC and NMFS 2005)

	Gulf of Alaska		Bering Sea/Aleutian Islands		Alaska Total	
Gear Type	# Vessels	Registered net tons	# Vessels	Registered net tons	# Vessels	Registered net tons
Hook and Line	630	24079	100	14416	674	31408
Pot	149	8806	82	10458	203	16722
Trawl	93	15193	149	52411	191	55740

3.4 Bering Sea-Chukchi Sea- Beaufort Sea LMEs

Case Study – Shipping Impacts on the Marine Environment on the Beaufort-Chukchi-Bering Strait Route - 2004 Scenario

Description of the Beaufort-Chukchi-Bering Strait Route and the Large Marine Ecosystems it Traverses

The Beaufort-Chukchi-Bering Strait Route is a potentially lucrative pathway for commerce from parts of Europe and Asia to markets in eastern Asia, particularly Japan, eastern Russia, and South Korea. Vessels transiting the Arctic Ocean likely would choose one of two routes, depending on origin, destination, and, of course, ice conditions. Regardless of which trans-polar route is taken, all eventually go through Bering Strait. Considerable time and cost can be saved.

These routes include one that traverses the Northwest Passage in the Canadian High Arctic and thence through the Alaskan Beaufort Sea and through Bering Strait, and another that passes through the Barents, Kara, Laptev, and East Siberian Seas along the northern coast of Russia, through the Russian Chukchi Sea, and then Bering Strait. The route analyzed in this case study is a route that traverses the Arctic Ocean and across the Alaskan Beaufort Sea and Chukchi Sea, and through Bering Strait, one of the most narrow sea lanes in the world. The route continues southward across the western Bering Sea and offshore the Kamchatka Peninsula to Japan and other eastern Asia destinations. The route traverses five Large Marine Ecosystems (LME) of the Arctic Ocean and North Pacific Ocean (Figure 1): the Beaufort Sea LME, the Chukchi Sea LME, the West Bering Sea LME, the Oyashio Current LME, and the Kuroshio Current LME. This case study focuses on vessel transit through the former three LMEs. This section also includes a review of traffic in a portion of the East Bering Sea LME from the eastern Aleutian Islands northward to or from small villages and ports along western Alaska.

The Beaufort Sea LME includes several small, seasonal ports along the northern Alaska coast, notably the shallow water docking facilities in the industrial Prudhoe Bay area and small boat access on the beach or into shallow water lagoons at Barrow. The Beaufort Sea LME is characterized by its extreme Arctic climate and long winters of ice cover, with only a few months of open water in July through September when ice may recede tens to hundreds of miles offshore, leaving variable amounts of open water during summer months. In some years open water is extensive, but in other years there may be little summer open water in the Beaufort Sea LME   Ocean currents are the generally clockwise because of the influence of the Beaufort Gyre, with a counter current flowing eastward along the southern edge of the Beaufort Gyre (Figure 2). During the open water season, winds govern nearshore Beaufort Sea water movement, and currents may be either east flowing or west flowing under west and east wind conditions, respectively. This LME is seasonally productive of prey organisms for millions of nesting birds that migrate north in summer; the Beaufort Sea also is the destination in summer for several species of whales that move into this region to feed, most notably the bowhead whale. Food chains in the Arctic are short; energy flow from primary production passes through benthic invertebrates, zooplankton, Arctic and saffron cod, and seals. The apex predator is the polar bear that feeds on marine mammals, primarily ringed seals.

The Chukchi Sea LME is arctic to subarctic in nature, and is covered by seasonal ice most of the year. Ocean currents are generally northward as water is transported into the Chukchi Sea from the northern Bering Sea. The Chukchi Sea LME is shallow with a broad Continental Shelf, and like the Beaufort Sea is seasonally productive of birds and marine mammals. The main ports in this LME are small boat access beachheads at villages along the Russian and Alaskan coasts, the pier at the Red Dog Mine in northwest Alaska, the shallow beaches and small harbor at the city of Kotzebue, and a small harbor in Nome.

The West Bering Sea LME and East Bering Sea LME are characterized by their subarctic climate, and may be strongly influenced by a persistent atmospheric low pressure system that produces intense storm activity and strong ocean currents, particularly through Aleutian Island passes. The northern portion of the West Bering Sea LME has highly productive marine waters over its Continental Shelf as well as the waters adjacent to the western Aleutian Islands. This LME produces moderately large commercial fishery catches by Russia and by some US fishing vessels in US waters of this LME. The East Bering Sea LME is similarly productive, providing habitat for millions of metric tons of harvestable fish species important to U.S. domestic commercial fisheries. The East Bering Sea LME includes small villages resupplied annually by small barges and vessels, the Red Dog Mine in northwestern Alaska, and the commercial fishing grounds used by vessels from small skiffs to very large factory trawlers and motherships up to 300 ft LOA or larger.

The West Bering Sea LME includes waters off the Russian Federation's eastern coast and the western Bering Sea and western Aleutian Islands and Commander Islands. Several moderate sized Russian ports are present in this LME, including Providenya, Anadyr, and Petropavlovsk. The Alaska Stream ocean current flows westerly through this LME, then flows northward in the western Aleutian Islands area as the Aleutian North Slope Current. Currents in the central Bering Sea flow counterclockwise generally along the continental slope around the deep Aleutian Basin. Currents of the West Bering Sea LME along the eastern Kamchatka Peninsula include the south flowing Kamchatka Current which merges with the Oyashio Current along the Kuril Islands, encountering and diverting to join the West Wind Drift. The Kuroshio Current flows northerly east of Japan and also encounters and merges with the West Wind Drift.

Vessel traffic in the Arctic Ocean and North Pacific Ocean transiting the Beaufort-Chukchi-Bering Strait Route passes through seasonally productive marine ecosystem of the Arctic and North Pacific Oceans (Figure 3). The route is rarely open, however, given the persistence of Arctic Ocean seasonal and multi-year ice. A few vessels are able to transit the region, primarily along the Russian Arctic coast, south through Bering Strait, and along the coast of eastern Siberia. In the US Beaufort Sea, seasonal barge traffic traverses the route to bring supplies to the Alaskan Prudhoe Bay oil fields. Seasonal tug and barges bring fuel and other supplies to coastal communities in Russia and Alaska. Some nearshore commercial fishing occurs in the Kotzebue Sound region and along the eastern Siberian coast and offshore areas. The route continues through the West Bering Sea LME and skirts the most productive waters of the eastern Bering Sea. After passage through the western Aleutian Islands and Commander Islands of Russia, vessels then continue to Asian ports southeastward from the western portions of the Aleutian Islands.

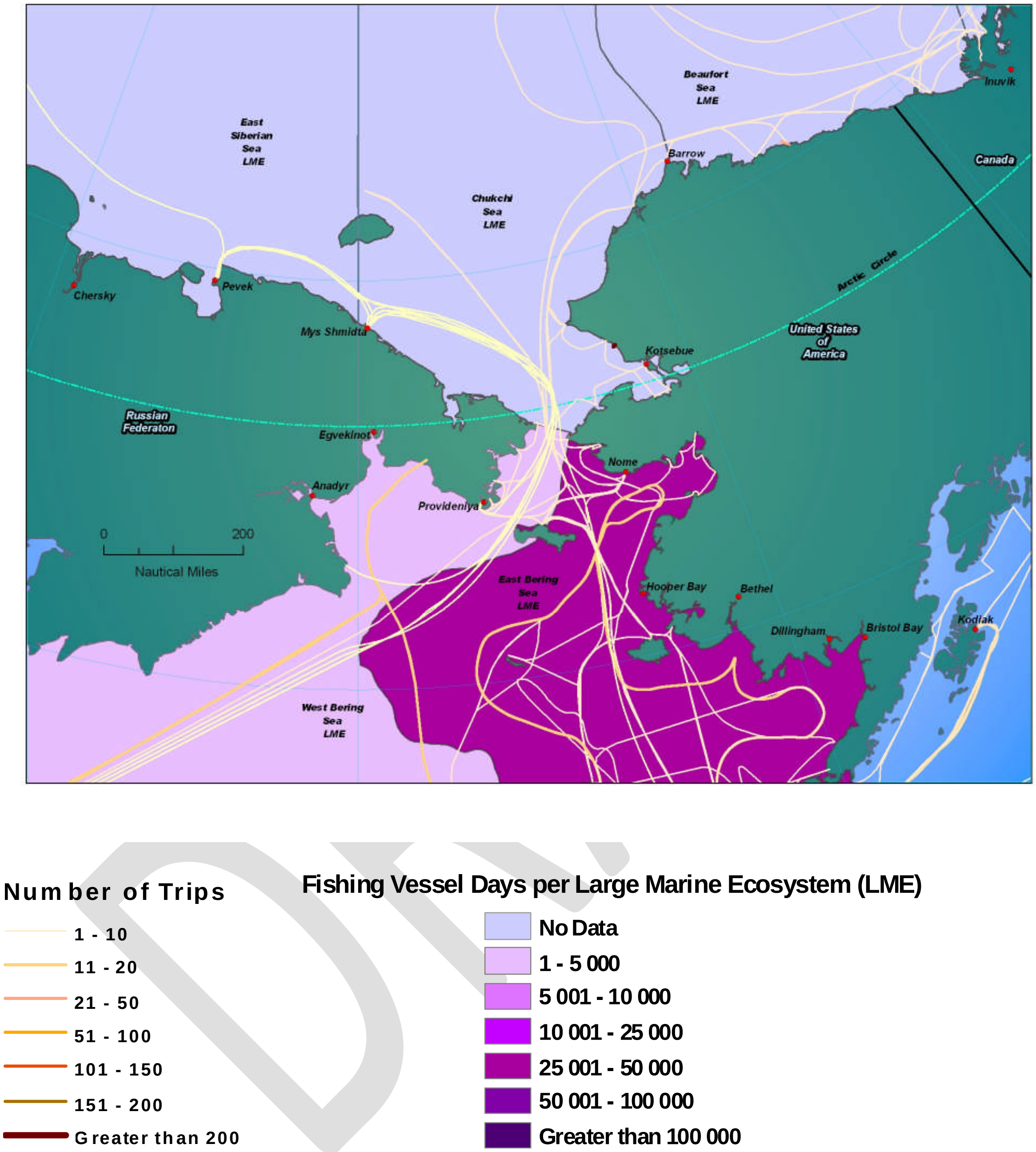
Another shipping route traverses the eastern Bering Sea from eastern Aleutian Islands passes northward to Bering Strait (Figure 3). This area is heavily fished for groundfish, crab, and halibut, and fish products are transported through this area mostly during spring through fall seasons. Annual summer resupply transits move goods, particularly fuel, to western Alaska villages. Red Dog mine ore is stockpiled throughout the winter, and then is transported south along this route every summer. Occasional sea lifts move oil field modules and supplies to the Prudhoe Bay region. Occasional marine research activities occur in the area, including annual trawl surveys throughout the U.S. portions of the Bering Sea and Aleutian Islands. Most of this traffic transits Unimak Pass and then southward to ports along the U.S. west coast.

Vessel Use of the Beaufort-Chukchi-Bering Strait Route

This Arctic Marine Shipping Assessment estimates that 396 U.S. vessels passed along this route in 2004 (Figure 3). Vessel use of this region by maritime commerce includes commercial fisheries[9], cargo shipping, recreational or ecotourism vessel voyages, military and U.S. Coast Guard activities including U.S. Homeland Security, oil and gas exploration, and marine research. Of these categories, general cargo ship traffic is the heaviest with about 200 annual transits in 2004. Bulk cargo carriers and tug and barge transits in 2004 were approximately 57 and 30, respectively.

Map of 2004 Vessel Activity for the Bering Strait Region

[9] Commercial fishing vessel activities are not considered in this assessment.



U.S. ice breaking capability is limited, and thus little to no ice breaker transits occur along the U.S. portion of this route. The U.S. is investigating feasibility of constructing a new ice breaker to replace one or both of the older ice breakers, the Polar Sea and Polar Star. Transport through ice infested waters of the Beaufort and Chukchi Seas is currently almost entirely by vessels with ice strengthened hulls such as tug boats and barges.

The city of Nome has a harbor and port faculties in Norton Sound. Shipping in the Nome area includes exported rock/gravel for the region and Nome is the primary location to load/unload heavy equipment. A small boat harbor is used by smaller cargo vessels and landing craft transporting freight and fuel to the region. A new 60 foot wide concrete barge ramp provides facilities for bulk cargo carriers.

Red Dog Mine about 90 miles north of Kotzebue generates zinc and lead concentrates which are stockpiled at a port site on the Chukchi Sea north of Kivalina until the shipping season. A shallow-water port provides for staging and exporting zinc and lead ore. The port is ice-free only 100 days a year. Barges deliver supplies, fuel and equipment each summer. Due to a shallow port, two lightering barges and four tugboats lighter the concentrate to ships anchored offshore (http://www.commerce.state.ak.us/dca/commdb/CIS.cfm?Comm_Boro_Name=Red+Dog+Mine)
.

Kotzebue is the service and transportation center for all villages in the northwest region of Alaska. Due to its location at the confluence of three river drainages, Kotzebue is the transfer point between ocean and inland shipping. The shipping season lasts 100 days, from early July to early October, when the Sound is ice-free. The harbor is shallow, and deep draft vessels must anchor 15 miles out, and cargo is lightered to shore using shallow draft barges.

Data from the Arctic Marine Transport Workshop (2004) proceedings indicate that for the period 1900-2004, nearly 180 transits of the Northwest Passage have been completed[10]; the largest number of passages occurred in 2004 (Figure 4). In 2004, 107 voyages were documented including 18 foreign (14 of which transited to Churchill) and 62 Canadian commercial voyages (Institute of the North et al. 2004).

Dozens of transits along the eastern Bering Sea area occur annually to transport heating fuel, food, building supplies, and other household and community items to coastal villages of western Alaska and upriver to villages along the Yukon and Kuskokwim River. Bering Sea and Arctic marine research vessels, some smaller tour vessels, and small fishing vessels routinely use the eastern Bering Sea area. During summer, hundreds of vessels fish for salmon, herring, halibut, sablefish, groundfish, and other species relatively close to shore and offshore to the Continental Slope throughout the western Alaska, Bristol Bay region, and eastern Bering Sea fishing grounds.

C. Environmental Sensitivity of the Beaufort-Chukchi-Bering Strait Route

The marine and coastal environment along this route include the shallow barrier island-lagoon and eroding peat shorelines of the Beaufort and Chukchi Seas, occasional cliffs and rocky outcroppings of the Chukchi coastline, and variable coasts along the Siberian and Kamchatka Peninsula coasts. The U.S. and Russia are separated by the U.S. Russia Convention Line of 1867 in the middle of Bering Strait, with Little Diomede Island in the U.S. and Big Diomede

[10] http://benmuse.typepad.com/arctic_economics/shipping/

Island in Russia only 3 miles apart (Figure 5). Productivity of the Arctic Ocean is considered to be low, probably due to long winters of low light penetration and thus lower plankton production. The Chukchi is more productive, due partly to the influx of nutrients and plankton in waters from the Pacific Ocean and Bering Sea flowing northward through Bering Strait. The Beaufort Sea is also influenced by the seasonal outflow of fresh water and nutrients from the Mackenzie River in the Yukon Territory. Productivity in the Bering Sea is higher, and this area supports large commercial fisheries in both US and Russian waters.

The bowhead whale is listed under the U.S Endangered Species Act (ESA) as endangered. This whale is a critically important marine mammal to residents of the Alaskan and Siberian coasts. The bowhead whale is hunted in its spring and fall migrations to and from the Beaufort Sea from wintering grounds in the southwestern Bering Sea. Several ice seal species are hunted by Natives of both countries including ringed and bearded seals, and all four ice seals that inhabit the Alaskan Arctic are currently under review by the U.S. National Marine Fisheries Service as possible candidates for listing under the ESA. All marine mammals in Alaska are protected under the Marine Mammal Protection Act which prohibits harassment of these animals, unless specifically permitted.

This region seasonally supports populations of shorebirds, nesting seabirds, whitefishes, and other marine resources, and benthic habitats provide important seasonal habitat for fish and invertebrates that, in turn, support other fish, marine mammals, and seabirds. The threatened spectacled eider summers in the Arctic and thousands flock together in winter in seasonal polynyas of the northern Bering Sea. The Arctic provides breeding and nesting habitat for millions of shorebirds, waterfowl, seabirds, and other bird species during summer months, many of which use nearshore waters for feeding. Fish move out of their overwintering habitat in freshwater rivers to forage in nearshore brackish waters of the Beaufort and Chukchi Seas, particularly whitefishes and Dolly Varden char. The West and East Bering Sea is seasonal and year round habitat for marine mammals, seabirds, and fish, many of which are harvested commercially. The Aleutian, Commander, and Kuril Islands ecosystem includes rich coastal and shoreline assemblages of kelp and urchin habitats, embayments with tidal wetlands and extensive eelgrass beds that annually support millions of migrating birds, and steep rocky slopes with cold water coral and sponge communities.

The marine environment of the Aleutian Islands and the West and East Bering Sea region is heavily influenced by the meteorological patterns from a persistent low pressure system termed the Aleutian Low; this prominent feature generates frequently stormy and turbulent weather and sea conditions, creating forcing conditions that enhance marine productivity but also pose periodic risks to shipping. Strong tidal currents in western Aleutian Island passes and a net northward transport of waters into the Bering Sea bring nutrients and biota important to the Bering Sea ecosystem (NPFMC 2007).

D. Vulnerable Resources and Environmental Risk

Shipping incidents, including vessel incapacitation and eventual groundings, fire or other damage at sea, contaminant spills, accidental loss of containers or other materials from vessel decks and holds, coastal shipwrecks, collisions, and the noise disturbance or other impacts from vessels presence and movement create opportunities for adverse impacts on the region's resources. Each of these potential incidents carries with it a risk to the region's ecological and human resources.

Ice dependent marine mammals will be more stressed as seasonal ice retreats further and gradually disappears under some future climate warming predictions. Marine mammals such as ice seals and polar bears will concentrate on remaining ice, increasing intra-specific encounters. Receding ice will remove the ice platform from which walrus and bearded seals access seasonal feeding habitats, forcing these mammals to ice further north or to shoreline areas where they are susceptible to human disturbance, predation, and where they will be vulnerable to oil spills from vessels incidents. Many marine mammals under stress from sea ice loss will also be susceptible to disturbance from shipping activities during their forays offshore to feed, and they will be exposed to potential collisions or displacement from feeding habitats by vessel noise.

1. Resources at Risk

The Western Arctic stock of bowhead whales (*Balaena mysticetus*) occurs in the Bering, Chukchi, and Beaufort Seas, and seasonally migrates through Bering Strait and the Chukchi and Beaufort Seas (Figure 6); in Bering Strait they are constricted physically to a relatively small corridor, exposing them to increased interactions with vessels transiting this area during spring and fall. Bowheads, listed in the U.S. as endangered under the ESA, travel into the Arctic from the Bering Sea during spring (May/June), and inhabit the feeding areas of the eastern Beaufort Sea during summer, primarily in the Amundsen Gulf south of Banks Island, returning south and then westward along the Alaskan Beaufort Sea coast to the Chukotka Peninsula, then southward into the Bering Sea in fall (September/October). Bowheads winter in the western Bering Sea where they are exposed to vessels transiting the western Bering Sea route.

Bowhead whales are harvested by Native communities in both Alaska and Siberia and are hunted in spring and again in fall. Bowhead whales are an important subsistence food source and the hunt and sharing of bowhead whale meat and blubber is a cultural tradition. Vessels may release toxic substances or loose debris off decks that can injure whales, vessels may strike and injure or kill whales, or ice strengthened vessels may create ice paths that draw bowheads away from nearshore hunting areas. Noise or other disturbance associated with vessel activities may divert bowhead migration or cause injury (see disturbance section). Any disruption of the spring and fall hunts, or any injury or mortality to bowheads would be considered a major issue to Alaskan and Siberian Native peoples.

Several other marine mammals may be susceptible to shipping incidents along this route. The polar bear, recently listed under the ESA in the U.S. as threatened because of warming trends and loss of sea ice, inhabits seasonal and multi-year ice. Ice is critical to the life cycle of polar bears. Pacific walrus are also adversely affected by loss of sea ice, and are loosing ice as a feeding platform during summer movements northward into the Chukchi Sea. Beluga whales move northward from wintering areas of the western Bering Sea to the Chukchi and Beaufort Seas, and may encounter vessels traveling through Bering Strait and along the western Bering Sea route as well as waters of the Chukchi and Beaufort Seas year round. Ice seals including ribbon, ringed, spotted, and bearded seals, also are loosing sea ice habitat seasonally and are forced further northward in summer to follow the receding ice. Polar bears feed on ice seals, and must follow the retreating ice to continue to find prey. These conditions are creating stress on polar bears, walrus, and ice seals. Shipping incidents that may adversely impact these marine mammals directly or through impacts on their prey will further exacerbate an adverse situation in the northern Bering Sea, Bering Strait area, and the Chukchi and Beaufort Seas.

Further south in the West Bering Sea and East Bering Sea LMEs, northern fur seals occupy breeding and birthing sites on the Pribilof Islands and Bogoslof Island in the U.S. and the Commander Islands, Kuril Islands, and Tyuleni Island in Russia during spring through fall (Figure 7). Females forage offshore throughout the Bering Sea, returning to nurse pups until their fall migration south. During the summer pupping and foraging period, adults do not feed and females are stressed from nursing, mating, and acquiring self nutrition. In fall, fur seals migrate south into North Pacific Ocean waters where they are pelagic and forage offshore. Harbor seals are distributed on haulouts along the coasts throughout the two LMEs including the Pribilof, Aleutian, Kuril, and Commander Islands in both countries. Sea otters occupy similar areas but remain nearshore to feed on shellfish.

The Spectacled Eider (*Somateria fischeri*) is a threatened species under the ESA, and the breeding population in Arctic Alaska is currently the largest in North America. Spectacled eiders are diving ducks that spend most of the year in marine waters where they feed on bottom-dwelling mollusks and crustaceans. Spectacled eiders overwinter in polynyas in seasonal sea ice, with the largest known concentration of thousands of birds in an area north of St. Lawrence Island in the northern Bering Sea (Figure 8).

The endangered short-tailed albatross is present year round in the West Bering Sea LME primarily over waters along the continental shelf edge (Figure 9). A surface feeding seabird, the short-tailed albatross is susceptible to contaminants on the sea surface and contaminated prey. This seabird concentrates in certain marine areas (Figure 10) (Piatt et al. 2006) where it may be particularly vulnerable to shipping incidents, particularly oil or other contaminant spills.

Forty-six species totaling approximately 80 million individual seabirds breed in Alaska and the Russian Far East. During the summer, seabirds gather in groups to breed and nest in colonies distributed on all parts of the Alaskan and Russian Far East coasts (Figure 11). Seabirds are abundant in the western Aleutian Islands, Commander Islands, and along the shoreline habitats of eastern Siberia and the Kamchatka Peninsula, nesting and fledging young along the rocky shores and islands; large colonies fledge millions of young annually. Albatrosses, fulmars, shearwaters, petrels, murres, kittiwakes, auklets, puffins, cormorants and gulls are common throughout the West Bering Sea LME, as are porpoises and whales, and thousands of Steller sea lions and harbor seals occupy haulouts and rookeries along the coast. Sea otters are present throughout the year (Figure 12).

The populations of several marine species are depressed, declining, or otherwise considered particularly sensitive and in danger of potential extinction, and are listed in the U.S. under the ESA. Portions of the nearshore region of the western Aleutian Islands are kelp-dominated algal forests that support large numbers of sea urchins that in turn support the southwest Alaska stock of northern sea otter which is listed as threatened under the ESA (Table 1). This region also provides habitat for the endangered Steller sea lion (Figure 13) and several species of endangered cetaceans (Table 1).

The ESA affords considerable protection for these species in the U.S. Activities that could potentially adversely affect these species or their designated critical habitat would require a process of formal consultation with the Federal agencies responsible for their management (National Marine Fisheries Service or U.S. Fish & Wildlife Service). Human activities found likely to adversely affect any of these species could be required to take action to mitigate, or change operations to minimize, such impacts. ESA-listed species present in the Beaufort-Chukchi-Bering Strait Route region are listed in Table 1.

Commercial fisheries in the West Bering Sea LME are predominantly prosecuted by Russian vessels. Information on the production of commercial species in the Bering Sea was provided in the Great Circle Route case study. Lower levels of harvest occur in the West Bering Sea LME, however. These include salmon, halibut, crab, and groundfish. Fish harvested in this marine ecosystem are important to the economy of Russia, and products are shipped throughout the world, particularly to Japan, South Korea, People's Republic of China, and Europe. In the eastern Bering Sea, however, large harvests of groundfish and crab occur annually, and hundreds of fishing vessels use this region primarily from January through October (Figure 14).

Human communities are present along the coasts of the Beaufort-Chukchi-Bering Strait Route; residents depend heavily on marine resources from the region, particularly marine mammals. Communities vary in composition, from the larger communities of Barrow and Kotzebue to smaller cities such as Wainwright, Gambell, and small to large communities along the Siberian and Kamchatka Peninsula coasts. Many small villages occur along the eastern Bering Sea route along the coast of western Alaska. Residents rely upon the marine environment for part of their economy, primarily from marine shipping, commercial fishing, and marine recreational activities. Characteristic of this region are many small, rural communities, most of which are largely Native Alaskan or Siberian in composition; these villages rely heavily on adjacent marine waters for commercial fishing and subsistence harvest of marine resources such as fish, marine mammals, and birds.

2. Potential Risks to Resources

Shipping activities may result in incidents that can have effects on the resources, habitats, and human communities along the Beaufort-Chukchi-Bering Strait Route. These include discharge of oily wastes or other contaminants from routing operations, accidental discharge of oil or other contaminants from accidents or groundings, at-sea fires or other incidents that result in debris or vessel groundings on adjacent lands, vessel noise and resultant disturbance to marine mammals, marine mammal and seabird collisions with vessels, and release of ballast water and potential exotics or nuisance biota to the marine environment or adjacent land. Vessel lighting may attract seabirds, resulting in bird strikes with vessel superstructures; this is a particular concern for shearwaters. Contaminants from vessel incidents can foul seabirds and marine mammals at sea or drift ashore and impact beaches and shorelines and biota inhabiting these areas. Contaminants may affect the forage base for important commercial species or prey for marine mammals or birds. Rats (primarily Norway rats, *Rattus rattus*) may be aboard some vessels; incidents that release rats to lands where seabirds nest can result in devastation to seabird colonies.

Shipping incidents can threaten millions in revenues to fishers, including vessel owners, captains and crew, as well as processors and affiliated industries that support fisheries (warehousing, cold storage, shipping, container manufacture, fuel distribution, shipyards and repairs, gear manufacture, etc.). Adverse effects from shipping incidents can also affect subsistence and personal use of marine resources by residents of communities in the region and Native people who rely on marine resources for subsistence.

One unique issue associated with shipping along the Beaufort-Chukchi-Bering Strait Route is the potential changes in the migration route used by bowhead whales by icebreakers (Figure 6). Ice strengthened vessels that transit seasonal ice of the Beaufort and Chukchi Seas and Bering Strait may create an “artificial channel” in the sea ice. If this occurs in spring when bowhead whales are migrating northward from the Bering Sea, through Bering Strait, and into the Chukchi and then Beaufort Seas, whales may move further offshore following the open leads created by ice breaking vessels, putting them out of reach of coastal whaling communities of Point hope, Wainwright or Barrow. Loss of whales by these villages could have severe impacts on food resources critical to the survival of residents and adversely impact a sociocultural lifestyle present in this region for millennia.

Aleutian, Commander, and Kuril Islands communities are dependent on fishing and the use of other marine resources from this region, particularly in smaller villages that partially subsist on these resources. Few human communities occur in the western Aleutian Islands and Commander Islands, however.

The Aleutian and Commander Islands are habitat for thousands of Steller sea lions which is listed as endangered under the U.S. ESA. The region is habitat for hundreds of thousands of harbor seals, and a declining population of sea otter. Northern fur seals inhabit the Pribilof, Commander, and other islands in the U.S. and Russian portions of the Bering Sea and North Pacific during spring through fall, then migrating southward to pelagic habitats throughout the North Pacific Ocean. The Aleutian Islands also are habitat for millions of seasonally nesting seabirds and these waters are used year round by the endangered short-tailed albatross.

The U.S. National Research Council has recently drafted a design for a comprehensive risk assessment of vessel incidents in the Aleutian Islands (NRC 2008). This study's recommendations include phased preliminary and focused risk assessments, and a quantitative fate and effects analysis to assess potential damages that could accrue to natural resources and socioeconomic systems associated with different hazards, sizes of spills and accident locations. The NRC (2008) study also recommended that the U.S. Coast Guard and the State of Alaskan manage the risk assessment and that it be guided by an advisory panel of experts and stakeholders and reviewed by a peer review panel. The study also recommended interim steps be taken including expansion of a vessel tracking system along the Great Circle Route, study of possible deployment of an Aleutian Rescue Tugboat, design of a vessel traffic information system for the Unimak Pass and Dutch Harbor areas, and consideration of options for tracking and monitoring/managing vessel traffic in congested areas in this region. The Great Circle Route merges with the Beaufort-Chukchi-Bering Strait Route analyzed in this case study.

3. Major Ecological Risk Issues of Concern along the Beaufort-Chukchi-Bering Strait Route

Bowhead whale strikes – The bowhead whale is listed as endangered under the ESA. Whales are susceptible to ship strikes when on the water surface and may be difficult to observe from vessels, particularly at night. Since few vessel transits of the Beaufort-Chukchi-Bering Strait Route have occurred, incidents of bowhead strikes are few. Some bowheads have been observed with propeller marks, indicating some encounters. With increasing vessel traffic in the Arctic, encounters with bowheads would likely increase. Adverse impacts on bowhead whales would also adversely impact Alaskan and Siberian Native subsistence and sociocultural activities.

Polar bears - The polar bear was recently listed as threatened under the ESA, providing this species with additional protection from human activities that may affect the mammal or its habitat. With shrinking ice habitat, forecasts indicate polar bears will become increasingly concentrated onto remaining ice habitat or on land where prey resources will not be available.

Polar bear disturbance or displacement from Arctic habitats from shipping activities would add stress to this population.

Spills of toxic materials – Spills or incidents that result in release of toxic materials, particularly petroleum products, may result in contact of toxins with marine organisms; those particularly susceptible include whales, pinnipeds, and seabirds. Bowhead whales, as well as beluga, gray, minke, sei, fin, humpback, and killer whales, move northward in spring and are present along the Beaufort-Chukchi-Bering Strait Route through fall where they forage in offshore marine waters of this region. Polar bears occupy ice habitat year round and would be susceptible to contact with spilled oil or other substances or ingestion if seals, their primary prey, were contaminated. Millions of shorebirds, waterfowl, and seabirds migrate to western Alaska and the Arctic, nesting on tundra habitats and coastal barrier islands and shorelines during spring and summer. Toxic materials released to the marine environment from shipping incidents could cause mortality to large numbers of seabirds and marine mammals.

The ESA-listed short-tailed albatross feeds at sea year round (Figure 9) and could be affected by contact with toxic materials or ingesting debris or contaminated fish. Short-tailed albatross are known to concentrate in areas where prey is abundant, such as the St. Matthew Canyon along the western Bering Sea shelf edge or along the central Aleutian Islands (Figure 10)(Piatt et al. 2006); these concentration areas make this seabird particularly susceptible to a shipping incident, possibly exposing the seabird to population level impacts. The endangered Steller sea lion forages partly in offshore waters; its population is stable or slightly declining at present. Shipping incidents that adversely interact with any endangered or threatened species of marine mammals or birds could worsen their already diminished abundance, possibly resulting in consultation with Federal agencies and curtailment of vessel activities or other measures taken against vessels, crew, and owners.

Toxic materials that reach shorelines in this region may injure or kill sea otters, the Southwest Alaska stock of which is listed as threatened (Figure 12). Oil or other contaminants may damage or render unproductive coastal and intertidal habitats used by many species. Endangered Steller sea lions haul out and occupy rookeries for mating and pupping throughout the Aleutian Islands in Alaska and the Commander Islands in Russia (Figure 13). Northern harbor seals also occupy rookeries and haulouts along southern portions of this route and are susceptible to contaminants that may drift close to shore. Millions of seabirds forage in coastal waters near nesting areas on Aleutian and Commander Islands and the coastal cliffs and shorelines of Siberia and the Kamchatka Peninsula (Figure 11).

Spills of toxic materials also may limit geographically or temporally, or entirely stop, commercial fishing; impacts could be severe economically and socially to Alaskan coastal communities and could be felt economically throughout other parts of the U.S., Russia, and the world. Particularly susceptible would be coastal herring and salmon fisheries prosecuted from spring through fall, and tainted fish or other marine organisms would transport toxins through the marine food web, with delayed effects on fisheries such as crab or other shellfish.

Introduction of Exotics – Some vessels release ballast water as a consequence of taking on cargo or to aid in vessel trimming. Ballast water may carry exotic organisms from other parts of the world, potentially introducing alien species that could compete or overrun native species in the marine environment, estuarine and shoreline areas, or on lands adjacent to the shipping lanes or in ports. Vessels may accidentally run aground, break up at sea, or accidentally discard debris that washes ashore, carrying with these incidents the threat of rat infestation to lands that currently are rat free. Of particular concern is the Norway rat, *Rattus rattus*, that may feed on seabird eggs, chicks and adults, threatening the millions of seasonal seabird occupants of the western Aleutian Islands and the Commander Islands. Rats have decimated the seabirds on many of the Aleutian Islands and many smaller islands in the Alaska Coastal Maritime Wildlife Refuge, which is home to millions of nesting seabirds. Ground nesting birds are vulnerable (Ebbert et al. 2007) such as puffins, auklets and storm petrels; these species also leave their eggs and young for extended periods while foraging and may become prey for rats.

E. Future Vessel Traffic

Observed and predicted decreases in the summer extent of the ice pack could lead to a substantial increase in commercial shipping in the Arctic. Traffic between Europe, East Asia, and the U.S. West Coast may move across through the Northwest Passage across Northern Canada or across an alternative route across the northern coast of the Russian Federation. In either case, the traffic would have to cross the Chukchi Sea and pass through Bering Strait (ACIA 2004).

There is also likely to be an increase in local traffic accessing the land areas in the action area, the Russian Federation's northern coasts, and Canada's Arctic waters. When it is clear of ice, Canada's Mackenzie River is navigable its entire length to the Great Slave Lake where an intermodal port at Hay River makes it possible to transfer cargo between the railroad and river transport. Currently the ice free period lasts from May to October. Expansion of the Red Dog Mine in northwest Alaska will increase barge transport of ore from the mine and through the eastern Bering Sea route. With a warming climate, increased interest in effects on the marine ecosystem will result in additional research cruises to the Arctic; already new research vessel expeditions to the Chukchi and Beaufort Seas have originated in China, Japan, Russia, and the U.S.

Because of increased shipping activity anticipate in the future, the U.S. Coast Guard's 17^{th} District has recently indicated an intention to establish an enhanced presence in northern Alaska. In 2008, the Coast Guard placed vessel and aircraft assets in Arctic Alaska for search and rescue activities during spring through fall, and is anticipating a year round presence in the U.S. Arctic. The Coast Guard is currently developing concepts for a Bering Strait vessel traffic management system and plans to coordinate this concept with Russian coast guard counter parts. The U.S. and Russia are considering construction of additional ice breaking vessels to support their national interests such as defense, research, law enforcement, and monitoring. The U.S. is considering replacement of two of its three polar icebreakers (O'Rourke 2008).

The U.S. is preparing for anticipated development of fishery resources in the Chukchi and Beaufort Seas. With continued warming trends, it is possible that fishery resources may develop and attract fishing vessels north of Bering Strait. However, very little information on fish resources in this region will limit fishery development. The North Pacific Fishery Management Council is preparing an Arctic Fishery Management Plan that will initially prohibit commercial fishing in the U.S. Arctic north of Bering Strait; the Plan will have provisions for opening a fishery in the future.

F. Key Findings

The Beaufort-Chukchi-Bering Strait Route traverses sensitive marine environments supporting populations of fish and wildlife important to the functioning of five Large Marine Ecosystems. Indigenous people living along the coasts of Alaska and Siberia depend on marine mammals and other marine organisms; shipping incidents that may disrupt this food supply could adversely affect entire communities.

An oil spill or other contaminant discharge in sea ice may be nearly impossible to contain and clean up. Spilled oil may drift and eventually contact and foul individual marine mammals such as ice seals, walrus, and polar bears or their prey. Many arctic mammals are threatened by climate warming and loss of seasonal sea ice and thus may be especially vulnerable to oil contamination of individuals or their prey.

Late winter and early spring is a particularly sensitive time period when marine mammals begin migrations to summer feeding areas and birds arrive at breeding and nesting sites. Marine mammals such as seals and whales give birth in this season, and spectacled eiders concentrate in the polynyas of the northern Bering Sea.

Bowhead whales are sensitive to vessel noise and when exposed may move away from normal migratory routes, possibly affecting movements to or from Beaufort Sea feeding areas, Bering Sea wintering areas, and areas where Alaskan and Siberian Natives traditionally hunt bowheads.

Vessel movement and disturbance or oil spills or other contaminant releases may adversely affect polar bears, recently listed in the U.S. as threatened under the ESA. Continued warming and subsequent loss of sea ice will stress polar bear populations and potentially exacerbate the effects of disturbance from vessel activities. With sea ice retreat, polar bears will concentrate in remaining ice habitat where an oil spill or other contaminant release that contacts this residual habitat could have population level impacts.

Climate warming is reducing the seasonal ice habitat used by walrus in the northern Bering Sea and Chukchi Sea, forcing walrus to coastal haulouts where they are susceptible to oil or contaminant spills that drift ashore. Without sea ice platforms, walrus must continue to forage in the pelagic environment and thus may be increasingly susceptible to ship strikes.

Increased vessel traffic in the Beaufort and Chukchi Seas will likely result in greater incidents of pollutant discharges and disturbance effects on foraging bowheads or other marine mammals and could result in a higher incidence of ship strikes of whales with the potential for serious injury and mortality. During spring and fall, portions of the shipping lanes along this route coincide with the migratory corridor of bowhead whales, particularly in the spatially constricted Bering Strait.

Vessel incidents could adversely affect major proportions of some of the world's populations of nesting shorebirds, waterfowl, and other birds that utilize breeding, nesting and foraging habitat along the coastal Beaufort and Chukchi Seas and along the coast of western Alaska. Contaminants could have a major impact on the major overwintering area for endangered spectacled eiders in the northern Bering Sea. Northern fur seals forage seasonally in discrete areas of the central and eastern Bering Sea where they are susceptible to shipping incidents during their pelagic foraging activities.

The eastern Bering Sea supports some of the largest commercial fisheries in the world. Increased vessel use of the eastern route that traverses the eastern Bering Sea will increase potentially adverse interactions with this region's rich fishery resources, fishing communities, and hundreds of fishing vessels and support vessels. Spills from vessel incidents may drift ashore to western Alaska areas where seasonal herring and salmon fisheries occur.

The route traverses remote areas with difficult access for incident response, rescue, and contaminant or debris cleanup. The U.S. Beaufort Sea coast has no port facilities or harbors suitable for refuge for medium to deep draft vessels. New aids to navigation, port development, escort vessels, search and rescue capabilities, harbors of refuge, and incident response strategies will be required.

Given its restricted geographic nature, confounded by ice movement and strong ocean currents, the Bering Strait area may become a choke point for vessels transiting the Strait. Vessel monitoring, and perhaps a multi-nation vessel management system, may be required in the Bering Strait area.

The Aleutian Low creates persistent high winds and stormy conditions that elevate risk to vessels and cargo transiting the western Aleutians and Commander Islands area. These severe weather patterns may reduce the effectiveness of response to spills or other incidents.

4. Future trends in environmental status and impacts

This section will consider future trends and address other changes that may be occurring in the Arctic simultaneously to a possible increase in Arctic shipping

4.1Governance

Text missing

(e.g. affecting regulations and practices)

4.2 Technology

Draft text in this section - not yet complete

Ice navigation is one element of the particularities of Arctic operations. Navigating the Arctic is a specialized trade. Ships operating in the Arctic environment are exposed to a number of unique risks. Poor weather conditions and the relative lack of good charts, communication systems and other navigational aids pose challenges for mariners. The remoteness of the areas makes rescue or clean-up operations difficult and costly. Cold temperatures may reduce the effectiveness of numerous components of the ship, ranging from deck machinery and emergency equipment to sea suctions. When ice is present, additional loads on the hull, propulsion system and appendages can be imposed. Vessels equipped for Arctic navigation also require more autonomy in fuel, more retention capacity and storage and additional spare parts and maintenance supplies. In addition, they are facing winter conditions, as is the case in other winter navigation areas, such as the St.Lawrence. Operational procedures such as ballast line circulation to prevent freezing or added machinery warming time are also used in the Arctic. Arctic bound vessels also require additional skills from the crew. While navigators are facing ice navigation conditions in the Arctic after the passage along the Coast through iceberg infested waters, ship engineers need additional skills to be able to solve any problem that may occur without outside support, often machining parts or developing temporary solutions. The operation of these vessels is 3 to 4 times more expensive than the operation of a regular bulk carrier or general cargo of a similar size.

Green Ship Technology in the Arctic

Technology has a role to play in the mitigation of environmental impacts in the Arctic and elsewhere. Many of the potential impacts from shipping that have been discussed in this assessment can be effectively reduced or eliminated through the use of current or developing technologies, as well as best practices. Examples include stack scrubbers which remove harmful substances such as sulfur and black carbon from a ship's emissions; water treatment systems for sewage, bilge water, ballast water and other discharges; technologies that harness wind or solar power to reduce the fuel consumption; or the use of cleaner fuels that emit less harmful substances when burned. Given the sensitivity of the Arctic environment and the potential impacts from shipping, the development and application of green ship technologies should be a priority. These new technologies can be expedited through industry incentives, such as the green ship technology fund in Norway; or regulatory requirements, such as the IMO International Convention for the Control and Management of Ships Ballast Water & Sediments.

4.4 Climate change

The Arctic climate is warming. The effects of this are now being seen in the retreating sea ice, melting permafrost and the changing timing of the onset of fall and spring, as well as the increase in variability within each season. These changes are affecting Arctic species and ecosystems. Where caribou used to migrate across frozen rivers, they now have to wade. Polar bears swim farther to find food and wait longer in the fall for the pack ice to reform, extending their fasting. Pacific walrus are now hauling out on land in the Chukchi Sea, where they used to haul out mainly on sea ice.

There is a multitude of ways in which the changing climate is affecting Arctic species and ecosystems, which are by nature highly evolved in function and finely balanced in the timing of seasonal events. Although some species will benefit from the changes, there are many that are now under stress as a result and, for some, at risk of steep decline. For many species, any potential impacts as a result of current or future shipping activity will be in addition to the stress they are already under due to the changes occurring in their environment. It is beyond the scope of the current assessment to examine the interaction between effects from climate change and effects from future shipping activities. This is in part because of the intrinsic difficulties and the many uncertainties about the future.

Climate experts are projecting that the main change in sea ice will be decreasing ice coverage in the summer along the coastal Arctic seas with the formation of first-year ice later the fall. Even with a warmer climate, the Arctic Ocean will still remain ice-covered for most of the year. As climate and sea ice conditions continue to change, the timing and movements of the animals' activity will also be modified, making predicting the potential for interactions between shipping and animals increasingly complex.

5. Findings

1] From an environmental point of view, Arctic shipping poses a threat to the region's unique ecosystems. This threat can be effectively mitigated through careful planning and effective regulation in areas of high risk.

2] Release of oil into the Arctic marine environment, either through accidental release, or illegal discharge, is the most significant threat from shipping activity.

3] Ship strikes of whales and other marine mammals are of concern in areas where shipping routes coincide with seasonal migration and areas of aggregation.

4] The introduction of invasive species into the Arctic marine environment from shipping can occur and the risk may be enhanced due to changing climate, possibly making conditions more favorable to some species. The most risk exists where a transfer of organisms from ecosystems of similar latitudes and conditions can occur. Of particular future concern is the transfer of organisms across the Arctic Ocean from the North Pacific to the North Atlantic or vice versa.

5] There are certain areas in the Arctic region that are of heightened ecological significance, many of which will be at risk from current and/or increased shipping. Many of these areas are located in geographically restrictive locations or chokepoints where much shipping activity also occurs, such as the Bering Strait, Hudson Strait, Lancaster Sound, Pechora Sea and the Kara Port.

6] Migratory marine mammals such as bowhead, beluga, narwhal and walrus have wintering areas in the southern extent of the sea ice and spring migration routes into the Arctic through systems of leads and polynyas also used by many seabirds, ducks and other marine birds during spring migration. These migration corridors correspond broadly to the current main shipping routes and travel through geographic chokepoints.

7] The black carbon emitted from shipping in the Arctic could have significant regional impacts by accelerating ice melt.

8] Ship emissions including greenhouse gases (GHGs), Nitrogen Oxides (NOx), Sulfur Oxides (SOx) and Particulate Matter (PM) may have negative effects on the Arctic environment and will increase in the Arctic region proportionately with increased shipping activity. Effective reduction of ship emissions can be achieved through the application of feasible and best available technologies, through air emissions reduction techniques and, most importantly, through effective implementation of relevant IMO regulations.

9] Sound is of vital biological importance to marine mammals and anthropogenic noise produced through shipping and other vessel activity can have various adverse effects on Arctic species.

10] Subarctic seas support some of the richest fisheries in the world in the Bering Sea and the Barents Sea. These two areas are also the location of the heaviest shipping traffic now occurring in the Arctic region. A potential accidental spill of oil or other hazardous and noxious substances in these areas could have large economic, social and environmental impacts.

11] Environmental effects on marine mammals, seabirds and fisheries from ship sourced disturbances, noise, or potential accidental/illegal release of oil and other hazardous and noxious substances may impact culturally and economically significant subsistence harvests of these animals.

12] The most immediate impacts of climate change in the Arctic will be the reduction of summer sea ice, longer open water seasons in the fall and the reduction of the year-round presence of multi-year ice. These changes may have far reaching implications for Arctic ecosystems and will also result in the lengthening of the current shipping season. Shipping in the future may be occurring much later into the fall and possibly earlier in the spring, thereby increasing the possibility of interaction between migrating and calving species and ships.

6. Research Gaps and Opportunities

Research Opportunities

Investigate the effects of ship noise and physical presence, including avoidance behavior on Arctic marine animals at the individual and population level. Such research would contribute to determining distances at which animals are disturbed from ships, the potential for ship strikes and assessment of the need for mitigation strategies if adverse effects are predicted.

q Complete regional modeling of ship emissions in order to investigate the current and potential impacts from these emissions along major routes and near key port regions in the Arctic. This will contribute to more accurate assessment of regional impacts on air quality, pollution, haze and visibility, and climate forcing due to the release and deposition of black carbon and other aerosols.

q Conduct baseline surveys of aquatic species in major recipient ports in the Arctic region and research the potential survival of species introduced through different vectors.Carry out a risk assessment of invasive species introduction under current international standards in order to determine the need for Arctic specific protections.

q Conduct further research on the transport, fate and effects of oil in ice-covered waters, and on technology, methods and procedures to clean-up and remove spilled oil to reduce environmental impacts.Research on the impacts of noise and visual disturbance to marine animals from ships and other sources at the individual and population the level would be valuable. Further research is needed into the regional effects and effective ways of limiting of Black Carbon emissions in the Arctic Impacts of icebreaking activity from shipping in ice covered waters

Accurate modeling of mortality rates of marine mammals from ship strikes in the Arctic region

Increasing knowledge of all Arctic ecosystem components and energy flow, eg. Amphipods, Polar Cod

Research optimal ship speed for lowering rate of ship strike, noise and emissions?

Development of circumpolar noise assessment/noise budgets.

Transfer and survival of species through hull fouling or ballast water from the northern Pacific to the northern Atlantic.

Research on the fate and toxicity of oil in ice.

Recommended Research – Ballast Water

Quantify risk of use of the IMO D2 Ballast Water Treatment Standard in the Arctic

Examine the dispersion characteristics of organisms at proposed ballast water discharge sites.

Categorize specific Arctic ecological risk factors for input to the GLOBALLAST software.

Conduct baseline surveys of species. in the Arctic

Conduct baseline surveys of species in major donor ports, including domestic ports that might serve as stepping stone invasion sources

Assessment of trade patterns into the Arctic to quantify risk by vessel type and ballast water transport flow.

Incorporation of Globallast or similar software to categorize risk for Arctic ports.

Economic studies to predict how trade demands might change to Arctic ports if longer season or less ice

Ballast water sampling study of ships heading into the Arctic.

A risk analysis should be carried out to categorize any threat from this vector (Cargo?).

Full scale examination of current state of hull fouling on ships / oil rigs entering the Arctic

An examination of the traditional whaling grounds for non native species attributable to Hull fouling would be illustrative as to the historical survival (or not) of such organisms

Examination of the effectiveness of current hull ice coatings as antifouling agents

7.0 References

Section 2.1

Section not yet complete

Section 2.2-Ship Emissions

1. Lauer, A., et al., *Global model simulations of the impact of ocean-going ships on aerosols, clouds, and the radiation budget.* Atmospheric Chemistry and Physics, 2007. 7(19): p. 5061-5079.

2. Eyring, V., et al., *Brief summary of the impact of ship emissions on atmospheric composition, climate, and human health*. 2007, Health and Environment Sub-Group of the International Maritime Organization: London, UK. p. 6.

3. Capaldo, K.P., et al., *Effects of Ship Emissions on Sulphur Cycling and Radiative Climate Forcing Over the Ocean.* Nature, 1999. 400: p. 743-746.

4. Wit, R., B. Kampman, and B. Boon, *Climate Impacts from international aviation and shipping.* 2004, Netherlands Environmental Assessment Agency.

5. Corbett, J.J., et al., *Mortality from Ship Emissions: A Global Assessment.* Environmental Science & Technology, 2007. 41(24): p. 8512–8518.

6. Eyring, V., et al., *Assessment of Transport Impacts on Climate and Ozone: Shipping.* Atmospheric Environment, 2008. under review.

7. Eyring, V. and J. Corbett. *Comparing Fuel Consumption, Carbon Dioxide and Other Emissions from International Shipping and Aircraft: A Summary of Recent Research Findings*. 2007 [cited 2008 July 17]; Available from: http://www.pa.op.dlr.de/SeaKLIM/Fuel_Emissions_International_Shipping.html.

8. Ocean Policy Research Foundation, *Research Study: The World's Changing Maritime Industry and a Vision for Japan*. 2008, Ocean Policy Research Foundation: Tokyo, Japan. p. 51.

9. Reddy, S.M. and O. Boucher, *Climate Impact of Black Carbon Emitted from Energy Consumption in the World's Regions.* Geophysical Research Letters, 2006. 34: p. L11802.

10. Flanner, M.G., et al., *Present-day climate forcing and response from black carbon in snow*. J. Geophys. Res., 2007. 112.

11. Corbett, J.J., et al., *Review of Marpol Annex VI and the NOx Technical Code: Allocation and Forecasting of Global Ship Emissions.* 2007, International Maritime Organization: London, UK.

12. Lack, D., et al., *Light absorbing carbon emissions from commercial shipping.* Geophysical Research Letters, 2008. 35: p. L13815.

13. Ramanathan, V. and G. Carmichael, *Global and regional climate changes due to black carbon.* Nature Geosci, 2008. 1(4): p. 221-227.

14. IPCC, *Climate Change 2007: Synthesis Report; Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* 2007: Geneva, Switzerland. p. 104.

15. Lauer, A., et al., *Global model simulations of the impact of ocean-going ships on aerosols, clouds, and the radiation budget.* Atmos. Chem. Phys., 2007. 7: p. 5061-5079.

16. Eyring, V., et al., *Multi-model simulations of the impact of international shipping on Atmospheric Chemistry and Climate in 2000 and 2030.* Atmospheric Chemistry and Physics. Chem. Phys., 2007. 7: p. 757-780.

17. International Maritime Organization, *Review of MARPOL Annex VI and the NOx Technical Code; Report on the outcome of the Informal Cross Government/Industry Scientific Group of Experts established to evaluate the effects of the different fuel options proposed under the revision of MARPOL Annex VI.* 2007. p. 48.

18. Sinha, P., et al., *Emissions of trace gases and particles from two ships in the southern Atlantic Ocean.* Atmospheric Environment, 2003. 37: p. 2139-2148.

19. Corbett, J.J. and P.S. Fischbeck, *Emissions From Ships.* Science, 1997. 278(5339): p. 823-824.

20. Corbett, J.J., P.S. Fischbeck, and S.N. Pandis, *Global Nitrogen and Sulfur Emissions Inventories for Oceangoing Ships.* Journal of Geophysical Research, 1999. 104(D3): p. 3457-3470.

21. Endresen, Ø., et al., *Emission from International Sea Transportation and Environmental Impact.* Journal of Geophysical Research, 2003. 108(D17): p. 4560.

22. Eyring, V., et al., *Emissions from international shipping: 1. The last 50 years.* Journal of Geophysical Research - Atmospheres, 2005. 110(D17): p. D17305.

23. Corbett, J.J. and P.S. Fischbeck, *International Technology-Policy: Challenges in Regulating Ship Emissions*, in *Improving Regulation: Cases in Environment, Health and Safety*, P.S. Fischbeck and S. Farrow, Editors. 2001, RFF Press: Washington, DC. p. 282-309.

24. Corbett, J.J., *Maritime Transportation and Global Climate Change*, in *Global Climate Change and Transportation: Coming to Terms.* 2002, ENO Transportation Foundation: Washington, DC. p. 131-142.

25. Corbett, J.J., *New Directions: Designing Ship Emissions and Impacts Research to Inform Both Science and Policy.* Atmospheric Environment, 2003. 37(33): p. 4719-4721.

26. Corbett, J.J., *Marine Transportation and Energy Use*, in *Encyclopedia of Energy*, C.J. Cleveland, Editor. 2004, Elesvier Science: San Diego, CA. p. 745-748.

27. Corbett, J.J. and H.W. Köhler, *Considering alternative input parameters in an activity-based ship fuel consumption and emissions model*. Journal of Geophysical Research, 2004. 109.

28. Endresen, Ø., et al., *Substantiation of a Lower Estimate for the Bunker Inventory: Comment on ''Updated emissions from ocean shipping'' by James J. Corbett and Horst W. Koehler*. Journal of Geophysical Research - Atmospheres, 2004. 109(D23302).

29. Endresen, O., et al., *Emission from international sea transportation and environmental impact*. Journal of Geophysical Research.D.Atmospheres, 2003. 108(D17).

30. Wang, C., J.J. Corbett, and J. Firestone, *Improving Spatial Representation of Global Ship Emissions Inventories*. Environ. Sci. Technol., 2008. 42(1): p. 193-199.

31. IMO, *Study of Greenhouse Gas Emissions from Ships*. 2000, International Maritime Organization.

32. Endresen, Ø., et al., *A historical reconstruction of ships' fuel consumption and emissions*. Journal of Geophysical Research, 2007. 112(D12301).

33. Corbett, J.J., C. Wang, and J. Firestone, *Estimation, Validation, And Forecasts Of Regional Commercial Marine Vessel Inventories, Final Report*. 2007, State of California Air Resources Board and the California Environmental Protection Agency and the Commission for Environmental Cooperation of North America: Sacramento, CA.

34. Eyring, V., et al., *Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050*. Journal of Geophysical Research - Atmospheres, 2005. 110(D17): p. D17306.

35. Corbett, J.J., et al., *Allocation and Forecasting of Global Ship Emissions*, submitted as a formal Annex submission to the International Maritime Organization, Editor. 2007, Clean Air Task Force and Friends of the Earth International: Boston, MA. p. 26.

36. Corbett, J.J. and J.J. Winebrake, *Sustainable Movement of Goods: Energy and Environmental Implications of Trucks, Trains, Ships, and Planes*. Environmental Management, 2007. November: p. 8-12.

37. Winebrake, J.J., J.J. Corbett, and P. Meyer, *Energy Use and Emissions from Marine Vessels: A Total Fuel Life Cycle Approach*. Journal of the Air and Waste Management Association, 2007. 57: p. 102-110.

38. Corbett, J.J. and J.J. Winebrake, *Emissions Tradeoffs among Alternate Marine Fuels: Total Fuel Cycle Analysis of Residual Oil, Marine Gas Oil, and Marine Diesel Oil*. Journal of the Air & Waste Management Association, 2008. 58: p. 538-542.

39. Buhaug, Ø., et al., *Updated Study on Greenhouse Gas Emissions from Ships, Phase 1 Report.* 2008, International Maritime Organization: London. p. 129.

40. Granier, C., et al., *Ozone pollution from future ship traffic in the Arctic northern passages.* Geophysical Research Letters, 2006. 33(L13807): p. 5.

Section 2.3-Discharges to Water

Not yet complete

Section 2.4-Disturbances

Amoser, S., L.E. Wysocki, and F. Ladich. Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities. *Journal of the Acoustical Society of America* 116 (2004): 3789-3797.

Andrew, R. K., B. M. Howe, and J. A. Mercer. Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast. *Acoustics Research Letters Online* 3 (2002): 65-70.

Arvenson, P.T., and D.J. Vendittis. Radiated noise characteristics of a modern cargo ship. *Journal of the Acoustical Society of America* 107 (2000): 118-129.

Bejder, L., A. Samuels, H. Whitehead, and N. Gales. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective *Animal Behaviour* 72 (2006): 1149-1158.

Blane, and Jaackson. The impact of ecotourism boats on the St. Lawrence beluga whales. *Environmental Conservation* 21 (1994): 267-269.

Bryant, P.J., C.M. Lafferty, and S.K. Lafferty. Reoccupation of Laguna Guerrero Negro, Baja California, Mexico by gray whales. *The Gray Whale*. New York: Academic press, 1984. 375-387.

Clark, C.W. Acoustic behavior of mysticete whales. In *Sensory Abilities of Cetaceans* (J. Thomas and R. Kastelein, eds.). Plenum Press. Pp. 571-583, 1990.

Clark, C.W., and W.T. Ellison. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. In *Echolocation in Bats and Dolphins* (J. Thomas, C. Moss and M. Vater, eds.). The University of Chicago Press. Pp. 564-582, 2004.

Cosens, S.E., and L.P. Dueck. Icebreaker noise in Lancaster Sound, N.W.T., Canada: Implications for marine mammal behavior. *Marine Mammal Science* 9 (1993): 285-300.

Curtis, K.R., B.M. Howe, and J.A. Mercer. Low-frequency ambient sound in the North Pacific: Long time series observations. *Journal of the Acoustical Society of America* 106 (1999):3189-3200.

Diachok, O.I., and R.S. Winokur. Spatial Variability of Underwater Ambient Noise at the Arctic Ice-Water Boundary. *Journal of the Acoustical Society of America* 55 (1974): 750-753.

Engås, A., O.A. Misund, A.V. Soldal, B. Horvei, and A. Solstad. Reactions of penned herring and cod to playback of original, frequency-filtered and time-smoothed vessel sound. *Fisheries Research* 22 (1995): 243-254.

Engås, A., E.K. Haugland, and J.T. Øvredal. Reactions of cod (*Gadus morhua* L.) in the pre-vessel zone to an approaching trawler under different light conditions. *Hydrobiologia* 371/372 (1998): 199-206.

Erbe, C., and D.M. Farmer. Masked hearing thresholds of beluga whale (*Delphinapterus leucas*) in icebreaker noise. *Deep-Sea Research II* 45 (1998): 1373-1388.

Erbe, C., and D.M. Farmer. Zones of impact around icebreakers affecting beluga whales

in the Beaufort Sea. *Journal of the Acoustical Society of America* 108 (2000): 1332-1340.

Evans, G. W. and K. English. The environment of poverty: Multiple stressor exposure, psychophysiological stress, and socioemotional adjustment. *Child Development* 73 (2002): 1238-1248.

Finley, K.J., G.W. Miller, R.A. Davis, and C.R. Greene. Reactions of belugas, *Delphinapterus leucas*, to ice-breaking ships in Canadian High Arctic. *Canadian Bulletin of Fisheries and Aquatic Sciences* 224 (1990): 97-117.

Foote, A.D., R.W. Osborne, and A.R. Hoelzel. Whale call-response to masking boat noise. *Nature* 428 (2004): 910.

Gavrilov, A.N., and P.N. Mikhalevskya. Low-frequency acoustic propagation loss in the Arctic Ocean: Results of the Arctic climate observations using underwater sound experiment. *Journal of the Acoustical Society of America* 119 (2006): 3694-3706.

ICES (International Council for the Exploration of the Sea). *Ad-Hoc Group on the Impact of Sonar on Cetaceans and Fish*. Copenhagen, Denmark: International Council for the Exploration of the Sea, 2005.

Kaatz, I. M. Multiple sound producing mechanisms in teleost fishes and hypotheses regarding their behavioural significance. Bioacoustics 12 (2002), 230-233

Kipple, B. M. and C. M. Gabriele. Glacier Bay underwater noise – 2000 through 2002: Report to Glacier Bay National Park by the Naval Surface Warfare Cent-Detachment Bremerton. Technical Report NSWCCD-71-TR-2003/DRAFT, 2003.

Kremser, U., P. Klemm, and W.-D. Kötz. Estimating the risk of temporary acoustic threshold shift, caused by hydroacoustic devices, in whales in the Southern Ocean. *Antarctic Science* 17 (2005): 3-10.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. The effects of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. *Marine Mammal Science* 15 (1999): 65-84.

Lewis, J.K, and W.W. Denner. Higher frequency ambient noise in the Arctic. *Journal of the Acoustical Society of America* 4 (1988): 1444-1455.

Malme, C.I., P.R. Miles, G.W. Miller, W.J. Richardson, D.G. Roseneau, D.H. Thomson, and C.R. Greene, Jr. *Analysis and Ranking of the Acoustic Disturbance Potential of Petroleum Industry Activities and Other Sources of Noise in the Environment of Marine Mammals in Alaska.* Anchorage, Alaska: Minerals Management Service, 1989.

Mann, D.A., D.M. Higgs, W.V. Tavolga, M.J. Souza, and A.N. Popper. Ultrasound detection by clupeiform fishes. *Journal of the Acoustical Society of America* 109 (2001): 3048-3054.

McDonald, M.A., J.A. Hildebrand, and S.M. Wiggins. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. *Journal of the Acoustical Society of America* 120 (2006):711-718.

Milne, A.R., and J.H. Ganton. Ambient noise under Arctic-Sea ice. *Journal of the Acoustical Society of America* 36 (1964): 855-863.

Moore, S.E., K.M. Stafford, D.K. Mellinger, and J.A. Hildebrand. Listening for large whales in the offshore waters of Alaska. *Bioscience* 56 (2006): 49-55.

National Research Council of the U.S. National Academies (NRC). Ocean Noise and Marine Mammals (National Academy Press, Washington, District of Columbia), 192 pp, 2003.

National Research Council of the U.S. National Academies (NRC). Marine Mammal Populations and Ocean Noise: Determining When Ocean Noise Causes Biologically Significant Effects (National Academy Press, Washington, District of Columbia), 126 pp, 2005.

Nowacek, D. P., L. H. Thorne, D. W. Johnston, D. W., and P. L. Tyack. Responses of cetaceans to anthropogenic noise. Mammalian Review 37 (2007), 81-115.

Parks, SE., C.W. Clark, and P.L. Tyack. Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. *Journal of the Acoustical Society of America* 122 (2007): 3725-3731.

Payne, R.S., and D. Webb. Orientation by means of long range acoustic signaling in baleen whales. *Annals of the New York Academy of Sciences* 188 (1971):110–141.

Popper, A.N. and P.L. Edds-Walton. Bioacoustics of marine vertebrates. In Encyclopedia of Acoustics, Vol. IV (M. J. Crocker, ed.), Wiley-Interscience, New York, Pp. 1831-1836, 1997.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. *Marine Mammals and Noise.* New York: Academic Press, 1995a.

Richardson, W.J., C.R. Greene, Jr., J.S. Hanna, W.R. Koski, G.W. Miller, N.J. Patenaude, and M.A. Smultea. *Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska-1991 and 1994 phases: Sound propagation and whale responses to playbacks of icebreaker noise.* Herdon, Virginia: Minerals Management Service, 1995b.

Ross, D. *Mechanics of Underwater Noise.* Los Altos, California: Peninsula Publishing, 1987.

Ross, D. On ocean underwater ambient noise. *Acoustics Bulletin* 18 (1993): 5-8.

Sarà, G., J.M. Dean, D. D'Amato, G. Buscaino, A. Oliveri, G. Genovese, S. Ferro, G. Buffa, M.L. Martire, and S. Mazzola. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. *Marine Ecology Progress Series* 331 (2007): 243-253.

SCAR (Scientific Committee on Antarctic Research). *SCAR report on marine acoustic technology and the Southern Ocean.* Antarctic Treaty Consultative Meeting, Edinburgh, Scotland, 2006a.

SCAR (Scientific Committee on Antarctic Research). *Marine acoustic systems used by National Antarctic Program vessels.* Antarctic Treaty Consultative Meeting, Edinburgh, Scotland, 2006b.

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. Indication of a Lombard vocal response in the St. Lawrence River beluga. *Journal of the Acoustical Society of America* 117 (2005): 1486-1492.

Scholik, A.R., and H.Y. Yan. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* (2001): 203-209.

Schusterman, R. J., D. Kastak, D. H. Levenson, C. J. Reichmuth, and B. L. Southall. Why pinnipeds don't echolocate. Journal of the Acoustical Society of America 107 (2000), 2256-2264.

Schusterman, R. J. Behavioral capabilities of seals and sea lions: A review of their hearing, visual, learning, and diving skills. Psychological Record 31 (1981), 125-143.

Simard, Y., N. Roy, and C. Gervais. Passive acoustic detection and localization of whales: Effects of shipping noise in Saguenay–St. Lawrence Marine Park. *Journal of the Acoustical Society of America* 123 (2008): 4109-4117.

Soto, N.A., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*). *Marine Mammal Science* 22(2006): 690-699.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals* 33(2007): 411-521.

Stirling, I., W. Calvert, and H. Cleator. Underwater vocalizations as a tool for studying the distribution and relative abundance of wintering pinnipeds in the high Arctic. *Arctic* (1983): 262-274.

Stockin, K.A., D. Lusseau, V. Binedell, N. Wiseman, and M.B. Orams. Tourism affects the behavioural budget of the common dolphin *Delphinus* sp. in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series* 355 (2007): 287-295.

Tyack, P.L. Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy* 89 (2008): 549-558.

Tyack, P.L. Acoustic communication under the sea. In S. L. Hopp, M. J. Owren, & C. S. Evans (Eds.), *Animal acoustic communication* (pp. 163-220). Berlin: Springer-Verlag, 1998..

USARC (United States Arctic Research Commission). *The Arctic Ocean and Climate Change: A Scenario for the US Navy*. Arlington, Virginia: United States Arctic Research Commission, 2001.

Uscinski, B.J., and P. Wadhams. Ice-ocean acoustic energy transfer: ambient noise in the ice-edge region. *Deep-Sea Research II* 46 (1999): 1319-1333.

Vasconcelos, R.O., M.C.P. Amorim, and F. Ladich. Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. *Journal of Experimental Biology* 210 (2007): 2104-2112.

Wartzok, D., Popper, A. N., Gordon, J., & Merrill, J. Factors affecting the responses of marine mammals to acoustic disturbance. *Marine Technology Society Journal*, 37 (2004), 6-15.

Wartzok, D. & Ketten, D. R. Marine mammal sensory systems. In J. E. Reynolds II & S. A. Rommel (Eds.), *Biology of marine mammals* (pp. 117-175). Washington D.C.: Smithsonian Institute Press, 1999.

Watkins, W.A. Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science* 2 (1986): 251-262.

Wysocki, L.E., J.P. Dittami, and F. Ladich. Ship noise and cortisol secretion in European freshwater fishes. *Biological Conservation* 128 (2006): 501-508.

Literature Cited-Greg Silber

Angliss, R.P., and R.B. Outlaw. 2005. Bowhead whale (*Balaena mysticetus*): Western Arctic stock. Alaska Stock Assessment Report. NOAA-TM-AFSC-180.

Best, P.B., J.L. Bannister, R.L. Brownell, Jr., and G.P. Donovan. Eds. 2001. Right whales: worldwide status. Journal of Cetacean Research and Management. (Special Issue) 2. 309 pages.

Bettridge, S. and G.K. Silber. 2008. Update on the United States' Actions to Reduce the Threat of Ship Collisions with Large Whales. Prepared for the International Whaling Commission's Working Group on Ship Strikes and Presented at the International Whaling Commission's Conservation Committee, Santiago, Chile, June 16, 2008.

Calleson, C.S. and R. K. Frolich. 2007. Slower boat speeds reduce risks to manatees. Endangered Species Research 3(3):295-304. 2007.

Campbell-Malone, R., 2007. Biomechanics of North Atlantic right whale bone: mandibular fracture as a fatal endpoint for blunt vessel-whale collision modeling. Ph.D. dissertation, Woods Hole Oceanographic Institution, Woods Hole, MA.

Greenland, J.A., and C. J. Limpus. 2006. Marine wildlife stranding and mortality database. II. Cetacean and pinniped. The State of Queensland. Environmental Protection Agency, Freshwater and Marine Sciences Unit, Environmental Sciences Division Conservation technical and data report. Volume 2005. Number 2.

Elvin, S.S., and C.T. Taggart. 2008. Right whales and vessels in Canadian waters. Marine Policy 32:379-386.

Hazel J., I.R. Lawler, H. Marsh and S. Robson. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. Endangered Species Research 3:105-113.

Jensen, A.S., and G.K. Silber. 2003. Large whale ship strike database. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/OPR 25, 37 p.

Kite-Powell, H.K., A. Knowlton, and M. Brown. 2007. Modeling the effect of vessel speed on right whale ship strike risk. Project report for NOAA/NMFS Project NA04NMF47202394, April 2007.

Knowlton, A.R., and S.D. Kraus. 2001. Mortality and serious injury of northern right whales (Eubalaena glacialis) in the western North Atlantic Ocean. Journal of Cetacean Research and Management (Special Issue) 2: 193 208.

Laist, D.W., A.R. Knowlton, J.G. Mead, A.S. Collet, and M. Podesta. 2001. Collisions between ships and whales. Mar. Mamm. Sci. 17(1): 35-75.

National Park Service. 2003. Glacier Bay National Park and Preserve, Alaska. Vessel Quotas and Operating Requirements. Final Environmental Impact Statement. U.S. Department of Interior.

Pace, R.M., and G.K. Silber. 2005 Abstract. Simple analyses of ship and large whale collisions: Does speed kill? Sixteenth Biennial Conference on the Biology of Marine Mammals, San Diego, December 2005.

Panigada, S., G. Pesante, M. Zanardelli, F. Capoulade, A. Gannier, and M.T. Weinrich. 2006. Mediterranean fin whales at risk from fatal ship strikes. Marine Pollution Bulletin. 52:1287-1298.

Philo, L.M., E.B. Shotts, and J.C. George. 1993. Morbidity and mortality. *In*: The Bowhead Whale. Burns, J.J., J.J. Montague, and C.J. Cole (*eds*.). Society of Marine Mammalogy Special Publication No. 21. Pp. 275-312.

Slutsky, J. 2007. Model scale simulation of a ship-whale encounter. Naval Surface Warfare Center Carderock Division, West Bethesda, MD. Report No. NSWCCD-50-TR-2007/053.

U.S. Fish and Wildlife Service. 2001. Florida manatee recovery plan (Trichechus manatus latirostris), Third revision. U.S. Fish and Wildlife Service, Atlanta, GA.

Van Waerebeek, K., and R. Leaper. 2008. Second Report of the IWC Vessel Strike Data Standardisation Working Group. Report to the International Whaling Commission's

Vanderlaan, A.S.M., and C.T. Taggart. 2007. Vessel Collisions with whales: the probability of lethal injury based on vessel speed. Marine Mammal Science. 23(1):144-156.

Section 2.5

Not yet complete

Section 2.6

BALLAST WATER

Arctic Flora and Fauna: Status and Conservation. (2001) Arctic Council's working group for the Conservation of Arctic Flora and Fauna

Chircop, A., (2007) Climate Change and the Prospects of Increased Navigation in the Canadian Arctic. WMU Journal of Maritime Affairs, October 2007, Vol 6, No 2 p 193-205

Corbyn, Z (2007) Atlantic Invaders Nature Reports, Volume 6, November 2007

Cruise Ship Traffic a threat to Arctic Waters, U.S. Expert Warns CBC News Friday July 25, 2008

Desgagnes Transarctik Inc, Taqrumut Transport, Nunavut Sealink and Supply Inc, (2008) Sealift Cargo Delivery Schedule (Revised June 18, 2008

D.M. McRae (1986) Management of Arctic Marine Transportation: A Canadian Perspective Arctic Vol 39 #4 p 350-359

Huebert, R., (2007) Arctic Shipping and the Arctic: Climate Impact Assessment Report Commissioned by the Arctic Council – Impacts of a Warming Arctic http://www.amap.no/acia/index.html

In Dead Water, Report , United National Environmental Program 2008-09-03

Jensen,O., (2008) Arctic Shipping Guidelines: Towards a Legal Regime for Navigation Safety and Environmental Protection

McGee, S., Piorkowski, R., and Ruiz, G., (2006) Analysis of recent vessel arrivals and ballast water discharge in Alaska: Toward assessing a ship mediated invasion risk. Marine Pollution Bulletin Volume 52,Issue 12 P 1634-1645

Niimi, Arthur (2004) Environmental and Economic Factors Can Increase the Risk of Exotic Species Introductions to the Arctic Region Through Increased Ballast Water Discharge. Environmental Management, Volume 33 Number 5 p 712-718

Niimi, A., (2007) Current and Future Prospects for Vessel Related Introductions of Exotic Species to the Arctic Region Can. Tech. Rep>Fish.Aquat.Sci 2720: 86p

Northern Transportation Company Ltd (2008) Sailing Schedule for Mackenzie River , Western Arctic / Eastern Arctic www.ntcl.com

Pimental, D., Lach, L., Zuniga, R., Morrison, D 2000 Environmental and economic costs of non indigenous species in the United States. BioScience 50: 53-64

Raaymakers, S., (2007) Possible effects of Climate Change on the Spread of Invasive Marine Species and Implications for Maritime Industries WMU Journal of Maritime Affairs October 2007, Vol6 No 2 p 235-240

Roberts, J., (2007) Proactive Environmental Planning for Emerging Shipping Routes in Arctic Waters. WMU Journal of Maritime Affairs, October 2007, Vol6 No 2 p 207-215

Tavares, M., and Gustavo, (2004) Southern Ocean: the North Atlantic Spider Crab found in the Antarctic Peninsula Antarctic Science 2004, 16. p 129-131

The Challenge of Arctic Shipping Science, Environmental Assessment and Human Values David L. Vanderzwaag and Cynthia Lawson McGill- Queens Press 1990

Watson-Wright, W, (2008) Climate Change and Risk Assessment – Implication for the Maritime Industries: Bridging the Science-Policy Gap Address to the International Conference on the impacts of Climate Change on the Maritime Industry 2-4 June 2008 World Maritime University

Wilkman, G., Arpiainen, M.,, et al (2008) Icebreaking Ore Carrier Project for Baffinland Iron Mines Corporation Paper presented at ICETECH Calgary 2008

Wookey, P., (2007) Climate Change and Biodiversity in the Arctic – Nordic Perspectives. Polar Research Volume 26 p 96-103

HULL FOULING

Anderson, C., Callow, M., Milne, A. 2003 The Development of Foul release coatings for seagoing vessels. Journal of Marine Design and Operations. B4:11-23

Apte, S., Holland, B.S., Godwin, L.S., Garner, J.P. 2000 Jumping Ship: a stepping stone event mediating transfer of nonindigenous species via potentially unsuitable environment. Biological Invasions 2:75-79

Bohlandeer, G.S and Presier, H.S. (1984) New Technology antifouling paints: U.S. Government research and assessment. NavEngJ. 96 125-131

Coutts, ADM., Moore K.M., Hewitt, C.I. (2003) Ships' sea chests: an overlooked transfer mechanism for non-indigenous marine species? Marine Pollution Bulletin 46:1504-1515

Cooutts, A.D.M., Dodgshun, T.J. 2007 The nature and extent of organisms in vessel sea chests: A protected mechanism for marine bioinvasions. Marine Pollution Bulletin 54: 875-886

Daffron, K.A., Glasby, T.M. and Johnston, E.L. (2008) Differential effects of tributylylin and copper antifoulants on recruitment on non indigenous species. Biofouling 24, 23-33

Drake, J.M, Lodge, D.M. 2007 Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. Aquatic Invasions 2: 121-131

IMO 1999 Antifouling systems on ships. International Maritime Organization Resolution A.895(21)

IMO 2001 International Convention on the Control of Harmful Anti-Fouling Systems on Ships

Lewis, P.N., Riddle,M.J. and Hewitt, C.L.(2004) Management of exogenous threats to Antarctic and the sub Antarctic islands: balancing risks from TBT and non indigenous marine organisms. Marine Pollution Bulletin 49, 999-1005

Savarese, J., (2005) Preventing and Managing Hull Fouling: International, Federal and State Laws and Policies Proceedings of the 14th Biennial Coastal Zone Conference New Orleans June 17-21 2005.

Takata, L., Flakner, M., Gilmore, S. 2006 Commercial vessel fouling in California: Analysis, evaluation and recommendations to reduce non indigenous species release from the non ballast water vector. Report to the California State Legislature. Marine Facilities Division, California State Lands Commission 83p

CARGO

Canada Shipping Act 2001 Cargo, Fumigation and Tackle Regulations SOR / 2007 – 128

Bond, E.J., (2004) Manual of Fumigation for Insect Control. Food and Agricultural Organization of the United Nations. FAO Plant Production and Protection Paper #54

CASUALTIES / SHIPWRECKS

Baychimo: Arctic Ghost Ship, Anthony Dalton BC Books 2006

Barr, W., and Wilson, E., (1985) The Shipping Crisis in the Soviet Eastern Region Arctic at the Close of the 1983 Navigation Season Arctic Vol 38 #1 P 1-17

Canadian Coast Guard, Ice Navigation in Canadian Waters, 1992 Report TP5064E

CNIIMF, FTL, Ice Damages to Propulsion Machinery on Russian Ice- Strengthened Cargo Vessels, FTL report 4436A, March 1995

Cowper, B., Malik,L Paterson, B., Investigation of Ice Damages and Material Properties for Ice-Class Propeller Blades, March 1994 FTL Report # 3695C-7.FR Presented to Coast Guard Northern

Cowper, B., Paterson, R., Examination of "Type" Ship Machinery Requirements for the Arctic Pollution Prevention Regulations (ASPPR) March 1995 Transport Canada Publication TP 12577

DF Dickins Associates Ltd (1992) Arctic Tanker Risk Analysis Project – Casualty Potential and Risk Profile Report prepared for CanArctic Shipping Company Ltd.

Prince of Wales, Northern Heritage Centre Yelowknife NWT. Archaeology Reports 1995, Cambridge Bay, Baymaud

Sharp, D., (2006) Ice Tanker Operations : Ship Operators Perspective Hamburg SMM – presentation by Unicom Management Services (Cyprus) Ltd.

Steam Whaling in the Western Arctic, John R. Bockstoce, Old Dartmouth Historical Society

Tunik, L. (Ed) 1994 1194 Northern Sea Route Directory of Icebreaking Ships, Backbone Publishing Company, New York 1994

Wells, D., Keinonen, A., Revill, C., Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992, January 1994 Presented to Coast Guard Northern

Whales, Ice and Men: History of Whaling in the Western Arctic , John R Bockstoce , University of Washington Press, 1986

Section 3.1

Not yet complete

Section 3.2

References (work in progress-list not yet complete)

(Prinsenberg 1986c).

(Prinsenberg 1986b).

(Roff and Legendre 1986).

(CAFF 2001).

Stirling et al. 1981).

(Brown and Nettleship 1981).

(Teilmann and Dietz 1998).

(Lunn *et al*. 2002).

(Sergeant 1974, Bowen *et al*. 1987).

(Lyngs 2003, Boertmann *et al*. 2004)

(Kingsley et al. 1985)

(deMarch et al. 2002)

(Gaston 2002).

(Macdonald et al. 2003).

(Wade and Perryman 2002).

(Frost et al. 2004).

(Divoky, Hatch, and Haney, 1988).

Boertmann, D., A. Mosbech, K. Falk and K. Kampp. 1996. Seabird colonies in western Greenland. National Environmental Research Institute (NERI) Technical Report Number 170. NERI, Denmark.

Boertmann D, Mosbech A (1998) Distribution of little auk (Alle alle) breeding colonies in Thule District, Northwest Greenland. Polar Biol 19:206–210

Egevang, C., D. Boertmann,A. Mosbech and M. P. Tamstorf. 2003. Estimating colony area and population size of little auks Alle alle at Northumberland Island using aerial images. Polar Biol 26: 8–13

Section 3.3

NPFMC (North Pacific Fishery Management Council). 2007. Aleutian Islands Fishery Ecosystem Plan. Anchorage, Alaska. 22 p. summary + DVD.

NMFS (National Marine Fisheries Service). 2005. Fisheries of the United States. Current Fishery Statistics No. 2004. U.S. Dept. of Commerce, Washington, D.C. 108 p.

NMFS. 2003. Alaska Groundfish Fisheries Programmatic Supplemental Environmental Impact Statement. U.S. Dept. of Commerce, NMFS, Juneau, AK. 9 Vols.

NPFMC and NMFS. 2005. Stock Assessment and Fishery Evaluation Report for the Groundfish Fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area: Economic Status of the Groundfish Fisheries off Alaska, 2004. NPFMC, Anchorage, AK and NMFS, Seattle, WA. 182 p.

Nuka Research and Planning Group and Cape International. 2005. Vessel traffic in the Aleutians subarea. Report for Alaska Department of Environmental Conservation. 51 p.

Ebbert, S.M., A.L. Sowls, and G.V. Byrd. 2007. Alaska's rat spill response program. Pages 332-337 in Managing Vertebrate Invasive Species: Proceedings of an International Symposium. USDA, National Wildlife Research Center, Fort Collins, CO.

NRC (National Research Council). 2008. Risk of vessel accidents and spills in the Aleutian Islands. Designing a comprehensive risk assessment. National Academy of Sciences, Transportation Research Board, Washington, D.C. Advance Copy. 185 p.

Section 3.4

ACIA (Arctic Climate Impact Assessment). 2004. Arctic Climate Impact Assessment. Cambridge University Press. 1042 p.

Ebbert, S.M., A.L. Sowls, and G.V. Byrd. 2007. Alaska's rat spill response program. Pages 332-337 in Managing Vertebrate Invasive Species: Proceedings of an International Symposium. USDA, National Wildlife Research Center, Fort Collins, CO.

Institute of the North, U.S. Arctic Research Commission, and International Arctic Science Committee. 2004. Arctic Marine Transport Workshop, 28-30 September, Scott Polar Research Institute, Cambridge University. L. Brigham and B. Ellis, Eds. Anchorage, Alaska. 18 p. + Appendices.

NPFMC (North Pacific Fishery Management Council). 2007. Aleutian Islands Fishery Ecosystem Plan. Anchorage, Alaska. 22 p. summary + DVD.

NRC (National Research Council). 2008. Risk of vessel accidents and spills in the Aleutian Islands. Designing a comprehensive risk assessment. National Academy of Sciences, Transportation Research Board, Washington, D.C. Advance Copy. 185 p.

O'Rourke, R. 2008. Coast Guard polar icebreaker modernization: background, issues, and options for Congress. Congressional Research Service Report for

Congress, Order Code RL34391. 52 p.

Piatt, J.F., J. Wetzel, K. Bell, A.R. DeGange, G.R. Balogh, G.S. Drew, T. Geernaert, C. Ladd, and G.V. Byrd. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross (Phoebastria albutrus) in the North Pacific: Implications for conservation. Deep Sea Research II (53):387-398.

Section 4

Not yet complete