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The Arctic sea routes: marine environmental impacts on effect of the climate change and opening of the passages for international shipping traffic

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The Arctic Sea Routes: Marine environmental impacts on effect of the climate change and opening of the passages for international shipping traffic

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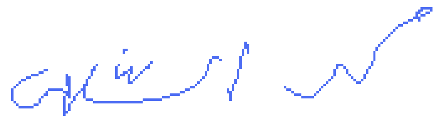
DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for, which a degree has previously been conferred on me. The contents of this dissertation reflect my own personal views, and are not necessarily those of the University.



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Abstract

Title of Dissertation: **The Arctic Sea Routes: Marine environmental impacts on effect of the climate change and opening of the passages for international shipping traffic**

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The Arctic Sea Route (ASR) can potentially halve the distance between the Far East and Europe. Although, the route was declared formally open for international shipping by *Gorbachev* in 1987. It was not used commercially, except by domestic Russian shipping companies. However, due to climate change and dramatic ice melting, there is an opportunity for the route to be used, at least in summer seasons, without ice breakers escort in the coming few years. Accordingly, both the shipping industry and the environment will be influenced by the use of these routes.

In fact, there are two main routes that could be used within the Arctic area: the Northern Sea Route (NSR) over top of Russia and the Northwest passages above Canada, that connect Europe and North America with the Far East.

The NSR is the first to be affected by the climate change; as a consequences, ships' traffic is expected to increase as both NW European countries and Far Eastern countries are expected to benefit from using these routes for the distance saving. Moreover, the Arctic region is an important destination due to its rich in natural resources. Consequently, due to the anticipated transit and the trade boom there will be some environmental consequences, as there will be a need for the ships transiting theses routes to dispose of oil sludge, garbage, sewage, and to manage its ballast, *inter alia*.

In fact, the Arctic is a pristine natural environment, where wilderness and beauty is unique in that it is largely untouched by human beings. Actually, unlike Antarctica, the ASRs are not well covered by international pollution prevention instruments, or even considered Special Area (SA) under the MARPOL convention. Therefore, there is a need to organize an international regime to regulate the marine environmental protection in the Arctic.

In this paper, the major threats to the natural environment of the Arctic, resulting from the main pollutants, and the feasibility of applying pollution combating techniques in such an environment will be researched. The threats to the environment are primarily due to accidental pollution and operational pollution. However, radioactive waste and other problems will also be discussed. Consequently, the industry should take the necessary steps to adopt and implement a new international environmental instrument in the ASR.

As a marine environmental researcher and an ex-seafarer, I believe that it is rational and necessary to take proactive measures now, in order to set up an international instrument to regulate environmental protection in the ASR.

Key words:

Climate change, Arctic Sea Routes, hazards in ice-infested waters, environmental protection, operational and accidental pollution, pollution combating techniques.

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List of Abbreviations

AFS	Anti Fouling Systems
AIS	Automatic Vessel Identification System.
API	American Petroleum Institute Standard
ASR	Arctic Sea Route
ATBA	Areas To Be Avoided
ATCM	Antarctic Treaty Consultative Meeting
AZIPOD	Azimuthing Podded Propulsion.
BW	Ballast Water
BWMC	International Convention on the Ballast Water Management
CG	Contracting Government
DAFF	Department of Agriculture - Fisheries and Forestry
DAS	Double Acting Ships
dwt	Dead Weight Tonnage
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
EVOS	*Exxon Valdez* oil spill
GBRMP	Great Barrier Reef Marine Park
GLPANS	The Great Lakes Panel on Aquatic Nuisance Species
IAP	International Arctic Program
IAS	Invasive Aquatic Species
IMO	International Maritime Organization
INSROP	International Northern Sea Route Program
LNG	Liquefied Natural Gas
MARPOL	The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the 1978 Protocol relating thereto (MARPOL 73/78), as amended. (1995, 1998, 2000)
MEPC	Marine Environment Protection Committee
MPA	Marine Protected Area
NAC	Norwegian Atlantic Committee
NSR	Arctic Northern Sea Route or the North East Passage.
NLS	Noxious Liquid Substances
SOx & NOx	Sulphur and Nitrogen Oxide
NWP	North West Passage

OILPOL	Oil Pollution 1954 convention
OPRC 1990	The International Convention on Oil Pollution Preparedness, Response and Co-Operation, 1990
PAME	Protection of the Arctic Marine Environment
Pollutant	The substances defined as oil, oily mixture and oil fuel in Annex I; noxious liquid substances in Annex II; and solids when carried in bulk, which are also identified as harmful substances in Annex III of the MARPOL Convention.
PPM	Part Per Million
PSSA	Particularly Sensitive Sea Area
SA	Special Area
SECA	Sulphur Emission Control Areass
SOLAS	The International Convention for the Safety of Life at Sea, 1974, as amended.
STCW	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978/1995, as amended.
TBT	Organotin tributyltin
TTS	Traffic Separation Scheme
UN	United Nations
UNCLOS	United Nation Convention on the Law of the Sea
USA	United States of America
USARC	United States Arctic Research Commission
VTS	Vessel Traffic Service
WMO	The World Meteorological Organization.
WMU	World Maritime University
WPO	World Intellectual Property Organization
WWF	World Widelife Fund

Chapter One

Introduction and vulnerability of the significant Arctic region

1. Chapter One: Introduction and vulnerability of the significant Arctic region

1.1. Introduction and objective of the study

Hidden on the top of the Earth, far away from noise and crowds lies a pristine area, where wilderness and beauty is unique in that it is largely untouched by human beings, which has been referred to as the future Mediterranean . The Arctic is commonly defined as the area north of the Arctic Circle of latitude 66°32'N and above that includes the area of the midnight sun. The Arctic sea area is one of the most affected areas of climate change; it is warming up significantly nowadays. Melting of the sea ice there has awakened the dream of using the Arctic Sea Routes (ASR) in shipping as they may significantly reduce the trip distance between East and West. Accordingly, there will be consequences of the increased shipping traffic in the area. Unlike most of the shipping routes including the Antarctic, the Arctic Sea is surprisingly poorly covered by international environmental instruments (Kitagawa, 2001).

In particular, the Arctic Ocean is not recognised as even a SA under any Annex of the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL), or a Particularly Sensitive Sea Area (PSSA), as shown in the Appendices IV and V. Unlike Antarctic, the Arctic has no treaties to regulate the different environmental concerns (Kleverlaan, 2008; Stares, 2008). Therefore, with the anticipated ship traffic boom, there will be significant environmental consequences as there are no rules to prevent ships from disposing their different types of waste into the sea, except the Article 234[1] of the United Nations Convention on the Law of the Sea (UNCLOS) with regard to any ice-covered waters, and different national laws of the coastal states that may differ from a country to country that perhaps based on MARPOL. Accordingly, there is a need

[1] *''Ice-covered areas Coastal States have the right to adopt and enforce nondiscriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas within the limits of the exclusive economic zone, where particularly severe climatic conditions and the presence of ice covering such areas for most of the year create obstructions or exceptional hazards to navigation, and pollution of the marine environment could cause major harm to or irreversible disturbance of the ecological balance. Such laws and regulations shall have due regard to navigation and the protection and preservation of the marine environment based on the best available scientific evidence''*(UN, 1982, p. 113).

to organize better unified international rules to regulate environmental protection in the Arctic[2].

Consequently, this study targets to emphasize the following:

- Identify the effect of the climate change on the Arctic routes in the coming decades.
- Show the related consequences on international shipping.
- Illustrate the vulnerability of the Arctic environment due to increased ships' traffic with regard to the operational and accidental pollution.
- Describe and discuss the lack of international instruments to regulate environmental protection of these routes.
- Discuss the feasibility of the oil combating techniques in ice-infested waters.
- Make proposals and recommendations for an international regime to monitor and regulate protection of the environment for this area.

1.2. Research methodology

The climate change and its effect on the maritime industry is a significant and motivating topic to read about. Particularly, the effect on the ASR inspired the author to find out more about related issues, I was surprised that the Arctic is not included under international maritime pollution prevention conventions such as MARPOL. Communication has been done with a maritime technical officer of the marine environment division in the International Maritime Organization (IMO), *inter alia*, as there was no clear explanation for this issue in the literatures.

A considerable number of articles, case studies, and reports, and even interviews with experienced members of the maritime industry were conducted. As the research topic is current and numerous related topics are still being reviewed and assessed, the research and collection of data focused mainly on recent technical papers and specialised conferences. A qualitative research approach was mainly followed, but a quantitative one

[2] In fact, most of the ships operating in the Northern Sea Route (NSR) were built after the MARPOL convention entry into force; only few ships were constructed before the convention date that have been modified to satisfy this treaty, and the Russian environmental regulations. Particularly, some other pollution causes such as the engine waste and exhaust, oily water, sewage, and garbage, *inter alia*, need to be discussed further (Kitagawa, 2001).

was conducted for some purposes such as, comparing distances between NW Europe and the Far East using both the traditional and NSR routes in Chapter Two.

The aim of the research was to find out whether the opening of the ASR for international shipping transit would open the environment for vulnerabilities, and if so is it possible to mitigate the impact on this unique Arctic environment? Consequently, it was also necessary to figure out how fragile the ASR environment is and whether it is able to withstand the pollution brought on by increased shipping traffic in the area. Hydrocarbons or oil in particular, one of the main sea pollutants was examined in order to determine the feasibility of the available pollution combating technologies in ice-infested waters. Finally, the author will try to provide some recommendations to mitigate the environmental vulnerabilities in the ASR[3].

1.2.1. Difficulties met during research

Some of the difficulties were to find suitable articles related to such a specific topic, which consumed quite a lot of time. Then it was found that some important data did not include dates, which reduced the credibility of the source, in the author's opinion. Therefore, more time was needed to find the available other supporting evidences.

Moreover, this current research topic was not very well supported in the literature, hence books and previous research in the World Maritime University (WMU) library or Malmo Library were extremely difficult to find. Therefore, it was seen to depend mostly on the World Wide Web in finding research papers, conferences proceedings and seminars that had been held recently, in addition to the WMU electronic library. Furthermore, a couple of visits to Alexandria and the Arab Academy libraries were also beneficial to some extent.

Furthermore, the greatest faced difficulty was to cover the research topic within the limited word count and page numbers allowed in the WMU guidelines on writing

[3] ('') is used for quotations and (``) is used for the author own comments.

dissertations. The research topic is relatively new and worth to be covered precisely, otherwise, it might be seen as there are gaps in covering the different related subjects. Therefore, the author tried his best to keep within the limits, to give the best overview and not a vague idea.

1.3. Background on the Arctic Sea Routes (ASR)

1.3.1. Physiography and description of the Arctic Ocean

The Arctic Ocean consists of a deep ocean basin, submarine ridges, continental shelves and marginal plateaus. It contains five main seas; the Barents, Kara, Laptev, East Siberians and Chukchi Seas that are located on the broad European and Siberian continental shelves. The 14 million square kilometers Arctic Ocean is surrounded by the continents of Eurasia, North America and Greenland, as shown in Figure 1-1. The Arctic Ocean is open to the Atlantic through the Sea of Norway and the Sea of Greenland, while it is linked to the Pacific Ocean via the narrow 80 km gap of the Bering Strait. The passage between the Danish province Greenland[4] and Ellesmere Island in Canada is roughly 20 km wide and 500 m. deep. The Scandinavian Peninsula is separated from Greenland by a 1400 km distance. The shallow Baring strait is only 60 m. deep at the deepest point. Yet, not all the Arctic Ocean is 4000 m. deep at its center with the deepest point reaching 5440 m. Approximately 70% of the Arctic Ocean is over 1000 m. deep and the remaining 30% is a broad continental shelf (Kitagawa, 2001). Theses distances and especially these depths will be considered when discussing the ballast water management in Chapter Three.

[4] ‘’***Greenland*** *(Kalaallisut: Kalaallit Nunaat, meaning "Land of the Greenlanders"; Danish: Grønland) is a self-governing Danish province located between the Arctic and Atlantic Oceans, east of the Canadian Arctic Archipelago. Though physiographically and ethnically an Arctic island nation and geographically a part of the continent of North America, politically and historically Greenland is associated with Europe, specifically Iceland, Norway, and Denmark. In 1978, Denmark granted home rule to Greenland, making it an equal member of the Rigsfællesskab. Greenland is, by area, the world's largest island which is not a continent in its own right*’’ (Wikipedia, 2008).

Figure 1-1: Arctic Ocean and Coastal Areas.
Source: (Arctic Council, 2004 as retrieved from Institute Geographic National francais, (2004))

The maximum annual air temperature in the Arctic is 8ºC in summer when the Arctic receives sun light for 24 hrs, which happens only near the coast (Kitagawa, 2001). While, in the shelf areas the sun can warm the water up to 4°C to 5°C during the summer (Orheim, 2003). On the contrary, in January the coldest temperature is in the range of -44°C and, which happens mostly on the Siberian and Greenland coasts. Yet, the average temperature is usually between -32°C and -36°C (Kitagawa, 2001).

1.3.2. Historical Background

The ASRs are the shortest routes linking East Asia and Europe, and from ancient times, traces of movement of the indigenous people can be found throughout the Arctic. The existence of ice-covered waters in the far North was well known in the classical Greek and Roman literature in the 4th and 5th centuries (Kitagawa, 2001).

In the 7th and 8th centuries, European explorations of the Arctic began with voyages of Irish monks. In the 10th century the Vikings ruled a vast domain from the Caspian Sea to the Spanish coast, and may be considered the first to contribute to the opening of the NSR in particular. However, they did not leave written records to support this idea. In the 14th century, the Basques fishermen ventured further north searching for whales. They were the first to seek routes thorough the Arctic to China. Actually, there were plenty of failed trials in the 1550s that tried to cross the NSR (Kitagawa, 2001).

The first real successful crossing of the NSR was by Adolf Erik Nordenskjoed, who succeeded in navigating easterly to Yokohama along the entire North East passage in July 1879. Unfortunately, since that time a vast majority of commercial voyages have not been successful. For example, out of 87 intended trips between 1874 and 1901, only 60 reached their destination, 22 ships returned back to ports while 5 were shipwrecked (Kitagawa, 2001).

It followed that the first Arctic ice breaker, was the *Yarmek* of 9,000 Tons and 10,000 HP was built in a British port under Russian Admiral supervision in the early 1900s. The following 1930s were a period of rapid development in the NSR as the Soviet merchant

Pacific Fleet and the northern Naval fleet were formed and both based in the Kola Peninsula. In 1935, the first cargo ship to cross the NSR was supported by an ice breaker. However, on 1 October 1987 Russian Secretary General Gorbachev declared the NSR as open for international shipping, after long time of being considered to have high strategic and military values during WWII and the Cold War (Kitagawa, 2001).

1.3.2.1.Northwest Passage (NWP)

The NWP is a sea route through the Arctic Ocean, connecting the Atlantic and Pacific Oceans along the northern coast of North America via the waterways among the Canadian Arctic Archipelago. It includes five to seven different seaways through the Archipelago, including the McClure Strait, the Prince of Wales Strait, and Baffin Bay via the Davis Strait (Kitagawa, 2008a).

There are plenty of recorded trials of crossing the passage, such as, the super tanker *Manhattan*. The ship was refitted with an ice-breaker bow, and crossed the NWP under the escort of a Canadian Coast Guard ice-breaker in 1969; it was the first commercial vessel to test the Passage. It crossed from East to West through the Baffin Sea and Viscount Melville Sound. She then took the route via the Prince of Wales Strait and south of Banks Island. In Canada, there were arguments about the transit of oil and gas carriers, due to the risk of pollution and the consequences on the ecosystem, and hence, it was finally seen that the Trans-Alaska Pipeline was more feasible mean for transporting oil (Kitagawa, 2008a).

However, this idea of using the NWP as a commercial sea route is now being claimed that global climate change melts multi-year sea ice in the Arctic. Especially, since it was found that the NWP became more accessible to ships without ice-breaker assistance in August 2007. It followed that there were at least three successful crossings by ships in 2007. Despite this success, the Passage, in the sense of a commercial sea lane, would require significant investment in costly escort ice-breakers, ice-strengthened vessels, navigation supporting information systems and staging ports in order to satisfy current

IMO requirements. Accordingly, the route is not anticipated to become a competitive alternative to the Southern routes within the next decade, or even decades, as per the Canadian commercial marine transport industry (Kitagawa, 2008a).

1.3.2.2.The Northern Sea Route (NSR) or Northeast passage

The NSR, formerly known as the Northeast Passage, is a waterway linking the Atlantic Ocean with the Pacific Ocean, mostly along the Russian coast of Siberia. The route was formally opened for navigation in the early 1930s and its administration was set up in 1932, and since then it has supervised navigation and built Arctic ports. The opening of the NSR gradually took on a strategic military project complexity, and remained as a sea route mainly for Russian cabotage (Kitagawa, 2008a).

In 1987 the NSR reached its highest shipping volume of 6.58 million tons because of the development and trade in natural resources. However, since then NSR shipping declined steadily. Some of the reasons behind the 1987 boom, which include the increase in domestic shipping volume in the West, that was supported by the exploitation of oil and gas, along with copper, nickel and scarce metals in Norilsk. In addition, in the East, there were other non-ferrous metals, including gold shipped from Chukotka and Yakutia. Although, no regular shipping is found in the NSR nowadays, in the early 2000s, some could be found from Murmansk to Dudinka in the West and between Vladivostok and Pevek in the East. While, the reason behind the recent decline in shipping transit is mainly due to the dependence on only one nation that is Russia (Kitagawa, 2008a) and the navigation difficulties that may face even the ice-strengthened ships. That in the opinion of the author will not last long due to the climate change and the related anticipated boom in shipping traffic.

Ice-strengthened vessels and powerful ice-breakers are needed for promoting navigation in the Arctic. In fact, Russia has introduced powerful escorting ice-breakers, and adopted nuclear-powered ice-breakers, at least for pursuing Russian strategic military projects (Kitagawa, 2008a), that would be considered a root source of pollution in Chapter Three.

1.4. Vulnerability and significance of the Arctic area environment

In the opinion of the IMO 'ships operating in the Arctic environment are exposed to a number of unique risks' such as adverse weather conditions and relatively poor charts, communication systems and other navigational aids. In addition, rescue or pollution clean-up operations are difficult and costly due to their remoteness. Furthermore, the effectiveness of various equipment onboard ships, including deck machinery and emergency equipment and sea suctions may be reduced due to cold temperatures. Particularly, in the presence of ice, ships can impose additional stresses on their hull, in addition to the loads on the propulsion system and appendages (International Maritime Organization [IMO], 2002, p. 2). Yet, the Arctic Ocean itself may be vulnerable to shipping as it is a unique environment.

In fact, Arctic species are adapted to the harsh climate and some flora and fauna have residence for longer times in the Arctic that is counted in thousands of years, rather than many other temperate life-forms. Arctic biological systems are young, characterized by low species diversity and a relatively high number of endemic species that may be found nowhere else on the planet (Orheim, 2003).

Perhaps the Arctic organisms and ecosystems are not necessarily more vulnerable than those of other regions. However, cold climate, short growing seasons and the few species to undertake degradation are among other factors that increase the vulnerability of the environment in the Arctic. Consequently, slow down of the chemical and biological processes is resulted, and thereby the degradation of contaminants is reduced (Working Group on the Protection of the Arctic Marine Environment, 1996).

Furthermore, there are some examples of Arctic organism species that may be vulnerable to the climate change as well as pollution such as:

- Slow biological process leads to slow re-vegetation that may be already damaged or removed in these areas. For example, large impacts on tundra from heavy vehicles may be observed for decades. Furthermore, slow re-vegetation may render Arctic plants vulnerable to major, long term environmental shifts such as the introduction of new species that would be expected with ship's wrong ballast management. Moreover, degradation of spilled petroleum hydrocarbons may last for decades, that would be discussed in 1.4.2.

- Population and ecosystem dynamics: the typical Arctic species live long and produce only few young. Such populations are vulnerable to high mortality among adults. In case of high extensive mortality among adult, due to oil spill for example, the consequences can last long.
- The habitat and home range quality, especially mammals, need large undisturbed territories to meet their needs for food, breeding and shelter. Some shipping activities may affect animal movement patterns and disrupt their optimal use of the area.
- Many Arctic organisms store energy in the form of body fat when food is available to withstand a future food shortage. Environmental contaminants can be digested by these organisms and hence it may enter the food chain of polar bears, and seal, *inter alia*. Similarly, as the Arctic contains rich fishing grounds, contaminations would also reach the human food chain (Ostreng, 1999).

Accordingly, it was seen to study the main causes of marine pollution that would be seen in the NSR. Any marine environment may be subject to both types of pollution, the operational and accidental pollutions, which may carry significant consequences to such environment.

1.4.1. Continual and accidental pollutants impact overview

The impact of continual or operational in addition to accidental pollutions on the NSR will be discussed briefly in Chapter Three. The anticipated boom in shipping traffic may make the NSR extremely vulnerable to pollution threats such as, exhaust, sewage and garbage from the continual pollution sources. Perhaps a vast majority of ships operating in the NSR are already equipped with pollution prevention requirements to deal with threats. Yet, not all the requirements are implemented such as water pollution from daily activities such as cooking and showering, which is considered by the Arctic coastal states as a minor threat to the environment and hence are not included in the national regulations (Kitagawa, 2001). This might necessarily be included in the future. Perhaps it is necessary to require the newly transiting ships to comply with internationally applied requirements under new rules such as those that are already being applied in the SA of MARPOL. Table 1-1 shows how sever may be the quantities of oil discharge at sea compared to the other types of waste according to types, numbers, sizes of ships and number of crew. The Table excludes passenger ships, which are considered a major waste producer. This will be discussed further in Chapter Three.

Table 1-1: Estimated Ship Waste Volumes.

Type of ship	No. of ships	Dw 10^3 t	Size of crew	Ship waste volumes				
				Oily water			Sewage m^3/day	Garbage kg/day
				Water m^3/day	Oil kg/day	Oil discharge to sea kg/year		
Container carrier	3	5.7 20 20	35 41 41	1.5 4.0 4.0	30 80 80	40	3.4 4.1 4.1	30 40 40
Timber carrier	84	10 8 4	21 38 21	2.5 2.0 1.3	50 40 25	490	2.1 3.8 2.1	20 35 20
LASH	2	34	77	6.0	120	25	7.7	70
Dry cargo ship	27	20	41	4.0	80	480	4.1	40
Reefer	3	3 17	31 46	1.3 3.6	25 70	16	3.1 4.6	30 45
Tanker	20	6	36	1.9	40	57	3.6	35
Multipur-pose ship	46	5.0 10 20	31 57 57	1.5 2.5 4.0	30 50 80	290	3.1 5.7 5.7	30 55 55

Source: (Kitagawa, 2001 & Ostreng, 1999)

Then there is the problem of accidental pollution. Despite the navigational difficulty along the ASR, it has not seen major oil spill accidents from tankers. Only small scale spills occurred during bunkering, which did not exceed 100-200 liters. According to the IMO, the average annual frequency of accidents for ships of 6000 gross tonnage or more is 31% for collisions with ice or other ships, and 41% for groundings. Table 1-2 estimates the oil spill quantity in the NSR, as an example, assuming that an average of 1/48 of the carried oil quantity is spilled in each accident, which is based upon the probabilistic approach.

Table 1-2: Estimated Oil Spill Quantity in the NSR.

Arctic Region	Transported quantity per year (1,000 tons)	No. of Journeys per year	Risk 1000 journeys	No. of spill-accidents per year	Spill quantity/ year (tons)	Average spill quantity (tons)
Total of the NSR	392,401	**50**	**0.4**	0.02	**3.3**	163.5
West Region	166,893	**23**	0.25	0.006	**0.9**	151
East Region	225,508	**27**	0.25	0.007	**1.2**	174

Source: (Kitagawa, 2001 & Ostreng, 1999)

The above calculation does not include the extraordinary events that might occur during operation such as undetected cracks (Kitagawa, 2001). However, it is noted that with the ship traffic boom the frequency of accidents is expected to increase.

1.4.2. Long-term impacts of oil spills

Two oil spill examples prove how oil impacts may last for decades and both of them happened in USA. The 1989 *Exxon Valdez* oil spill (EVOS) in Prince William Sound, Alaska has persisted far beyond initial forecasts. In 2005, EVOS oil was found still toxic under beaches across the spill impact area; scientists predict that this subsurface oil may persist for more decades ahead (World Wide Fund for Nature [WWF], 2007).

However, after nearly 40 years, an oil spill from a grounded barge in Cape Cod, Massachusetts, lingering effects of the spilled oil have been documented. The oil residues out of the spilled 200,000 gallons are still damaging the health of the salt marsh and impacting the crabs and grass beds; the crabs have been observed to show signs of toxic impacts from the 4 decades old oil (Smith, 2007 & WWF, 2007). The spilled oil from *Exxon Valdez* was $10.9x10^6$ gallons or 258,000 barrels (Gentile & Harwell, 2005), which means 54.5 times the quantity of the 1969 spill that carries more severe consequences. The EVOS has left oil residues as shown in the photograph in Figure 1-2. The photo was taken in 2001, 12 years after the EVOS occurred, in an excavated hole on an impacted beach. The EVOS will be discussed further in Chapter Three.

Figure 1-2: The Presence of EVOS Oil in an Excavated Hole on an Impacted Beach 12 Years After the Spill.
Source: (WWF, 2007 as retrieved from Culbertson, et al., 2007)

The natural conditions in the NSR are completely different from those found elsewhere in the world. However, some similarities can be found in the Bay of Bothnia, Gulf of St-Lawrence and the Great Lakes. Furthermore, the Arctic is vitally important in terms of the Earth's environment. Any recent or anticipated activity in the Arctic including navigation, exploration and even fishing must presume a careful understanding of the nature of the Arctic. In fact, it may take several decades of monitoring to determine the effect of opening the NSR for international shipping traffic on the natural environment. Actually, the ecosystem of marine life in the Arctic Ocean is one of the most neglected areas regarding surveying and research. Because of its tough natural environment, surveying is extremely expensive, time-consuming and inefficient in these areas. Accordingly, vast stretches of ocean areas still await for observation and surveying

(Kitagawa, 2001). The implications of research done by the International Northern Sea Route Program (INSROP)[5] were enormous on some carefully selected species studied to the impact from shipping pollution sources such as, noise, air pollution and marine pollution. More long-term studies are needed, if NSR shipping was found to have a strong impact on Arctic ecosystems, at that time such shipping must be subject to numerous restrictions, or in some cases new restrictions would have to be added to existing ones; perhaps some other shipping activities would be prohibited entirely in the maximum extent (Kitagawa, 2001), which will be discussed in Chapter Five.

1.5. The lack of international maritime instruments regulating pollution from ships in the Arctic

Although, both the Arctic and the Antarctic Oceans are two sides of the same coin, equally unique in the geographical and geophysical sense, the Antarctic was fortunate enough to get international recognition by being incorporated as a SA under MARPOL. Furthermore, the Antarctic has a treaty, which came into force on 23 June 1961 that aims to:

- *demilitarize Antarctic, to establish it as a zone free of nuclear tests and the disposal of radioactive waste, and to ensure that it is used for peaceful purposes only*
- *promote international scientific cooperation in Antarctic;*
- *set aside disputes over territorial sovereignty.* ("The Antarctic Treaty - Background Information," 2007). On the contrary, the Arctic Ocean is not been considered a SA under any of the MARPOL convention Annexes, as mentioned in 1.1.

Even the Southern South Africa area has just been recognized as a SA under MARPOL since March 2008 ("IMO: Air pollution prevention tops MEPC agenda," 2006) while the Arctic region has not yet been taken into consideration.

Arctic shipping is not explicitly addressed in all of the conventions, except for very few general marine environment contexts in some conventions, which do not contain special

[5] A five-year inter-disciplinary and multi-national research programme on navigation conditions along the Northern Sea Route (NSR).

requirements concerning the Arctic. For example, UNCLOS, Article 234, gives coastal states the right to adopt and enforce laws and regulations for the prevention, reduction and control of marine pollution from ships in ice-covered areas within the limits of the Exclusive Economic Zone (EEZ). It is thought that the UNCLOS is enough to regulate its environment as it contains an Article about the ice-infested water (Stares, 2008). Yet, the Article does not contain any specific or special regulations limiting pollution from ships; it is only extending the limitations of the coastal state sovereignty in ice-infested waters with regard to environmental concerns. Figure 1-3 shows the EEZ of the Russian Federation as an example where it may enjoy the rights given in Article 234, and may explore the area for natural resources, which will be discussed in Chapter Two.

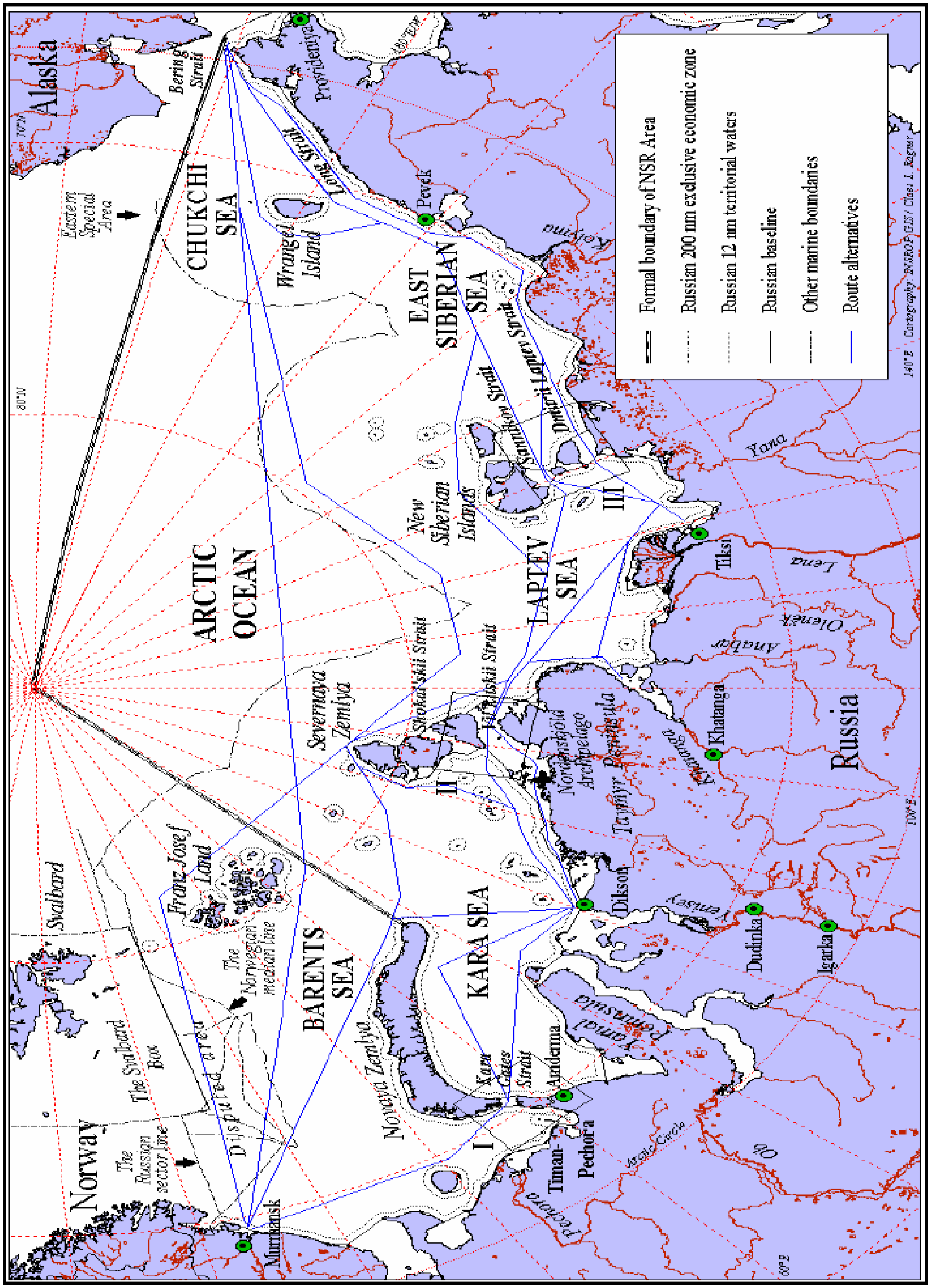

Figure 1-3: The NSR and the 200 Mile Economic Zone of the Russian Federation. Source: (Stepanov, Ørebech, & Brubaker, 2005)

Furthermore, in MARPOL there is no single special requirement for Arctic waters pollution prevention, such requirements have been adopted only for the Antarctic, where it is prohibited to discharge any oil or waste from ships under Annexes I and V. However, the Arctic countries have voluntary agreed to implement MARPOL's special area requirements for ships sailing in Arctic waters. Moreover, the International Convention on Oil Pollution Preparedness, Response and Co-Operation, 1990 (OPRC 1990) contains regulations concerning co-operation in responding to oil spills, but does not include the Arctic in any of its regulations. Finally, the International Convention for the Safety of Life at Sea, 1974 (SOLAS74) does not contain any special regulations for navigation in the Arctic. Only a part of Chapter V is related to navigation in ice-covered waters of the North Atlantic (Ostreng, 1999).

In Chapter Two, evidences prove that climate change is accelerating the possibility of opening the NSR for navigation at least in summer without ice-breakers assistance in the near future. In addition, a discussion will follow regarding related consequences for both the Arctic itself and the maritime industry.

Chapter Two

The anticipated use of the Arctic Sea Route in shipping and the consequences for both the shipping industry and the Arctic region

2. Chapter Two: The anticipated use of Arctic Sea Route in shipping and the consequences for both the shipping industry and the Arctic region

2.1. The impact of climate change on the Arctic region

There is plenty of proof that the Arctic Sea area is warming. The Arctic ice cap is decreasing in thickness and area. Ships and aircrafts operating in the Arctic have reported on the diminished summer ice coverage, and regional warming up. For example, the European Space Agency announced in September 2007 that ice shrinkage had opened up the passage for the first time since the beginning of records in 1978. Moreover, scientific models strongly suggest that seasonal sea lanes may appear as soon as 2015 through the usual ice-locked Arctic. If this trend continues, disappearance of the summertime ice cap could be possible by 2050. Over the next 20 years, the volume of Arctic sea ice will decrease by approximately 40%, and the sea ice lateral extent will be sharply reduced by at least 20% in summer (Whitney, Bradley, & Brown, 2001).

Furthermore, Figure 2-1 shows a prediction of the shrinking of summer sea ice in the Arctic region up to the year 2095, as per the Canadian prediction model, where it is very obvious that there will be a general ice free area allowing shipping to have better opportunity to navigate through the Arctic. Accordingly, that will increase the opportunity of using the ASR without ice breaking assistance, at least in summer seasons, which adds a commercial importance to the ASR and attraction to the shipping industry stakeholders.

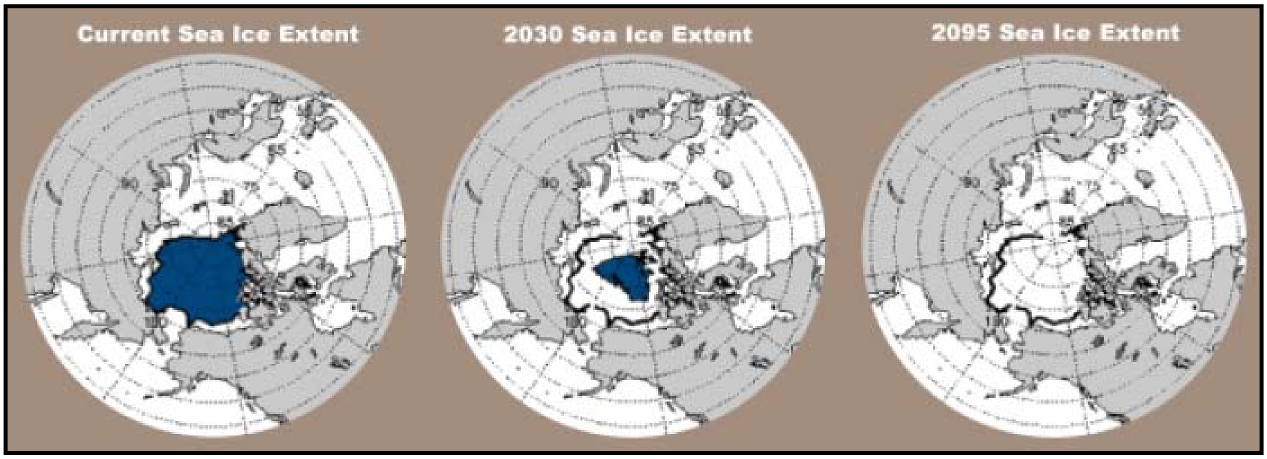

Figure 2-1: Projected Summer Ice Change.
Source: Naval Operations in an Ice Free Arctic as derived from USGCRP 1999

2.1.1. The Northern Sea Route

The focus is on the NSR, as it is the first to be ready for longer periods of navigation due to the effect of the climate change (Reykjavík, 2004 & Norwegian Atlantic Committee [NAC], 2006). On one hand, shipping traffic is expected to increase as most of the NW European countries are expected to benefit from using these routes in trading with the Far East. In particular, Canada, Russia and Norway are expected to see boom in shipping trade via the NSR. On the other hand, Japan and most of its neighbouring countries are expected to benefit from the routes in the container and other types of trades. Petroleum trade between Norway and Japan is also expected to ascend if the route is properly used. Even the passenger traffic is expected to grow, especially in the tourism sector. Figure 2-2 shows both the NSR and NWP with the summer sea ice extent in 2004, which also proves, at least, the NSR readiness for navigation, as it has less sea ice that appears in gray colour.

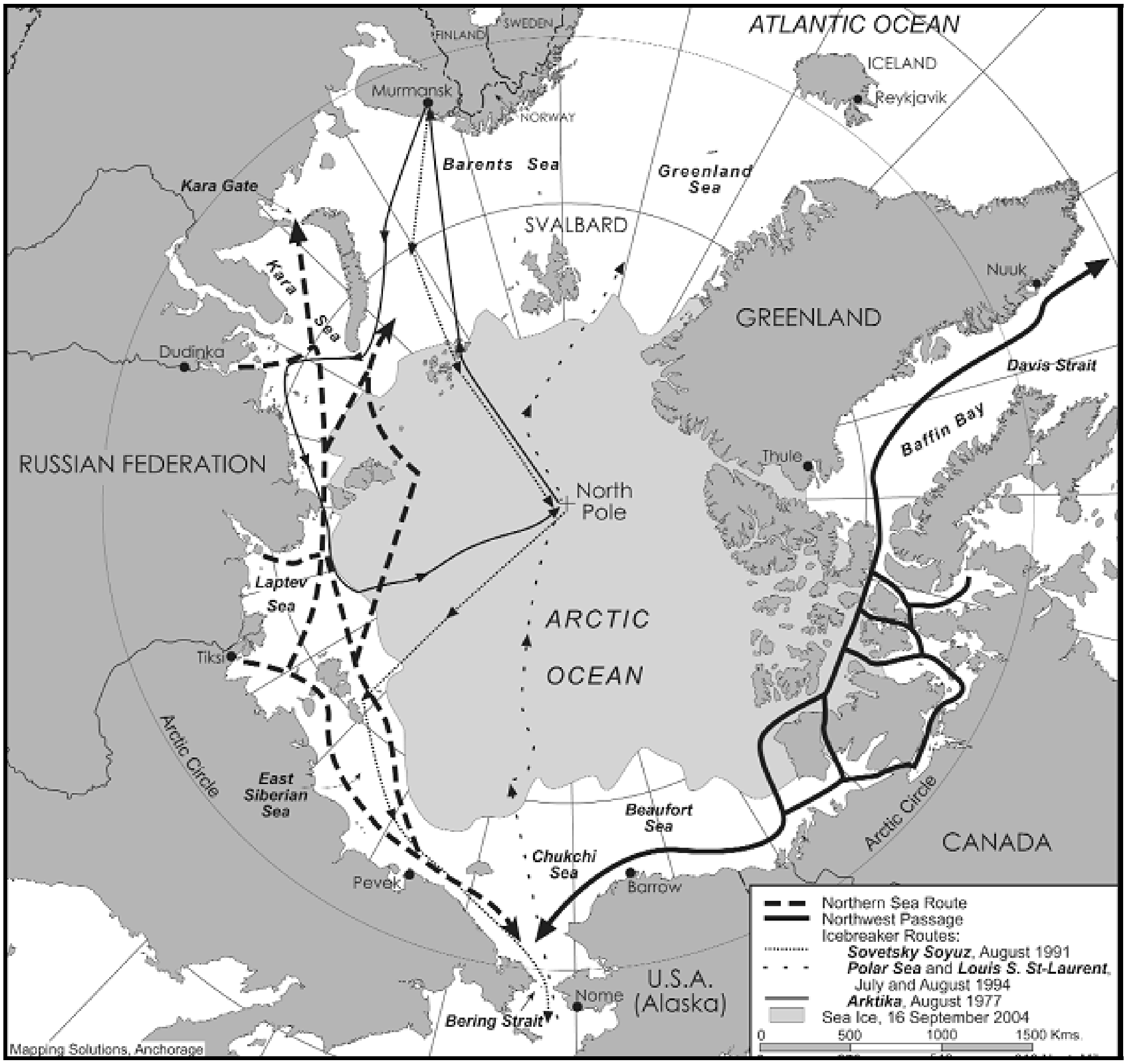

Figure 2-2: The Arctic Northern Sea Route and Northwest Sea Passages with the Ice Extents in 2004. Source: Arctic Marine Transport Workshop 28-30 September 2004

2.1. The consequences for the shipping industry

Reducing trip distance has always been an attractive practice for the stakeholders of the shipping industry to cut voyages times and increase profits; therefore, climate change increases the hope of using the ASR for navigation as it can potentially halve the distance between the Far East and Europe, as will be discussed below. The NSR could save about 35% to 60% of commercial voyages between the Far East and Europe, instead of passing through Suez or Panama Canal (Mulherin, 1996), as shown Figure 2-3.

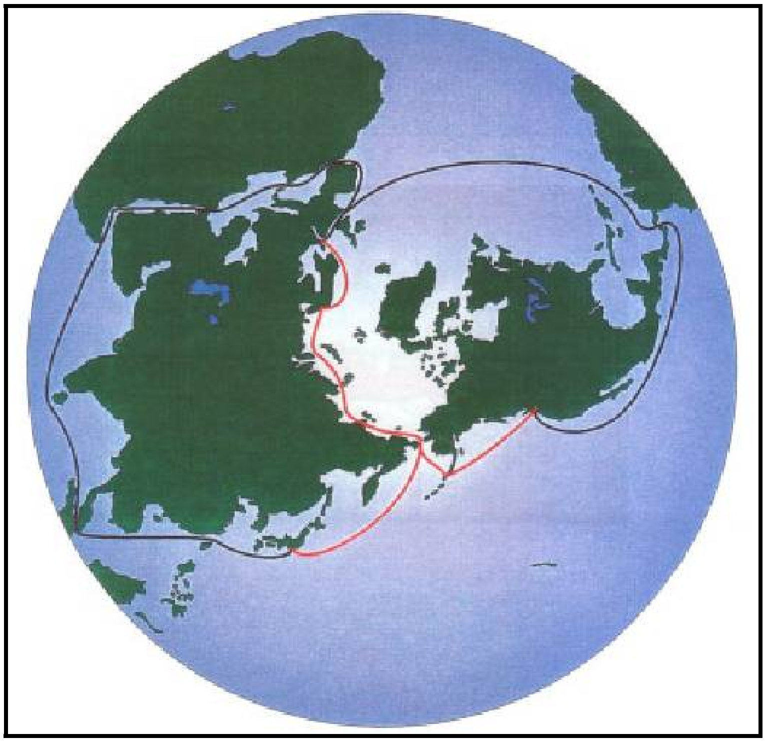

Figure 2-3: The Trip Difference Between the NSR and the Traditional Routes. Source: NSR final report

In order to show the commercial importance of the NSR, a comparison calculation was done for an imaginary trip between Norway, the oil exporter, and Japan, the major oil importer, using the ordinary and the NSR routes. The saved distance found to be 6607 NM. when using the NSR, which means more than a 43.2% distance savings ("Veson Nautical distance 2004," 2004 & Couper, 1983). Table 2-1 shows the differences in the distances and sailing time between using the ordinary - convenient Suez Canal route, and NSR at a presumed 14 knots speed, where there will be a saving of about 15 sailing days.

Table 2-1: Distances Differences Between the NSR and Suez Canal the Traditional Route.

Port of departure / destination	**Distance in nm.**	
Way points	**Via Suez canal**	**Via NSR**
Oslo / Murmansk	-	1417
Murmansk / Provideniya	-	3690
Provideniya / **Tokyo**	-	1500
Oslo / Tokyo (Total)	11633	6607
Sailing days / 14 knots	34.62	19.66

Source: After Veson Nautical distance 2004 & (Couper, 1983)

For all the above reasons along with the huge petroleum and minerals reserves that will be discussed later in this Chapter, the Arctic will most probably see a significant increase in the sea borne traffic in the next few years. Therefore, there will be further demand for certain related shipping activities and services in NSR. For example, routing systems, mandatory or recommended vessel reporting systems including Automatic vessel Identification System (AIS) will definitely be needed (Kitagawa, 2001). Therefore, opening the NSR to international shipping traffic may add a new dimension to the maritime economics; Appendix II contains an overview on the economical consequences due to opening the NSR to international shipping traffic, and how it would reduce the operation costs.

2.1.1. Navigation consequences

Although, the depth limitation in general along most of the NSR does not exceed 40 to 60 m. there are some banks where the depths do not exceed 8 to 15 m. (Vasilyev, 1999). As the ice melts, ships will find better opportunities to go farther in deeper water allowing for deeper draft ships to use the NSR (NAC, 2006), which is limited to a maximum of 20 m. (Sæther, 1999). Actually, there is a challenge in planning and risk assessing for the transit using the NSR for the extreme variation in ice conditions along the routes from year to year. Yet, with the recent melting rate, the central Arctic Ocean may be opened to shipping earlier than the Northwest Passage at least with the most powerful ice-breakers (NAC, 2006).

2.1.2. A booming demand for ice class ships

The demand for strengthened ships is evidence for the Arctic attraction for shipping, especially oil tankers (Marine Link, 2006 & NAC, 2006), and the escalated Russian energy trade (Duggal, 2006). Also there is a great expectation for the continuous economic Arctic region growth for some time. Ice class tankers saw significant increases in the last decade; a boom of 33% in the dead weight tonnage (dwt) was expected in the world tanker fleet in 2006. Some shipowners are seriously considering that the Russian oil exports will continue to grow and will escalate the demand on ships, what requires more flexibility on ice class building offers (NAC, 2006).

In the year 2004, there was about US$ 4.5 billion invested in building new 1A ice class tankers. In 1992 ice-class tankers only formed 3% of the world's tanker dwt, while in 2006 the ice-class tankers reached 8% and it is expected to reach 10% in 2008 at 18 million dwt. In addition to the anticipated West Siberian oil production, the Russian oil exported via the Baltic Sea, which require ice class ships in winter seasons, are also developing tremendously (Duggal, 2006). Moreover, due to the accelerated phase out of single hull tankers[6] there will be expectations of additional demand on the 1A ice class tankers, with a 14 million dwt growth (NAC, 2006). Although, it is well known that ice class ships are more expensive than the traditional design, the new building premiums of the 1A ice class ships in particular has reduced in value, which offers a better trading flexibility option of investments (Duggal, 2006).

Table 2-2 shows the orders of ice-class tankers in 2006 with respect to number of ships and dwt. A dramatic increase of about 63% in class 1A or higher ships carries more than a 28% increase in the dwt. Moreover, the total ice-class fleet will increase in number by about 24% and 66% in dwt, while the total tanker fleet will increase by more than 22% in number and 1.5% in dwt (NAC, 2006).

[6] Appendix I contains a list of the single hull tankers phase out.

Table 2-2: Ice-class Tankers in Operation and on Order in dwt in Million Tons in 2006.

	Current fleet		On order	
	No.	dwt	No.	dwt
Class 1A / higher	262	4.2 m	165	11.6 m
Class 1B / lower	735	19.3 m	69	3.9 m
Total ice class fleet	997	23.5 m	234	15.5 m
Total tanker fleet	5825	344.0 m	1295	90.9 m

Source: (NAC, 2006)

2.1.3. Development of ice-class ships design

Originally, ice breaking technology depended on plenty of techniques such as the bow slop, the reduced friction hull coatings and perhaps also the air bubbling or the ships' listing systems (NAC, 2006). Yet, there are new ship designs and ice breaking technology available in the market nowadays, such as the Azipod propulsion system, which is considered to be the most suitable for heavy duty Arctic operations; and is therefore significant demand in shipyards (The Front Runner, 2005). AkerFinnyard also added a new ship design and technique of ice breaking called the Double Acting Ship (DAS) in which the ice breaking operation is done by the stern of the ship while the bow may be made in the normal bulbous bow shape, which is used in navigation in open water (NAC, 2006), in order to overcome the stern propulsion difficulty (Wilkman, n.d.), and to reduce the fuel consumption by up to 50% during breaking operations (NAC, 2006). Moreover, normally the ice breaking ships consume much more fuel than traditional bow shape ships when they are used in open waters (Canada Transport, 2005); sometimes only reaching 20 to 40% efficiency (Juurmaa, Mattsson, & Wilkman, 2001). Therefore, the DAS design would allow for better saving on fuel consumption in ice-infested waters and in open water navigation if fitted with a normal bulbous bow shape. However, many DAS were built with slopped ice breaking bow and Azipod propulsion.

Actually, others say that the Azipod design, originally for the Kvaerner Masa-Yards together with ABB, saw escalating demand because of its high manoeuvrability and allowance to steer the ship in the stern direction in ice-infested waters, which was really difficult for the traditional ship design, in addition to the double acting purpose usage (Juurmaa et al., 2001), as it allows also better speed and more efficient fuel consumption in the ice free waters.

In fact, the unique DAS design depends on the ships stern frame slope in ice breaking (NAC, 2006), as shown in Figure 2-4 where a tanker ship is moving astern in 80 cm ice to break it at 5 knots (Wilkman, n.d.). Using the stern direction movement is a technique, which was originally used by the traditional ice breakers a century ago. Nowadays, there are only a few ships already using DAS, such as 'the tankers *Uikku* and *Lunni*, which have made several voyages in the Northern Sea Route' (Juurmaa et al., 2001, p. 3).

Figure 2-4: A DAS Tanker Ship Breaking the Ice while Steering Astern.
Source: (Wilkman, n.d.)

Figure 2-5 shows the Azipod direction while the ship moves astern to break an ice layer with the slop stern, and the propeller flushes the hull (Wilkman, n.d.). Even in ballast condition the capability to penetrate rubble fields was slightly better. At a speed of 1.8 m/s a ship was able to move in 4.5m. in thick rubble. Furthermore, a DAS ship may be able to move astern in ridges of 6-7 m., but when on ballast it may be able to perform better as it is estimated to move in 8 m. thick ridges (Juurmaa et al., 2001). However, there is a running debate about the Azipod high initial cost and its operation feasibility in ice multi layers (Kitagawa, 2008b).

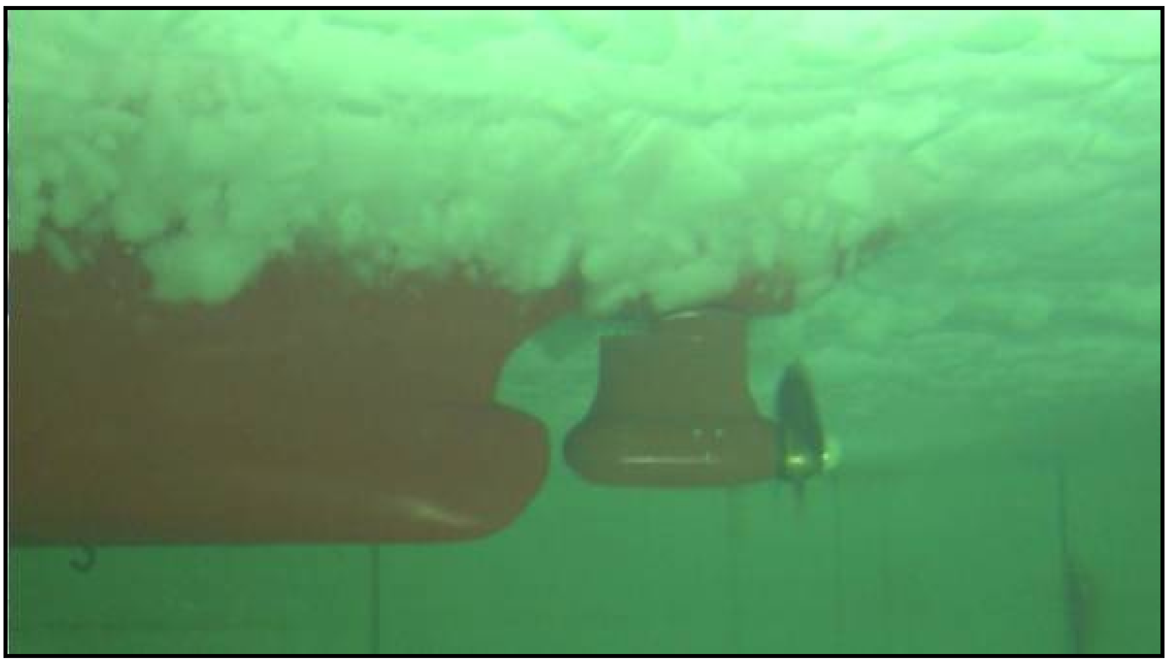

Figure 2-5: DAS Ship With Azipod Moving Astern to Break an Ice Layer.
Source: (Wilkman, n.d.)

Figure 2-6 shows a double acting tanker ship with a normal bulbous bow and an Azipod propulsion, which would sail with lower fuel consumption in both open and ice-infested waters (Juurmaa et al., 2001).

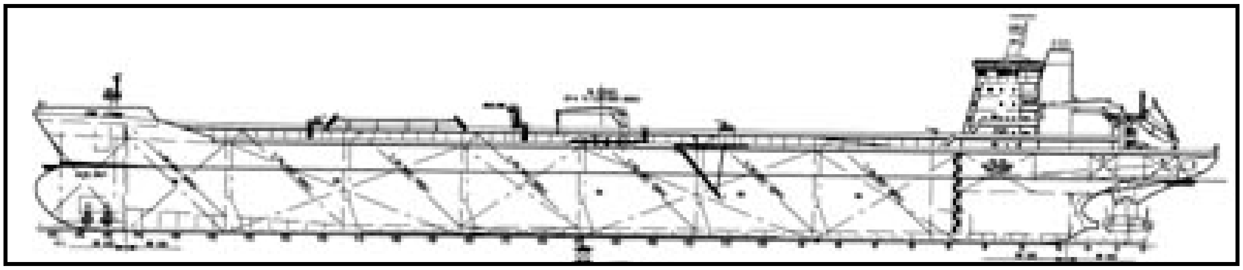

Figure 2-6: A 90,000dwt DAS Tanker.
Source: (Juurmaa et al., 2001)

In fact, the DAS is one of the most beneficial innovations serving navigation in ice-infested waters such as the Baltic Sea and the NSR, which would reduce the running cost in general, especially the fuel consumption; reduce the need for ice breaking assistance. Therefore, navigation in the NSR most probably will be available even in winter without ice breaker assistance. Consequently, there would be great motives for faster precautionary actions to protect the environment from the consequences of the escalated demand on using the NSR in shipping.

2.1.4. Additional safety and environmental regulations

Among the effects of climate change on the shipping industry some rules would need to be implemented to regulate safety and environmental protection in the NSR, as inadequate rules are experienced in the polar region. Most of the available regulations are set by classification societies, for ice strengthened ships, or the local governments to ensure less compilation and less accessibility to the market (NAC, 2006). Therefore, there is a potential need for international instruments to regulate the safety and environmental protection for ships using the NSR and for related rules for the costal authorities.

The IMO made good efforts in setting Guidelines for Ships Operating in Arctic Ice-Covered Waters in 2002, they are voluntarily implemented. In particular, the environmental protection and damage control in Chapter 16 of these Guidelines, built mainly with regard to the lack of waste reception and repair facilities, communications limitations, unique navigational and environmental hazards and limited response capabilities of available assistance in Arctic ice-infested waters (IMO, 2002). In other words, it emphasizes a potential need to cover gaps in rules, regulating such important issues like environmental protection and damage control in highly sensitive areas like the NSR.

2.1.5. The need for an ice navigator/pilotage during passage

In fact, due to climate change and plenty of mild winter seasons, the ice navigation experience may be forgotten and a new generation of inexperienced ice navigation crews may emerge (Hänninen, 2003). Navigation in ice is of direct concern because it restricts and sometimes controls the ship's movements and manoeuvrability; it affects position determining as it forces the navigator to change the course and speed frequently; it severely affects the visibility and the appearance of landmarks, and it even affects the celestial navigation due to the obscured horizon and celestial bodies. Even charts are affected by several plotting problems; in addition, it may hinder aids to navigation establishment or even their maintenance. Furthermore, it may reduce the electronic equipment performance for example (Bowditch, 2002).

Accordingly, ice navigators have become an escalated need for safe Arctic passage, especially with the expected move towards the North. New IMO and various domestic standards and regulations are expected to impact the shipping industry in the future. Particularly, regarding the need for ice navigators and pilotage services in the NSR and how they may be established. However, unlike what is usually thought of as the cold bleakness of the NWP, the route is reasonably charted and frequently used. For instance, there are 6 complete merchant passages and various other partly complete ones that reported every day, in addition to the ordinary Canadian Coast Guard ships movement. Yet, the route is still a navigational challenge, which requires special knowledge and skills, in addition to what the normal navigational officer may have. Although, the sea ice is shrinking along the route, at least in the Beaufort Sea, navigation in ice will remain a potential barrier and challenge for both the passage and navigators (Snider, 2005).

For these reasons, along with the IMO Guidelines for Ships Operating in the Arctic Ice-Covered Waters, these ships should carry at least one qualified[7] ice navigator, who is required to keep monitoring the ice conditions at all times while the ship is under way in presence of ice. Moreover, operating and training manuals are required to be available on board to assist the ice navigator. Furthermore, Chapter 14 of the Guidelines gives attention to the training or self study on the cold climate survival, which could be faced in such trips; such training should include not only the deck and engine officers but also ´all the crew members`. Finally, the ice navigator must have a documented evidence of compilation of an approved suitable training program in ice navigation, as per Regulation 14.2 (IMO, 2002).

Although, these 2002 IMO Guidelines are still a soft law, Canadian law requires all ships passing the Canadian Arctic waters always to have an ice navigator. Furthermore, the ice navigator must be qualified to act as a master or a person in charge of a deck watch. In fact, using an ice navigator in the NSR may be useful, similar to the practice in the Gulf of St. Lawrence that has been found beneficial with respect to efficiency and economics (Snider, 2005).

2.2. Consequences for the Arctic region: The Arctic as a destination

Although climate change would allow better shipping routes in the Arctic within the coming decades, the marine industry may be eager to target the Arctic itself, particularly, in Canada, Russia and Norway.

2.2.1. Canada

For example, the marine sector in the Canadian part of the Arctic is growing steadily in parallel to growth in population. The population growth in the northern part of Canada is 16% per decade where a marine transport capacity is being built up to support the communities and development activities. Moreover, the mining sector in Northern Canada, a major marine industry user, is strong with expectation of growth. The oil and gas resources in the Mackenzie Delta are also under development, and the planned

[7] As per chapter 14 of the guidelines.

placing of pipelines in the delta would increase the oil and gas activities in the Beaufort Sea, which may be reflected in the marine industry as well (NAC, 2006).

2.2.2. Russia

Not only the shipping industry would be affected by the warming Arctic, but also mineral explorations particularly in Northern Russia where the shallow continental shelf north of Siberia can be more easily explored due to the melting ice. Furthermore, the Russian economy has grown steadily since 1999 at a rate of 6.5% per year, especially, in the Arctic regions mainly due to increased oil production, which has risen 10% per year. The Russian economy is supposed to cope with the expected petroleum boom as 88% of the oil and all the gas exported from the Russian North was either via pipe line southwards or via NSR westwards. Ice strengthened tankers are used in transporting crude and refined oils from the White Sea to Murmansk, where it is transferred to large tankers for export to the European market, after the oil is transported from western Siberia, where most of the Russian oil is located (Duggal, 2006). Those oil types are originally transported from western Siberia to the White Sea by train (BarentsObserver.com, 2008 & NAC, 2006), but if the NSR is ready for navigation it would reduce the multiple cargo handling. Accordingly, the transport time and cost would be reduced, especially with the anticipated production boom. Figure 2-7 shows both the location of Murmansk and Siberia, furthermore, it emphasizes how the majority of the NSR is Russian.

Figure 2-7: The Murmansk Location in the NSR.
Source: http://www.vaumc.org/index.cfm/fa/content.view/menuID/1058.htm Retrieved on 13 April 2008

About 5.4 million tons is the transport capacity, which by some estimations will be tripled or quadrupled shortly. Moreover, a recent UN report states that oil production on the Russian shelf and oil transport in the Barents Sea will be multiplied by six by 2020, or by 32 million tons per year. In fact, there are higher figures given by some other analysts, anywhere from 36 to 130 million tons per year, in addition to anticipated boom in liquefied natural gas (LNG) production in the area of Shtokman, which will create more ship load in the region (NAC, 2006). Other expectations go for triple quantities of production in 2010 compared to 2002 (Germanischar Lloyd: Annual Report 2006, 2006).

Finally, only a nine day trip is needed for an oil tanker from West Siberia and Tyumen – Pechora basins, at a deepwater terminal on the Barents Sea, to reach the United States, which is much less than a trip from the Middle East or Africa `that takes at least 2 weeks`. LNG facilities at Murmansk are also promising as a gas export source for

American markets (Duggal, 2006). Accordingly, ice class tankers and LNG ships are required to be available shortly in the market to absorb the escalating transportation demands.

2.2.3. Norway

The maritime traffic in the Svalbard archipelago is already increasing mainly because of the Norwegian coal cargo. Norwegian coal production in the area significantly increased ten times in the last decade, although there was a drop by about 73% in the Russian production, as per Table 2-3 (NAC, 2006).

Table 2-3: The Norwegian and Russian Coal Production in the Period 1994 - 2004.

Year	Norway	Russia
1994	290,000 tons	485,000 tons
2004	2.9 Million tons	132,000 tons

Source: (NAC, 2006)

Moreover, fishing is booming in Svalbard, where in 2004 there were 200 newly registered fishing vessels in Svalbard and many others are still heading to the area for fishing. Svalbard is also a tourist destination especially in summer on board cruise ships (NAC, 2006).

2.3. Conclusion

Due to the effect of climate change, both the Arctic region and the shipping industry will be affected with the ensuing anticipated ship traffic either for transportation or exploration, which carries new innovations in ship design or propulsion systems, in addition to the need for an ice navigator, *inter alia*. There would be a need to regulate the environmental protection within the NSR. The former Canadian Prime Minister, Paul Martin, in emphasizing the importance of the NSR usage, declared in November 2004 that change and the opening of the NWP for transportation would lead to environmental consequences. Defiantly, more attention to NSR environmental protection is highly required. For example, stricter regulations may be adopted regarding the disposal of waste from ships and the establishment of port reception facilities along the NSR, to allow ships to deliver oil sludge and residues, garbage, sewage, and to manage its ballast. In Chapter Three there will be a discussion of the different shipping marine based pollution sources and the lack of international instruments to regulate such an area.

Chapter Three

The Arctic Sea Routes’ environmental vulnerabilities and the lack of environmental regulations

3. Chapter Three: The Arctic Sea Routes' environmental vulnerabilities and the lack of environmental regulations

3.1. Introduction and types of maritime environmental menace

In this Chapter a study of the different operational and accidental causes of pollution is carried out and in particular the types that are expected to affect the Arctic Ocean environment as a result of ships traffic increase. Moreover, an illustration of the current marine pollution prevention conventions including the gaps in each of them in covering the Arctic Ocean is carried out. Finally, a conclusion of the effects and consequences of such breaches, which may appear in the Arctic fragile region, is done.

Although, oil is not the only significant pollutant to the marine environment, great concern has been shown for oil pollution from ships. The main source of oil pollution from ships is from operational causes. For example, a vast majority of ships are propellered by diesel engines using fuel oil. In fact, due to operational causes there would be unavoidable leakages of lubricate and fuel oils, which may remain in the ships bilge tanks, and hence there would be a need to get rid of such residuals. Even engine exhaust gases are considered a pollutant and at least some of it will eventually return to the sea. Oil also can be a source of pollution during washing operations on tankers, if the residue is discharged over board and the load on top technique is not followed. In addition to oil, there are other noxious cargoes such as chemicals and radioactive materials, which can create a great risk to the environment in case of accidents such as groundings or collisions (Churchill & Lowe, 1999).

Furthermore, there are some other pollutants such as antifouling paints, which are supposed to protect the ship's hull from the growth of certain species of foul, which would result in a rougher surface of the ship's hull, which in turn results in slower speed, and more fuel consumption `that results in more exhaust gases`. Even the ballast water moved with ships may introduce some invasive species to the marine environment in the place of the ballast discharge (IMO, 2005). Moreover, navy or merchant nuclear-powered ships may also cause some pollution due to the disposal of the spent fuel and the radioactive waste. Furthermore, whatever the propulsion system of a ship is, it may pollute the sea if garbage is thrown overboard or sewage is discharged directly into the sea (Churchill & Lowe, 1999).

3.1.1. Operational pollution

Marine pollution threats are not only caused by accidents such as the *Exxon Valdez* in Alaska 1989 (Fall, Miraglia, Simeone, Utermohle, & Wolfe, 2001), but also by operational pollution. The IMO has succeeded in regulating the sea based pollution sources when adopted MARPOL, the Antifouling and Ballast Management conventions, *inter alia*. However, there are gaps in covering the Arctic Ocean regarding the operational pollution causes as will be discussed in this Chapter.

3.1.1.1.MARPOL convention

In this part, a general description of the different Annexes of MARPOL and an overview of the lack in covering the Arctic Sea area are given. Particularly, the lack of recognition of the Arctic as a SA is emphasized.

3.1.1.1.1. Annex I.

Actually, according to different MARPOL Annexes, ships are regulated to dispose their waste, and perhaps this is done into the sea, with limitations under the regulations, depending on the area where they operate, and the type and size of the ship. For example, ships are allowed to ‘’discharge into the sea oil or oily mixture necessary for the purpose of securing the safety of a ship or saving life at sea’’ according to Regulation 4 (IMO, 2006a, p. 56).

Furthermore, the discharge of oil from machinery spaces of all ships is regulated by Regulation 15, where one can find that the discharge of oil or oil mixtures outside or inside special areas must not exceed 15 Part Per Million (PPM) . Particularly, it is forbidden to discharge any amount of oil in the Antarctic, from ships less than 400 GT, unless it complies with Regulation 15-C as follows:

> ‘’*.1 the ship is proceeding en route;*
>
> *.2 the ship has in operation equipment of a design approved by the Administration that ensures that the oil content of the effluent without dilution does not exceed 15 parts per million;*
>
> *.3 the oily mixture does not originate from cargo pump-room bilges on oil tankers; and*
>
> *.4 the oily mixture, in case of oil tankers, is not mixed with oil cargo residues’’.* (IMO, 2006a, p. 69).

In contrast, the regulation does not prevent or give special attention to the discharging of oil/water mixtures in the Arctic Ocean; therefore, it would be dealt with as other areas and the 15 PPM rule would be applied, however, the Arctic environment worth stricter regulations or even to totally ban the discharging of oily mixture to the sea similar to the Antarctic.

For the cargo areas on oil tankers, there are also rules to regulate discharging of oil, for example, within SAs no discharge for oil or oil mixtures is allowed. Only clean or segregated ballast water to be discharged into sea. Yet, outside special areas, including the Arctic Ocean, discharging of oil would be allowed if the following conditions are satisfied:

> *‘’.2 the tanker is more than 50 nm from the nearest land; and*
>
> *. 3 the tanker is proceeding en route;*
>
> *.4 the instantaneous rate of discharge of oil content doesn't exceed 30 litres per nautical mile;*
>
> *.5 the total quantity of oil discharged into the sea does not exceed … 1/15,000 (tankers delivered before 31/12-79) … or … 1/30 000 (tankers delivered after 31/12-79) of the total quantity of cargo which was carried on the previous voyage.*
>
> *.6 the tanker has in operation an oil discharge monitoring and control system and slop tank ….’’* (IMO, 2001a, p. 117).

Not being as a SA under MARPOL Annex I, Regulation 34-A, would be applied in the Arctic Ocean including the Arctic routes. Therefore, ships would be allowed to apply Reg. 15-A and B of the 15 PPM contents of the oily mixture, unless the domestic laws of the coastal states prevent any oily/water discharge, which may require suitable reception facilities to contain the sludge and bilge contents from ships.

3.1.1.1.2. Annex II

MARPOL Annex II which regulates the control of pollution by Noxious Liquid Substances (NLS) in Bulk prevents in Regulation 13.8 any discharge of NLS in the Antarctic. Although it is very strict in allowing discharging in other places, for instance, Regulation 13.2 stipulates the discharging of Category X, Y or Z residues into sea or even ballast water, tank washings or other mixtures containing such substances is prohibited, unless:

- The tank has been emptied to the maximum extent, and
- The ship is proceeding en route at a speed of at least 7 knots, and
- The discharge is made below the waterline, not exceeding the maximum rate, and
- The discharge is made at a distance of at least 12 nautical miles from the nearest land and the water depth is more than 25 meters (IMO, 2006a).

Unlike the Antarctic, the Arctic is not considered in Annex II; therefore, discharging of NLS will be allowed the same as any other area, according to Regulation 13.

3.1.1.1.3. Annex IV

According to Regulation 11 of Annex IV, which regulates discharging of sewage into the sea, the ship must comply with the following requirements, as shown in Figure 3-1:

- The ship must have a separate holding tank and it is allowed to empty its contents while the distance from shore is 12 miles or more while en route with a speed of not less than 4 knots and,
- Only comminuted and disinfected sewage is allowed to be discharged for a distance not less than 3 miles from shore (IMO, 2006a, Reg. 11.1.1), and

- Only ships equipped with sewage treatment plants, which can produce no visible floating solids and no discoloration of the water are allowed to discharge at any distance from shore (IMO, 2006a, Reg. 11.1.2).

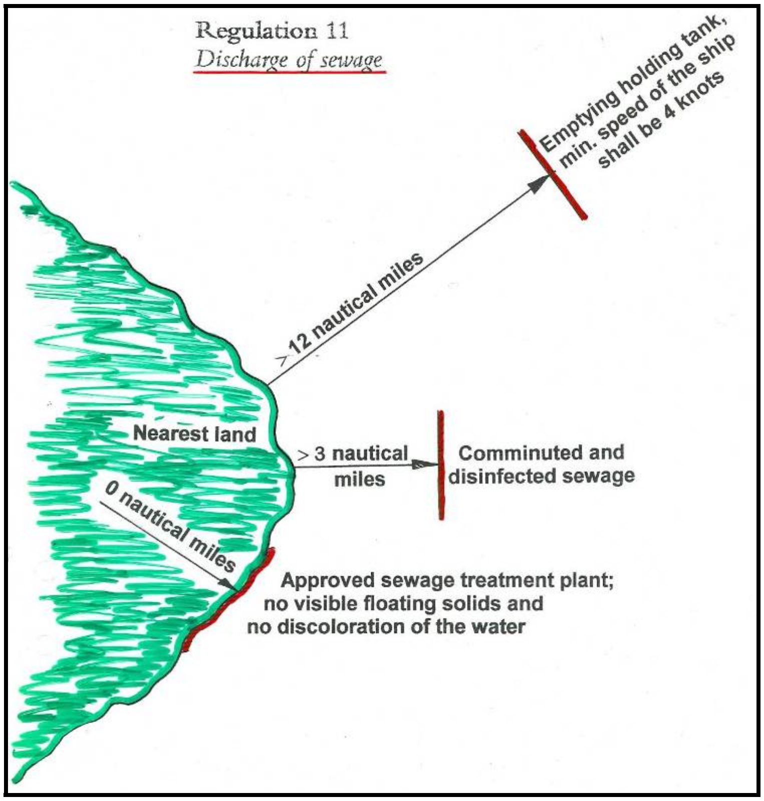

Figure 3-1: Discharging Distances of Sewage into the Sea.
Source: (Jonsson, 2008b)

In Regulation 12 of Annex IV there is an obligation for the contracting governments requires ships operating in waters under its jurisdiction and visiting ships while in its waters to comply with the rules in Regulation 11.1 regarding the discharging of sewage, in addition to establishment of ports and terminals for the reception of sewage (IMO, 2006a). Accordingly, there will be a need to establish such terminals along the NSR to serve cruise ships in particular, which are expected to be operated in the areas as the passenger ships are a major source of black water most often combined with solid waste (International Arctic Programme [IAP], 2004).

3.1.1.1.4. Annex V

Garbage is another source of pollution and ships are regulated to discharge it according to MARPOL Annex V, where again the Antarctic is one of the SAs and the Arctic is not. As per Annex V, not any kind of plastics and synthetic fishing nets are allowed to be discharged into sea. However, outside the special areas, including the Arctic, ships are free to dispose their dunnage, lining and packing materials on a distance not less than 25 miles from the nearest land. At 12 miles or more, food waste and most other garbage are allowed to be disposed of at sea. While the ship is 3 miles or less form the nearest land it is allowed to dispose only comminuted or ground garbage, which can pass through an opening not greater than a 25 mm screen (IMO, 2006a, Reg. 3-1).

In contrast, disposal of garbage within special areas is prohibited except for the food waste, which may be allowed at a distance not less than 12 miles from land, except for the Antarctic where the disposal is completely forbidden. The contracting governments shall ensure that ships operating in the Antarctic area have capacity enough to retain their garbage on board and to discharge it in a reception facility after departing the area (IMO, 2006a, Reg. 5). This regulation is not applied to the Arctic, leaving the opportunity for the national legislation of the coastal states to be the only regulator for such disposal. Table 3-1 summarizes the disposal of garbage within and outside special areas.

Table 3-1: Garbage Disposal in and out of Special Areas.

Garbage type	All ships except platforms	
	Outside SAs	**Inside SAs**
Plastic – includes synthetic ropes and fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited
Floating dunnage, lining and packing materials	> 25 miles offshore	Disposal prohibited
Papers, rags, glass, metal, bottles, crockery and similar refuse	> 12 miles offshore	Disposal prohibited
All other garbage including papers, rags, glass, etc. comminuted or ground	> 3 miles offshore	Disposal prohibited
Mixed refuse types	*	*
* When garbage is mixed with other harmful substances having different disposal or discharge requirement, the more stringent disposal requirement shall apply.		

Source: (After, Jonsson, 2008b)

The anticipated tourism cruise ships must be dealt with properly, as the IMO estimates the waste generated on board as 3.5 kg/person per day; therefore, a relatively small 200 passenger cruise ship would produce 700 kg of solid waste a day, which is huge quantity compared to a general cargo ship that would produce only 60 kg/day in total waste (IAP, 2004 as derived from [GLPANS, 2001]).

Obviously, this may lead to a severe breach of the environmental protection policies in the Arctic as ships will be free to dispose of their garbage the same way as in non SAs, which is severely threatening the environment because of the low temperature and the ensuing slow biodegradation process. In that case ships would have to comply with the national legislation of the Arctic coastal states, the only available regulator, which may lead to confusion for the ships' crew as they have to deal with many law requirements while sailing along the route.

3.1.1.1.5. Annex VI

Finally, in Annex VI of the convention, which regulates the air pollution from ships, there are rules to regulate the Sulphur and Nitrogen Oxide (SOx & NOx) contents, bunker quality, engines exhaust and incinerators, *inter alia*, for their severe effects on ozone depletion, in addition to causing acid rain and other major environmental consequences. For instance, to reduce the sulphur content in the exhaust, the maximum allowed sulphur content in the fuel oil shall not exceed 4.5%. Yet, for some particular areas like the Baltic Sea, North Sea and the English Channel the limit is only 1.5%; otherwise, the exhaust must be treated to contain no more than 6.0 g SO_x/kWh. The NSR is not included in this Sulphur Emission Control Areas (SECA).

Using the NSR will shorten the distance for ships and hence the emission of the exhaust gases will be less. These gases will still exist and increase in such a pristine area. Therefore, the Arctic deserves better regulations to prevent all different kinds of pollution under MARPOL convention. Furthermore, other conventions such as the antifouling convention must be well considered.

3.1.1.2.The International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS 2001 convention)

Fouling is a term used to describe the marine organisms that attach to a ship's hull. The resulted roughness of the ship's hull increases friction within the underwater area, which result in more fuel consumption thereby increases exhaust gas emissions. Even the internal pipe system and sea chests may face attachment from some organisms. Accordingly, these particular areas need a special coating not only to prevent rust and corrosion but also to prevent fouling (Jonsson, 2008b). Algae, mussels, barnacles, and microorganisms or types of fouls are more active especially when ships have a long stay or are slowly navigating in lakes and inshore water, unlike when they are in the open sea at full speed. Dr. Harald Müller, head of the lab at Relius Coatings' industrial coatings area, explains:

> *"Panels without any protective coating that were exposed to the elements in the North Sea and the Baltic Sea were covered with a growth that was several centimetres thick after only one month, which would result in marked weight gains for the ships, slower crossings, and considerably higher fuel consumption."* (Oldenburg & Münster, 2008).

New innovation of anti-fouling paint, which contains the organotin tributyltin, was introduced in 1960-70s, which used the organotin tributyltin (TBT), and this revolutionized the anti-fouling markets with its high performance (IMO, 2001c). Based on releasing toxic biocides into the water, those types of paints contained metals like tin, copper, lead and arsenic (Jonsson, 2008b).

There were great benefits from using those types of paints. For example, the self polishing paints that reduce the fuel consumption. Anti-fouling saves up to 20% of the propulsion (Oldenburg & Münster, 2008), which is estimated to save 2 billion dollars annually (Champ, 1999). Yet, researchers proved that the TBT is responsible for the disruption of the endocrine system of marine shellfish, leading to the development of male sex characteristics in female marine snails. Furthermore, it affects the immune system of some marine organisms. For example, shellfish develop shell malformations after being exposed to extremely low levels of TBT (Jonsson, 2008b).

Plenty of research has been carried out to try and find different methods of dealing with the fouling problem without an impact on the marine environment. Accordingly, the IMO took the initiative to issue an instrument in 1990. The AFS convention was adopted in 2001, and the Maritime Environment Protection Committee (MEPC) issued a resolution recommending Governments to adopt measures to eliminate the use of TBT-based antifouling paint especially on non-aluminium hull vessels of less than 25 meters in length. The resolution also recommended eliminating the use of antifouling paints with a leaching rate of more than 4 microgrammes of TBT per day. The AFS 2001 convention will enter into force on 17 September 2008 requiring alternatives for TBT anti-fouling, including copper based coatings and silicon based paints to ensure that the ship's paints does not harm the marine environment[8] (IMO, 2001c).

3.1.1.2.1. Implementation of the AFS 2001 convention

The convention applies to ships having the nationality of a Contracting Government (CG) to the AFS 2001, ships not flying the flag of a CG but operating under the authority of a CG, and to all other ships that enter a port, shipyard or offshore terminal of a CG (IMO, 2001b, Article 3). Moreover, ships including hydrofoil boats, air-cushion vehicles, submersibles, floating craft, fixed or floating platforms, floating storage units and floating production storage and off-loading units shall apply the convention (IMO, 2001b, Article 2.9). No more favourable treatment should be given to ships of non-Parties to this Convention. Warships, naval auxiliary, or other ships owned or operated by a Party and used, for non commercial services are exempted from applying the AFS 2001[9] (IMO, 2001b, Article 3).

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[8] The harmful effects of anti-fouling systems were first considered by the IMO's MEPC in 1988 to restrict the use of TBT compounds on seagoing vessels. Accordingly, resolution MEPC.46(30), "Measures to control potential adverse impacts associated with the use of tributyltin compounds in anti-fouling paints", was adopted at the MEPC 13th session in 1990. Since that date onwards, MEPC received confirmation about the toxicity of TBT compounds and the availability of existing alternatives, monitoring their effectiveness and threat to the marine environment.
In the 21st session of the IMO Assembly in 1999 the resolution A.895(21) was adopted. The MEPC was urged to work towards developing of an international binding instrument to regulate and ban the harmful antifouling systems used on ships, especially the TBT which acts as biocides in antifouling systems on ships by 1 January 2003. A complete prohibition on the presence of these TBTs was planned to be on ships by 1 January 2008. A working group was established at MEPC, which took on the task of developing such a draft instrument.

9 On effect of the IMO Council decision, the International Conference on the Control of Harmful Anti-Fouling Systems for Ships, 2001, was held in London from 1 to 5 October 2001. The Conference adopted the AFS Convention, together with four Conference resolutions relating to:

- The early and effective application of the AFS Convention,
- Future work by the Organization pertaining to the AFS Convention,
- Approval and test methodologies for anti-fouling systems on ships, and
- The promotion of technical co-operation.

In Annex 4 of the convention - Article ll(1)(b) and (2) and Regulation 1(4)(a) there are some other guidelines to the convention are:

Furthermore, none of the ASF 2001 regulations banning the organotin based paint are applicable to fixed or floating platforms (Showalter & Savarese, 2004) engaged in exploration and exploitation of the seabed, subsoil and natural resources thereof under the sovereignty of a coastal Party State. In this case, the coastal state administration will be the authority to decide whether to require these platforms to comply or not (IMO, 2001b, Article. 2.1). In other words, in the case of the Arctic routes Russia, Canada, Norway and the USA are to decide their own regulations, meaning 4 different requirements, without any unification that may lead to confusion.

3.1.1.2.2. Domestic law implementation

Although, the convention is not yet entered into force some countries, such as Japan, have already banned the TBT-based antifouling paint for most ships (IMO, 2001c). In fact, there are some other countries that have already adopted domestic regulations in similarity to what is required in the convention, such as some states in the USA in 1988 (Showalter & Savarese, 2004). The requirements of Alaska and Canada were examined for the purpose of this study as they have a similar environment and are from the closest to the Arctic region.

There is ban on selling and/or using TBT-based marine antifouling paint in coating in Alaska. In addition, it is forbidden to sell, rent, lease, import or use a vessel, fishing gear, or any other items intended to be partially or completely submerged in the water, if painted or treated with TBT-based paints, *inter alia*. However the law

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- ‘’Guidelines for survey and certification of anti-fouling systems on ships (resolution MEPC. 102(48)),
- Guidelines for brief sampling of anti-fouling systems on ships (resolution MEPC. 104(49)), and
- Guidelines for inspection of anti-fouling systems on ships (resolution MEPC. 105(49))’’.

allows for some organotin paints with low release rate[10] to be applied only on the aluminium vessels and lower out board drive motors (Showalter & Savarese, 2004).

Furthermore, in Canada, another Arctic rim country, the antifouling paints may not be sold in or imported unless the product has been registered, conforms to prescribed standards, and is packaged and labelled as required by law. After a special review of TBT antifouling paints, "determined that the use of TBT antifouling paints represents an unacceptable risk to the marine environment". Canada completely banned the sale and use of TBT antifouling paints in 2002 anticipating the global ban on TBT. Although, copper-based biocidal antifouling paints are currently the only paints registered for use in Canada, they are banned in the Netherlands, Sweden and Denmark[11] (Showalter & Savarese, 2004), `but not in all the Arctic council countries`. For example, Russia is not signatory to the convention (IMO, 2007). Accordingly, non party ships would be free to navigate through the adjacent waters and even to enter and use the ports and shipyards, such as Russia's Sevmash shipyard, unless the Coastal state domestic law bans such practices.

3.1.1.2.3. Focusing on the problem

Navigating in ice-infested areas needs to be done slowly, meaning more emission concentration of the anti-fouling paints in a smaller area. Moreover, as the ship moves in ice-infested areas, massive friction occurs particularly in the underwater area were the anti-fouling is located. Although, the relationship between the ice thickness and the removal of the foul is unknown, the forces due to this friction are enough to remove even the anti-fouling paints (Antarctic Treaty Consultative Meeting [ATCM], 2007) leaving it on the seabed, poisoning the sea. Accordingly, even the ice class ships navigating in ice-infested waters may lose underwater anti-

[10] The convention requirements.
[11] For example, on September 29, 2003, Denmark adopted new regulation stipulating that the use of antifouling paints on pleasure boats "may maximally release 200 µg Cu/cm2 after the first 14 days and maximally 350 µg Cu/cm2 after the first 30 days." Yet, new pleasure boats for export and ships undertaking long journeys are exempt from the new copper emissions standards (Showalter & Savarese, 2004).

fouling paints, which would increase the harm to the environment if it was TBT-based.

In other words, not only ships using the NSR will suffer loosing the paints of the underwater area, that carries a commercial value, but also the environment would be harmed if the AFS 2001 is not implemented in the NSR. Therefore, ships navigating in the NSR are required to be not only ice class painted, but also non TBT-based anti-fouling coated to avoid the effect of these substances, when removed under the ship-ice contact (Hänninen, 2003).

Finally, unlike the Arctic, the Antarctic area seems to be better monitored environmentally. Five vessels, regularly travelling to the Antarctic, have been surveyed for hull fouling and were found to have substantial fouling. In fact, ice cannot reach the sea chests as they are recessed and guarded by grates, which means higher hull fouling assemblages in such areas. A study conducted on a ship regularly travelling to the Antarctic found that after three years an extensive fouling assemblage of the invasive Mediterranean mussel travelled, `most probably in the ballast water`, and survived the exposure to the Antarctic weather conditions (ATCM, 2007). This example highlights the importance of the implementation of the ballast water convention.

3.1.1.3.The Ballast Management Convention

Ballast Water (BW) is mainly used for stability purposes and it reduces the stresses on ships' hulls especially in ballast voyages and maintains certain trim and list even during the loaded voyages. BW may also be taken on board to ensure sufficient immersion for the ship's propeller and rudder to maintain good steering ability, especially during rough weather. It is also required by some IMO conventions to have certain quantities of BW on board. For example, it is mandatory by MARPOL to have sufficient quantity of BW on board oil tankers of 20,000 dwt or more, if the product carried is of 30,000 tonnes or more, and delivered after 1 June 1982. These ships shall be provided with segregated ballast tanks to ensure safe operation without using any cargo tank for ballasting, in addition, some other specific requirements, such as the moulded draft taking into considerations the length of the ship and the acquired trim condition are also required under MARPOL (IMO, 2006a, Reg. 18).

BW may be considered one of the major threats to the marine environment (IMO, 2005), as it introduces and spreads Invasive Aquatic Species (IAS). These IAS may be moved from one environment to another. BW, as well as residual water and sediments remain in a BW tank and may include organisms such as pathogens, phytoplanknotson, zooplanknotson, macrophytes, mollusks, invertebrate resting stages and fish, which most probably when discharged into the water of another port would establish a new population of species or expand the existence of others (The Great Lakes Panel on Aquatic Nuisance Species [GLPANS], 2001).

Australia for example categorizes the BW into two types according to its level of threat: high risk and low risk BWs. For instance, they consider any salt water taken from ports or any coastal area other than the Australian territorial sea, 12 Nautical miles from shore, as high risk BW. On the other hand, the low risk water is:

- ''*Fresh Water from any source,*
- *Ballast water that has been assessed as `low-risk` for discharge (at specified ports / locations on specified dates) by the BWDSS,*
- *Ballast water that has been exchanged at an approved location (mid-Ocean) by an approved method,*
- *Ballast Water taken up inside Australia's territorial seas''.* (Department of Agriculture - Fisheries and Forestry [DAFF], n.d., p. 4).

Similarly, for the purpose of this research such categorization of high and low risk BWs may be used in respect to the NSR. Accordingly, any ship on a ballast voyage has two options: to change its BW before entering the NSR or to deliver its BW to a reception facility along the route if necessary. Otherwise, there will be a threat to the environment or the safety of the ship itself.

3.1.1.3.1. Implementation and the required standards

In 1997, the IMO Assembly adopted resolution A. 868(20) titled "Guidelines for the control and management of ships' Ballast Water to minimize the transfer of harmful aquatic organisms and pathogens". In 2003 the IMO council agreed to adopt an international instrument, and an international conference on the BW Management for ships was held in February 2004, which adopted the International Convention on the Ballast Water Management (BWMC)[12] (IMO, 2007).

The BWMC convention applies to ships flying the flag of a Party country and others, which operate under the authority of a Party to the convention (IMO, 2007). These ships mainly have to adopt the convention by following one of the following options in Regulation B-4, in particular, ships applying the Regulation D-1[13]:

> ‘’*.1 whenever possible, conduct such Ballast Water exchange at least 200 nautical miles from the nearest land and in water at least 200 metres in depth, taking into account the guidelines developed by the Organization;*
> *.2 in cases where the ship is unable to conduct Ballast Water exchange in accordance with paragraph 1.1, such BW exchange shall be conducted taking into account the guidelines described in paragraph 1.1 and as far from the nearest land as possible, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 meters in depth’’* (IMO, 2005, p. 20).

Perhaps applying the above mentioned requirements is difficult to adopt in the NSR, as ships are supposed to navigate coastally along the NSR, meaning that the distance from shore definitely will be less than 200 miles. Along the route the waters are shallow (Brubaker, 1999), and water depths are less than 200 meters in most of the NSR parts. In some places such as the Siberian shelf depths do not exceed 40-60 meters and in some places the water depth is less than 20 meters

[12] In fact, Canada was first to introduce the IAS to the IMO in 1988 upon discovering them in the Great Lakes. In response, the MEPC in 1991 adopted the first voluntary guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' BWs and sediment discharges into the marine environment.

[13] Those ships have a 95% volumetric exchange of BW and use the pumping-through method.

while some banks may reach 8-15 meters (Vasilyev, 1999). This makes the adoption of the Regulation B-3 1,1 nearly impossible. In such areas, where ships may have difficulties in complying with the requirements, the coastal authorities may designate some ports where ships may conduct the BW exchange, taking into consideration the shortest deviation from their routes. Appendix III includes the alternatives to manage and exchange the ballast water.

3.1.1.4. Russian radioactive waste in the Arctic

For six decades or more there were environmental breaches such as 'strip mining, oil spills, forest clearing, overfishing, and the improper disposal of radioactive material', which have severely affected the polar areas, perhaps beyond repair (McCannon, 1998, p. 177). The Ex-Soviet Union dumping of radioactive waste disclosure in the Barents and Kara Seas is among the main reasons for such environmental breaches. Actually, it is well known now that the Northern Fleet and the Murmansk Shipping Company has been carrying out such dumping operations for decades. The Murmansk Shipping Company is operating 7 nuclear powered ice-breakers engaged in keeping the NSR open for navigation particularly the West part of it between Murmansk and Dudinka. It is also known that the total radioactive waste dumped into the Arctic seas in the Soviet Union era is double the quantity compared to all the previously known worldwide dumping. Such radioactive waste descend from nuclear vessel reactors, which still contain high-level paid out fuel (Stokke, 2000).

Although, the former Soviet Union was a party to the Inter-Governmental Conference on the Convention on the Dumping of Waste at Sea - 1972 (London Convention), which came into force on 30 August 1975 (IMO, 2008a), parts of the dumping operations were conducted in the North. In fact, it took a long time to come up with a widely accepted solution for the problem of how to deal with the high level waste and the spent nuclear fuel, there were at least 5 decades of violation of nuclear waste. Not only the civilian nuclear ice breakers are the sole nuclear waste source in the Arctic, the navy and military origins are a major source of spent fuel, especially in the Soviet Union era (Stokke, 2000).

It was also documented in 1993 that about 16 nuclear reactors have been dumped in the Kara Sea since the 1960s and, due to failure in removal of the spent fuel before dismantling, 7 of them are considered dangerous. The northern fleet dumped low and medium level solid waste in flimsy containers, which are subject to corrosion. This is in addition to the Barents Sea, which has seen disposal of liquid waste used in cooling, incineration, or deactivation installation since the mid 1960s (Stokke, 2000). However, there is no significant release of radioactive waste including dumping of hot reactors. Furthermore, it is not certain that a rapid release of all the dumped activity would not result in considerable danger to marine food-chains according to some model scenarios (Stokke, 2000).

The current nuclear ships operating in the Arctic, among other ships operated by the North Fleet, generate nuclear liquid and solid waste above the capacity of the reception facilities for storage and treatment. On top of that, the ships and submarines are subject to run out of service due to old age, complying with the Russian Strategic Arms Reduction Treaty regime, which would increase the problem of reception facilities capacity. Moreover, there is a lack of adequate transportation facilities out of the area (Stokke, 2000).

In fact, not only the London convention regulates the dumping operations, but it is also the responsibility of the coastal state to control the dumping operation as per UNCLOS - Article 210 (UN, 1982). Accordingly, it is highly recommended to enlarge nuclear reception facilities capacity, including the interim storage, and to set an adequate transportation capability for the final destination of the radioactive waste or the spent fuel, to cope with the recent needs and the anticipated escalating use of the NSR.

3.1.2. Accidental pollution

3.1.2.1.Overview

Spilling oil in ice-infested water could cause severe marine pollution and a great risk for the environment for prolonged periods of time. For example, the double purpose passenger and supply ship *Bahia Paraiso* ,which grounded in January 1989 in the Antarctic, clearly highlighted the dangerous consequences of pollution as a result of increased shipping traffic in ice areas. Due to grounding the hull tore open causing a spill of some 250,000 gallons of diesel oil into the frigid waters, and killing plenty of marine lives (Vukas, 2004), which is a scenario that may similarly happen in the NSR.

The EVOS, discussed in 1.4.2, is another dramatic example of marine pollution in frigid waters. While manoeuvring to avoid glacial ice it became stranded in Alaska, which resulted in severe consequences from an oil spill in cold water with low biodegradation rates (Radm, n.d.). On March 24, 1989, the tanker *Exxon Valdez* spilled 11 million gallons of crude oil into the Pacific Gulf of Alaska. Over 1,200 miles of coastline of the Alaska Peninsula were contaminated with oil, which caused massive damage to the natural marine environment, in addition to damages of $1.15 billion as assessed by the federal US District Court (James, Barry, & Johanna, 2005). Navigating in ice-infested waters of the NSR increases accident occurrence probability and may result in a similar scenario to the *Exxon Valdez* and would lead to more severe consequences.

3.1.2.2.The risk of navigating in ice

In addition to what is already discussed in 2.1.5, navigating in ice is really a risky operation due to the harsh weather condition, poor visibility, the ice-hull contacts and the related restricted manoeuvrability, *inter alia* (Bowditch, 2002). Due to climate change, it is expected that icebergs to increase in number (Skjoldal, 2008), while converting to calves or bergy bits (Bowditch, 2002). Those growlers may shape natural uncontrolled navigational obstructions that increase the probability of ramming.

Moreover, steel plates, from which a ships' hull is mostly made, would be subject to brittle fractures due to navigation in such cold waters (Jonsson, 2008b; Kobayashi & Onoue, n.d.). That may cause spill accidents or at the very least flooding of the ship. Actually, even with 19 mm steel plates, brittle fracture may occur in -6°C temperatures, such as what happened to M/V *Lake Carling* ("Review of UR S6 for Side Shell Plating Exposed to Low Temperatures," 2007). Cracks and dents are the most common damage to ice class ships due to sailing in ice-infested waters (Hänninen, 2003). However, the ordinary 1A class plating thickness for ocean going ships may vary around only 10 mm if high tensile still is used (Jonsson, 2008a).

A study was carried out for ships operating in the Baltic Sea, an Arctic similar ice-infested water environment, regarding damage happened during the winter of 2002-2003. The statistics gathered showed about 98 incidents for 111 ships, where 30% of the incidents were structural damage that happened due to ship-ice interaction. The remaining incident causes were varied, including propeller and rudder damage due to contacting or grounding in ice (Hänninen, 2003).

The found damage types were mainly dents in the plating, frames, stringers and web frames ranging from 10 mm up to 100 mm deep. Moreover, ruptures and cracks in plating due to fatigue, which was observed, especially in junctions between plates and frames in the underwater area due to friction with ice. Furthermore, wear in painting occurred due to ice abrasion, especially in the water line, bilge and bottom areas including bilge keel rupture, dents and damage, as shown in Figure 3-2 (Hänninen, 2003).

Figure 3-2: A Bilge Keel Rupture and Propeller Damage of Ship Number 100.
Source: (Hänninen, 2003)

In addition, some dents and holes were found even above the water area due to collision with other ships or ice breakers. Finally, propeller blades or the control system of the controllable pitch propellers suffered damage most commonly due to backing in ice. And even some engines suffered malfunction due to heavy ice conditions. Table 3-2 shows the most common ice damage and the related effects on the different parts of the ship (Hänninen, 2003).

Table 3-2: The Most Common Causes of Ice Damage.

Type/position of damage	Description
High speed in ice	High speed in ice can damage the ship's side plating above the water line in the bow area due to extended ice loading by the bow wave.
Bilge and Bilge keel damages	Due to contacting with ice edges when turning in the ice channel.
Rudder and propeller damages	Backing in ice would cause damage to the aft area including the propeller and rudder.
Mid ship area on the flat side region damages	Due to moving ice filed, the ice channel may be blocked; in such case the ship may get stuck in ice and damages occur to the side of the mid ship area.
Ship's side, bilge and bottom area damages	Ice ridges may extend 3 m above and 20 m below the water level which may damage the ships side, bilge and bottom especially when the ship is towed.
General hull's parts and propulsion system damages	Due to maneuvering in ports, especially in ice rubble.
Cumulative ice damages	Ships may have relatively large cumulative deformation on the plating and on the frames especially if bad repaired or not ice strengthening.

Source: (After Hänninen, 2003)

Actually, the major damage types in the Baltic Sea incidents were found mainly due to collision and grounding. Collision with other ships or ice breakers may happen when ships are moving in convoys and one of the preceding gets stuck in ice or suffers an engine failure, and then the following ship would not succeed in stopping and collide with the front ship, as shown in Figure 3-3[14]. Grounding may occur due to ship's drift with moving ice or while seeking for easier route in difficult ice condition. Poor visibility due to long dark winter combined with snowfalls and wind make ice navigation really difficult and increase the probability of an accident occurrence (Hänninen, 2003).

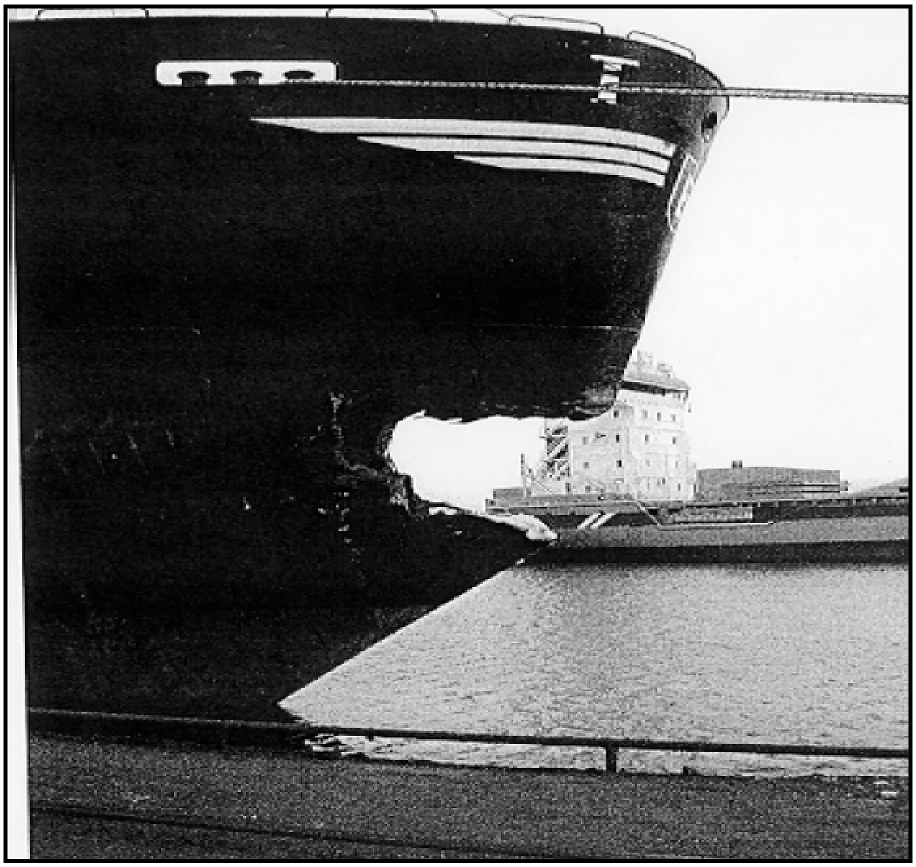


Figure 3-3: Damaged bow due to Collision with an Ice-breaker.
Source: (Hänninen, 2003)

Therefore, for all the above it is wise that the IACS allows the use of grade A steel for ice class ships to reach 30 mm in -10°C to be able to withstand the above

[14] In fact, even when escorted by ice-breakers it is also difficult to maintain the safe distance between ships. On one hand, as if the distance was so close a collision could happen with the ice-breaker that has an engine failure. On the other hand, if the distance is so wide, the just opened passage may be blocked again before the escorted ship could follow due to the rapid freeze up of the water due to extreme cold.

mentioned stresses under freezing temperature ("Review of UR S6 for Side Shell Plating Exposed to Low Temperatures," 2007).

3.2. Conclusion

For the above operational and accidental mentioned reasons, the probability of accidents occurrence to ships using the NSR is relatively high and the consequences will be sever. Particularly, oil tankers carry significant importance, the disastrous effect would be great, and the consequences would be massive, not only for the low feasibility of many oil spill combating techniques that will be discussed in Chapter Four, but for the fragility of the Arctic environment also.

Chapter Four

Available oil pollution combating techniques and the feasibility of their application in the NSR

4. Chapter Four: Available oil pollution combating techniques and the feasibility of their application in the NSR

4.1. Overview

Among the different pollutants discussed in Chapter Three, hydrocarbons carry significant importance. The more accessible Arctic becomes as a destination or for transportation of oil and gas on effect of the climate change (Chapter 2), which increases the possibility of operational or accidental pollution (Chapter 3). Therefore, there is a need to consider proper oil spill combating techniques. Oil spill combating techniques vary, and the doubt about their feasibility, if applied in the harsh Arctic environment, will be discussed in this Chapter. Table 4-1 shows tankers are among the ships with the highest number of accidents during the period 1999-2003 in the Canadian Arctic, with 15 cases while all the other ship types and accidents numbered 39 during the same period. Accordingly, the possibility of having a major oil spill due to one similar accident in the NSR would be expected, especially if the tanker was loaded.

Table 4-1: Accident Details for the Canadian Arctic (1999-2003).

	2003	2002	2001	2000	1999
Shipping Accidents	7	2	4	8	17
Accidents Aboard Ship	4	0	0	0	3
Vessels Involved in Shipping Accidents by Type of Vessel	17	8	4	2	7
Cargo/OBO/Tanker	3	5	3	0	4
Ferry/Passenger	3	1	0	0	0
Tug/Barge	2	0	1	2	0
Fishing	0	1	0	0	0
Other	9	1	0	0	3
Vessels Lost	0	2	0	1	0
Fatalities	3	0	0	4	0
Incidents	1	1	1	2	1

Source: (Icebreaking Program Report on Performance, 2005)

In fact, it is not an easy task to choose, which combating technique should be applied in which conditions. The choice is among mechanical, in-situ burning and chemical dispersants, in both ice-infested waters and in open water. For the Arctic environment, choosing the right technique is of utmost importance due to the unique environment. The Arctic area is fragile to pollution as the cold climate may slow the biodegradation processes, and some oil residue may be found under ice layers for decades, as already mentioned in 1.4.2.

4.2. Fate of oil in ice-infested waters

In open waters it is possible to some extent to predict the direction and speed of the movement of an oil stain. Normally, the slick will drift with a speed that is a resultant of both the surface current speed and 3.4 % of the wind speed. The wind effect on the oil slick is that it will move in the wind direction plus 15° (in the northern hemisphere) due to "Coriolis Effect",[15] while movement due to current effect is of the same direction of the current[16] (Ghalwash, 2004). Consequently, it is possible to foresee the destination of the oil slick will be in a direction of the resultant force of the wind and surface current, *inter alia*, and hence to be prepared with the proper response actions, which is not the exact case in ice-infested water.

In ice-infested water it is really challenging to estimate where the bulk of the oil is destined. Oil spilled on or in ice would face many different fates, each one of which needs a different clean up approach. For example, oil may encapsulate in ice during winter while it may melt on water in summer. It may pool on or under the ice layers, or it may be trapped in free floating ice or in the worst case can be absorbed by the ice (Newton, 2005). Moreover, oil that moves under ice is more difficult to track than oil on open water (WWF, 2007).

[15] In the southern hemisphere it is the wind direction minus 15° from.
[16] Tidal stream must be also considered.

4.2.1. Overview of the Arctic Ocean environmental characteristics

The Arctic Ocean has a unique environment, and therefore the consequences of a single oil pollution accident could be catastrophic for plenty of reasons, such as the cold climate and the frigid water and their effect on slow biodegradation. In particular, weathering of spilled oil in ice is considerably slow due to low temperatures and reduced solar radiation, also restricted oil evaporation is due to the limited area and greater oil layer thickness. The only advantage of oil spills in icy areas is that the oil will not spread much, meaning that less area would be affected by the pollution. An ice lip will be created around the spill preventing its horizontal movement and its subsequent spread. However, this small area of spill will also reduce the possibility for the oil to evaporate. Figure 4-1 shows the performance of oil in broken ice, which indicates less opportunity for biodegradation and evaporation.

Even in broken ice layers, shown in Figure 4-1, major amounts of oil will be covered by ice. Therefore, the amount of oil on ice pooling places affected by solar radiation and evaporation will be relatively lower than the subsurface pooling in ice and the entrained oil. Moreover, ice lips will continue to grow around and underneath the oil encapsulating it and prevent any change in its physical composition for the entire winter until at least the spring. At that time, the oil will find the easiest way to the surface of the first year ice, spreading over it and causing localized melting and a weathering process similar to the open ocean process (Doerffer, 1992).

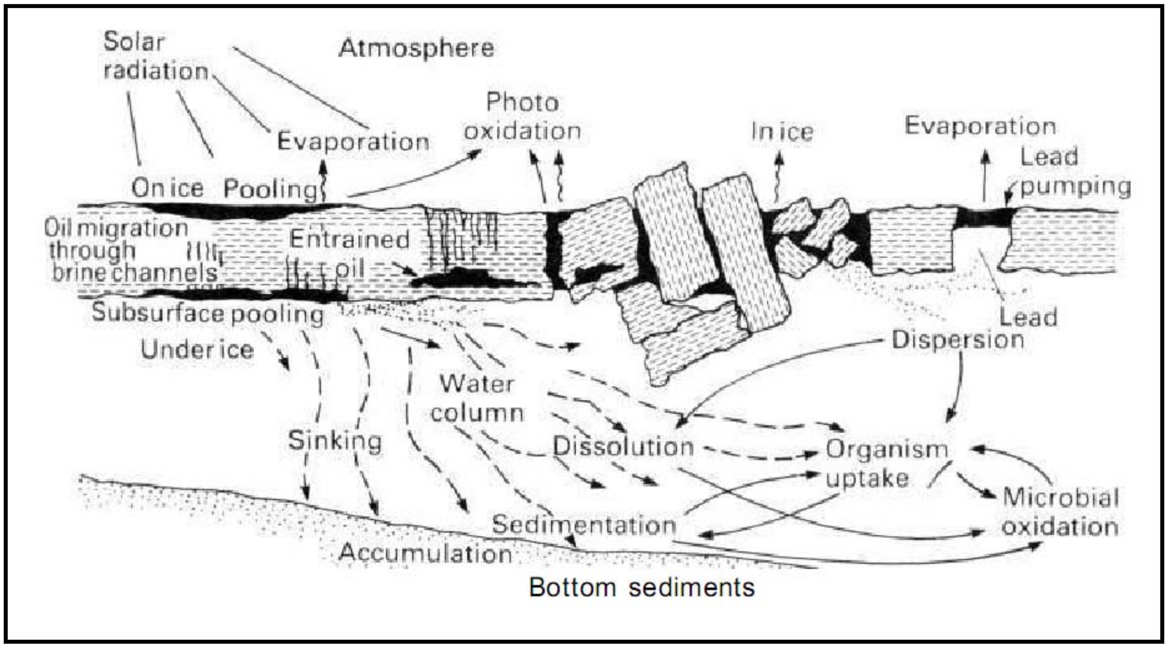


Figure 4-1: Performance of Oil in Broken Ice.
Source: Doerffer, 1992

4.3. Oil combating techniques and their application in ice-infested waters

There are four essential entities that will greatly suffer from an oil spill in ice conditions: the oil industry, the public in general, the governments involved or all governments in the Arctic and most significantly, the environment (United States Arctic Research Commission [USARC], 2006). Therefore, research has been conducted on oil spill technologies in ice-infested waters to study the applicability of ordinary techniques and what more can be done in dynamic ice condition spills.

Combating techniques are divided mainly into three categories: mechanical, in-situ burning, and chemical dispersants techniques (DeCola, Robertson, Fletcher, & Harvey, 2006). WWF has a similar categorization, mechanical recovery where oil is first contained in an area using a containment method then removed using skimmers; and non-mechanical recovery, which includes the usage of chemical countermeasures, burning, or bioremediation; and manual recovery using simple hand tools such as pails, shovels or nets (WWF, 2007). However, oil combating techniques usually employed in open water are not necessarily feasible in ice-infested water; therefore, each approach needs to be researched further. In the next part of this Chapter a discussion of oil spill combating techniques will be conducted and their application in ice-infested water. Each of these techniques faces significant logistical, technical, and safety challenges in high ice concentrations.

4.3.1. Mechanical technique

The fundamental objective of this technique is to recover the spilled oil mechanically and to remove oil from the environment, hopefully, before it reaches the shore. Moreover, it is aimed to prevent, to the maximum extent, the possible entry of oil into the water column through natural dispersion, *inter alia*. The overall strategy must consider the possibility of shoreline pollution and estimate the need for beach cleanup, that aims to remove the pollutant and to return the beach to its normal condition with the minimum damage in the least applicable time, and minimizing the subsequent problems of final disposal and/or recycling of recovered materials (Cormack, 1999).

In Mechanical recovery, natural or man-made barriers are used in containment of the oil and then subsequent removal of the oil from the surface is done (DeCola et al., 2006). Booms are deployed from vessels or anchored to fixed structures or land, then different types of skimmers may be used for recovery of the oil from the water's surface. The collected oil must be transferred using pumps and hoses to temporary storage until it can be properly disposed of (WWF, 2007). Figure 4-2 shows a typical mechanical recovery operation in open water where it is seen that two boats are towing a boom to contain the spill while another is using a skimmer to pump the oil from water surface to the temporary storage barge.

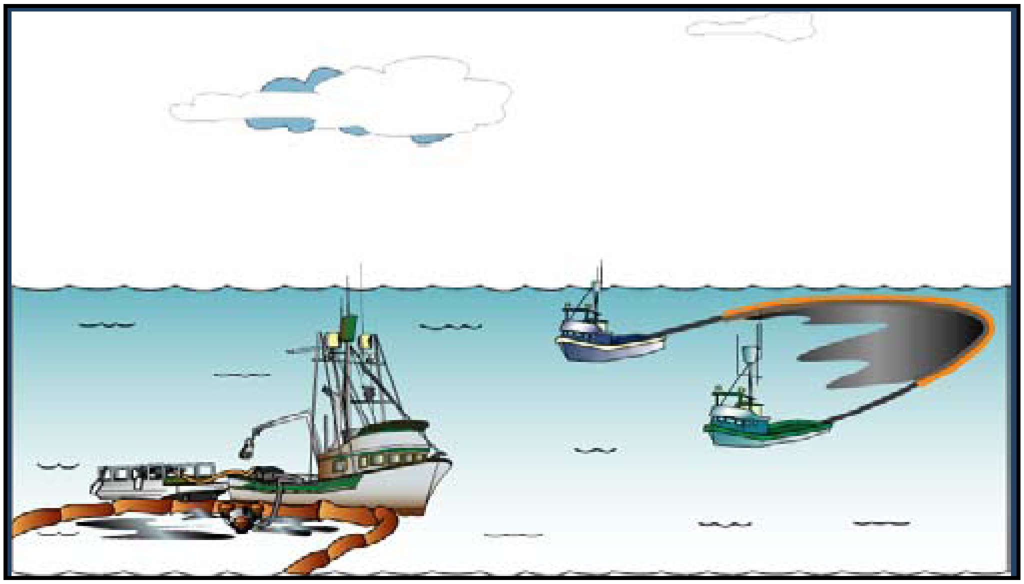


Figure 4-2: Typical Mechanical Recovery in Open Water.
Source: (WWF, 2007)

Actually, oil recovery even in open water at real spills does not have a good record of performance. For example, only about 9,400 tons of emulsion containing 75% water was recovered in the *Exxon Valdez* incident in the very logistically isolated region of Prince William Sound, Alaska. This real disappointment in the reliability and low encounter rate of the mechanical combating technique has caused a change in US attitudes towards chemical dispersants, which tends to be the most commonly used (Cormack, 1999). Yet, that is not usually the case in ice-infested waters.

For example, `prediction of the oil slick destination is hampered by two factors`. First, the movement of oil on, under, or among offshore ice cannot accurately be predicted under the available mathematical models, although considerable research and development is ongoing. Second, `Darkness and poor visibility would increase the difficulty of tracking of the slick`. Prolonged darkness in Arctic winter, long periods of fog and low visibility may not only complicate or preclude the operation of support vessels or aircraft, but it could also prove to be among the most important limitations for any offshore operation attempting to locate and recover oil in ice (DeCola et al., 2006).

Although, it seems at a glance that the Arctic weather conditions may impact the effectiveness of spill response methods, sometimes these same conditions may provide opportunities that would not exist in open water. For example, high concentration ice coverage may act as a natural containment barrier to facilitate mechanical recovery or burning of the oil (WWF, 2007). In particular, oil trawls may collect and concentrate even submerged oil; it was found that ice concentrations of 60% or higher provides an effective means of reducing oil spill spreading. On the other hand, with the diminished spreading rate of oil due to ice concentrated coverage, recovery rates would be severely impacted by logistical inaccessibility because of vessel, mechanical and human limitations (DeCola et al., 2006).

Furthermore, solid ice pack can be used as a support base for heavy equipment and vehicles, if there is safe access. Long summer days offer longer daylight that could increase operational periods, if other occupational safety aspects are complied with including sufficient staffing and safe access to the operational area. Oil may be more viscous in colder temperatures and that may reduce the oil spreading speed (WWF, 2007). However, there is a lack of real experience with large ice-infested water oil spills and most of the data depend on small scale field experiments or laboratories.

Below 60% ice concentration, additional containment tools would be required, while in practice most containment booms can be used in light brash ice with concentrations of up to 30%. Therefore, ice concentration in the range of 30% to 60% is the most challenging to mechanically recover, as the conventional booms become ineffective and the ice condition is not sufficient to contain the oil. Furthermore, in dynamic sea ice conditions, most skimmers operate with significantly reduced efficiency, especially when drifting ice pieces are present within the slick (DeCola et al., 2006).

Moreover, in ice-infested waters some recovery systems may reach their operating limits far below the expected theoretical limits. For example, although the estimated theoretical limit to mechanical recovery is about 20% with containment booms and skimmers, the real practice demonstrated only a 10% operating limit in the offshore response exercises in Beaufort Sea during fall freeze-up of the year 2000 (DeCola et al., 2006). Therefore, it is extremely difficult to estimate when such technology may or may not be feasible due to this situational complexity.

The extreme cold temperature in the Arctic is another important aspect to be considered. For long periods of time in Arctic and sub Arctic regions low temperature have an impact on both personnel and equipment, and have the potential to significantly slow down or even cease oil spill response operations. In order to avoid hypothermia, response personnel need frequent breaks and they must wear additional bulky cold-weather clothes, which slow down their movement. For example, during a training exercise conducted on the Alaska North Slope in April 2000, it was common practice to take shelter nearly every 30 minutes, because at that time of the year air temperatures ranged from -20º C to -40º C. Equipment and machinery are also vulnerable to extreme cold. For nexample, mechanical recovery is one of the response systems that depend mainly on pumps and hoses that without warming systems would be vulnerable to freeze-up. Vessels and the vessel-based equipment are vulnerable to icing as sea spray freezes on exposed surfaces leading to difficulties in the operations control. Below 0º C, metal is also subject to brittle failure. Accordingly, mechanical response devices including fittings, and seals designed for warm temperate oil spills must be redesigned for the Arctic extreme cold conditions (DeCola et al., 2006).

The presence of sea ice adds a potential menace for the oil spill response, which is already inherently risky in open water, increasing the possibility of accidents. Therefore, all responders and vessel operators are required to be appropriately trained and outfitted with proper safety equipment to operate in a range of ice environments (DeCola et al., 2006).

In general, mechanical recovery in ice infested-water is extremely difficult and is not an effective response option for large scale oil spills, especially in 30% ice coverage or above. Plenty of new mechanical technology for recovery in ice-infested waters has been introduced. However, applying these technologies on a major oil spill scale is still a challenge. Research projects are being conducted to focus on methods of improving oil spill response in ice-infested waters (DeCola et al., 2006). Yet, unfortunately there are still low expectations for progress in this area (Newton, 2005), however, they could still be used where possible. For instance, Sakhalin Energy Investment Company in the Russian Far East, has indicated that mechanical recovery is the only response option that will be allowed in the Piltun oil feeding area. However, some other advocate the in-situ burning of spilled oil as a primary response tactic, in lieu of mechanical ones (DeCola et al., 2006).

4.3.2. In-Situ burning technique

Unquestionably, in-situ burning is the most effective oil-in-ice responses of them all, but only under one condition: it is initiated very soon after the spill and before spreading of oil over a large area. Yet, it should be noted that there are currently strong objections from the environmental communities and most governments about in-situ burning (Newton, 2005), due to the resulted exhaust gases, for instance. Actually, the success of this technique depends mainly on how thick the oil slick is. Therefore, the in-situ burning window of opportunity is limited to the condensation of the oil over a confined area and how the oil is dispersed with the water within a few hours after the accident. For that reason some types of chemical herders, currently under development, may be used to thicken a slick to allow for better ignition, in addition to the use of suitable fire resistance containments (WWF, 2007).

Oil containment for in-situ burning can be accomplished either with natural barriers such as the coast line or man-made booms. Fire boom used for in-situ burning must be constructed of fire-resistant materials and they are divided into one of three categories: traditional fabric booms,[17] metal booms, and water-cooled booms. Although, most of the booms used with the in-situ burning technology do not hold up under repeated burns, they are often relatively inexpensive (DeCola et al., 2006).

[17] Coated with a special coating to make it fire resistant.

Figure 4-3 shows a typical open water in-situ burning operation with the assistance of two tug boats and aerial ignition. A controlled burn of floating oil that is contained to the appropriate thickness is one spill combating technique. Ignition can be done by releasing a burning, gelled fuel from a helicopter or by releasing a fire torch from a vessel or other nearby point. Some or all of the oil will burn off leaving some residual non-volatile compounds that may float, sink or be neutrally buoyant depending upon the oil type and the burn success. The exhaust gas emitted after burning must also be considered. It must be below threshold levels (WWF, 2007) as it would include: a smoke plume, combustion gases, unburned hydrocarbons, organic compounds, soot particles, and the residue that remains at the burn site (DeCola et al., 2006).

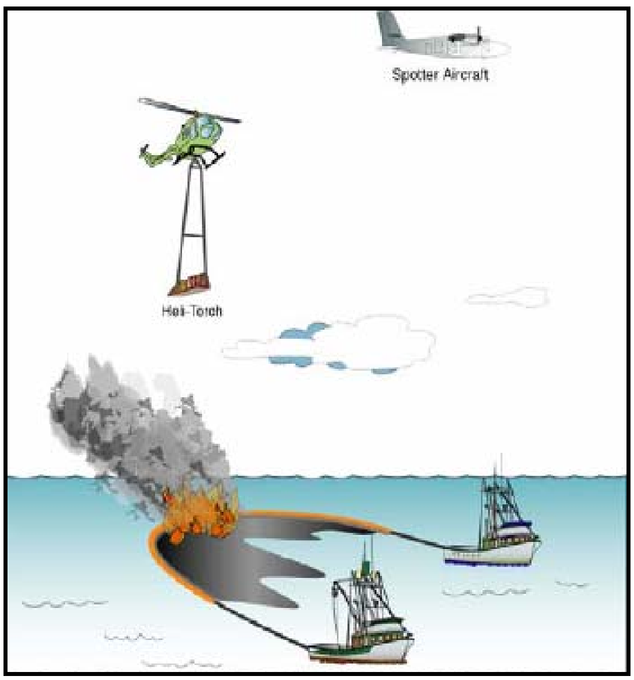


Figure 4-3: A Typical In-situ Burning Operation in Open Water.
Source: (WWF, 2007)

There is a strong objection to adopting in-situ burning, not only for the exhaust but also for its efficiency, among most governments. The efficiency of the in-situ burning technique is a subject of considerable technical debate among experts (Newton, 2005). Some of the experts do not consider the in-situ burning technique as a primary oil spill response tool in the Arctic, especially in dynamic ice conditions, even though ice can be considered means of containment. In ice coverage between 30% and 70%, in-situ burning has not been found effective in actual field tests. Yet, above 70% ice coverage, sea ice may provide natural containment. At higher ice concentrations, significant logistical, technical, and safety challenges remain in tracking, accessing, and igniting the oil slicks and recovering burn residues (DeCola et al., 2006).

Burn residues are another point of contention; burn residues have differing behaviours depending on the parent oil chemical composition and physical properties, the weather conditions, and the oil slick thickness. Therefore, recovery of the burn residues is not an easy operation, as the oil may remain buoyant or sink immediately after cooling, which would cause a great health risk if ingested by gray whales. It is therefore better collect burning residue before burning further oil, yet that would narrow the window of opportunity. The recovery operation may be done with large strainers, nets, or hand tools, with viscous-oil sorbents, or with standard viscous-oil skimmers to be used with the burning boom or may be left to a secondary boom (DeCola et al., 2006).

Some cooling models estimate that residue would reach the water temperature within 5 minutes for 3 mm thick residues and most probably they sink once they are cooled. Once they sink it would be really difficult to recover them and a suspended net along the bottom across the apex of the burn area would be useful in recovery of some residues. However, recovery of burning residue in ice-infested water has not been studied (DeCola et al., 2006).

Actually, in-situ burning has not been widely used in cold climate spills; hence all the available information about the use in the Arctic area is based on experiments. Generally, it seems that the ice would reduce efficiency of the in-situ burning process and increase the burning residual. In-situ burning efficiency in open water may reach 98% for certain oil types, but, the best efficiency of in-situ burning were found to be 50% for weathered crude oils and 80% for fresh oil in slush ice (DeCola et al., 2006).

If the ice is thick enough, it may allow for personnel and equipment to be moved to the slick area to ignite it (WWF, 2007). On the other hand, 30% to 60% of ice concentration is considered the most difficult range from an in-situ burning perspective, because it is less likely to use the ice as a natural containment device and even the man made containment boom deployment is difficult (DeCola et al., 2006) or impossible (WWF, 2007).

Finally, extreme cold temperatures in the Arctic would make ignition ineffective or difficult and may cause the fire to slow or cease (WWF, 2007). However, oils of 38°API gravity or above are more easily ignited than the ones below 20°API (DeCola et al., 2006). Ships used to reach the slick area must be ice strengthened or ice breakers, but, helicopters may also be used in good visibility that is essential also for the ignition and tracking of the slick processes, while fog may last for days in the Arctic (WWF, 2007).

Indeed it seems that the ice condition may impact the in-situ burning process, regardless of the advantage of using the ice as a natural contentment in 70% or above heavy ice coverage. Further research and field trials would be needed to develop the in-situ burning technology to be improved and to overcome its residual problems.

In fact, a combination of methods including chemical herders to thicken the oil to allow for better in-situ burning is ideal. Moreover, this technique is also used to increase the window of opportunity during burning that can achieve maximum effectiveness. Herders and chemical dispersants also carry promise to improve the effectiveness of some other response technologies (Newton, 2005).

4.3.3. Chemical dispersants technique

Natural cleansing or allowing oil to be degraded and removed by nature is not an active method and it takes a long time to be fully effective. In open water, where there is no threat to any sensitive onshore or offshore habitats or species, spills will evaporate, weather, disperse and degrade naturally[18]. The low concentration of microorganisms at

[18] On the open Oceans, oily film is undesirable because it constrains the air and light transfer to seawater, which are essential to support the marine life, moreover, oily slicks damage Crustacea beds and beaches in coastal waters (Doerffer, 1992).

the oil/water interface in the seawater never allows high rates of biodegradation of oil droplets, hence, natural biodegradation of oil requires months and sometimes years to be completed. Therefore, speeding up the proliferation of these microorganisms in order to stimulate biodegradation by adding some chemical dispersants is a potential oil combating technique (Doerffer, 1992).

Chemical dispersants have been an active part of oil spill response considerations internationally for more than 3 decades, yet, nowadays, instead of being the single, most important recovery technology, they have become disallowed, `in some countries`, as a response tool (Hillman, 1998). Dispersants are a group of chemicals sprayed on oil slicks using spray nozzles, pumps and hoses applied and monitored from a vessel or aircraft, as shown in Figure 4-4 (WWF, 2007). Dispersion of oil droplets increases oil dissolution, and provides materials, which may be ingested by organisms allowing break-up and disappearance of a surface slick. Enhanced biodegradation is a potential oil spill fighting tool (Doerffer, 1992). However, chemical dispersants have a limited window of opportunity for effective application; a prompt, accurate application of the chemicals is required. Furthermore, the type of chemical to be used must be chosen properly to comply with the spilled oil, emulsification, and salinity with regard to weather conditions and sea state (WWF, 2007), which increases the difficulty of application in harsh remote areas due to logistical constraints of such environments.

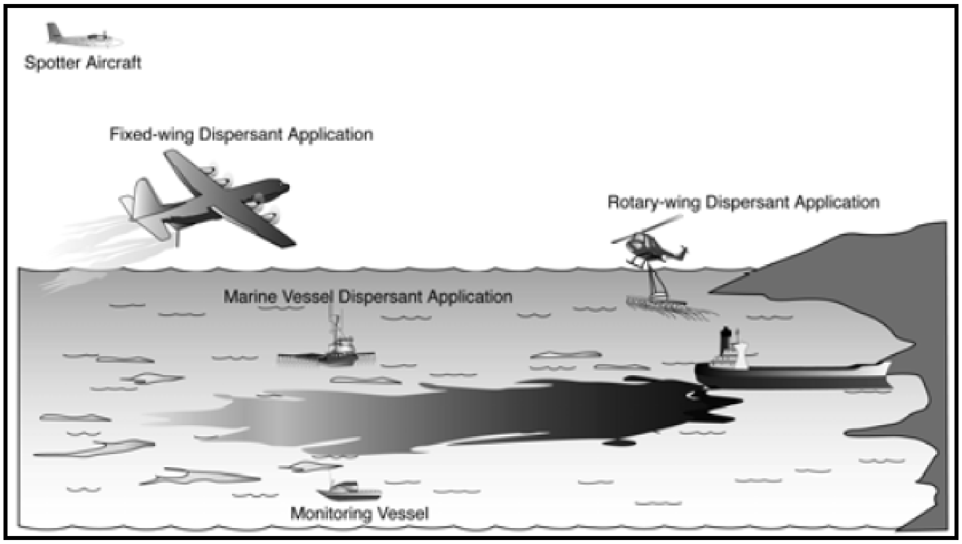


Figure 4-4: Dispersant Application Plateformes.
Source: (DeCola et al., 2006)

Chemical dispersants are not, and will never be, the only solution for recovery, and it is advised to be used where clean-up operations are technically and/or economically impossible. Dispersants are advised also in sensitive areas, where other treatments would be more harmful than the oil itself, and in ice-infested waters or under ice (Doerffer, 1992). However, no effective dispersant exists for viscous or cold oils. Dispersants are an important response technique in open water especially with high mixing energy, which is a relatively difficult achievement in ice-infested water (Newton, 2005).

Using chemical dispersants in ice-infested waters carries both pros and cons. For example, some recent studies indicate that the dispersion process can be enhanced by the interactions between ice floes in high ice concentrations. Researchers in Norway are considering the reduced rate of oil weathering in sea ice may extend the window of opportunity for dispersant use. On the other hand, regarding the dispersant's toxicity, dispersants may be more toxic than the untreated oil. Even the un-dispersed oil residue left behind following a dispersant application was found to be more toxic than untreated oil. Although no studies so far considered the toxicity of dispersed oil for gray whales, it was found that direct exposure to misapplied dispersant can harm birds and mammals (DeCola et al., 2006).

Unlike the general conception, that low temperature may reduce the dispersant effectiveness. Chemical dispersants have been formulated to be non-viscous in cold temperatures. The viscosity of the spilled oil will become higher at low temperatures, but perhaps not too high for effective chemical dispersion. Table 4-2 shows the result of laboratory work done on weathered north slope crude treated with plenty of dispersants at 0ºC and 10ºC[19] (Ross, 1998). The efficiency of these dispersants seems to increase in colder weather. The dispersants products of A, B, D, and E showed a significant increase that varied from 2% to 15% while the efficiency reduction happened only in the products C, F, and G, which varied from just 1% to 4%. In other words, the chemical dispersants efficiency change value saw increase of nearly 3.3% on average. Yet, more research and trials are deeply needed before dispersants are considered a primary response technology in the Arctic or sub Arctic regions.

Table 4-2: Effect of Temperature on Dispersants Effectiveness.

	Dispersant Effectiveness %	
Temperature	**50°F**	**32°F**
A	60	62
B	19	34
C	64	63
D	46	49
E	50	60
F	35	33
G	82	78

Source: (Ross, 1998 as retrieved from Byford et al. 1983)

4.3.4. Watch and monitor technique

This technique is followed only when it is already ensured that the oil slick is moving under current, `tidal stream`, and wind effects to the open sea or at least not to a potential coast, which allows the natural biodegradation process to take place (Doerffer, 1992). Software modelling programs are beneficial in predicting the destination of the oil slicks when fed with the correct data such as the current and wind directions and forces at the

[19] 0° C (32° F) and 10° C (50° F).

time of the accident. However, this calculation processes is only feasible in open waters; in ice-infested waters it is really difficult to estimate where the oil slick is destined, as discussed in 4.2. Furthermore, in the Arctic cold temperatures, natural biodegradation is extremely slow and it will take a long time to take full effect. Oil may be covered by ice and due to darkness or poor visibility it would be really difficult to track the slick. Therefore, neighbouring countries along the NSR are supposed to cooperate and communicate especially if this technique is going to be followed in order to avoid or at least to reduce any beach damage from a spill.

4.3.5. Ice deflection technology

In fact, responding to oil spills in ice-infested waters is worthy of more attention and should be considered in future research. There are already some new techniques that have appeared in the field such as some types of ice deflection devices, which have been utilized with varying degrees of success that are to be used in addition to ice booms and the grading belts. Figure 4-5 shows a relatively simple idea of ice deflection response, where a metal grate positioned in front of a skimmer is used to deflect small pieces of ice away from the skimmer, not to be blocked with ice pieces. Positioning of the deflection devices is very important to ensure only ice deflection from recovery devices, but not oil. During the 2000 offshore response trials, mentioned previously, in the Alaska Beaufort Sea, this technique was used to deflect ice grates. The grate appeared to succeed in deflecting surface oil; however, some oil slicks were not deflected but rather deferred away from the skimmer (DeCola et al., 2006 as retrieved from Robertson and DeCola, 2001).

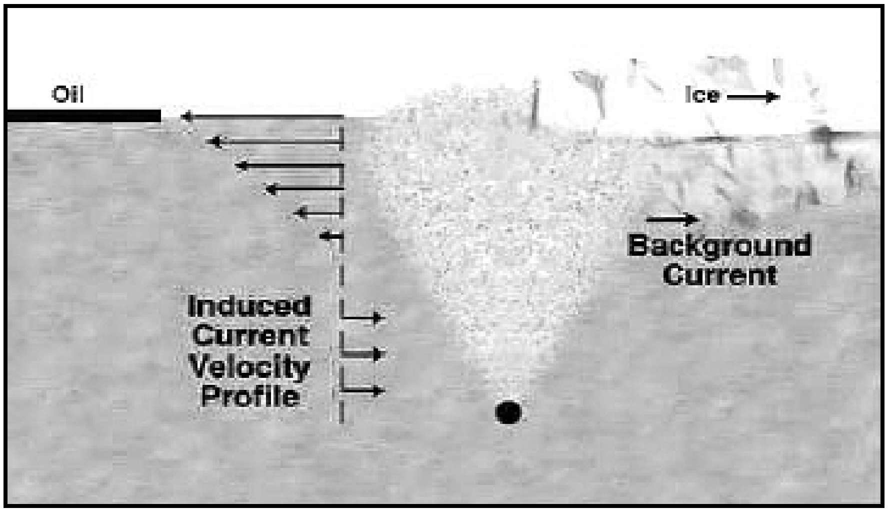


Figure 4-5: A Relatively Simple Pneumatic Deflection Concept.
Source: (DeCola et al., 2006)

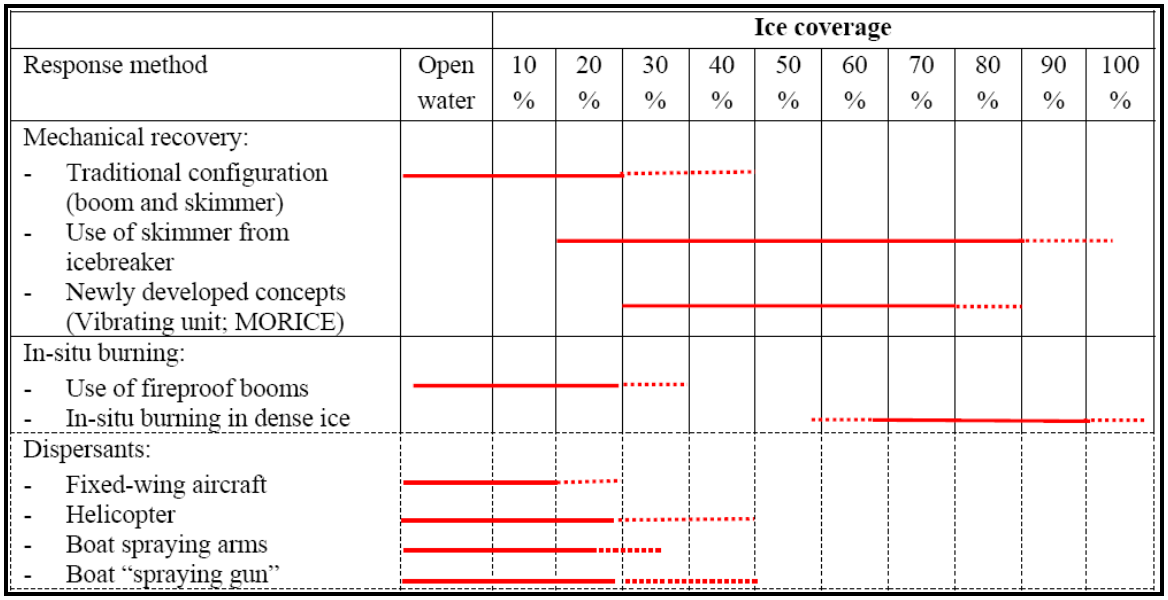
4.4. Feasibility of the available oil spill combating techniques

Deciding, which combating technique to be applied depends on many aspects: the type of the oil spilled, the available window of opportunity, the direction and force of wind and current in the area, and the severity and accessibility of the affected beach, *inter alia*. Even in open water it is not an easy task to choose, which response technology to be adopted (Ghalwash, 2004). Adding to this, the previously discussed factors affecting ice-infested waters that could negatively impact the combating operation efficiency including the spill reception possibility.

Table 4-3[20] shows the expected effectiveness of the operational limits of oil spill response systems in ice-infested waters. However, only a few of these methods have actually been tested in ice-infested waters. Therefore, there is a lot of doubts associated with the listed technologies. In addition, the Tables in Appendix VIII summarize the Arctic weather conditions and the potential impacts on each oil spill response options

[20] The dotted lines mean a reduced efficiency and the continue lines means the best efficiency.

Table 4-3: Indication of Expected Effectiveness of Different Response Methods as a Function of ice Coverage.



Source: (DeCola et al., 2006)

Actually, the basis for most of the recovery technologies limits lies on small scale tests that examine the operating limits of a specific technology or type of equipment rather than the entire system. These analyses were held in testing laboratories or test tanks or even small scale trials, `not in real cases. Perhaps, they provide valuable data about the operating limits of individual technologies, but, they may give wrong overall estimation` (WWF, 2007). Further, trials would be beneficial in finding new oil-in-ice response technologies.

4.5. Conclusion

There is no single perfect oil spill response solution to the challenges in ice-infested waters. In-situ burning, mechanical recovery, ice-deflection technologies have shown some limited effectiveness in ice-infested waters. Limitations found include ice conditions such as, coverage percentage, thickness, presence of leads; and operational and logistical issues such as, remote areas and lack of equipment, *inter alia*. However, chemical dispersants are considered promising[21] for treating oil spills in ice-infested waters; but further studies are needed to establish their applicability (DeCola et al., 2006).

The recent legal condition of the Arctic as a non-special area would allow chaotic dumping and disposal of oil and waste at sea from ships due to the lack of international rules for regulating such operations. Although, both Canada and Russia claim the NWP and NSR are internal waters, which mean that they have full sovereignty, yet, that does not prevent the application of an international environmental regime. Furthermore, there is also a need to build and maintain a stable, well functioning navigation service; for example, traffic separation schemes, port reception facilities and plenty of shipping service infrastructure along the routes.

Major pollution disasters were behind adoption of new rules and regulations. For example, the *Exxon Valdez* 1989 was behind the double hull regulations and the phase out of single hull tankers[22] was accelerated after the *Prestige* accident in 2001 (European Commission [EC], 2003). Therefore, it is wise now to take proactive and precautionary measures to protect the NSR from these types of pollution, not to wait for a pollution disaster to react upon it.

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[21] *Alaska decision makers have agreed through pre-approvals that dispersants are a viable response tool* (Morris, 1998, pp. 12, 20).

[22] Appendix I contains the phase out of single hull tankers.

Chapter Five

Conclusion and recommendations

5. Chapter Five: Conclusion and Recommendations

5.1. General conclusion and a proposal for mitigation strategies

As a result of the climate change phenomenon and diminishing ice cap in the Arctic Ocean, the opportunity of using the ASR without ice breaking assistance is increasing, at least in summer seasons, in the near future. Not only reducing the trip distance between East and West, but also the availability of natural resources in the Arctic region are adding a commercial value to the ASR.

The NSR is one of the ASRs and the first to be affected by climate change that would see an increase in shipping traffic in the near future. Accordingly, new operational and accidental pollutions would be seen within the NSR. Particularly, with the modest feasibility of the ordinary pollution combating techniques in ice-infested waters the ASR and especially the NSR would need a specialised international environmental pollution combating instrument. Unfortunately, the Arctic is not included under any of the international environmental protection conventions; Article 234[23] of the UNCLOS was seen sufficient to regulate all ice covered waters all over the world.

Perhaps, Article 234 was been put in 1982, when the Arctic was not yet easily accessible by international shipping traffic, yet, under the recent climate change phenomenon the opportunity became easier. Consequently, it is time now to take suitable precautionary environmental measures such as considering the NSR a PSSA or at least a formal SA under MARPL.

Adding new areas to the list of PSSAs and SAs is open, for example, Southern South Africa was considered in 1 March 2008 as a SA under MARPOL Annex I. The Baltic Sea is another example, although, it is a SA under Annexes I, V and VI, it was classified as a PSSA on April 2004[24]. Similarly, the ASR or at least parts of it, particularly within the

[23] As per Appendix V.
[24] The Baltic Sea is the world's largest brackish water sea and home to many seabirds, *inter alia*, as a PSSA in April 2004. The birds and animal species in the Baltic sea are sensitive to oil spills and pollution, and the little exchange of water with the North Sea make it significantly vulnerable to environmental disturbances.

NSR, may be considered PSSAs or SAs. Appendix VI contains an overview proposal of new PSSA in the Northern part of Norway, as an example.

5.2. Focus on the NSR

The Arctic region is still a clean environment region compared to most areas of the world (Orheim, 2003), and it is one of the environmentally sensitive areas for many reasons that need special care and more attention. In line to what has already been done by the IMO to protect the environment in various other sea areas in the world[25], there will be a need to take precautionary environmental protection measures for the NSR, in anticipation of ship traffic increase. Consequently, there will be a need to build and maintain a stable, well functioning navigation services; for example, Traffic Separation Schemes (TSS), port reception facilities and multiple shipping services infrastructure along the route.

Adoption of such precautionary measures may include but are not limited to the following:

- Extended limit of territorial sea is possible for 20 nm. for more surveillance and environmental control;
- Vessel Traffic Service (VTS);
- TSS including AIS coverage through stations;
- Electronic Chart Display and Information System (ECDIS) to allow better tracking and monitoring vessels in the vicinities;
- Tow-vessels to be placed at strategic locations;
- Places of refuge and beaching;
- Control of exhaust emissions to air;
- Management of oily waste, sewage and garbage including reception facilities;
- Ballast-water management;

Accordingly, measures are to be taken to strengthen the safety of shipping traffic within these areas, such as establishing strictly separated shipping traffic lanes and setting up compulsory pilotage systems and mitigation measures to be adopted to protect the area from the environmental threats (World Wide Fund for Nature [WWF], n.d.).

[25] The IMO has relevant, important and practical value and a key role in controlling and reducing the operational and accidental causes of pollution. It is the UN's specialized agency for pollution protection and it is also considered a law making body, *inter alia*. Although, some of the maritime pollution prevention conventions were adopted before the creation of the IMO itself such as OILPOL 1954, the IMO used to adopt conventions and adapt amendments to reach its desired objectives. Quite few conventions and regulations have been adopted to reduce the opportunities of pollution accidents. More effort can be made to promote environmental protection in the future, such as creating new PSSAs and SAs in various sea areas of the world.

- Measures related to loading and unloading of cargo ‘such as deploying of oil containment booms around ships during cargo operations’, and
- Contingency management and planning regime including environmental risk analysis and oil-spill contingency assessment (International News and Analysis Marine Protected Areas [MPA news], 2002).

5.2.1. Implementation of PSSA Area(s) within the NSR

A PSSA has a broader and higher profile than Marine Protected Areas (MPA) and SAs offering a comprehensive approach to seek better monitoring and awareness from the shipping industry, which has been available since 1991. PSSA is an area, which needs special precaution to be taken because of its significance for recognized ecological, socio-economic, or scientific attributes that may be vulnerable to damage by international shipping activities, in order to prevent, reduce, or eliminate the threat or identified vulnerability (IMO, 2006b).

In order to create a PSSA, the concerned Member States should submit an application to the IMO - MEPC that contains information about `the NSR` vulnerability to damage from international shipping activities, in addition to the proposed associated protective measures to prevent, reduce or eliminate the identified vulnerability (IMO, 2006b). PSSAs are created in several areas around the world to reduce these threats by implementing focused regulatory instruments, such as shipping lanes, Areas To Be Avoided (ATBA), or discharge restrictions, *inter alia*. The proposal is expected to identify at least one associated protective measure and hence, if approved, the designated PSSA appears on international nautical charts (MPA news, 2002).

Appendix VII contains some general benefits and challenges that may face creating PSSAs, which may lead us to think about other available alternatives.

5.2.2. Other alternatives to PSSAs

5.2.2.1. Areas to be avoided and reporting systems

SOLAS would allow another accepted IMO alternative and a relatively quick establishment such as the TSS within a state’s EEZ. Mandatory sea lanes and navigational rules in and out of a specific area, as well as precautionary areas to be navigated with special care can be established. ATBA can also be established if needed, and it may be applied to all vessel traffic or a specific type of vessels, due to a particular danger or ecological or environmental condition. IMO approved many more ATBAs than PSSAs and measures would appear on international charts just like PSSAs, in a few months period rather than years needed for PSSA designation. For example, NSR may be treated the same like the Antarctic, where it is prohibited to discharge any oil or waste from ships under MARPOL Annexes I and V.

Furthermore, IMO may approve mandatory or voluntary vessel reporting systems that are also helping practice, such as what is applied in the Canadian part of the ASR. At least AIS tracking stations would help in improving safety of navigation, especially when combined within a TSS.

5.2.2.2.The NSR as a SA under MARPOL 73/78

MARPOL defines a SA as an area in which the adoption of special mandatory methods for the prevention of sea pollution is required for some technical reasons relating to their oceanographical and ecological condition and to their sea traffic. These SAs are provided with a higher level of protection than other areas of the sea (IMO, 2008c); consequently, along the lines of the argument presented in this paper, the NSR is worthy to be a formal SA.

The Arctic countries have voluntary agreed to implement MARPOL SAs requirements for ships sailing in the Arctic waters (Ostreng, 1999), but, that does not mean that there is no need to formally consider the ASR or at least some selected environmental potential parts of it, as SAs under the MARPOL Annexes I, II, V, and VI.

5.2.2.3.MPAs in the NSR

Banning some activities in an area is another alternative. Some sensitive places in the world may be excluded from petroleum activities, such as the Lofoten Islands in northern Norway, which were considered petroleum-free in December 2003. However, the oil industry claimed that it could exist in harmony with valuable and vulnerable environments, the Norwegian government, supported by the WWF, countered that the industry had failed to demonstrate that it could operate without threatening the environment (WWF, n.d.). The same policy may be adopted in places of the NSR, where it is seen that oil explorations and transportation accidents may be significantly severe to the environment.

5.3. What can be done

If at least the Arctic rim agreed to protect the Arctic marine environments and resources properly, a voluntary moratorium on resource exploitation in the Arctic Ocean may be adopted, until Arctic international environmental regime, perhaps under UNCLOS is completed. Such process may take a decade (MPA news, 2007). This time may be deeply needed also for more long-term studies on the NSR shipping to find out to what extent it impact the Arctic ecosystems. At that time such shipping must be subject to numerous restrictions, or in some cases new restrictions would have to be added to existing ones (Kitagawa, 2001).

The Arctic Council,[26] an existing intergovernmental forum for Arctic governments and peoples, may play an important role in securing this commitment (MPA news, 2007), and the Protection of the Arctic Marine Environment (PAME) working group can convince to the viability of applying a protection regime for the Arctic regions. These measures include coordinated actions, programmes and guidelines, complementing existing international arrangements (Transport Canada Seaway and Domestic Shipping Policy, 2005). Figure 5-1 illustrates the Arctic shipping assesment, origins, linkages, the Arctic countries and the different commisions including PAME.

[26] The PAME members include national representative of 8 Arctic Council States (Canada, Denmark (including Faroe Islands and Greenland), Finland, Iceland, Norway, Russian Federation, Sweden and United States).

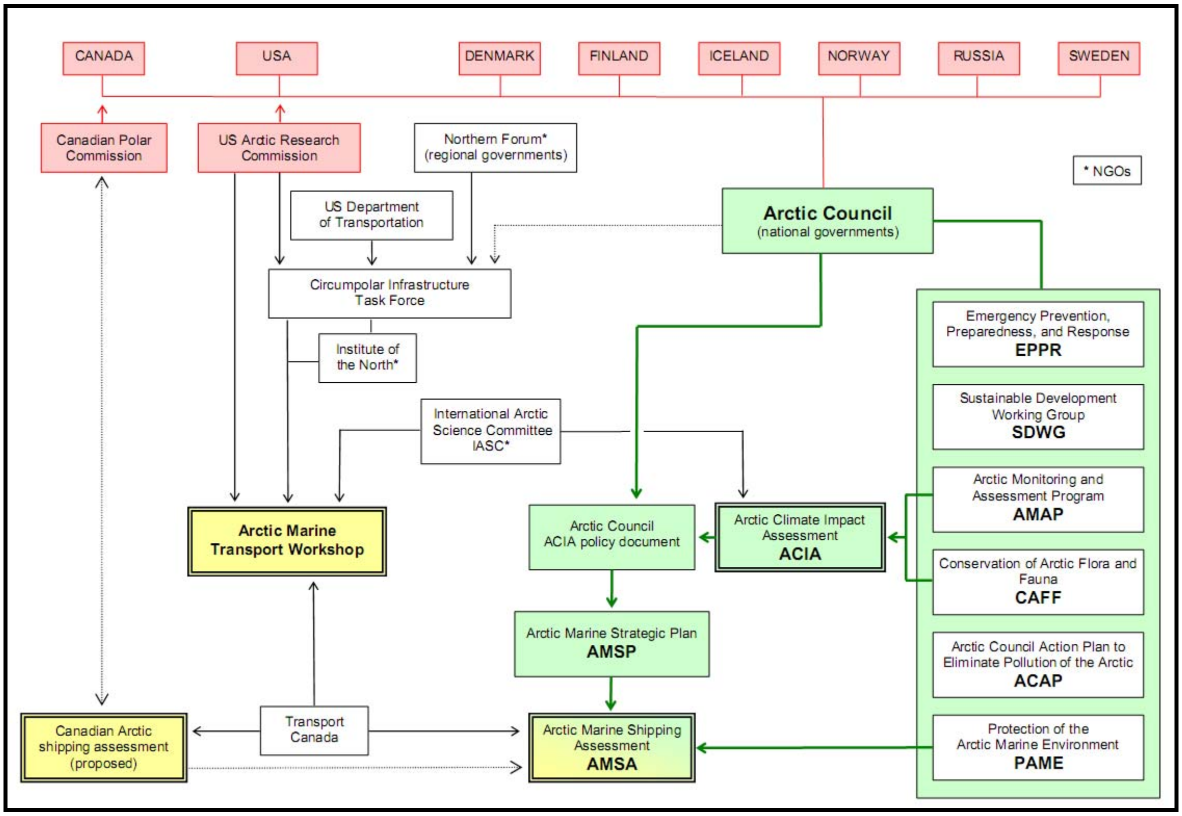

Figure 5-1: Arctic Shipping Assesment - Origins and Linkages.
Source: (Transport Canada Seaway and Domestic Shipping Policy, 2005)

In general, the newly applied regulations would include stricter rules on discharging oil/water mixtures such as 15 PPM alarm system to be fitted onboard ships, if discharging is not totally banned. Furthermore, stricter rules to regulate or to forbid the NLS discharge, in addition to strictly apply the rules under Annex V regarding the garbage disposal. Moreover, SECA regulation is needed along the NSR to reduce SOx & NOx emission similar to the Baltic and North Seas. Furthermore, highly restricted ballast discharge prohibition regulations are needed. Furthermore, all pollutants from daily activities that are not considered by the Arctic coastal states as major threats to the environment are to be included in the national regulations.

In fact, Article 234 of UNCLOS gives the right to the coastal states to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas within the limits of the EEZ (UN, 1982). Therefore, the water waste like cooking, and showering in addition to exhaust, sewage and garbage must be targeted in the new recommended NSR environmental regulations.

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Appendices

7. Appendix I: Phasing out of Single Hull Tankers

Phase out of single hull tankers:	***Year***
Category 1	• *for ships delivered in 1973 or earlier* • *for ships delivered in 1974 and 1975 2005** • *for ships delivered in 1976 and 1977 2006** • *for ships delivered in 1978,1979 and 1980 2007** • *for ships delivered in 1981 or later*
Category 2	• *2003 for ships delivered in 1973 or earlier* • *2004 for ships delivered in 1974 and 1975* • *2005 for ships delivered in 1976 and 1977* • *2006 for ships delivered in 1978 and 1979* • *2007 for ships delivered in 1980 and 1981* • *2008 for ships delivered in 1982* • *2009 for ships delivered in 1983* • *2010* for ships delivered in 1984* • *2011* for ships delivered in 1985* • *2012* for ships delivered in 1986* • *2013* for ships delivered in 1987* • *2014* for ships delivered in 1988* • *2015* for ships delivered in 1989 or later*
Category 3	• *2003 for ships delivered in 1973 or earlier* • *2004 for ships delivered in 1974 and 1975* • *2005 for ships delivered in 1976 and 1977* • *2006 for ships delivered in 1978 and 1979* • *2007 for ships delivered in 1980 and 1981* • *2008 for ships delivered in 1982* • *2009 for ships delivered in 1983* • *2010 for ships delivered in 1984* • *2011 for ships delivered in 1985* • *2012 for ships delivered in 1986* • *2013 for ships delivered in 1987* • *2014 for ships delivered in 1988* • *2015 for ships delivered in 1989 or later*

** subject to CAS compliance*

Source: (Jonsson, 2008b)

Observation: Only 7 years remaining for the last single hull tanker in service, what is explaining the boom demand on the new tanker ships building, including the ice class.

8. Appendix II: Overview on the Economic Consequences of Opening the NSR for International Shipping Traffic

The operational costs of shipping are always a subject of interest, although the capital costs take a significant part in running shipping companies. Capital costs in shipping are mainly the costs to own a ship, new or second hand, while the operational costs are related to making the ship seaworthy such as the technical expenses, manning, and insurance. Although the capital costs seem to be fixed for a single ship, the prices of ships fluctuate greatly over time and they vary enormously according to the ship's type and size. Similarly, the operating costs are also varied; for example, the insurance premiums priced on statistical probability of losing a ship is based on the vessel age, size, previous claims record, equipment type, *inter alia.* In addition to the capital and operational costs, there are also the voyage costs, which are needed to put the vessel in service such as the fuel, and port costs (Ma, 2007a). Accordingly, shipping stakeholders are considering the best economical aspect in building and managing both ships and cargo handing in ports, following the basic shipping economical concepts.

In fact, profit maximization is the objective of each commercial company; based on this fundamental desire, shipping companies are simply trying to find all available options to reduce costs and to increase the revenue (Ma, 2007a).

Based upon the economics principles the maritime stakeholders saw to increase ships speed and size and the cargo capacities and rates of the ports, which almost reached an optimal level on economy of scale. A diminishing return phenomenon appears after a certain limit of the escalated input where the added value of cost is not resulting in the same rate of output revenue. In other words, after a certain value of the inputs, the resulted outputs will not be with the same proportion as per Figure 8-1 where the profit curve increases with the increase in ships speed until it reaches approximately 19 knots then the profit starts to reduce with an increase in speed as the total cost curve goes very high (Ma, 2007b).

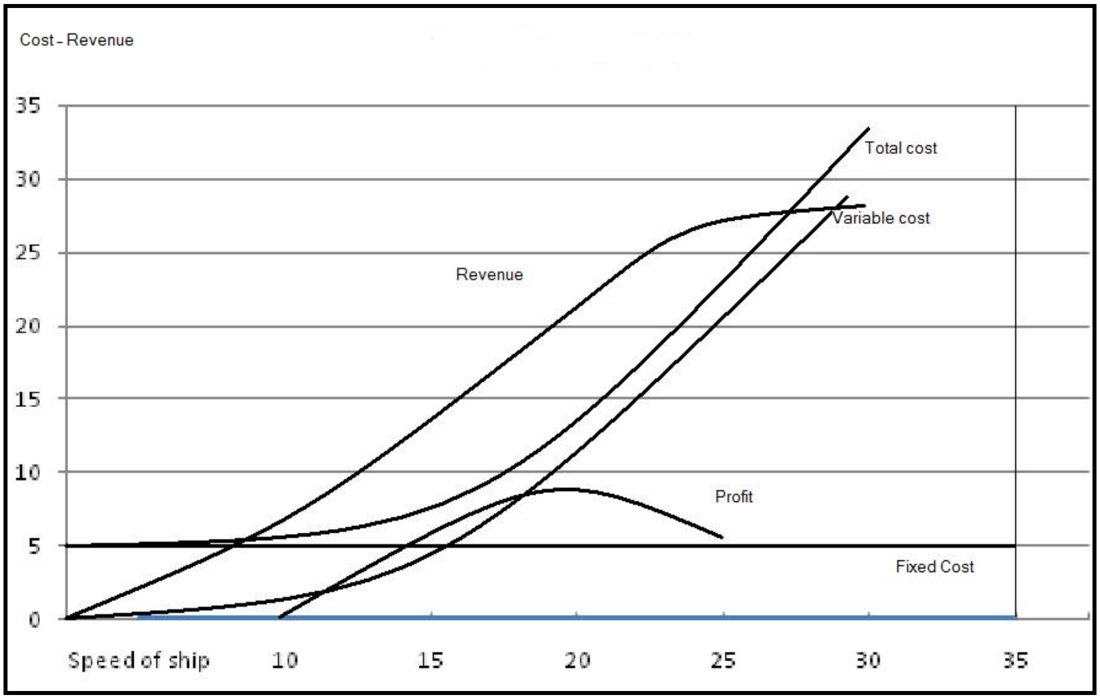

Figure 8-1: Economics of Speed and the Diminishing Return.

Source: (After Ma, 2007a; Ma, 2007b)

Accordingly, maritime stakeholders are always trying to avoid this diminishing return when deciding to build bigger and faster ships and to optimize the operating speed, or accelerate the cargo handling operations in ports. For example, a shipping company may decide to reduce the sailing speed of its ships according to the low freights and high bunker price, and vice versa. Furthermore, the super tankers in early 1986 were operating on 10 knots. But, when the freight rates rose in 1988-89 their speed escalated to 12 knots. Accordingly, high freight value cargo, such as containers, is worth faster ships to increase the amount of cargo delivered during a certain period of time (Stopford, 1997).

Even the size of the ship is determined in a way similar to the economics of speed; the bigger the ships size the bigger the profit, until a certain limit. In the diminishing return point the added value will not increase the income with the same rate (Stopford, 1997). For instance, Figure 8-2 shows the economics of size with regard to the cargo and ship costs; it illustrates that approximately 100,000 dwt is the optimum ship size in relation to the ship's cost. However, 50,000 dwt is the optimum size with regard to the cargo cost. Nevertheless, the intersection between the cargo and ship costs gives us the optimum ship size, which is nearly 100,000 dwt, as per Figure 8-2. Therefore, the added value to the ship size after 100,0000 tons would not reflect the same proportion of revenue (Ma, 2007). Accordingly, there was a need to find another way to reduce the operational cost such as speeding up the cargo handling operation in a way to reduce the port stay.

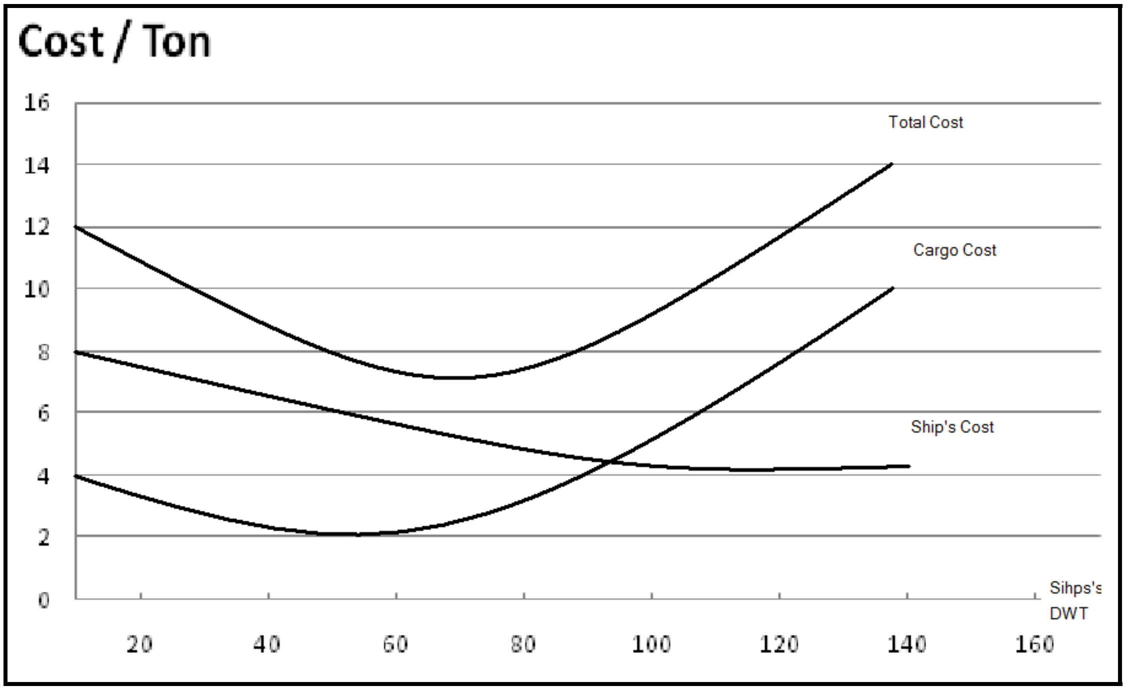

Figure 8-2: Economics of Size.

Source: (After Ma, 2007a)

Similarly, it is also wise to reduce the ships stay in ports not only because they are gaining money for sailing and not for staying in port, but also to reduce the round trip periods. The same economic principles, economy of scale and the diminishing return, definitely apply in the cargo handling operations. Therefore, there is also a certain limit where the port is to adjust the loading/discharging rates; otherwise the diminishing return would result in reducing the revenue in relation to the added value. Table 8-1 shows the optimum size of cargo gang and the effect of the diminishing return. The optimum number of persons is 7 persons and the added value would reduce average outputs in effect of the diminishing return.

Table 8-1: Cargo Handling and the Optimum Size of Gang.

No. of Persons	Tons handled	Average output
1	10	10
2	30	15
3	60	20
4	98	25
5	140	28
6	180	30
7	215	31
8	240	30
9	252	28

Source: (Ma, 2007a)

By applying these economic principles basics and to avoid diseconomy of scale in the cargo handling capacities, there is a need to find a new substitute to reduce the operational cost, such as shortening the trip distance. Normally, trip distances are fixed and well known, therefore, it is not very easy to ponder a substitute, yet, the climate change may carry a solution for such problem.

Because, navigation in the NSR requires special type and design of ship, ice class ships, this will add additional cost to the fixed capital cost but not to the operational cost, unless the passage requires ice breaker assistance, which will be negligible on effect of the climate change and melting of the Arctic sea ice.

A special design of ships and propulsion systems like the Double Acting Ships (DAS) using Azimuthing Podded Propulsion (Azipod) is preferable in such an environment (Juurmaa, Mattsson, & Wilkman, 2001).

Insurance premiums are another aspect to be considered when deciding to employ ships along the NSR as there is little international experience to determine how expensive that coverage will be. Particularly, to set proper insurance coverage more information will be needed on environmental risks, shipping services along the routes especially in the Russian part including its legislative development (Norwegian Atlantic Committee [NAC], 2006). On the other hand, new building price premiums for ice class tankers, especially the 1A has seen a reduction over the years, and hence, investment in new built tankers is seen as a good long term strategy, even in open competition market in the ice region (Duggal, 2006). Moreover, there is a great concern about the need of well trained ice crews in addition to the anticipated increase in the number of crewmembers in general and the related increase in manning costs.

To sum up, it is wise for the shipping industry stakeholders to consider using the NSR for shipping traffic as it would significantly reduce the ships operating costs and hence increase the revenues. Building ice class ships may carry certain additional costs, but that will be included in the capital cost, which is considered a fixed cost. New ships insurance premiums are expected to cover the adventures of employing ships on such routes, all of, which would create new shipping markets. In fact, climate change has introduced a new hope of reducing the escalating operating costs, particularly, as a result of high fuel prices and manning costs.

9. Appendix III: Alternatives to Managing and Exchanging Ballast Water

Figure 9-1 shows the 4 options of ballast management: (1) to retain the BW until after departing the port or the area of interest (2), to exchange the high risk water with clean open/deep sea water (3) to deliver the high risk water to a reception facility assigned by the coastal authority, and (4) BW on board treatment by the available technology. In each of these methods the ship's master should ensure the safety of the ship regarding the stresses on the hull at every stage of the exchange operation.

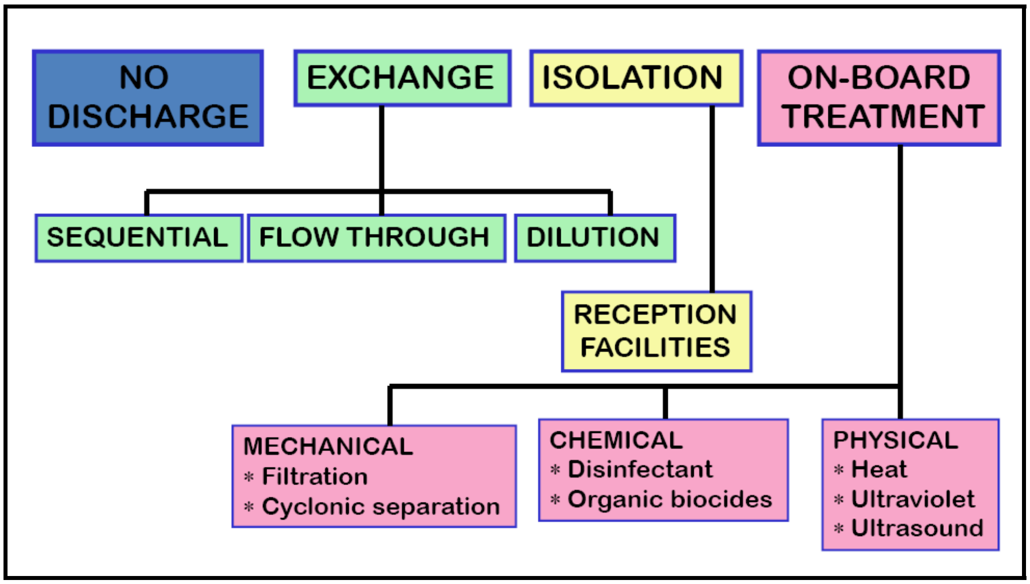

Figure 9-1: The Four Options of Ballast Management.

Source: (Jonsson, 2008b)

- **Retaining high risk BW on board:**

The first option is to retain the high risk water on board during the NSR passage, which may a threat if there was a need to pump out the BW. Navigating in ice-infested water may require usage of the ballast capabilities to assist in breaking the ice. Ice class ships and ice breakers depend mainly on their propulsion and the bow shape in breaking ice, a positive trim of one meter assists in breaking and bringing the propeller and the sea chests under the ice surface (Canada Transport, 2005). A ship with 2° trim aft in ice free water may end up with only 0.5° during ice breaking due to the downward force of the ice (World Intellectual Property Organization [WPO], 2007), therefore, loading BW aft of the centre of gravity would help in better ice breaking. By filling the ballast tanks particularly in the forward part, the weight of the bow increases in a way that enables the ship to break the ice ("Ice navigation ", 2000).

Ships unable to comply with the BW exchange rules will be forced to retain the BW on board, but they may transfer the BW amongst tanks on board (DAFF, n.d.) to change the ship's trim to allow a similar effect as ballasting. Actually, retaining an amount of BW on board is essential for winter navigation in general, as it may be used for back flushing to free the ice-blocked sea chests. In addition it may be used in re-circulating cooling water for the engine (Canada Transport, 2005). Therefore, it is better to exchange the BW of a ship before entering the NSR; otherwise, a ship would be forced to breach the requirements of the BWMC. Particularly, if the BW is considered high risk and there is a need to de-ballast the ship or a single tank for one of the reasons above.

- **Exchanging high risk water with clean open and deep sea water:**

In order to achieve 95% of the required volumetric exchange of high risk BW in Regulation D-1 of the BWMC, there are 3 tested alternatives of pumping through methods to ensure full ballast exchange as follows:

  - **Sequential exchange (empty/refill) method:**

The sequential Exchange (empty/refill) method means emptying BW tank(s) in the open sea, as per Regulation B-4, before refilling them from the deep water. Then it is to be ensured that the new contents of the ballast mix achieved contain no more than 5% of high risk BW. Yet, there are some drawbacks of this option as it may cause a severe amount of stresses on the ship hull, especially in a ballast voyage where it is essential for a ship to have a considerable amount of BW on board in order to reduce the stresses on the hull and maintain a considerable head of water above the propeller and the rudder for better steering. Moreover, BW ensures a certain air draft passes under bridges and berths under low cranes and conveyors.

In contrast, discharging BW from a double bottom reduces the stability of the ship as it reduces the metacentric height, and especially during the de-ballasting operation where a free surface effect would appear, which will increase the metacentric height loss (Derrett, 1984). Then a sloshing effect would appear between the full capacity and empty situations creating the possibility of damage to the tank sides and welding (Jonsson, 2008b). Therefore, ship masters must seriously consider those stresses and effects while planning for sequential exchange. Particularly in the NSR it is preferable to exchange the BW before entering the passage as it will be really difficult to start the operation while en route not only for the technical reasons mentioned above, but also because of the shallow water and coastal navigation and the difficulty in complying with the BWMC requirements in Chapter Three.

  - **Flow-Through Method:**

In order to overcome the stresses and stability problems, the Flow-Through Method is another alternative, where clean deep sea water is pumped in each tank with a capacity equivalent to 300% of a tank's full volume to achieve an acceptable 95% volumetric exchange. Even if the process is started with a partly empty tank, the 300% capacity is still necessary[27] (DAFF, n.d.). Yet, ship masters must bear in mind when

[27] Counting for the 300% starts from the commencement of pumping in operation not from the over flow.

using this method that the tank sides and tops are subject to high loads, which they may not be designed for (Jonsson, 2008b), especially BW tanks could be subject to over pressure during this operation (DAFF, n.d.).

- **Dilution method (simultaneously pump in / pump out):**

This method of BW exchange is suitable mainly for tankers as they are fitted with additional piping/pumping arrangements, which may allow BW to be pumped in from one side of the tank and another BW line is used for pumping out simultaneously. To reach the 300% of each tank's full capacity it is necessary to use 2 separate BW lines and different pumps for an acceptable exchange (DAFF, n.d.).

- **Delivering the high risk water to a reception facility assigned by the coastal authority:**

In fact, complying with the requirements of Article 5 of the BWMC, and ensuring avoidance of any high risk BW exchange during a NSR crossing, the coastal authorities are supposed to offer adequate port facility services to receive the high risk BW from ships to reduce the possibility of exchanging it during passage.

- **Ballast water on board treatment:**

Other technological methods of managing BWs may be accepted, provided that they perform the same desired standard of protection of the environment, human health, and resources, and are approved in principle by the MEPC. During the MEPC(52), 6 papers were submitted providing information about technologies under development or already developed. Among these, there are 13 available potential technologies as shown in Table 9-1. A filtration or hydrocyclon, ultraviolet light combination and various filtration options seem to have an outstanding value as primary options (Sassi, Viitasalo, Rytkönen, & Leppäkoski, 2005).

Table 9-1: Potential BW Management Technologies Identified in the MEPC 52.

Manufacturer	Technology
Alfa Laval & BenRad, Sweden	Filtration + AOT (Advanced Oxidation Technology)
Alan Taylor & Associates, Australia	Heat treatment
Browning Transport Management .Aquahabistat. (AHS), USA	De-oxygenation
De-oxygenation	Chemical disinfection
Environmental Technologies Inc., USA	Filtration + sonic radiation
Hamann New Modular BWM Systems, Germany	Hydrocyclon separation + chemical Disinfection
Hyde Marine Inc., USA	Filtration + UV
Marenco Group, USA	Filtration + UV
Marine Technology Institute Co., Japan	Physical disruption/killing
MEPI, USA	Filtration, Bromine and Oxidation
NEI Treatment Systems, LLC, USA	De-oxygenation
Nutech O3 Inc., USA	Ozone
OptiMarin AS., Norway	Hydrocyclon separation + UV

Source: (After Sassi et al., 2005)

The future may see more advanced technologies to perform the required environmental standards (Sassi et al., 2005). The BW standard to be achieved by such technology is defined in Regulation D-2[28] in Table 9-2. Perhaps the on board BW treatment is one of the most appropriate methods of BW management in the NSR

[28] In Regulation D-2, the requirements for the BW Performance Standard have been defined as the following:

‘’ 1 Ships conducting Ballast Water Management in accordance with this regulation shall discharge less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension and less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations described in paragraph 2.

2 Indicator microbes, as a human health standard, shall include:

.1 Toxicogenic Vibrio cholerae (01 and 0139) with less than 1 colony-forming unit (cfu) per 100 millilitres or less than 1 cfu per 1 gram (wet weight) zooplankton samples;

.2 Escherichia coil less than 250 cfu per 100 millilitres;

.3 Intestinal Enterococci less than 100 cfu per 100 millilitres.`` (IMO, 2005).

due to the short passage time and the coastal navigation, therefore, researchers and scientists may need to keep searching for the most effective and efficient treatment plants.

Table 9-2: BW Performance Standards.

Section D: standards of ballast water management	
Reg. D-1: Ballast water exchange standard	• 95% volumetric exchange; or • 3 times pumping through the volume of each tank
Section B: Management and control requirements for ships	
Reg. B-4: Ballast water exchange	• 200 nm and 200 depth, or if not possible • 50 nm and 200 m depth, or if not possible • In areas designated by the port state • Ballast water exchange shall only be undertaken when safety of the ship is guaranteed.

Source: (Jonsson, 2008b & IMO, 2005)

Among the other alternatives, ships applying Regulation D-1 of the convention shall exchange at least 95% of the BW volume, and that may happen by pumping through a tank's volume for 3 times (IMO, 2005), thereby deeming the BW on board to be low-risk (DAFF, n.d.). In fact, all the BW management alternatives have negative consequences as the fuel consumption would increase dramatically due to using extra BW pumps, which in turn will significantly affect not only the operation cost of ships, but also will cause more emissions of hazardous gases, SOx & NOx and CO2, included in the exhaust gases (Jonsson, 2008b). Accordingly, Article 195 of UNCLOS may be breached, as one kind of pollutant or hazardous material would be converted into another.

Moreover, ballast tanks need heating systems to prevent the water from freezing (International Association of Classification Societies [IACS], 2007 & Kitagawa, 2001), which means again more cost and gas emissions. Managing or exchanging frozen BW is impossible and the expansion of water volume when frozen would affect the strength of a tank (Jonsson, 2008b).

10. Appendix IV: Special Areas Under MARPOL

Special area means a sea area where for recognized technical reasons in relation to its oceanographical and ecological condition and to the particular character of its traffic the adoption of special mandatory methods for the prevention of sea pollution by oil is required.

Table 10-1 shows the world special areas under the MARPOL convention that is not including non of the Arctic regions.

Table 10-1: Special Area Under MARPOL

Special Areas	Adopted[29]	Date of Entry into Force	In Effect From
Annex I: Oil			
Mediterranean Sea area	2 Nov 1973	2 Oct 1983	2 Oct 1983
Baltic Sea area	2 Nov 1973	2 Oct 1983	2 Oct 1983
Black Sea Area	2 Nov 1973	2 Oct 1983	2 Oct 1983
Red Sea area	2 Nov 1973	2 Oct 1983	*
"Gulfs" area	2 Nov 1973	2 Oct 1983	1 Aug 2008
Gulf of Aden area	1 Dec 1987	1 Apr 1989	*
Antarctic area	16 Nov 1990	17 Mar 1992	17 Mar 1992
North West European Waters	25 Sept 1997	1 Feb 1999	1 Aug 1999
Oman area of the Arabian Sea	15 Oct 2004	1 Jan 2007	*
Southern South African waters	13 Oct 2006	1 Mar 2008**	1 Aug 2008
Annex II: Noxious Liquids			
Antarctic area	30 Oct 1992	1 July 1994	1 July 1994
Annex V: Garbage			
Mediterranean Sea area	2 Nov 1973	31 Dec 1988	*
Baltic Sea area	2 Nov 1973	31 Dec 1988	1 Oct 1989
Black Sea Area	2 Nov 1973	31 Dec 1988	*
Red Sea area	2 Nov 1973	31 Dec 1988	*
"Gulfs" area	2 Nov 1973	31 Dec 1988	1 Aug 2008
North Sea	17 Oct 1989	18 Feb 1991	18 Feb

			1991
Antarctic area (south of latitude 60 degrees south)	16 Nov 1990	17 Mar 1992	17 Mar 1992
Wider Caribbean region including the Gulf of Mexico and the Caribbean Sea	4 July 1991	4 April 1993	*
Annex VI: Prevention of air pollution by ships (SOx Emission Control Areas)			
Baltic Sea	26 Sept 1997	19 May 2005	19 May 2006
North Sea Area	22 July 2005	22 Nov 2006	22 Nov 2007

Source: (After IMO, 2008c & Kleverlaan, 2008)

Observation:

Neither the Arctic Ocean nor any of its sear or routes are included in the list, while the Antarctic, a similar environment to the Arctic is included in Annex I, II, V.

11. Appendix V: Particular Sensitive Sea Areas in the World.

Table 11-1 shows the PSSA all over the world that not includes any of the Arctic regions.

Table 11-1: Particular Sensitive Sea Areas in the World with the action taken to protect the environment and the MEPC resolution.

Area	Proposing State(s)	Associated Protective Measures[30]	MEPC resolution
Great Barrier Reef	Australia	IMO-recommended Australian system of pilotage; mandatory ship reporting system	MEPC 30, September 1990 resolution MEPC.44(30)
Archipelago of Sabana-Camaguey	Cuba	Area to be avoided	MEPC 40, September 1997 resolution MEPC.74(40)
Sea Area Around Malpelo Island	Colombia	Area to be avoided	MEPC 47, March 2002 resolution MEPC.97(47)
Marine Area Around the Florida Keys	United States	Areas to be avoided; mandatory no anchoring areas	MEPC 47, March 2002 resolution MEPC.98(47)
Wadden Sea	Netherlands, Denmark, Germany	Mandatory deep water route	MEPC 48, October 2002 resolution MEPC.101(48)
Paracas National Reserve	Peru	Area to be avoided	MEPC 49, July 2003 resolution MEPC.106(49)
Western European Waters	Belgium, France, Ireland, Portugal, Spain, and the United Kingdom	Mandatory ship reporting system	MEPC 52, October 2004 resolution MEPC.121(52)
Torres Strait as an Extension to GBR PSSA	Australia and Papua New Guinea	IMO-recommended Australian system of pilotage; two-way route	MEPC 49, July 2003 resolution MEPC.133(53)
Canary Islands	Spain	Areas to be avoided; traffic separation systems; recommended routes; mandatory ship reporting system	MEPC 51, March 2004 resolution MEPC.134(53)

Area	Proposing State(s)	Associated Protective Measures[30]	MEPC resolution
Galapagos Archipelago	Ecuador	Area to be avoided; mandatory ship reporting system; recommended tracks	MEPC 51, March 2004 resolution MEPC.135(53)
Baltic Sea Area	Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden	Traffic separation schemes, deepwater route, areas to be avoided, mandatory ship reporting system, MARPOL Special Area; MARPOL SO_x Emission Control Area	MEPC 51, March 2004 resolution MEPC.136(53)
Papahānaumokuākea Marine National Monument	United States	Areas to be avoided; recommended/mandatory ship reporting system	MEPC 56, July 2006 (approved in principle) To be formally designated by MEPC 57

Source: (After IMO, 2008b & Kleverlaan, 2008)

Observation:

Neither the Arctic Ocean nor any of its route or sea are included in the PSSAs.

12. Appendix VI: A Proposal of a new PSSA in the Barents Sea

There is a project under, which a proposed Area as PSSA in northern Norwegian Sea and the Barents Sea designated as a PSSA, as indicated by a red line in the map in Figure 12-1. The Areas indicated in gray are suggested to be as a traffic separation scheme while the areas hachured in red are of high environmental vulnerability (Stepanov et al., 2005).

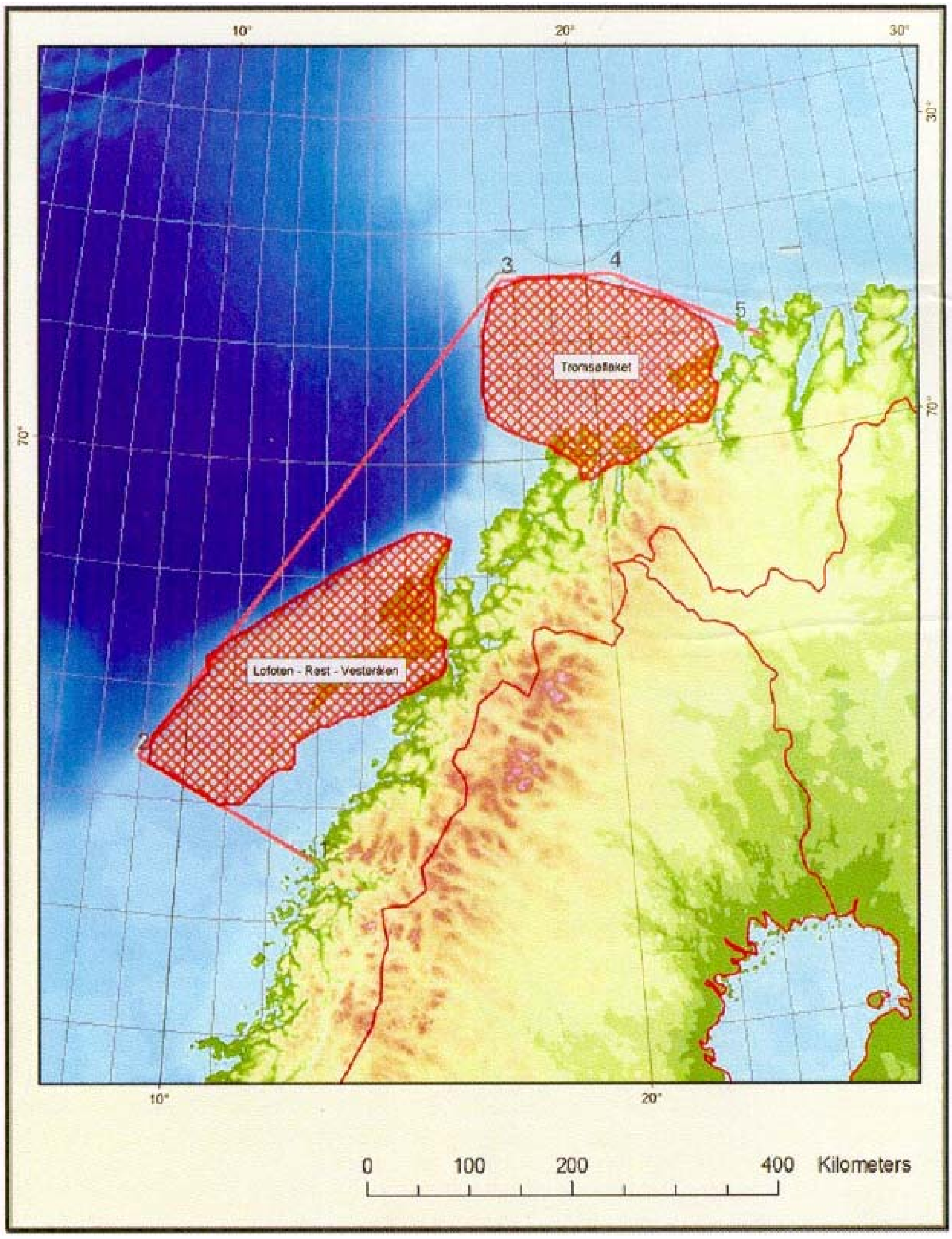

Figure 12-1: A Proposal Project to Designate a PSSA in the Norhtern Norwagian Sea and the Barents Sea.

Source: (Stepanov et al., 2005)

13. Appendix VII: General Benefits and Challenges of Applying PSSA Status:

13.1. General benefits of creating PSSA

Designation of a PSSA will send a message to shipping stakeholders that such an area has been deemed one of the most sensitive worldwide sea areas. PSSA instruments would also allow for extraordinary measures, far beyond existing IMO measures, such as, speed restrictions, prohibitions on ballast water discharges within the PSSAs, or air pollution emission limitations, *inter alia*. For example, the inner route of the Great Barrier Reef Marine Park (GBRMP) in Australia has a compulsory pilotage system for vessels over 70 meters in length that is not an ordinary IMO measure, yet, it approved such practice within a PSSA (MPA news, 2002).

Furthermore, associated protective measures in PSSAs may include ATBT, banning of dumping of waste, installation of port reception facilities, anchoring prohibition areas, and enhancement of surveillance and monitoring for illegal discharges. Moreover other technologies may be applied to minimize the impact of shipping on sensitive marine areas and species. Furthermore, mariners may take special care when transiting a PSSA. A comprehensive approach to the regulation of shipping activities, and a combination of domestic and IMO measures can provide wider protection extended areas beyond the territorial sea. When designating a PSSA, ecological criteria are also to be given the highest priority for more protection of the marine environment (Stepanov et al., 2005).

Moreover, by being identified as a PSSA on the international charts, navigators are to take extra care while navigating through the NSR. Coastal states are to take extra additional protective measures to best address the risks associated with international shipping in the area (MPA news, 2002). Adoption of ships' routeing and reporting systems near or in the area that can be adopted under SOLAS would significantly enhance the navigational safety within the NSR. The area may be listed on the World Heritage List, that would give a potential consideration (IMO, 2006b).

13.2. PSSA implementation challenges

Compliance with the PSSA requirements is a challenge for any coastal state as some of the associated measures such as ATBAs, *inter alia*, requires domestic regulatory actions that may be time consuming and have to adhere to the law making body even before bringing it to the IMO.

Hence, several IMO committees must approve a submitted proposal before final designation. PSSA guidelines were updated in 2001 to clarify the program and the proposal submission process, as the original 1991 guidelines were overly complex, and mixed PSSAs with the concept of SAs (MPA news, 2002). The 2001 guidelines came as well in response to a series of oil-tanker disasters such as the *Patmos* in 1985, the

Haven in 1991, the *Evoikos* in 1997, and the *Erika* in 1999, *inter alia* (Stepanov et al., 2005). Yet, there is no need to wait for more disasters to happen to react to them; it is better to set a precautionary environmental instrument.

However, PSSA designation can pose elimination to some human activities and threats, yet, if a country in the region is negatively affected by the applied regulations, then good reasons may be submitted to cease the designation of a PSSA. Therefore, strong proof must be supplied, showing that adequate protection cannot be provided in any other ways. The Russian point of view states that PSSAs can only be designated in exceptional cases where it can be shown that designation is the only tool to provide adequate protection (Stepanov et al., 2005).

For example, WWF-Russia is working with different governmental organizations on creation of a new system of protected areas across Russia, including MPAs, PSSA, fisheries refuges, and ATBA. However, it is hard to convince governments to limit human activities in areas where oil and gas fields overlap. The idea of designating the ASR is as one large protected area or even developing a series of specially protected nature areas associated with sensitive biotopes, that in some cases may result in large protected areas. For example, a national park in the Novosibirskie Islands in northern Siberia may be as large as the Great Barrier Reef in Australia. However, the idea may be unrealistic due to a very strong bureaucracy and a lack of interdepartmental links and cooperation, when speaking about Russia, to the limit that a single institution, may be able to block any initiative if it does not fit its particular interests (MPA news, 2007).

14. Appendix VIII: Tables of Arctic Weather Conditions and the Impacts on oil Combating Technique

Tables 14-1 to 14-3 show the potential impacts on oil spill response with regard to different weather condition.

Table 14-1: Typical Arctic Conditions and Potential Impacts on Oil Spill Response Options with Regard to Sea Ice.

Conditions	Potential impacts on spill response			
	General constraints	**Mechanical recovery**	**In-situ burning**	**Dispersants**
Sea ice[3]	Ice can impede access to the spill area, making it difficult to track and encounter oil. Remote sensing techniques are being improved and refined to detect oil under and among sea ice, but they are not yet mature. Ice can impede or limit vessel operations, especially for smaller work boats. Boats without ice-capable hulls should not operate in heavy ice conditions. Slush ice may clog seawater intakes or accumulate in vessel sea chests.	Containment boom can be moved, lifted or torn by ice. Skimmer encounter rate may be reduced by ice chunks, and skimmers and pumps may clog. Limited manoeuvrability may prevent or delay accurate skimmer or boom deployment. Attempts to deflect the ice from recovery areas may also deflect the oil. Ice must be separated from recovered oil. Ice may provide natural containment. Reinforced vessel hulls or ice scouts may be required. Ice movement can be unpredictable or invisible. Vessel operators must be experienced in the ice conditions of the area.	Certain ice conditions (i.e. slush ice) may reduce burn effectiveness or impede ignition. Fire boom deployment may become difficult or impossible. Residue recovery requires vessel support. Ice may provide natural containment, and burning in ice leads may be possible.	Oil under ice is inaccessible to dispersant application. Ice can dampen required mixing energy. Dispersants generally less effective at lower salinities. In most regions, dispersants are not considered an operational technology for use in sea ice.

Source: (WWF, 2007)

Table 14-2: Typical Arctic Conditions and Potential Impacts on Oil Spill Response Options with Regard to Sea Ice with Regard to Wind and Temperature.

Conditions	Potential impacts on spill response			
	General constraints	Mechanical recovery	In-situ burning	Dispersants
Wind	High winds can make it difficult to deploy effectively the crew, vessels, equipment required for a response. High winds can make air operations difficult or unsafe.	High winds can move boom and vessels off station or tear boom off the anchor point (Potter, 2004).	In-situ burning is not generally safe or feasible in high winds.	Accurate application of dispersants is difficult in high wind conditions.
Temperature	Prolonged periods of sub-freezing temperatures can impact personnel safety, or require more frequent shift rotations. Extreme cold temperatures may be unsafe for human operators. Cold may cause brittle failure in some metals. Cold air may freeze sea spray, creating slick surfaces. Icing conditions may make vessels unstable.	Skimmers freeze up. Freezing sea spray can accumulate on boom and cause it to tear, fail or overwash. Increased oil viscosity makes it difficult to recover and pump.	Extreme cold temperatures may make ignition more difficult or ineffective, and may cause burn to slow or cease.	Cold temperatures and increased oil viscosity may reduce dispersant effectiveness.

Source: (WWF, 2007)

Table 14-3: Typical Arctic Conditions and Potential Impacts on Oil Spill Response Options with Regard to Sea Ice with Regard to Visibility and Sea state.

Conditions	Potential impacts on spill response			
	General constraints	Mechanical recovery	In-situ burning	Dispersants
Limited visibility (including months of darkness in far northern areas)	Any condition that reduces visibility may preclude or limit oil spill response operations, particularly any involving aircraft or vessel operations. Limited visibility may make it difficult or impossible to track the spill location and movement. Fog banks make vessel or aircraft operations extremely dangerous.	Accurate deployment of vessels and equipment requires sufficient visibility to deploy and operate equipment. Work lights may be used during darkness, if safety allows.	In-situ burning is not recommended during darkness (USCG, 2003). Aerial ignition and/or aerial monitoring require visual flight conditions.	Aerial application and/or aerial monitoring requires visual flight conditions. Vessel application requires visual confirmation of slick location.
Sea state	Waves can have varying impacts depending on their form. Short, choppy waves generally have a greater impact on a response than long ocean swells. Currents and tidal changes may also affect response operations.	Booms and skimmers do not function well at high sea states. Equipment must be suitable (rated) for typical sea states. Fast currents, changing tides and short period waves can make it difficult to keep boom and vessels on station. It is dangerous to manoeuvre booms and skimmers in rough seas. A common rule-of-thumb limitation for boom is a 2-3m significant wave height.	High sea states make containment and ignition difficult and potentially unsafe.	High sea states typically enhance the effectiveness of chemical dispersants to disperse the oil.

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Source: (WWF, 2007)

Observation:

There is no particular perfect oil spill response solution ice-infested water. In-situ burning and mechanical recovery technologies have some limited effectiveness in ice-infested waters. Only, chemical dispersants are considered promising[31] for treating oil spills in ice-infested waters; but further research and practical study are needed to establish their real applicability.