Servicing the Arctic

Report 1: Design requirements and operational profile of an Arctic Offshore Support Vessel

Arctic Minor Team

Literature Survey

TU Delft
Delft University of Technology

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Abstract

Background The Dutch maritime industry has only limited knowledge about Arctic engineering, in spite of a growing market and interest by the oil and gas industry. This literature survey is the first in a series of three reports to develop a concept design of an Arctic Offshore Support Vessel (AOSV). The purpose is to give a perspective on Arctic shipping with a specific focus on offshore platform support and to provide a design framework for AOSVs. The information in this report is based on technical papers from the Internet, contact with different companies and Arctic courses from the Aalto University in Espoo, Finland.

Results In general oil companies have a rising interest in the natural resource in the Arctic region. Next to their spending in Research and Development (R&D), also shipyards, suppliers and operators are eager to increase development for the harsh environments. This study shows, that every region in the Arctic has different weather and infrastructure conditions as well as different national laws and regulations. Next to that, operations in the harsh environment have high impact on the performance of the ship and its crew.

This report gives an overview on technology available for operating in the Arctic, such as double acting hull, azimuth thrusting and other ice breaking technologies. Increasing research in Arctic engineering results in new, more reliable technologies and opens the possibility to design more advanced Arctic vessels. A big challenge in Arctic engineering is to have a optimal compromise between open water and ice behavior.

Due to higher costs for among others R&D, material and equipment an AOSV will be more expensive. Operators, on the other hand, are also willing to pay more for them, because of the high amount of natural resources in the Arctic region.

The expected focus of the industry is on Baffin Bay, Barents Sea and Beaufort Sea. This study discusses the estimated oil reserves, existing infrastructure and environmental impact. Also the operations an AOSV is likely to perform are given.

Conclusions This report gives a wide overview on Arctic shipping. For most of its subjects more in depth research is needed to get a better understanding of the effects and specific demands of the Arctic. Nevertheless it is possible to develop AOSV that can operate in those three areas mentioned. But in the end a perfect AOSV cannot be made, it can only be optimized for some of the predefined requirements as stated in the operational profile.

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Preface

A minor gives the possibility to focus on a certain subject, or to broaden your vision. A lot of standard minors are available on a various amount of subjects. We, five maritime bachelor toptrack students at TU Delft, decided to create our own unique minor, the 'Arctic Minor'. The minor is a open part in the bachelor phase of the study Maritime Engineering wherein students gain a total of 30 European Credit Transfer and Accumulation System (ECTS). This is a total of 840 hours of work per person.

Our point of view was that we wanted a challenging, up to date minor, hands-on experience with problems that are going on in real life. Furthermore, we would like to develop social, networking and English language skills.

The Arctic Minor was started up September 2012, but the first steps were already taken a year earlier in October 2011. Meanwhile we prepared everything, like the project and sponsorship to our stay in Helsinki. We also attended several seminars about arctic issues.

The subject that was chosen is Arctic Engineering. We want to investigate the engineering of an Arctic Offshore Supply Vessel, with focus on subjects such as machinery, hydromechanics and construction. From September to December 2012 we were in Finland to study at Aalto University in Helsinki to follow courses dealing with the arctic subjects gathering information which is used in this and next reports. These courses take up 15, or half, of the points that are gained in a minor.

The other 15 points consist of a project is in cooperation with Dutch companies and the TU Delft. Our partners are DAMEN, MARIN and DNV. The project is divided in three parts. First a literature study is performed to gather information and can be found in this report. The goal of this research is to set up design requirements and an operational profile of an Arctic Offshore Supply Vessel. After this part we move to Damen to continue the project. At this place we are going to study the existing Damen concepts and finally we will make an own conceptual design. Finally we will use the topic of arctic engineering in our final intensive bachelor research project in a later half year of our study.

This literature study was based on a detailed planning which was approved by all the involved parties. Based on this planning the report is written. We started with marginal knowledge of the Arctic, so the first step was to gather information about the geographical areas and the market. After that the operations of Arctic Offshore Support Vessels were researched. Meanwhile, we decided to write part I to give an overview, the report is a literature study, so no actual conclusions are included, but a summary is made in part I

One of the problems was to write the report concise and terse, while discussing all the relevant information. Some chapters are rewritten after some feedback sessions. Another goal was to put as much information in schemes and tables to present the information clearly.

Our resources were, among others, reports of research institutes, class societies, oil companies and websites of the industry. All the information used is quite recent, because the interest in the Arctic research is increasing.

Part I gives you insight in the contents of this report, it gives a general overview. More detailed information about the subjects mentioned in part I can be found in part II.

We hope that this report contains the information you expect to find in it.

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It is a great pleasure for us to thank everyone who helped us setting up the Arctic Minor and writing the first report. We would like to thank our supervisor Peter de Vos for the support and guidance he showed throughout the whole Arctic Minor, and especially his guidance by setting up the literature research.

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Finally we are obliged to thank each other for the pleasant collaboration.

Those who cannot understand how to put their
thoughts on ice
should not enter into the heat of debate.
-Friedrich Nietzsche

Glossary

CH_4	Methane.
CO_2	Carbon dioxide.
NO_x	Nitrogen oxide.
SO_x	Sulfur oxide.
$	United States Dollar.
ABB	Asea Brown Boveri, Swiss based multinational in the power and automation technology areas.
ABS	American Bureau of Shipping, Class Society.
Act	A product resulting from a decision by a legislative or judicial body.
AHTS	Anchor Handling Tug and Supply vessel.
Albedo	Reflectiveness of snow.
AOSV	Arctic Offshore Support Vessel.
Barrel	An oil barrel is equal to 159 L.
bbl	Barrel. An oil barrel is equal to 159 L.
BCC	Body centered cubic.
BV	Bureau Veritas, Class Society.
CCS	China Classification Society, Class Society.
circadian rhythm	"Cyclical 24-hour period of human biological activity" - Britannica Encyclopedia.
Class Notation	Notation to determine applicable rule requirements for assignment and retention of a certain category of ships.
ClassNK	Nippon Kaiji Kyokai, Class Society.
Code	Collection of laws or regulations pertaining to a specific activity or subject.

CPP	Controllable Pitch Propeller.
DAT	Double acting tanker.
DBT	Ductile-to-Brittle Transistion.
DBTT	Ductile-to-Brittle Transistion Temperature curve.
DNV	Det Norske Veritas, Class Society.
DP	Dynamic Positioning, computer-controlled system to maintain a vessel's position and heading.
ECN	Energy research Centre of the Netherlands.
EER	Escape, Evacuation and Rescue.
EEZ	Exclusive Economic Zone.
ETA	Estimated Time of Arrival.
FCC	Face centered cubic.
FDD	Freezing degree days.
FPSO	Floating Production, Storage and Offloading platform for oil or gas.
Frostbite	Damage to a part of the human body as a result of exposure to freezing temperatures.
FSO	Floating Storage and Offloading vessel.
FY	First year ice.
GA	General Arrangement of a ship.
GL	Germanischer Lloyd, Class Society.
Guideline	Recommendation giving guidance on how to behave in a situation.
Hypothermia	An abnormally low human body temperature.
IACS	International Association of Classification Societies.
IMO	International Maritime Organization.
ISO19906	International Standard for Arctic Offshore Structures.
JIP	Joint Industry Project.
KR	Korean Register of Shipping, Class Society.
Lankford coefficient	The Lankford coefficient (also called Lankford value or R-value) is a measure of the plastic anisotropy of a rolled sheet metal. .

Law	A set of rules generally regarded and accepted as binding in relations between states and nations.
LR	Lloyd's Register, Class Society.
MARPOL	International Convention for the Prevention of Pollution from Ships.
MMBTU	A standard unit of measurement used to denote the amount of energy in fuels, 1 BTU = 1.055 kJ.
MSV	Mining Support Vessel.
MY	Multi year ice.
N	North.
ND	No data available.
NORSOK	Norsk sokkels konkurranseposisjon, The competitive standing of the Norwegian offshore sector.
OGP	International Oil and Gas Producers Association.
Operational Profile	Quantitative characterization of how a vessel will be used.
OSV	Offshore Support Vessel.
PAME	Protection of the Arctic Marine Environment.
PM	Particular Matter - Tiny pieces of solid or liquid matter associated with the Earth's atmosphere, usually part of the emissions of a ship.
Polar low	"A polar low is a small, but fairly intense atmospheric low pressure system found in maritime regions, well north of the polar front. Its typical diameter is 100-500km and average life span is 18 hours. The polar low gives strong and rapidly changing winds and dense showers of snow or hail, and is generally more unpredictable than the larger and more common synoptic lows." - DNV.
PRS	Polski Rejestr Statkow, Class Society.
PSV	Platform supply vessel.
Regulation	A rule, principle, or condition that governs procedure or behaviour.
RFD	Reginald Foster Dagnall, Founder of the lifeboat company RFD Beaufort.
RINA	Registro Italiano Navale, Class Society.
ROV	Remotely Operated underwater Vehicle.

RS	Russian Maritime Register of Shipping, Class Society.
Rule	Authoritative statement of what to do or not to do in a specific situation. It clarifies, demarcates, or interprets a law or policy.
S	South.
SAR	Search And Rescue.
SBM	Single Buoy Mooring Inc..
SINTEF	Stiftelsen for industriell og teknisk forskning, Norwegian research organization.
SIRC	Seafarers International Research Centre.
SOLAS	International Convention on the Safety of Life at Sea.
STCW	International Convention on Standards of Training, Certification and Watch keeping for Seafarers.
Tier	A rank or class.
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, Dutch Organization for Applied Scientific Research.
Transition temperature	The temperature where an amount of 20 (USA) of 27 (Europe) J is lost in a Charpy test.
UNCLOS	United Nations Convention on the Law of the Sea.
UNOLS	University-National Oceanographic Laboratory System.
USA	United States of America.
USGS	United States Geological Survey.
WWF	World Wildlife Fund for Nature.

Introduction

In the Arctic are vast amounts of valuable resources. Gathering these materials requires special knowledge about the extraction itself in Arctic conditions and the special support to cope with the environment. The global demand for resources is increasing, while large and relatively accessible oil and gas fields can no longer be exploited cost-effectively. Therefore, exploration and production are moving to new, more challenging locations. The Arctic is such a location: About 30% of the world's undiscovered gas and 13% of the world's undiscovered oil may be found in the Arctic, mostly offshore with water depths of less than 500 meters [1]. The access to these resources is easier than at the Antarctic, where the conditions are even harsher and large scale ice breaking is impossible, due to the fact that the Antarctic has more and much harsher glacier ice and consists of land instead of water [2, 3]

The oil and gas industry is seriously interested to operate in the Arctic, followed by other industrial branches. Research is going on by lots of companies and institutes all over the world to ensure safe and efficient operations in the Arctic. Companies specialized in Offshore Support Vessels (OSV) have to think about the adaptations that have to be made and the challenges that have to be met when operating in the Arctic regions. Arctic designing is always a compromise between the efficiency in ice and open water.

Target

The total study on Arctic Offshore Support Vessels (AOSV), is composed of three reports. This is the first report of three, a literature study on the present knowledge, explaining principles and a reference point for the following two reports. The second report will be a comparison of three state of the art offshore vessels operating in ice. The last and third report gives a possible solution for specific requirements for an AOSV, which have yet to be set. This first report, the literature study is needed to gain knowledge about the Arctic and to give a overview of the available literature.

By means of a literature study two purposes will be achieved: 1) To give a broad perspective on Arctic shipping with specific focus on offshore platform support and 2) To provide a design framework for AOSVs.

These two goals are met by the following main question: "What are the design requirements and operational profile of an Arctic Offshore Support Vessel?".

Scope of Work

There are several definitions of the Arctic, in this report it is defined as the region above 66.3° north. Therefore this report is about the Arctic and some Sub-Arctic regions, the Baltic, Caspian Sea and the Sea of Okhotsk, because there is also ice in winter time. The subjects covered in this report include: companies, projects, technologies, environment and geography of the Arctic. These are reviewed in this report and are not limited to the definition of the Arctic.

Anyone with basic shipbuilding knowledge should be able to read this report. More specifically, the knowledge of a bachelor maritime engineering student.

When information was available hard numbers are mentioned for, for instance, performance rates. However, such information is not always public or even available. It will be mentioned but not further explained. Most literature is found on the Internet, mainly because of the recent and fast developments. Most of the literature is from 5 years ago or more recent.

Structure

Because of the large size of the report, two parts are set up. Part I is a combination of all the information gathered in the literature survey. A brief overview is given about the market in chapter 1, existing technologies and Arctic risks and conditions in chapter 2 and design considerations of AOSVs in chapter 3.

Part II is a more comprehensive explanation of all the different topics covered in the literature survey. This part gives a more complete view on the Arctic as the general ice features in chapter 4 and the geographical Arctic areas with each its conditions in chapter 5. Chapter 6 deals with the additional risks when operating in the Arctic. Also the concerns of environmental organizations are discussed. The legislation is covered in chapter 8, to explain which rules should be abided when operating in the Arctic. Chapter 9 deals with the history of ice breaking vessels with the involving innovations and solutions. Special care should also be given to the human factor when operating in the Arctic, chapter 7 deals with this topic. The comprehensive market survey is given in chapter 10 followed by a study about the feasibility of Arctic projects in chapter 11. Chapter 12 is an important chapter since it combines the information from previous chapters to give the design requirements and considerations about Arctic Offshore Support Vessels. The final conclusion and initial design operations are given in the conclusion, chapter 13.

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Part I

Overview of Arctic offshore issues

Chapter 1

Market Overview

To determine the operational requirements of an AOSV, the market has to be known. According to some market research three areas in the Arctic are of main interest for near future development: the Baffin Bay, the Barents Sea and the Beaufort Sea. Licenses are already sold, projects are going on and they have high estimated natural reserves of oil and gas. Future operations are to be performed in these areas. The Barents Sea has the best weather conditions to operate compared to the Baffin Bay and the Beaufort Sea. However, the other areas are also feasible to take into consideration, especially in combination with a certain operational sceanario, for instance seasonal operations. (12-1)

This chapter gives an broad overview of the possible market for an AOSV. Firstly, the main players in the market of Arctic offshore operations are mentioned. Secondly, an overview of current offshore projects in the Arctic is given. Finally, the economical feasibility study is summarized, explaining why operation in the Arctic is profitable.

This chapter is an overview of other contents of this report. Therefore references to other chapters in part 2 are given throughout this chapter.

1-1 Main players

This section discusses the main players of the Arctic. Only oil companies, shipbuilders, governments and environmental organizations are mentioned in this chapter since other companies as subcontractors will follow them. The specific goals, influences and prospects of all the different parties are shown in more detail in chapter 10.

Oil Companies There are several oil companies that show interest in the Arctic. Shell is highly interested in going to the Arctic. The focus of Shell is on the Beaufort, Chukchi Seas and Sakhalin. Gazprom is also involved in one of the Sakhalin projects and is the major stockholder in the Stockman project, together with Total and Statoil. Statoil also has activities in the Baffin Bay. (10-1) West Greenland is an area with high potential, there is no infrastructure yet, but this gives a lot of opportunities.

Shipyards and builders The major shipbuilders that build ships with ice class IA or higher include: Arctech, Keppel and STX Europe. Arctech is a shipyard that is responsible for producing about 60% of all the icebreakers. Keppel started going into the Arctic market in 2008 and has built two icebreakers, four rescue vessels and the first ice-class FSO in the Caspian region. STX is a shipbuilder who is focusing on the Arctic offshore market, and is moreover shareholder in Arctech and Aker Arctic, an Arctic testing and design company. (10-3 10-4)

Governments Governments can and have big influence. For instance, the Russian government is a big factor in the activities above Russia, such as the Russian part of the Barents Sea. At the moment they are motivated to explore and drill for oil and gas [1]. They claim to be the owner of the North-East passage, however this is still being disputed. Even though the Stockman field is not owned by the government, they are capable of stopping the project completely.As shown in chapter 8 ships have to abide by the Russian rules to sail in their Exclusive Economic Zone (EEZ). Also the government of USA is a big factor in the activities in the Beaufort and Chukchi Seas, since these areas are partly in their EEZ. As in Russia the USA have their own national legislation which has to be followed. One of the goals of the USA is to not be dependent on the middle-east for oil. This is one of the reasons they encourage Shell to continue their efforts [2]. (10-8)

Environmental organizations Besides the industry, environmental organizations are also interested in the Arctic. The WWF is active to protect the Arctic from the effect of marine, oil and gas issues and tourism[3]. Greenpeace sees four major threats in the Arctic region: melting, oil drilling, industrial fishing and conflict among Arctic nations [4]. Both organizations share the opinion that an oil spill is the biggest problem when going to the Arctic. (10-9)

1-2 Current projects

In this section the large influential projects in the Arctic are mentioned (10-2). More details about these and more current projects can be found in chapter 5 for weather overviews, table 5-14 for ports, table 10-2 for projects, chapter 9 for ship types and technical solutions, section 12-4 for offshore activities and appendix A for charts.

Stockman The Shtokman field (also known as Stockman) is located in the Barents Sea. The exploration drilling is done and the wells testing has been done. However at the moment, the project has been suspended because of the high costs in combination with the low gas prices. At the moment the plan is to transport the oil and gas from the field using sub-sea pipelines. The big difficulties are the distance to the shore, sea depth and the depth of the resources.

Varandey Varandey terminal is located near the coast of the Pechora sea. This is a transport terminal for oil from several fields on Russian's mainland. To reach this transport terminal a double acting tankers are used. At the moment no new exploration activities are planned here. The closest port is Naryan-Mar which has an airport, bunkering possibility and repairs but no hospital. This area has difficulties with stormy winds, wave heights and ice build up.

Prirazlomnoye The Prirazlomnoye field is also located in the Pechora Sea. Production from this and nearby fields via 40 wells is planned to start in 2012 from a gravity based platform. This oil will then be transferred out of the area by ice breaking tankers via a floating storage platform and thereafter with regular oil tankers. The closest port is also Naryan-Mar.

Sakhalin The Sakhalin projects are located in the Okhotsk Sea. They consist of Sakhalin-I and Sakhalin-II. The exploration of both projects is finished and they are producing oil. The biggest difficulties are pack ice, severe waves and earthquake risk.

Canada All the projects in Canada are close to Newfoundland. They are all already in production, and their biggest difficulty is ice bergs.

1-3 Economic feasibility

Operating in the Arctic involves several additional costs due to the harsh weather and ice conditions, remoteness and the need for safe operations. Figure 1-1 shows these additional cost factors for operating ships in the Arctic in an overview. (11)

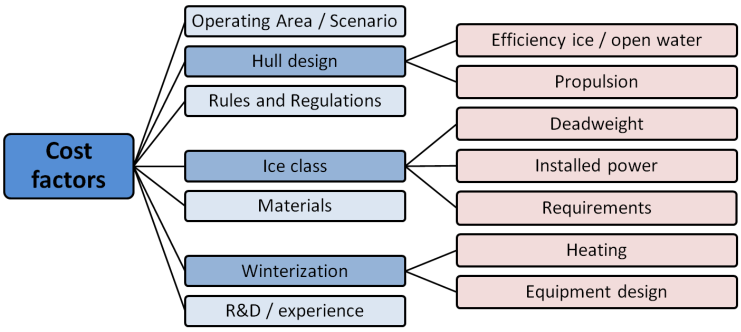

Figure 1-1: Additional cost factors of operating in the Arctic

The cost factors showed are either production or operational costs. For instance, a ice capable hull has less efficiency in open water than a conventional hull, and therefore higher operational costs. And an ice going vessel needs ice strengthening for which more steel and working hours are used.

Figure 1-2 shows the different driving factors which explain why companies are interested in the Arctic.

The estimated existing natural reserves, with respect to the global reserves with their market prices, in combination with the changing environment, have led to the booming interest in the Arctic. At the moment the oil price is in the range of $80 to $110 which means that operating in the lower Arctic regions becomes feasible and companies will be able to make profit on the operations in the Arctic.

Together with the oil and gas industry, subcontractors and research institutes develop new methods and concepts for the Arctic regions to make safe operations possible. An example of this is the Arctic Operations Handbook JIP of the Dutch industry, which is currently under development.

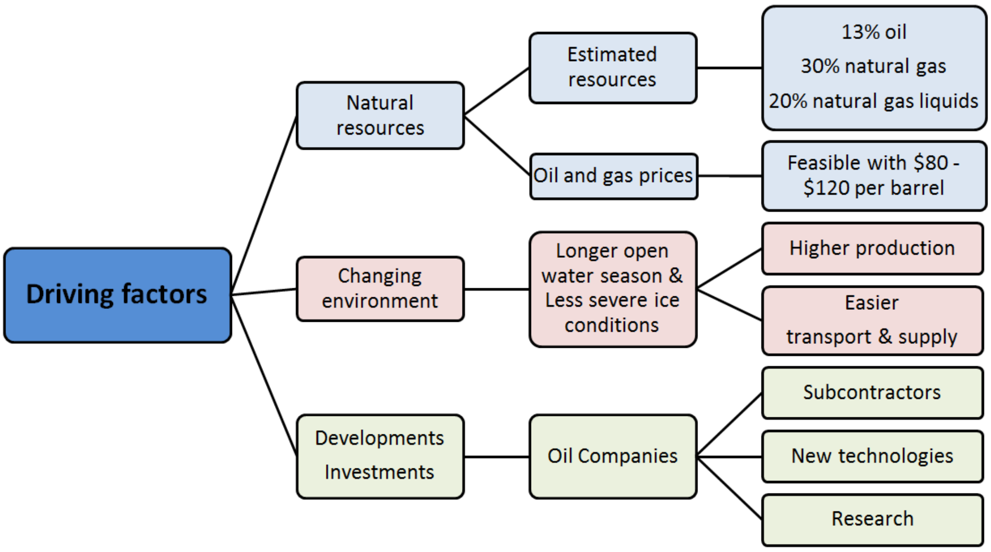

Figure 1-2: Driving factors to operate in the Arctic

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Chapter 2

Overview of Arctic Shipping

The amount of ships navigating in the Arctic is limited compared to open water navigation. The requirements for vessels in the Arctic are different. For most ice-going vessels the shape of the hull is designed to break the ice and special propulsion measures have to be taken for optimal ice navigation. In this chapter the causes and solutions for these and other difficulties of Arctic shipping are summarized.

Technologies used in the Arctic are explained first. Secondly, the causes and solutions for human failures are explained. The third and final section deals with the risks of and for the Arctic.

This chapter is an overview of other contents of this report. Therefore references to other chapters in part 2 are given throughout this chapter.

2-1 Icebreaker technology

An overview of icebreaker technologies is given in this section. The technologies are divided into propulsion, hull shape and others technologies.

2-1-1 Hull shape

The following list indicates some of the hull technologies.

- **Bending** By breaking the ice by bending, less energy is needed to sail trough the ice compared to crushing. Effective bending can be accomplished by making a 50 to 60 degree angle of attack. (9-2-1)

- **Ice knife** With an ice knife the vessel can cut through ice at certain parts of the hull to prevent for instance ice sliding underneath the hull. (9-2-4)

- **Double acting hull** With this kind of hull, the stern from the vessel is designed to sail through ice. The main advantage is that, because the vessel can sail backwards through ice, the bow can be designed to sail effectively through open water. (9-2-1)

2-1-2 Propulsion

The propulsion technologies from the last years, and their advantages are listed below.

- **Nuclear power plant** Energy density from the fuel that is used. (9-2-3)
- **Diesel electric** High torque at low speed, which is very useful for an icebreaker. (9-2-3)
- **Azimuth thruster** 360° rotating capability, improved maneuverability and decreased turning circle. (9-2-2)
- **Bow propellers** Milling the broken ice in smaller pieces and flushing the ice away to reduce ice friction resistance. (9-2-2)
- **Bow thruster** In general bow thrusters are not used in the Arctic, but they are installed for open water operations. Often a azimuth truster is used, which is more effective. (9-2-2)

2-1-3 Other technologies

There are also some technologies which are not specifically for the hull shape or for the propulsion, these technologies include:

- **Airbubling** This system decreases the friction by injecting air. (9-2-4)
- **Polymer coating** This coating decreases the friction. With an unpainted hull the friction coefficient is between 0.2 and 0.3, a low friction paint can reduce this to 0.05 to 0.17. (9-2-4)
- **Multi functionalism** Icebreakers have nowadays more functions than breaking the ice: the missions of icebreakers are mingling with offshore supply/support vessels. (9-2-4)

2-2 Human factors

In the Arctic, next to hazard on the ship and to the environment, seafarers are at higher risk. Table 2-1 gives an overview on hazard and performance-influencing factors and their effects on seafarers. (7)

There are multiple ways to reduce the effects of these factors as shown in figure 2-1.

Table 2-1: Hazard and performance-influencing factors and their effects on Arctic seafarer's. Based on [1, p. 2-5]

Factor/ Effect on seafarer	Slipping, Tripping, Falling	Falling objects	Manoeuvring/ navigation difficulties	Shifting cargo	Lifesaving equipment not assessable	Fatigue	Freezing injuries	Decreased human performance	Low Morale	Sunburn/ Slow blindness	Isolation	Communication problems	High level of Stress
Ice accretion on the ship's structure	●		●										
Ice accretion on deck and overhead	●	●		●	●								
Sea ice conditions			●			●							
Low Temperatures						●	●	●					
Cold Water Immersion								●					
Precipitation and fog	●						●						
Sea states	●		●	●		●							
Atmospheric pressure systems			●										
Extremes of daylight and darkness						●		●	●				
Glare and ultraviolet light			●							●			
Morale						●					●	●	
Remotness			●			●							
Noise and Vibration						●						●	●

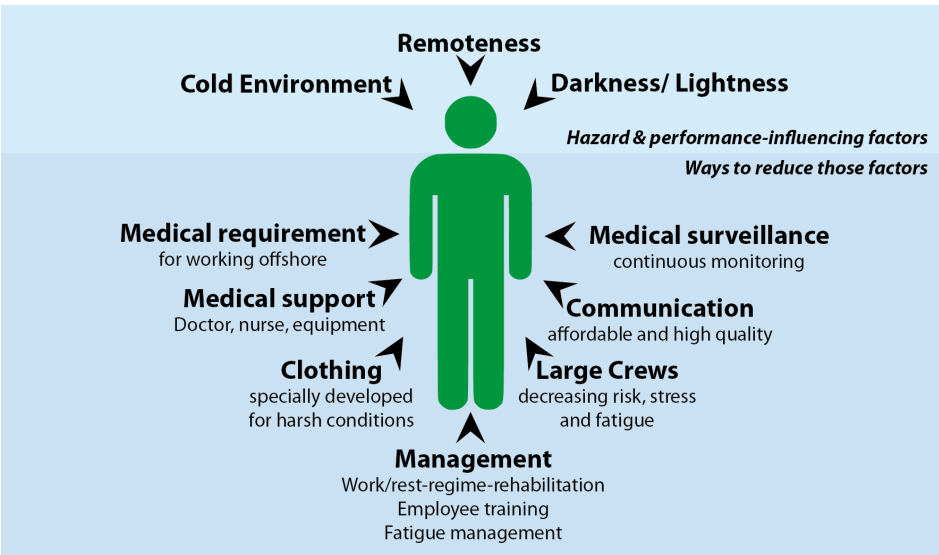

Figure 2-1: Hazard and performance-influencing factors and ways to reduce those factors of an Arctic Seafarer. Own work, based on [2, p. 64]

2-3 Arctic risks

Operating in the Arctic brings risks imposed by the Arctic and risks for the Arctic. Risk can be divided in probability and consequences.
The following direct and incidental hazards are most dangerous for the vessel.

1. **Ice accretion** This is the formation of ice on a vessel[3]. It adds weight to the ship, decreasing its stability. Mainly a problem for smaller vessels. (6-1-1)

2. **Ice damage** Due to unexpected harsh ice conditions in combination with insufficient ice strenghthening, ice damage to the hull and being entrapped in ice could be incountered. (6-1-1)

3. **Collision and Grounding** The weather conditions, the existence of icebergs, the remoteness and the lack of a sufficient navigational data [4] form an additional hazard to navigation errors. (6-1-1)

4. **Beset** Beset means that a ship gets trapped in ice. This can happen due to thick ice or pressure ice. (6-1-1)

For each hazard the probability of occuring and the consequences of that event to be analysed to get the risk involved. When a vessel is subjected to one of the hazards above, there are possible consequences involving the environment and people on board. This could lead to an oil spill or loss of life. The characteristics of the Arctic environment (sea ice, cold temperatures, darkness etc.), increase the consequences of these events and limit the cleanup and rescue options. (6-1-1)
There are also some direct environmental risks, like sound, gases and PM. The sound may interfere with the sound mamals make for communication and the gases that are emitted when using a ship may have an effect on the environment. (6-1-2) In general it can be stated that the consequences in the Arctic are higher, therefore the probability needs to be reduced to get acceptable risks of operating in the Arctic.

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Chapter 3

Supplying the Arctic

Offshore operations in the Arctic have to be supplied by AOSVs. These vessels can have various tasks and equipment to deal with. Because of the great variation in requirements, design choices have to be made. From the final choice of operational requirements the AOSV can be designed, which brings its own challenges and solutions.

The first section gives an overview of possible requirements of an AOSV. The combination of the requirements and technologies available is made in the second section.

This chapter is an overview of other contents of this report. Therefore references to other chapters in part 2 are given throughout this chapter.

3-1 Requirements of an Arctic Offshore Support Vessel

As already mentioned the industry concentrates on three areas within the Arctic circle: Baffin Bay, Barents Sea and Beaufort Sea. The information about these areas can be found in tables 10-2 and 12-1. In the Sub Arctic region the focus is mainly on Sakhalin and South Greenland. Information on these areas can be found in table 10-2

Table 3-1 gives an overview of the requirements that belong to operations with their additional class notations. (12-4)

There are also operations that combine activities listed in table 3-1. Important factors that go together with these operations are winterization and ice strengthening issues, EEZs and their legislation, environmental awareness and a qualified and trained crew. Moreover, the vessel, with its hull form and propulsion system, has to be designed to perform the operations efficiently.

Table 3-1: Overview of offshore support operations

Offshore operations	Explanation	Technical challenges in the Arctic
Ice management	Reducing ice loads for floating installation (12-2)	Design for heaviest ice conditions in that region, iceberg towing, general emergency support.
Towing	Towing of floating objects	Higher bollard pull, winterized towing winch.
Anchor handling	Total process of placing and replacing anchors	Ice capable DP system, winterized towing winch.
Supply	Transport of project cargo and personnel transfer	heated deck areas and tanks.
Underwater operations	Needed for research, maintenance or exploration motives	ice-strengthened Moonpool, little or no ice under the hull.
Seismic operations	Used to get an estimate of the properties of the subsurface of the earth, widely in use for oil exploration	short streamers or ice buoy, external barge with equipment included
Oil spill Recovery	The vessel must be capable of oil spill recovery	At the moment of writing there is research going on to develop methods for recovery of oil in ice.
Emergency operations	Escape, Evacuation and Rescue (EER), fire fighting and medical treatment	Rescue and fire fighting services to offshore installations.

3-2 Challenges and solutions

The Arctic is a harsh environment and to operate there you need to be well prepared. This section gives an overview off what is needed to be prepared and will give some recommendations for OSVs in ice. To define the challenges an operation area needs to be chosen. This choice brings consequences as shown in figure 3-1.

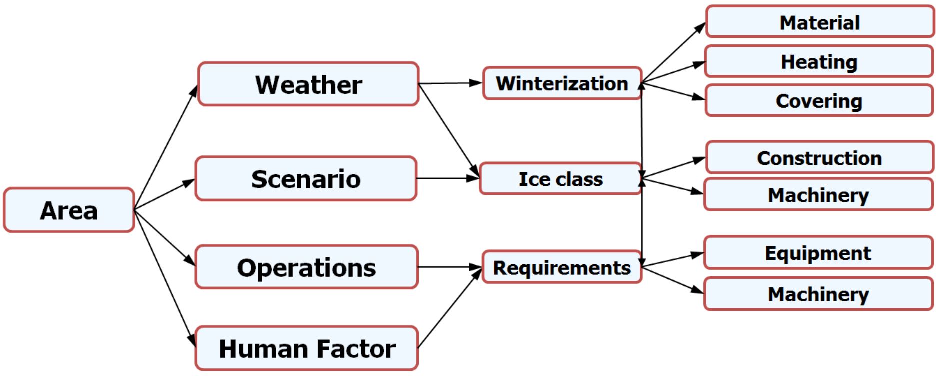

Figure 3-1: Flow chart of the impact an area has on the Design

An example of a machinery solution is the use of azimuth thrusters, they are nearly always more advisable than conventional propellers as can be seen in subsection 9-2-2. On the winterization subject, covered decks could be a solution because they greatly improve the workability.

Part II

Important factors for Arctic Offshore Support

Chapter 4

Ice Regimes

In this chapter the nature of sea ice will be discussed. The forming of the ice itself and the properties of this material will not be addressed. For more information on this topic view the lecture slides of TU Delft course Arctic Engineering or Aalto University course Ice Mechanics[1]. First the ice will be divided by age and movement type. The following sections each cover a specific ice feature in detail and these definitions will later on be used to explain the weather conditions. Table 4-1 gives an overview of the terms that will be dealt with.

4-1 Age of the ice

Ice can be classified by age. The reason this is useful is because older ice is stronger. The main cause for this is decreasing salinity which allows the ice to be more dense. For more information on this consult [1, 2]. Two kinds of ice are defined this way, first-year ice (FY) and multi-year ice (MY). Sea ice is considered FY as soon as it reaches a thickness of 30 cm[3, WP4]. This first year ice can reach a thickness up to 2.5 meter. When first-year ice survives the summer it will become multi-year ice. The group of multi-year ice is further split up in second year ice en multi-year ice. Old ice usually has a thickness between 1.2 and 5.0 m[3, WP4].

Table 4-1: Common ice features

First Year (FY) Ice	Multi Year (MY) Ice	Glacial Ice
Level ice	Ice floes	Ice islands
Ice floes	Ice ridges	Icebergs
Rafted ice	Rubble fields	
Ice ridges		
Rubble pile		
Rubble fields		

4-2 Movement and concentration

Ice can be further defined according to the movements and the concentration. In this report there will be two main types, drift ice and landfast ice. Drift ice is continuously moved by currents and wind, while landfast ice is attached to land and does not move at all. If the ice is drifting, a certain notation is used to denote the concentration. This notation uses a fraction of ten, with 10 out of 10 being the maximum, for instance: "The ice floe has a concentration of 7/10". When the ice reaches a concentration of 10/10 it can either be consolidated or not. Consolidation occurs when loose ice freezes together. As can be expected, this ice has a much greater strength than unconsolidated ice.

4-3 Level ice

Level ice occurs when growing sea ice is left undisturbed. It consists of ice with a fairly uniform thickness. This feature is found mostly on landfast ice. Level ice is often used in calculations of resistance in ice and can sometimes also be found in ship contracts. When this occurs it is usually used as a design condition defining the speed of the vessel in a certain thickness level ice. Like trials in open water, it is not realistic to assume the ship will often operate in these conditions.

4-4 Ice floes and rafted ice

Ice floes are defined as: "any relatively flat piece sea ice 20 m or more across (individual feature)"[4, 1]. They are subdivided further by the following types:

Table 4-2: Ice floes classification

Type	Size
Giant	> 10 km
Vast	2-10 km
Big	500-2000 m
Medium	100-500 m
Small	20-100 m

these floes can sometimes slide over each other under influence of winds and currents. When this happens the ice will look similar to figure 4-1 and is called rafted ice. This seems like a harmless process, but it will effectively double the average ice thickness locally. More importantly it is usually not visible at all.

4-5 Rubble pile and field

Rubble piles are accumulations of broken ice blocks. These are usually formed by natural or man-made obstructions like offshore platforms. Fields of rubble are generally formed by ice layers colliding and cover large areas of the sea.

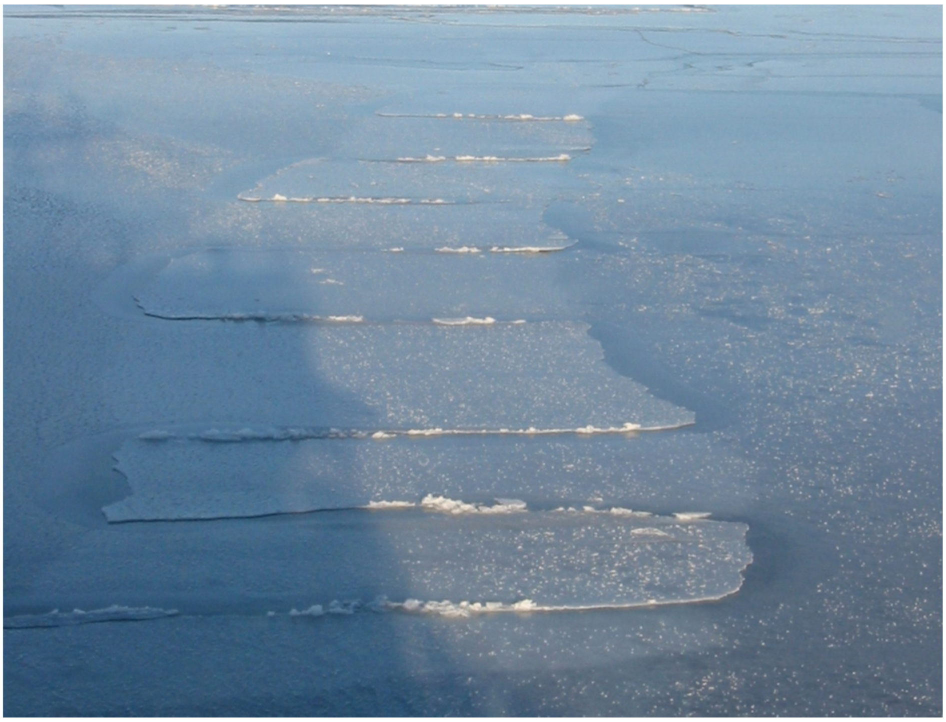

Figure 4-1: Rafted ice [1]

4-6 Ice ridges

Ice ridges are formed when two ice features collide. They essentially form the same way as rubble fields, but instead of breaking on multiple places the ice continually breaks on one place making one "ruble line". "A ridge is a linearly extended pile of broken ice blocks with a sail and a keel extending above and below the water line with a triangular-shaped cross section"[5, Ice mechanics], as shown in figure 4-2. As shown in the figure the keel of the ridge can be about 5 times as large as the sail. As time passes, the ridge becomes more than a pile of ice blocks. Because the openings between the rubble are relatively small, they freeze very fast. This causes a consolidated layer to form in the ridge that can be a lot thicker than level ice next to the ridges.

4-7 Ice islands and Icebergs

Ice islands and icebergs are formed by glaciers. The ratio of underwater and mass and height compared to above water can vary greatly and depends on shape, origin and composition. This ratio can vary from 1:1 to 1:7 making it hard to predict the mass with just the sail visible [3]. Icebergs can be classified as shown in table 4-3. Weathered bergs reflect radar pulses very bad and are therefore hard to detect, especially the bergy bits and growlers.

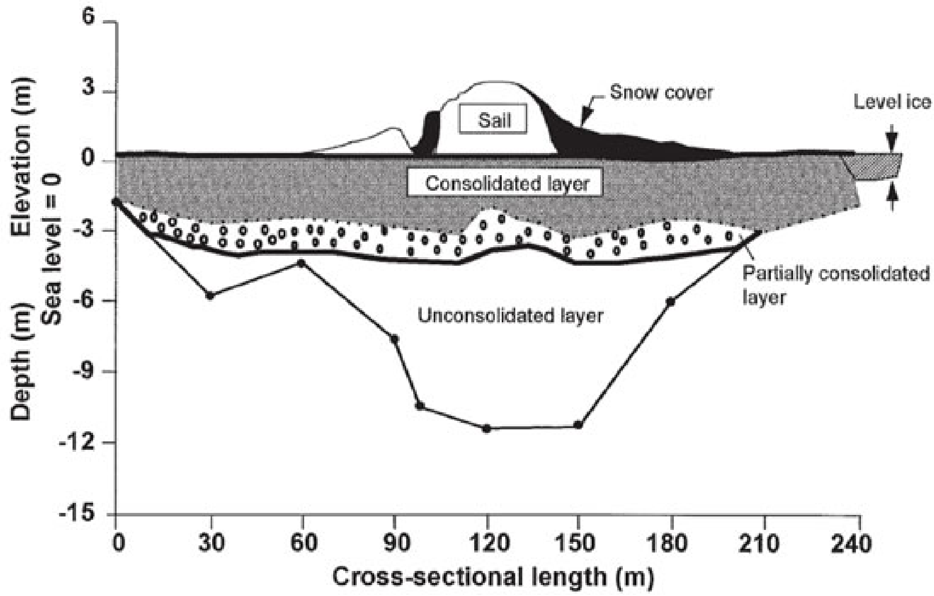

Figure 4-2: Pressure ice ridge [1]

Table 4-3: Iceberg classification

Type	Sail height [m]	Mass [t]
Growlers	< 1.5	
Bergy bits	1.5 to 5.0	< 5400
Small bergs	5.0 to 15	5400 to 180000
Medium bergs	15 to 45	180000 to 2000000

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Chapter 5

Geographical Areas

In this chapter the areas in the Arctic will be defined. This will be done using maps and explanations found in section 5-1. These maps give all sorts of information about the areas like depth, resource probability and port locations. There are several definitions in existence for the arctic. The IMO at the moment defines the arctic as shown in figure 5-1.

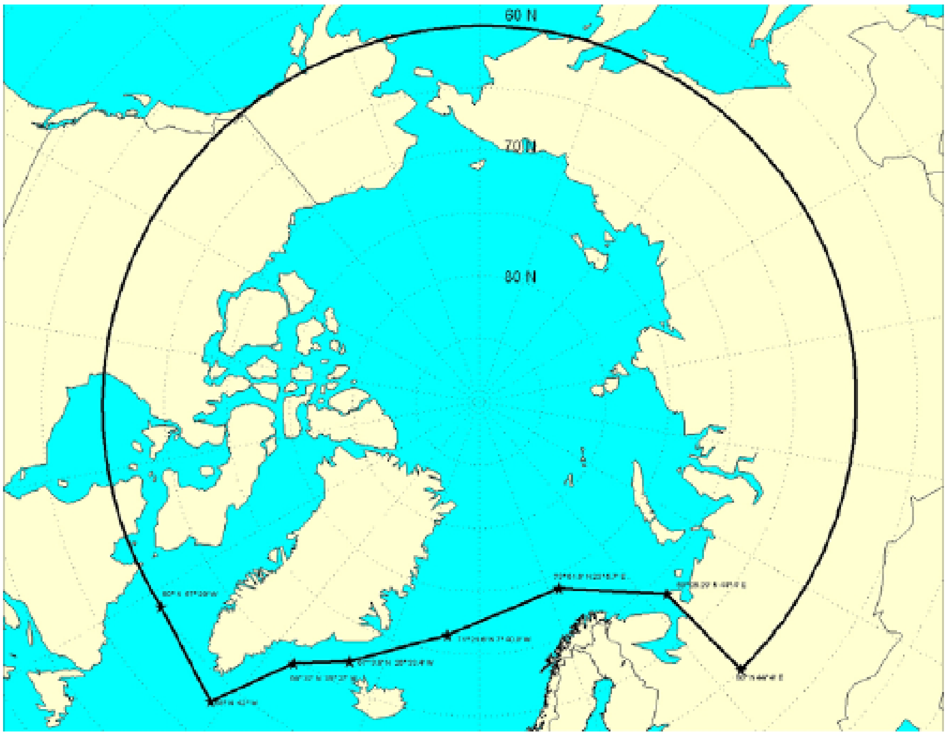

Figure 5-1: Geographical definitions of the Arctic by IMO [1]

However, they note that this definition is not complete as it does not include boundaries for "protections to avoid negative consequences of shipping impacts" from the Arctic Council [1].

Because this definition is not complete yet a different one will be used in this report. In this case the polar circle will be used, this is the circle of latitude 66° 33" N. This circle is the southern limit of the midnight sun, where there is at least one day each year when the sun does not set [2].

In this chapter different maps of the Arctic are given, the weather of each Arctic region is discussed and finally the existing ports in the Arctic are given.

5-1 Maps

The following maps will provide information on Arctic areas. They contain the following information:

- General map defining Arctic areas (figure A-1)
- General map defining EEZs (figure A-2)
- General map showing ports (figure A-3)
- Resource map, showing probability of oil/gas in Arctic areas (figure A-4)
- Depth chart, showing depth lines in Arctic areas (figure A-6)
- Environmental map, defining areas with endangered species
- Weather maps and tables, showing important weather data such as winds, waves and ice conditions (section 5-2).

All maps except for the weather maps can be found in the appendix A, the weather maps will be used in section 5-2. In the final section there is an overview of the harbours in all arctic areas. This will be done with table 5-14.

5-2 Weather

In this section the weather of relevant areas near the Arctic circle is specified in more detail. The section is meant to give an impression in the conditions in the arctic areas. These conditions are the most severe and maximum conditions you can expect in year round operations. There are some areas are not mentioned in this chapter because they are not in the Arctic circle. For a more detailed overview of the weather conditions of the Arctic and sub-Arctic areas the ISO 19906 [3] can be consulted.

Freezing degree days In this chapter the term "freezing degree days" will be used, Freezing Degree Days (FDD) is a measure of how cold it has been for how long. It is simply daily degrees below freezing summed over the total number of days the temperature was below freezing. However, since this is about sea ice, the freezing temperature is around $-1.8\,^{\circ}$C. This is illustrated by table 5-1 made by the National Snow & Ice Data Center[4].

Table 5-1: FDD example

Total Days Below Freezing	Average Daily Temperature	Degrees Below Freezing	Cumulative FDD
1	$-5.8\,°C$	$4\,°C$	4
2	$-2.8\,°C$	$1\,°C$	5
3	$-11.8\,°C$	$10\,°C$	15

5-2-1 Baffin bay

Baffin bay is located to the east of Greenland as seen in figure A-7. A part of the Davis Strait in the Labrador Sea is also included in this area of focus, which has less severe ice, but harder open water conditions. The area is defined north of 70 °N. The water depth in this area varies from 100 to 400 m. It has harsh ice condition with both first- and multi-year ice floes. The multi-year ice finds its way into this area from the Lancaster and Smith Sound. The number of icebergs found annually in the region is over 2000 and their mass can go up to an annual maximum of 20×10^6 million tonnes. Further information can be found in table 5-2.

Table 5-2: Weather data Baffin Bay

Parameter	Average annual value	Unit
Freezing degree days	5000	$degree \times days$
Wind speed at 10 m elevation	18	m/s
Significant wave height, annual max.	4.1	m
Near surface current	10	cm/s
First Ice	mid November(S) early October (N)	
Last Ice	July(S) late August (N)	
First year ice floe	1.6	m
Ridges sail height (first year)	0.5 to 1.5	m
Ridges keel depth	5 to 8	m
Icebergs		
Mass	20	million tonnes
Present	12	months
Number per year	>2000	

5-2-2 Canadian Arctic Archipelago

The Canadian Arctic Archipelago is the area north of Canada as seen in figure A-8. The water depth in this area varies from 100 to 500 m. Winter temperature varies from minus 30 to minus 40 °C. There are second-year ridges and ruble fields and relatively large icebergs. Further information can be found in table 5-3.

Table 5-3: Weather data Canadian Arctic Archipelago

Parameter	Average annual value	Unit
Freezing degree days	7000	$degree \times days$
Wind speed at 10 m elevation	ND	m/s
Significant wave height, annual max.	ND	m
Near surface current	10	cm/s
First Ice	end August	
Last Ice	August	
First year ice floe	2.2	m
Ridges sail height (first year)	4	m
Ridges keel depth	20	m
Icebergs		
Mass	400	million tonnes
Present	12 (northern half only)	months
Number per year	Few	

5-2-3 Greenland

Greenland is defined as seen in figure A-9. These figures represent the area south of 70 °N. The water depth in this area goes up to 2000 m in the central Baffin Bay area, but reaches no more than 1000 m in coastal areas as seen in figure A-6. The area is prone to rain, fog and even cyclones. This is caused by the regular polar low in the north of the country. The area typically has only first year ice, though some multi-year ice occasionally comes in from Lancaster sound. The east of Greenland is covered by multi-year ice from the Arctic ocean most of the year. Icebergs can be found everywhere east of Greenland. Further information can be found in table 5-4.

Table 5-4: Weather data Greenland

Parameter	Average annual value	Unit
Freezing degree days	ND	$degree \times days$
Wind speed at 10 m elevation	25	m/s
Significant wave height, annual max.	7	m
Near surface current	100	cm/s
First Ice	January	
Last Ice	May	
First year ice floe	ND	m
Ridges sail height (first year)	ND	m
Ridges keel depth	ND	m
Icebergs		
Mass	0.5 to 1	million tonnes
Present	12	months
Number per year	ND	

5-2-4 Beaufort Sea

Beaufort Sea is located north of Alaska, between the Chukchi Sea, the Arctic Canadian Archipelago and the Arctic Ocean as seen in figure A-10. This area has high winds because of the big thermal difference of the water and land. The area has three zones of ice, arctic polar, seasonal and landfast ice zones. The arctic polar zone is consists of multi-year ice from the Arctic Ocean. The presence of this ice in the Beaufort Sea depends highly on the winds. The seasonal ice grows in one season from the landfast ice. this ice can have a length from a few kilometers up to 300 km. Still there can be a lot of second-year and multi-year ice floes. This landfast ice can form to a depth of 20 m. On rare occasions an ice island forms from a glacier. Although they are rare, they can be enourmous. Islands up to 697 km^2 across and 60 m deep have been documented[3]. Further information can be found in table 5-5.

Table 5-5: Weather data Beaufort Sea

Parameter	Average annual value	Unit
Freezing degree days	4500	$degree \times days$
Wind speed at 10 m elevation	24	m/s
Significant wave height, annual max.	3.7	m
Near surface current	40	cm/s
First Ice	October	
Last Ice	July	
First year ice floe	1.8	m
Ridges sail height (first year)	5	m
Ridges keel depth	25	m
Icebergs		
Mass	10	million tonnes
Present	Poorly known	months
Number per year	Poorly known	

5-2-5 Chuckchi Sea

Chukchi Sea is located north of the Bering Street, between the Beaufort Sea and the East Siberian Sea as seen in figure A-11. In this figure the sea is divided in four areas. The depth of these areas varies from 0 to 100 m. The specific areas and weather data correspoding with them is to be found in the ISO 19906 [3]. The entire Chukchi Sea is covered by ice for a big portion of the year. Multi year ice can be found everywhere in concentration of 4/10 in the north and up to 2/10 in the south. Further information can be found in table 5-6.

Table 5-6: Weather data Chuckchi Sea

Parameter	Average annual value	Unit
Freezing degree days	3300 (S) 4000(N)	$degree \times days$
Wind speed at 10 m elevation	39 (S) 43 (N)	m/s
Significant wave height, annual max.	6 to 8	m
Near surface current	<0.5	cm/s
First Ice	Dec (S) Nov (N)	
Last Ice	May (S) July	
First year ice floe	1 to 2.5	m
Ridges sail height (first year)	1 to 3	m
Ridges keel depth	8 to 15	m
Icebergs		
Mass	-	million tonnes
Present	-	months
Number per year	None	

5-2-6 Okhotsk Sea

Okhotsk Sea is located north of the Japan, between the Russia and the Pacific Ocean as seen in figure A-12 The average depth of the sea is 800 m, being 0-100 m in coastal areas and >2000 m near the pacific ocean [5]. In winter, depending on the severity, 60 % to 97% of the sea is covered with ice. According to the ISO 19906 earthquakes and tsunamis can occur and should be part of the design process [3]. Further information can be found in table 5-7.

Table 5-7: Weather data Okhotsk Sea

Parameter	Average annual value	Unit
Freezing degree days	1950 (S) 3000(N)	$degree \times days$
Wind speed at 10 m elevation	29 (S) 30 (N)	m/s
Significant wave height, annual max.	9 to 12.3	m
Near surface current	110 to 120	cm/s
First Ice	November (S) Mid-October (N)	
Last Ice	May (S) July	
First year ice floe	0.9 to 1.3	m
Ridges sail height (first year)	4.8 to 6.2	m
Ridges keel depth	16 to 20.7	m
Icebergs		
Mass	-	million tonnes
Present	-	months
Number per year	None	

5-2-7 North Caspian Sea

In this report only the north of the Caspian sea will be covered. This is the part where sea ice occurs. Caspian Sea is located north of Iran, situated in the north between Russia and Kazakhstan as seen in figure A-13 This sea is known to be shallow, having an average depth of 5 in the north. It has a relatively low salinity due to the fresh water supply from rivers, varying from 2 ‰ to 12.8 ‰ as opposed to 30-35 ‰ in open seas. Ice in this area does not form as quickly as in arctic region due to temperature but, combined with the low amount of snow and ice movements, does reach thicknesses of 0.8 m.

Table 5-8: Weather data North Caspian Sea

Parameter	Average annual value	Unit
Freezing degree days	800	$degree \times days$
Wind speed at 10 m elevation	25	m/s
Significant wave height, annual max.	1.3	m
Near surface current	50	cm/s
First Ice	Mid-November	
Last Ice	End of March	
First year ice floe	0.8	m
Ridges sail height (first year)	1 to 2	m
Ridges keel depth	limited by water depth	m
Icebergs		
Mass	-	million tonnes
Present	-	months
Number per year	None	

5-2-8 Baltic Sea

The Baltic sea encloses several regional areas such as the Gulf of Finland, Bothnian Sea and the Gulf of Riga. It is located North of Poland, Lithuania, Latvia and Estonia between Sweden and Russia and south of Finland as shown in figure A-14 It has a relatively low salinity due to the fresh water supply from rivers, varying from 6 ‰ to 20 ‰.

Table 5-9: Weather data Baltic Sea

Parameter	Average annual value	Unit
Freezing degree days	700 (S) 1200(N)	$degree \times days$
Wind speed at 10 m elevation	ND (S) 6.4 (N)	m/s
Significant wave height, annual max.	4.0	m
Near surface current	75	cm/s
First Ice	Jan (S) Dec (N)	
Last Ice	April (S) May	
First year ice floe	0.4 to 0.6	m
Ridges sail height (first year)	1.5 to 2.0	m
Ridges keel depth	10 to 12	m
Icebergs		
Mass	-	million tonnes
Present	-	months
Number per year	None	

5-2-9 Barents Sea

Barents Sea is located north of Norway. It is situated between the Kara Sea, the Norwegian Sea and the Arctic Ocean as seen in figure A-15. The Pechora Sea is included in the numbers here. The average depth of the area is 222 m with a maximum of 600 m. The ice in this area never completely covers the sea. In the worst period is only goes up to 60 %. This is due to the relatively warm North Atlantic Current, see figure 5-2, who keeps the Norwegian Sea and parts of the Barents Sea free of ice. The main ice fraction is the first-year ice with, on average, 15% as opposed to 10% for multi-year ice. In the winter there is a lot of pressure in the ice due to onshore drifting. This causes a lot of ridges and other formations with a sail up to 5 m and a keel up to 20 m. Further information can be found in table 5-10.

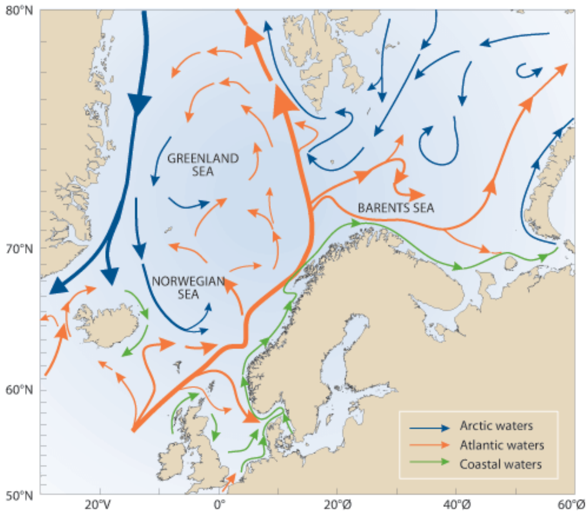

Figure 5-2: North Atlantic Current [6]

Table 5-10: Weather data Barents sea

Parameter	Average annual value	Unit
Freezing degree days	2000	$degree \times days$
Wind speed at 10 m elevation	25	m/s
Significant wave height, annual max.	2.5	m
Near surface current	65	cm/s
First Ice	All year	
Last Ice	All year	
First year ice floe	1.4	m
Ridges sail height (first year)	4.2	m
Ridges keel depth	16	m
Icebergs		
Mass	5	million tonnes
Present	Very region dependent	months
Number per year	10 to 40	

5-2-10 Kara Sea

Kara Sea is located north of Russia, between the Barents Sea, the Laptev Sea and the Arctic Ocean as seen in figure A-16. For a big part of the year Kara Sea is coverred in 7/10 to 9/10 ice concentration. Most second- and multi-year ice occurs in the north. as well as the icebergs in this area. These phenomena occur mostly around Severnaya Zemlya and Novaya Zemlya. In the winter strong ice pressures causes stahmukhi to form along the coast with a maximum size of 15 m sails and 25 m keels. Further information can be found in table 5-11.

Table 5-11: Weather data Kara Sea

Parameter	Average annual value	Unit
Freezing degree days	2946 to 4975	$degree \times days$
Wind speed at 10 m elevation	34 to 40	m/s
Significant wave height, annual max.	7 to 10	m
Near surface current	80 to 120	cm/s
First Ice	mid October(S) All year (N)	
Last Ice	early August(S) All year(N)	
First year ice floe	1.4 to1.8	m
Ridges sail height (first year)	1.3 to 1.8	m
Ridges keel depth	ND	m
Icebergs		
Mass	ND	million tonnes
Present	ND	months
Number per year	ND	

5-2-11 Laptev Sea

Laptev Sea is located north of Russia, between the Kara Sea, the East Siberian Sea and the Arctic Ocean as seen in figure A-17. This sea is completely covered with ice for about nine months. Because the ice constantly moves to the Arctic Ocean there are large open water areas beyond the landfast ice before the sea ice starts. Only small icebergs from the Severnaya Zemlya Archipelago are found in the Laptev Sea. These bergs follow the Talmyr current, further east icebergs are rarely found. Further information can be found in table 5-12.

Table 5-12: Weather data Laptev Sea

Parameter	Average annual value	Unit
Freezing degree days	5342 to 5805	$degree \times days$
Wind speed at 10 m elevation	34 to 51	m/s
Significant wave height, annual max.	4 to 5.5	m
Near surface current	0.7 to 1.1	cm/s
First Ice	All year	
Last Ice	All year	
First year ice floe	1.4 to 2.4	m
Ridges sail height (first year)	1 to 2	m
Ridges keel depth	ND	m
Icebergs		
Mass	ND	million tonnes
Present	ND	months
Number per year	ND	

5-2-12 East Siberian sea

The East Siberian Sea is located to the north of Russia, between the Laptev Sea, Chukchi Sea and the Arctic Ocean as seen in figure A-18. This sea is very shallow, with depths ranging from 10 to 40 m. Complete ice coverage lasts from October to May/June. Multi-year ice from the Arctic Ocean covers from 12 to 30% of the Sea. Further information can be found in table 5-13.

Table 5-13: Weather data East Siberian Sea

Parameter	Average annual value	Unit
Freezing degree days	4710 to 5370	$degree \times days$
Wind speed at 10 m elevation	42 to 62	m/s
Significant wave height, annual max.	4 to 5.5	m
Near surface current	70 to 110	cm/s
First Ice	All year	
Last Ice	All year	
First year ice floe	1.4 to 2.4	m
Ridges sail height (first year)	1 to 2	m
Ridges keel depth	ND	m
Icebergs		
Mass	ND	million tonnes
Present	ND	months
Number per year	ND	

5-3 Ports

Table 5-14 gives an impression of the ports near the Arctic Ocean. These ports could be used for supplying the Arctic, Search and Rescue operations and any other type of support that might be necessary. The ports in the table are more or less capable of these tasks. This list is not complete, smaller ports are left out when larger alternatives are already present.

Between the ports, some similarities can be found. Most ports have an airfield available, be it sometimes only one strip. These airfields are used to supply the northernmost towns. Some ports have no roads leading to them, for example Barrow. Other ports, such as Murmansk are very well connected, via roads and railways. Most towns have some form of medical center available, hospitals are common.

Looking at the towns themselves, the population is decreasing. Any industries, especially in Russia, were moved from the Arctic regions to more profitable regions. In general, there are possibilities for tourism, but this is only for places easily accessible from the south, such as Norway. An increase of industry in the Arctic regions may provide more jobs in this harsh environment.

Table 5-14: Table of Arctic Ports

Name	Country	Airport	Bunkering	Hospital	Ice	Repairs	Depth (m)	Length (m)	Connection	Tug	Icebreaker	Pilot
Akureyri	Iceland	yes[7]	yes[8]	yes[9]	never[10]	yes[11]	10[12]	200[12]	road[13]	yes[8]	NR	yes[8]
Arkhangelsk	Russia	yes[14]	yes[15]	yes[16]	winter[16]	yes[17]	9.2[18]	190[18]	railway, road[18]	yes[19]	yes[20]	yes[21]
Barrow	United States	yes[22]	yes[22]	yes[23]	non summer[24]	no			airport[24]	NS	NS	yes[22]
Churchill	Canada	yes[25]	yes[26]	yes[25]	free aug-oct[27]	minor[26]	11.5[26]	225[26]	railway[28]	yes[26]	yes[29]	yes[26]
Hammerfest	Norway	yes[30]	yes[30]	yes[13]	never[31]	yes[32]	8.5[33]	170[33]	road[13]	yes[34]	NR	yes[30]
Honningsvåg	Norway	yes[13]	yes[35]	yes[36]	never[37]	no			road[13]	yes[38]	NR	yes[38]
Kirkenes	Norway	yes[13]	yes[39]	yes[40]	never[41]	no[41]	4.9[42]	150[42]	road[13]	yes[41]	NR	yes[41]
Murmansk	Russia	yes[13]	yes[43]	yes[44]	never[45]	yes[43]	6.4[43]	150[43]	road[13]	yes[43]	NR	yes[43]
Naryan-Mar	Russia	yes[13]	yes[46]	no[46]	yes[46]	yes[46]	3.4[46]	150[46]	road[13]	no[46]		yes[46]
Tiksi	Russia	yes[13]	yes[47]	yes[47]	yes[47]	minor[47]	6.4[47]		road[13]	no		yes[47]
Pevek	Russia	yes[13]	yes[48]	yes[48]	winter[49]	minor[48]	4.9[48]	150[48]	road[13]	no[48]		no[48]
Vardø	Norway	yes[13]	yes[50]	yes[50]	never[51]	minor[50]	6.4[50]	150[50]	road[13]	yes[50]	NR	yes[50]
Nuuk	Greenland	yes[52]	yes[53]	yes[52]	winter[3]	yes[54]	8[54]		road, airport [52]	NS	NR	yes[53]
Upernavik	Greenland	yes[55]	yes[56]	yes[57]	yes[3]	yes[58]	4.6 [58]	152[58]	airport,railway[58]			yes [59]

NS is Not Specific to that port, NR is not required

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Chapter 6

Arctic Risks

In this chapter the focus is set on the risk of operation in an Arctic environment. A simple definition of risk is, that risk is probability times consequences [1].

$$Risk = Probability * Consequences$$

Therefore there are two parts to consider, the probability of an accident occurring and the consequences of that accident. The first part of the chapter will focus on consequences that are unique to the Arctic region or have an greater impact while operating in the Arctic. In a second part a short discussion about the probabilities in the Arctic is shown. The maritime industry is highly interested in reducing the risks that may influence the environment and performs studies on this topic [2, 3]. They should be taken into account when designing a ship for the Arctic, focusing on reducing the probability of an accident happening.

6-1 Consequences

Operating in the Arctic brings greater consequences for the environment in case of an accident, due to fact that consequence containing measures are difficult in this area. This section will distinguish three types of environmental consequences:

1. Direct Operational consequences, caused directly by ship operations
2. Direct Environmental consequences, caused by all ship operations
3. Indirect consequences, which come from multiple operations and cannot be directly related

6-1-1 Operational consequences

Direct consequences while operating in the Arctic are mentioned in this section. These direct consequences can occur when operating in the Arctic or other ice infested waters.

Ice accretion This is the formation of ice on a vessel [4]. It adds weight to the ship, and has negative effects on: [5]

- Stability
- Manoeuvrability
- Resistance (increased draugth, trim)
- Accesability and operabilty of equipement
- Possibility of injury of crew

The amount of icing is dependent on the wind, direction and speed of the vessel, salinity and temperature of air and water. The design of a vessel should be made to avoid icing, for stability and other safety reasons, as shown in the IMO guidelines [6]. DNV defines requirements for the winterization of a vessel along with additional class notations, as can be seen in section 12-4.

Ice damage Ice damage to the hull and being entrapped in ice could be encountered due to to unexpected harsh ice conditions in combination with insufficient ice strengthening and engine power. Especially when turning or manoeuvring in ice, there is a higher probability to damage. The less strengthened parts of the hull are then exposed to ice such as the midship or the aft shoulders. When the ship is stuck in ice, the weaker parts of the ship are exposed to the higher crushing loads than the bending loads, which occur when navigation ahead or astern.

Collision and Grounding When a vessel is aground or is involved in a collision there are possible consequences involving the environment, potential hazard of sinking and loss of life and danger to navigation of other ships. The weather conditions, the existence of icebergs, the remoteness and the lack of a sufficient navigational data [7] form an additional hazard to grounding or collisions. Because they increase the time needed for search and rescue (SAR) operations, EER operations are difficult as well. Fortunately, developments are going on to chart the Arctic and also the navigation means will develop, according to Holfort [8].

Oil spill Ice damage, collision and grounding can all be the cause of an oil spill. The cold temperatures, sea ice, extreme and unpredictable weather conditions and the darkness are characteristics of the Arctic environment. This increases the consequences of these events and limit the clean-up options. Unfortunately, there is a response gap because existing clean-up methods are insufficient in the Arctic, see section 12-4-4. The consequences of an oil spill are known to be dire, disturbing local ecosystems completely [9]. Animals living in shore regions are prone to the effects of an oil spill, due to the fact that oil accumulates there. In the Arctic the oil will accumulate against ice, which could be usable for clean-up. However, the oil can also go underneath the ice and then recovery becomes very hard. Information about oil spill recovery can be found in 12-4-4.

Beset Pressure ice and navigating in thick ice can let the vessel get stuck. If the vessel is stuck and can't move without help it's called beset. In a simulation of the North West Passage the time a vessel is kept beset is assumed to be one week [10]. In pressure fields the vessel can get severely damaged through the immense forces acting on the hull.

6-1-2 Direct environmental consequences

The effects of sound and gas emissions, which occur while using a ship, are direct environmental consequences of interest by environmental organizations.

Sound Ships produce sound when using any kind of engine or generating flow. The noise level is dependent on the design, age, speed, size and engine of the ship. These sounds may interfere with the sounds marine mammals make for communication purposes. The exact impact of sound on these mammals is still unknown [11]. The University of Applied Sciences Van Hall Larenstein performed a study that shows "walruses do not seem disturbed by the sound of outboard engines at distances greater than 400 meters" [2]. However, species like the narwhal show avoidance to ships up to from a distance of 40-55 km. "This noise pollution is known to alter the movements of migrating bowhead whales and other cetaceans and is thought to be a form of stress contributing to at least some species decline or lack of recovery." [3].

Gases Gases as CO_2, CH_4, SO_x and NO_x are emitted when using a ship. These gases have an effect on the environment, but no sources of direct effects were found. The influence on global climate is nonetheless widely accepted. The IMO has already set up rules to decrease the amount of sulfur in fuels [12], effectively reducing the amount of SO_x emitted.

Particular Matter (PM) The albedo, reflectiveness, of snow is partially dependent on the amount of PM in the snow [13]. If the albedo decreases, the snow will absorb more energy and thus melt. PM emissions depend largely on the type of engine and fuel used. Research of TNO and ECN has shown that the amount of PM is the least while using a four-stroke engine using fuel with a sulfur content lower than 1% [14].

6-1-3 Indirect consequences

Prolonged shipping in the Arctic will come with consequences larger than one trip can give.[15]. The following consequences are a result of constant emissions and presence in an area.

Although some of these consequences are accepted and valid worldwide, environmental organizations have, exacerbated by the media, great influence and are to be take seriously, see section 10-9.

Global warming It is widely accepted that CO_2, CH_4 and NO_x gases have effect on global warming. The impact of CO_2 emissions of ships is relatively small, only 2.7% in 2007 according to the IMO [16]. The IMO still wants to reduce the amount of CO_2 emitted by ships and provides recommendations to do so. Global warming is a global issue and can not be reduced to areas. Consequences of global warming are higher in the Arctic compared to other regions in the world. Table 6-2 gives an overview of emissions per fuel type.

SOx The SOx regulations are changing the coming years. There are a series of step changes in allowed sulphur levels in fuel oil as shown in tableE-1.

Table 6-1: Fuel oil sulphur limits in % m/m [17]

Outside an ECA established to limit SOx and particulate matter emissions	Inside an ECA established to limit SOx and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020∗	0.10% m/m on and after 1 January 2015|

∗ depending on the outcome of a review, to be concluded in 2018, as to the availability of the required fuel oil, this date could be deferred to 1 January 2025.

The ECA defined by MARPOL include:

- Baltic Sea area, as defined in Annex I of MARPOL (SOx only);
- North Sea area, as defined in Annex V of MARPOL (SOx only);
- North American area (expected to enter into effect 1 August 2012), as defined in Appendix VII of Annex VI of MARPOL (SOx, NOx and PM); and
- United States Caribbean Sea area (expected to enter into effect 1 January 2014), as defined in Appendix VII of Annex VI of MARPOL (SOx, NOx and PM).

This means most of the Arctic is not included in the ECA.

NOx The NOx requirements include a tiered system. The highest, tier III, will be into effect for ships built on or after the first of January 2016. This rule states:

- 3.4 g/kWh when n is less than 130 rpm
- 9* $n^{(-0.23)}$ g/kWh when n is 130 or more but less than 2000 rpm
- 2.0 g/kWh when n is 2000 rpm or more

where n is the rated engine speed (crankshaft revolutions per minute)

These rules apply to marine diesel engine with power output of more than 130 KW installed on a ship.

The other possibility when tier III is required, is when a ship is operating in an emission control area. At the moment of writing there are several of these area but the Arctic is not included yet [18].

Loss of habitat The most clear example of loss of habitat, is the case of the decreasing amount of polar bears [19]. Some other examples can be found in a thesis on Arctic cetacean [3]. An overview of the areas that contain species endangered by operations in the Arctic can be found in appendix A-5.

Invasive species When in a certain area species start to live, that did not naturally live there, that species are called invasive species. With more activity in the Arctic, there is a bigger risk of bringing invasive species to this region [20]. The invasive species may cause instability to the ecosystem and threaten the existence of native species in the area.

6-2 Environment considerations

This section will cover the rules regarding Marpol regulations and the implications of that in the arctic. Then a comparison between the emission levels of different types of engine will be made, followed by a recommendation of the engine type.

Table 6-2: Order of magnitude of diesel engine exhaust emissions. The spe has been determined using and sfc between 160 and 220 g/kWh [21]

	pollutant emission ratio (per) in g/kg	specific pollutant emission (spe) in g/kWh
CO_2 (86 % C in fuel)	3200	500-700
SO_x per % S in fuel	20	3.2-4.4
NO_x	40-100	6-22
HC (gaseous)	0.5-4	0.1-0.9
CO	2-20	0.3-4.4
Particulates	0.5-2	0.1-0.4

6-2-1 Fuel comparison

In this subsection a comparison is made between the usable fuels in relation to storage, efficiency and emissions,

LNG as a fuel is a real alternative to diesel fuels due to the emissions and price. according to the European Maritime Safety Agency: "It (LNG) provides a basically complete reduction

Table 6-3: Comparison of LNG and Diesel engines [21],[22]

	LNG	Diesel	Unit
CO_2	- 20-25 %	500-700	[g/kWh]
SO_x	$\approx$ 0	3.2-4.4	[g/kWh]
NO_x	- 85-90% of diesel	6-22	[g/kWh]
Fuel storage	300-500%	100%	[m^3]
Engine Size	100%	100%	[m^3]
Investment	1-8 million extra	100%	[€]
Fuel price	$\approx$ 50 %	100%	[€]

of sulphur dioxides and particulate matter and some 90% reduction of NOx. For green-house gases, LNG's reduced carbon factor signifies a reduction of some 20% in CO2 emission compared to refined oil products. The figure includes a certain emission of non-combusted methane, the so-called "methane slip", which engine manufacturers are currently seeking to reduce. Other advantages of LNG include that no sludge is produced and that there is no visible smoke." As can be seen in figure 6-1 the price of LNG has been more stable over the last few years than marine fuels and is also significantly cheaper per tonne.

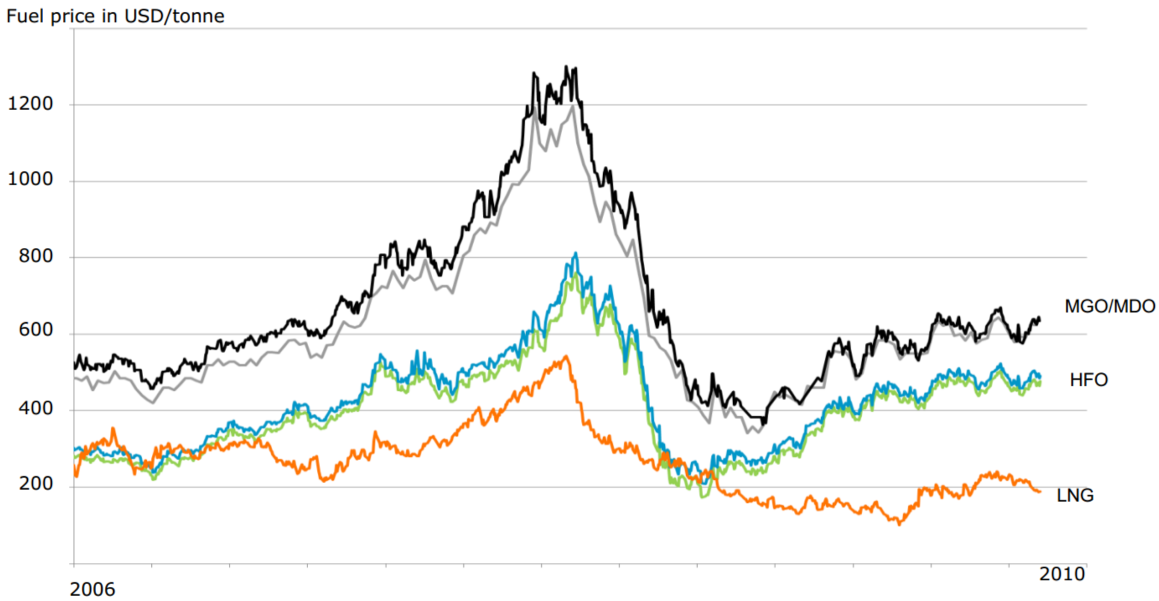

Figure 6-1: Bunker fuel prices fluctuations between October 2006 and March 2009 [22]

However, it is estimated that LNG requires 3-5 times more storage space than for oil. This will be in addition to the regular required space in case of the use of a dual fuel engine. Some other

Garbage Within MARPOL, annex V deals with the garbage management aboard a vessel. A summary of restrictions to the discharge of garbage into the sea under regulations 4,5 and 6 is given in appendix E The rules for garbage disposal are the same as on open water, except that an ice-shelf is treated as land. Besides the rules of garbage disposal there are several other rules in the MARPOL regarding garbage management, but again these are no different than in open water.

6-3 Probability

This sections focus on the probability of the consequences to occur. It is clear that the consequences to operate in the Arctic are higher than in other regions. To keep the risk at the same level the probability needs to be less than in other regions. Reducing the probability means increasing safety margins and more expenses in safety. The term "zero tolerance" that is used by many companies and organization for the operation in the Arctic comes down to invest in smallest probability of a disaster happening.

To determine the probability of an event happening and their consequences, risk analysis is used. Managing risk can be divided in risk analysis (Scope definition, Hazard identification and Hazard estimation), risk evaluation (Risk tolerability decisions, Analysis of options) and risk reduction/control (Decision making, implementation, monitoring). Risk analysis and risk evaluation is often referred to as risk assessment [1].

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Chapter 7

Crew Conditions

Every merchant ship needs a crew to handle the ship. The ship has to be designed so that able seamen can operate it. Therefore the conditions the crew operates in and the difficulties they are facing while working on board need to be known. The classification societies provide rules and regulations on this topic for ship design, but in general not many research on crew conditions has been done.

With the Barents 2020 [1] report an in-depth look at the human factors and Arctic working environment is presented. According to the report the NORSOK S-002 "Working Enviroment [2]" requirements are "the best currently available functional standards [1, p. 56]". The Barents 2020 report gives suggestions and comments on the NORSOK S-002 report and includes different aspects such as general issues seafarers face, the effect of harsh environment and operational issues.

In this chapter general issues of seafaring are discussed in the first section. The effects that are unique to Polar conditions are then discussed in second section.

7-1 General issues for seafarers

According to various researches on the death of seafarers, suicide is significantly higher than among workers ashore and the general population [3]. In most of these cases mental illness was the cause for the suicide.

In this section, four of the most important issues are discussed: social isolation, fatigue, family life and the impact of technology. Finally, the consequences of these causes lead to mental illness among seafarers.

7-1-1 Social isolation

According to a research in 2003 social isolation is a significant issue for seafarers [4]. Being at sea, seafarers are in a working situation daily with work related talks to fellow crew man. This seldom to allows a good relationship between each other. Due to different leave periods and other geographical situations, maintaining these relations is difficult. Next to that, expensive communication, makes maintaining relationship to friends on shore is challenging. In many cases the contact with family is the only contact to shore. More information on this topic can be found in [4, 5, 6] and in section 7-1-3.

7-1-2 Fatigue of seafarers

The Britannica Encyclopedia defines fatigue as a "specific form of human inadequacy in which the individual experiences an aversion to exertion and feels unable to carry on" [7]. Fatigue happens often to seafarers and it is a major problem among them. In general seafarers on shorter routes have an increased risk in suffering fatigue, "poor sleep quality, environmental factors, high job demands and high stress [8, p. 38]". Next to that workdays from more than 12 hours, switching between sea and port work, low job support from the employer [8, p. 38] and noise and vibration affected accommodation areas [9, p. 5] are factors that lead to an increased change of fatiguing .

Fatigue is a real big safety issue in Cardiff University Research "Adequate Crewing and Seafarers' fatigue: the International Perspective" by Prof. Andy Smith. It is clearly stated, that more that 25% of the 1856 Seafarers that have taken part in the research had fallen asleep while on watch, 37% said their working hours are sometimes so high that the safe operation of the vessel is put to danger, 50% state that there work hours have increased in the past 10 years and almost 50% claim that the long working hours have an influence on their personal safety and health [10, p. 5]. Additional readings about this topic include [8, 11, 12, 10, 13, 14].

7-1-3 Family life

Family life has a lot to do with the work rhythm of seafarers with on and off board periods of several months. Research shows that partners ashore have problems with the absence of the partner at sea [5]. Emotional loneliness, stigmatizing by others and social loneliness are common consequences. Moreover the reports only describe the issues and give no solutions. However it is commonly accepted that shorter periods away and more frequent calling will reduce these effects. Other research papers on this topic include [15, 16, 17, 4].

7-1-4 Impact of technology on seafarers

In the last decades the importance of technology on board has increased and will continue to grow in the future. With an increasing amount of technology on board of vessels, seafarers need to be trained to make the best use of the technology provided. As research shows, the knowledge transfer among seafarer's is not working well, for example in the handover between, junior officers and senior officers are in respectably 10 % and 7 % of all cases inadequate [18, p. 5]. For more information on this topic please refer to the Seafarer's International Research Centre at Cardiff University [19, 18].

7-2 Effects of harsh environments on the crew

Going into ice and cold conditions means that seafarers encounter even more issues compared to open water conditions. Three of these exposure situations are displayed in figure 7-1, along with stress management to reduce the human failures from a management point of view.

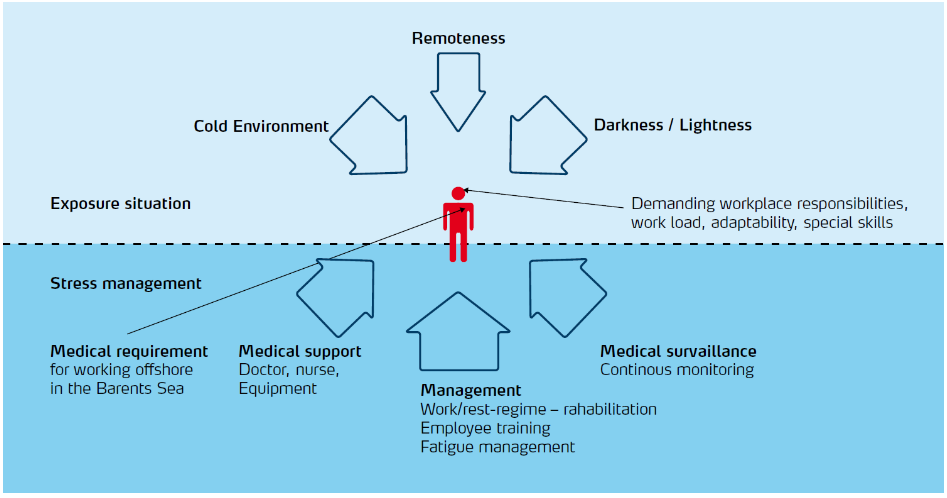

Figure 7-1: Exposure situation and stress management of a Seafarer in Arctic Conditions. Adapted from [1, p. 64]

In this section both the hazards and performance-influencing factors and stress management are discussed. This is based on the findings of the Barents 2020 report [1] and Lloyd's Register's study on human performance in ice and cold conditions[9].

7-2-1 Social isolation and fatigue of seafarers

Social isolation can be even worse for seafarer's going to Arctic regions, due to less shore leave and increasing difficulties in communication. This may lead to a decreased morale and in a decreasing motivation to sign a contract on an ice-going ship [9, p. 5]. In the Arctic the risk of feeling exerted is even increased compared with open water operations. Next to the factors of the open sea, specific hazard and performance influencing factors of the operation in ice and cold conditions are extreme wind and wave conditions and extremes of daylight and darkness [9]. Severe weather can lead to motion induced fatigue [20] while a disrupted circadian rhythm due to complete darkness or daylight can result in inadequate nutrition and insufficient quality and quantity of sleep[9, p. 4].

7-2-2 Hazards and performance-influencing factors

Ice is a challenging substance for the crew of a ship. To secure the stability of a vessel while ice accretion occur on the ship's structure, seafarers are often put in a highly hazardous situation while inspecting the ice grow or by removing it. Icing on the exposed deck can lead to difficulties in operating deck equipment such as cargo handling, emergency and lifesaving equipment. Even standard movement can get affected, for example the likelihood of tripping, falling and slipping increases on snow or ice covered stairs, decks and handrails. Another hazard is ice falling from superstructures on the seafarer. Health and safety regulations therefore need to reduce these hazards [9, p. 2].

Low temperatures effects can be divided into physical and cognitive effects according to [9, p. 2-3]. Physical effects are due to temperature and wind chill, that cool down the body and can lead to freezing injuries within minutes. In really harsh environments with an air temperature of -35 °C and a wind speed of 50 km/h freezing injuries are expected within 2 minutes [9, p. 3]. Cognitive effects of low temperature, on the other hand, occur due to a decrease in psychological processes and physical capability. This results in a decreased ability of decision-making and judgement [9, p. 3] and is therefore a health and safety threat.

Another issue is that, according to the IMO, survival time in cold water is twenty times less the time in air. Therefore the first 3 to 5 minutes of a cold water immersion are crucial in surviving [9, p. 3-4].

Low temperatures come along with fog together with snow, hail and rain so that the visibility can be reduced tremendously. Therefore health and safety hazards such as slipping, tripping, falling and freezing will increase with reduced visibility [9, p. 4].

Sea states in the higher latitudes can be more extreme compared to other geographical areas, resulting in high waves and extreme winds. This can also increase the likelihood of health and safety hazards, motion induced fatigue, motion sickness and the danger of shifting cargo [9, p. 4].

The ongoing daylight in the summer and the complete darkness in the winter has an impact on the circadian rhythm of people. A disrupted biological clock can lead to a increase in fatigue as mentioned in section 7-1-2 [9, p. 4].

7-2-3 Developments in training

To reduce the possibilities of encountering hazards and performance-influencing factors, one should use Stress Management and Training and Competence according to Barents 2020 [1, p. 64-65]. Stress Management should focus on requirements, monitoring and supporting the seafarers in harsh environments. This lays the focus on medical requirements before the trip, Medical surveillance and medical support while on the vessel and management of the operator such as proper work scheduling, employee training and fatigue managements.

Training and Competence includes special aspects of working in the Arctic. The Barents 2020 committee suggests that the trainings should include among others: Basics of body temperature, hazards related to ice and cold conditions, clothing requirements and Fatigue and stress management [1, p. 65] and gain competence through those trainings.

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Chapter 8

Laws and Regulations

This section deals with the rules and guidelines that are to be applied for Arctic shipping. In fact, there are no global laws for the Arctic region yet. Each country has its own rules and regulations but there are, however, some guidelines available.

The first section deals with the international rules and standards specified to their particular sections concerning the Arctic. The second section points out where information can be found on the various national legislation of the Arctic coastal states and finally the ongoing developments are mentioned, such as the new Polar Code.

8-1 International rules

Not only in the Arctic, but for all waters around the world international rules and standards exist. "The IMO (International Maritime Organization) facilitates through the adoption of numerous codes and guidelines the implementation of international rules and standards" [1, 2]. Figure 8-1 shows the four most important instruments affecting ships that operate in the Arctic.

There are more instruments, but they do not contain any specific information about the Arctic. Detailed information about these international instruments can be found in a report written by IMO [2, Sec 2.3] and Arctic Counsel [4, Sec 3.5.2], which is a high-level intergovernmental forum to promote cooperation, coordination and interaction among the Arctic States.

- UNCLOS (United Nations Convention on the Law of the Sea). Only Article 234 is meant specifically for the Arctic: "coastal states have the right to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas..."[5].
- SOLAS (International Convention on the Safety of Life at Sea). The only requirements in this convention directly related to polar areas concern the safety of navigation which can be found in Chapter V [6]. Moreover, SOLAS has adopted other instruments including, among others, the requirements of the IACS and the Intact Stability Code.

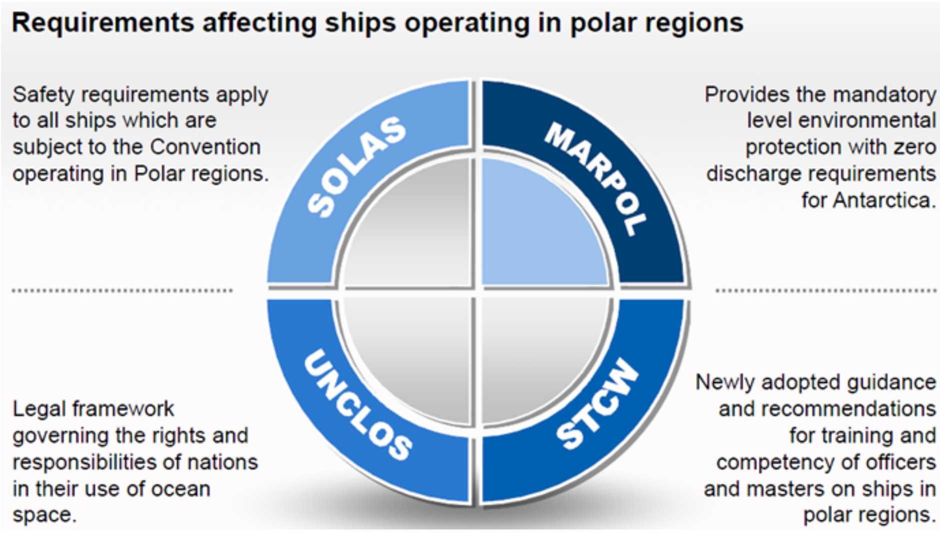

Figure 8-1: International instruments with their specific subjects[3].

- IACS (International Association of Classification Societies) requirements for Polar Class ships. "The IACS Unified Requirements for Polar Ships apply to ships constructed of steel and intended for navigation in ice-infested polar waters" [7]. The IACS provides technical support and guidance for the IMO and develops unified interpretations of the international regulations.
- Intact Stability Code. It contains provisions for ships operating in areas where ice accretion is likely to occur which would adversely affect the ship stability[8, 2, Part B, Chapter 6].

- MARPOL (International Convention for the Prevention of Pollution from Ships). The Arctic is not considered a special emission control area under the MARPOL Convention, only the Antarctic area was designated. Therefore no additional requirements exist concerning the Arctic. But it should be taken into account, if a part of the Arctic will be become a special area, Tier III, the zero discharge regime and all other special regulations should be applied. Even in the international waters.

- STCW (International Convention on Standards of Training, Certification and Watch keeping for Seafarers). This convention stresses the importance for officers in charge on board polar ships to have sufficient and appropriate experience with the arctic waters[2].

8-2 National Legislation

All Arctic coastal states have defined their own national regulations valid in their EEZs [1, p. 52] mostly concerning the environmental protection and safety made specific for the area of legislation. The legislation of each coastal state in the Arctic (The USA, Russia, Canada, Norway, Iceland and Denmark/Greenland) can be found in a report written by the Fridtjof Nansens Institutt [9, sec. 2.3].

8-3 Classification societies

DNV, and other classification societies as ABS, LR and RS, have class notations for different ice conditions and operation areas. In the DNV "rules for classification of ships" the notations are explained [10]. They consist of low arctic ice classes for first year ice and high arctic polar classes for multi year ice. Also the requirements of the IACS are integrated. Furthermore, there is a difference between ice notations and winterization notations.

Tables C1 and C3 in the class rules by DNV show the differences of the existing notations [11]. In appendix C the equivalent ice classes of different classification societies are shown.

The low arctic ice classes, developed as the Finnish-Swedish Ice Class Rules (FSICR), are intended for all ship types and are developed for operations in the Baltic Sea. The operating conditions are first year ice with a thickness up to 1.0 m. No ramming should be involved in the ice breaking process, the vessels do not have ice breaking as main purpose and are not suitable for year round operations in the Arctic.

Therefore, more ice classes are needed. Multi year ice, extended operation season as well as ramming are features the vessel must be capable of. The DNV arctic ice rules are intended for ships that operate in the high Arctic, but in the near future the IACS Polar Ship Rules (PC Rules) will replace the existing DNV arctic ice rules, so only the PC rules will be used. The PC Rules are divided into seven classes, ranging from the highest ice class PC1, which is to be linked to an icebreaker capable of operating safely anywhere in the Polar oceans at any time of year, to the classes PC6 and PC7, which are intended for Summer/Autumn operation in first year ice. Nowadays, a vessel still has a traditional class notation eventually complemented by a Polar Class notation.

8-4 Developments

The development and implementation of safety and operational standards are crucial. The development of ISO standards - such as ISO 19906 2010 concerning Arctic offshore structures for the oil and gas industry and the supplementing Barents 2020 project - are good examples of this. Moreover, since it is nearly impossible to comply with all laws in the whole Arctic, the IMO works on a new harmonized Polar Code. Currently a vessel faces different technical requirements for navigation within the EEZ's of the coastal states[3, 9, 12].

Guidelines for ships operating in polar waters (IMO) "The Guidelines aim at mitigating the additional risk imposed on shipping due to the harsh environmental and climatic conditions existing in polar waters." These guidelines are not mandatory rules yet, but they provide only guidance about construction, equipment, operation and environmental issues[13].

Polar Code A new mandatory code for arctic shipping is in development. The goal of this code is to provide for safe ship operations and the protection of the Arctic environment and will represent a harmonization of existing national legislation[14]. "It is intended that the Polar Code will supplement relevant international regulations, including SOLAS and MARPOL, in order to address the risks that are specific to operations in polar waters"[15].

Barents 2020 and ISO 19906 The goal of the Barents 2020 project was partly to develop a guidance document for the design of floating structures in ice based on risk analysis aimed at supplementing the ISO 19906, which is the basis of the Barents 2020. Furthermore, it is intended to obtain updated and harmonized industrial safety, working environment and operational standards. The objective of the ISO 19906 (International Standard on Arctic Structures) is to ensure that Arctic offshore structures provide an appropriate level of reliability with respect to personal safety, environmental protection and asset value. The ISO 19906 is especially aimed at Arctic offshore structures instead of ships. Therefore it will be supplemented by the Barents 2020 project to obtain a complete international abided standard, which will be in line with the international requirements as mentioned in subsection 8-1[16, 17].

Dutch Industry A joint industry project led by the Maritime Innovation Programme is going to develop operational guidelines for Dutch industry involving offshore activities in the Arctic regions[18]. The guidelines will contribute to internationally accepted standards and guidelines for Arctic operations. This helps the Dutch industry to understand operational constraints and safety issues in the Arctic environment for its own fields of activities, such as dredging and pipe laying[19].

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Chapter 9

Ship Types and Solutions

Since before the 20th century, there are icebreakers in operation around the world. Some key aspects have never changed like the ice breaking method. Over the years the implementation of the ice breaking principle is improved by more efficient hull forms and propulsion methods.

This chapter contains a chronological history of icebreakers and the innovations used on them. Figure 9-1 shows a chronological overview of the developments in ice breaking technology. The timeline starts with the first icebreaker with a propellor, altough some there were some paddle wheel river icebreakers in America.

Section 9-2 discusses the technologies in more detail. Finally materials applicable to the Arctic are discussed in section 9-3.

In depth studies of hull forms and ice breaking technologies are not included in this chapter. It will be addressed in the next reports.

9-1 History of ice breaking vessels

This section provides a chronological description of ice breaking vessels, mentioning the most innovative designs. Starting form the development of the double acting ship concept, also other vessels with another main purpose are capable of ice breaking.

Icebreakers until 1900

Pilot was the first steam power icebreaker using a propeller. The bow was specially designed to have a low angle of attack, enabling the vessel to slide on the ice and break through it. Later, the design of the Pilot was used in other icebreakers as well[1], such as the German 'Eisbrecher I'.

Murtaja, 'The Breaker', was the first steam powered sea icebreaker of the Finnish state. It had a single stern propeller with 1200 kW. She was delivered in 1890 by the Finnboda

Shipyard[2]. The vessel that was 47.55 m long overall, a breadth of 10.95 m and a draught of 5.5 m could break level ice up to 47 cm. She had the same round bow as the German icebreaker 'Eisbrecher I'[3]. The Yermak was the biggest icebreaker of its time, with a length of 93 m. It had three stern and one bow propeller, with a total power of 7.46 MW[4].

Important Icebreakers 1900-1950

The icebreaker Krasin, is used as a rescue and escort vessel. This vessel has rescued many other ships, including another icebreaker[5]. During the second world war it was repaired and armed and operated in the northeast of Europe. It was 98.5 m long and had an installed power of 7600 kW[6].

The Jääkarhu was the last steam powered icebreaker, built for Finland in The Netherlands. It was 78.5 long and had two propellers in the stern and one in the bow.

The world's first diesel-electric propulsed icebreaker was delivered in 1932 and called Ymer[2]. This vessel had a total power of 2.2 MW, this power went to two propellers.[7].

Although diesel-engines were already in use, the icebreaker Stettin (build in 1933) was equipped with a steam piston engine. They chose for this engine because steam engines can be reversed within a very short time, compared to the diesel engines of that time. The vessel had a new bow design called Runeberg-bow, with this bow the ice was not broken by the weight of the ship but by a sharp cutting edge. Stettin was equipped with a 1.6 MW engine and with a speed of 1-2 kn it could break ice up to a thickness of 0.5 m[8].

Important Icebreakers 1950-2000

The first ice breaking vessel with two bow equipped propellers was build in 1952 and called 'Voima'. Because of the propellers she was possible to turn around without moving forward. First she was powered by six 1500 kW diesel engines, after an expensive refit she had six diesel engines each producing 2140 kW. Because the refit she had the vessel is still in service and is the oldest Finnish ice breaking vessel.

The largest icebreaker and flagship of the Canadian Coast Guard is nowadays the "Healy Arctic Icebreaker" Louis S. St-Laurent. The vessel was build in 1969, and had a modernization between 1988-1993. This modernization included a lengthening of the hull, a new propulsion and navigational equipment[9]. She now has a length of 120 m, three fixed-pitch propellers and five diesel engines which can deliver a total of 22370 kW to the three shafts[10].

Lenin (not to be confused with the previous icebreaker Lenin) was the first nuclear icebreaker, launched in 1957[11]. The nuclear reactor had two cooling problems before it was replaced in 1970. The icebreaker had serviced most of its miles in ice. In 2000, Lenin was decommissioned and used as a museum[12]. The improved version of the Lenin, the Arktika class, was completed in 1974. It was 150 m long, 136 m between perpendiculars, and was powered by two 171 MW nuclear reactors, with a maximum power output of 54 MW at the propeller. Five more vessels of this class followed, which are able to navigate through 5 m of ice and are able to penetrate through ridges of up to 9 m. It had an air bubbling system, polymer coatings and an ice knife to go through ice easier. There was a helicopter on board to observe the ice ahead[13].

The vessel Vladimir Ignatyuk was build in 1982 for use in Anchor Handling and ice breaking in the Beaufort Sea[14]. She was equipped with 4 main engines with a maximum capacity of 17300 kW, two shafts and variable pitch propellers. The vessel has a length of 88.02 m and she is still in use.

In 1993, the Fennica was built. This ship is an icebreaker, with offshore supply capabilities. The ship has a length of 116 m overall and 96.7 between perpendiculars. It is able to break 1.0 m ice and was the first ship equipped with azimuth thrusters, Fennica has 2 with a combined power of 12000 kW. This ship has dynamic positioning, towing and craning capabilities.

The Arcticaborg and her sister vessel Antarcticaborg who are operated by Wagenborg Kazakhstan, are build in 1998[15]. The vessels are fitted with towing and anchor handling equipment. Pollution control, rescue and fire fighting capabilities are also installed. Furthermore the vessels are equipped to remove waste water and sewage from the rigs. They can carry fresh water, dry cargo, liquid mud, fuel oil, cement and barite. They are specially designed for shallow waters, have a length of 65.1 m, 2 Azipod propulsion (1650 kW), one bow thruster (150 kW) and can break ice up to 90 cm[16].

Ice going vessels 2000 and onwards

MV Tempera, a 2002 built aframax tanker, was the first ship specially designed to apply the Double Acting Tanker concept. While going ahead, the vessel has a regular open water efficiency and while going astern, the vessel has ice breaking capabilities. This reduces the need for icebreaker assistance[17]. The double acting concept was based on the experiences with the vessels Uikku and Lunni, these were the first two vessels who could effectively sail astern through ice, but they were not specially designed for this [18]. In 2011 the Finnish pollution control vessel Louhi was taken into use. Louhi was originally built as a multi functional vessel, but later converted to a pollution control vessel. It can sail through 1 m ice with 3 kn speed and can recover oil in ice[19]. In September 2012 the Wagenborg vessels Sanaborg and Serkeborg were delivered. The vessels have a small draft and ice pods, equipping them for subarctic operations in shallow water[20].

In December 2013 Helsinki shipyards will deliver the 'Oblique Icebreaker'. This icebreaker can break the ice when sailing, forward, backwards and asides. It will be the first 'skew-going' icebreaker and will be used for oil-spill response and salvage operations[21]. With a length of 60.5 m and 7500 kW power, it can break ice of 1 m in ahead and astern at design water line[22].

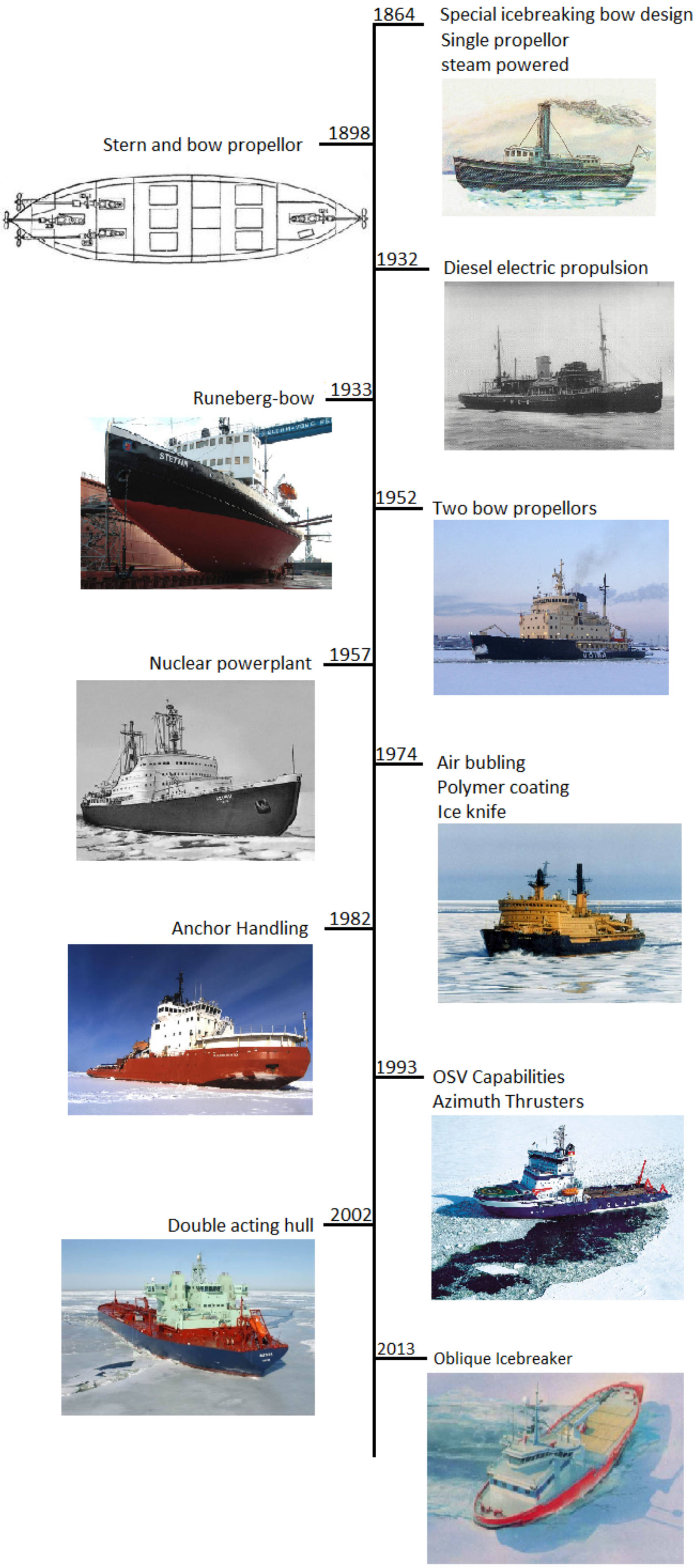

Figure 9-1: Icebreaker innovations Timeline (ownwork), Image sources chronological [23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]

9-2 Ship components

Various components, hull forms and tasks used on ice breaking vessels will be treated in this section. It will be explained how they work and why they are suitable to use on ice breaking vessels.

9-2-1 Hull

Is this section the basic properties of an ice breaking hull are discussed without going in detail.

Bow An icebreaker has a typical bow or stern shape with a low angle of attack, allowing it to slide on the ice and break it with the weight of the vessel. If the vessel has a high angle of attack, the ice would be crushed instead of bended. The first icebreaker with such a hull, the Pilot, had a bow angle as low as 20°[4]. Different bows and their characteristics are given in figure 9-2. The choice for a certain bow form depends on the operational profile of the ship and the consideration of the ice performance vs the open water behavior.

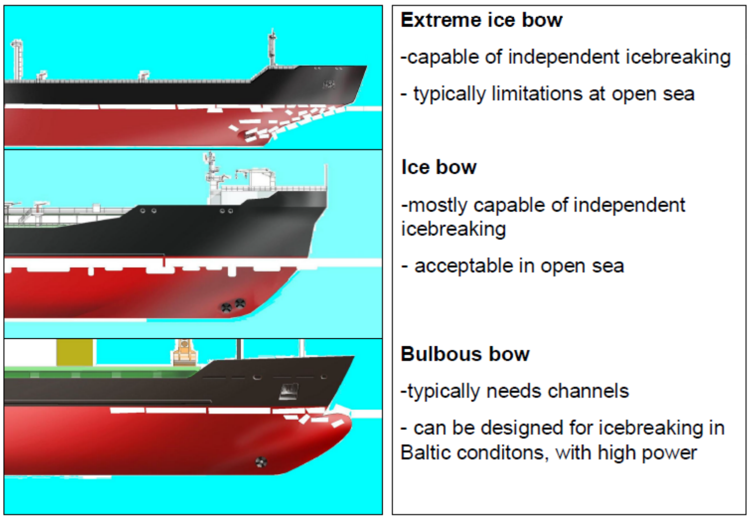

Figure 9-2: Bow shapes and their characteristics, based on [34]

Midship The shape of the midship section is also of importance, mainly for the maneuvering properties but also for the ice resistance. Different types of midship sections and their characteristics are shown in figure 9-3.

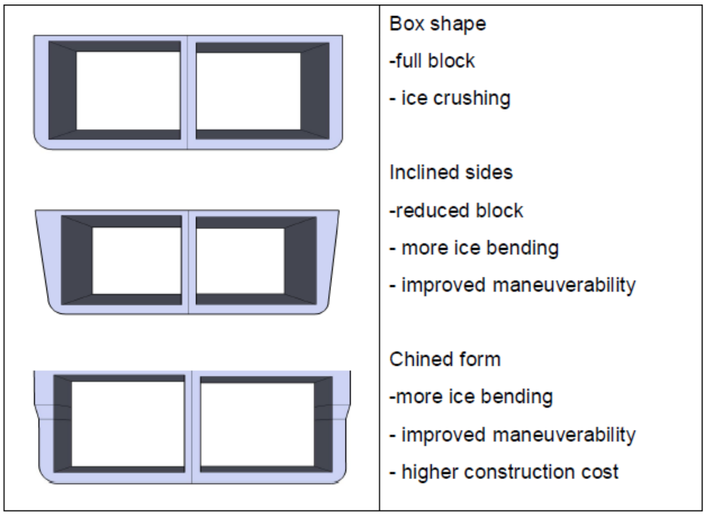

Figure 9-3: Different midship sections and their characteristics, based on [34]

Stern Almost all the traditional icebreakers have good capability to sail backwards through ice, even though they are not designed for that. The last 10 years there has been a lot of development, because of this running astern through heavy ice could be considered as the main way of operation. This is referred to as the double acting ship concept (DAS). A key in this development was the azimuthing propulsion [35]. When the vessel can sail backwards through ice, the bow can be more optimized for open water, which gives a higher efficiency for the whole vessel. An other advantage is, when the vessel is sailing backwards, a flow is created along the hull. Because of this flow the friction will decrease. DAS is used for astern operations in medium and thick first-year ice with ridges. In thin first year ice and open water the vessel sails ahead [36]. The differences between a traditional and an ice breaking stern, are given in figure 9-4.

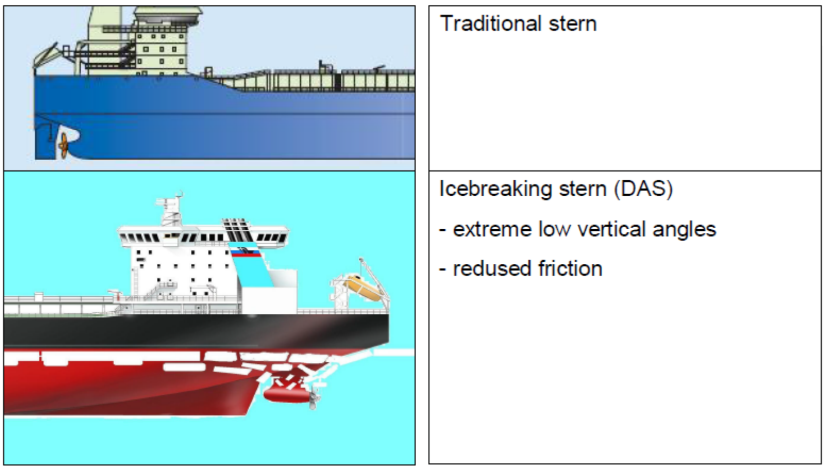

Figure 9-4: traditional and ice breaking stern, based on [34]

9-2-2 Propulsion

This section discusses the propulsion methods used for ice breaking vessels.

Azimuth

For a vessel in ice it is very important that she has a good maneuverability[37]. An azimuth thruster can be rotated 360 degrees in the horizontal direction, in this way the thruster can perform the propulsion and steering duties for a vessel. It directs the generated thrust in the desired direction and "eliminates the use of rudders to direct the thrust"[38, p. 186]. This improves the maneuverability a lot and results in a decreased turning circle compared to a classical propulsion rudder configuration.

Great maneuverability at low speeds is a key element for ice-going vessels, in case they get stuck in ice. The thruster water flow can be used to push away ice floes that got stuck underneath the vessel, on the side or at the stern region of the ship. Experiments have shown that flushing with a thruster reduces ice friction [17]. Some other benefits of an azimuth thruster are: Reduced building costs, easy and late installation and the engine room of the vessel is smaller[39]. Azimuths are especially designed to withstand high ice load. If required an azimuth thruster can be turned towards the ice and can mill it away. Based on this concept the double acting hulls were developed. The combination of a special stern structure with azimuth thrusters makes vessels were suitable to sail stern first through ice.

In general there are three different kinds of azimuth thrusters, two have a mechanical drive and the other has an electrical drive [40, 38]

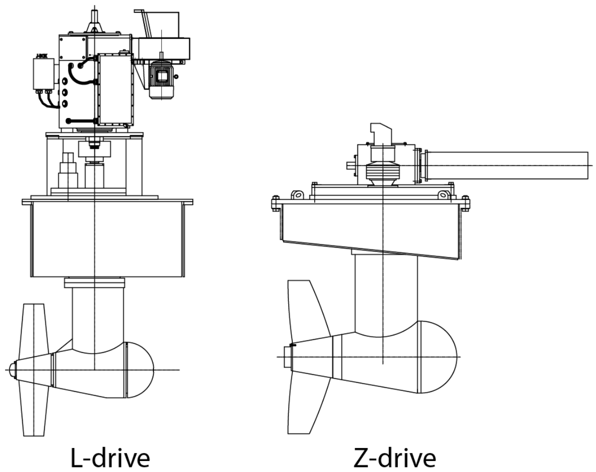

Figure 9-5: Comparison of an l and z drive thruster. Own work. Technical drawings of [41, 42]

A mechanical drive thruster has a direct propulsion train and can either be in a Z configuration, with the engine standing a couple of meter away connected by a shaft, or a L configuration, with the engine on top of the thruster in the aft-ship as shown in figure 9-5. A L configuration is often used with a diesel-electric propulsion train, with generators that convert mechanical energy to electricity and than thruster converting electrical energy to mechanical energy that generate thrust.

In the indirect electrical drive the electric motor is sitting in the pod of the thruster. The thruster has therefore no shaft lines going into the thruster, just a small shaft between inside the pod between the electrical motor and the propeller. The size of the electrical motor is the limiting factor of a pod azimuth.

An advantage from the electrical drive is that it has less vibrations and noise combated to a shaft propulsion system[43]. On the other hand, is the weight of a mechanical driven thruster less. The efficiency of a mechanical driven thruster higher, although it is a 'tough job' to reach this efficiency, because accelerating and decelerating makes the engines change their RPM. This effects the efficiency. With an electric drive the engine can keep running on the same revolutions, because the switchboard requires a constant engine revolution. Therefore an electrical drive will have a higher efficiency when the rotational direction and speed changes often [44]. When sailing at a constant speed the efficiency of the mechanical drive is higher, because the electrical drive loses some efficiency in the switchboard and electrical engine. There are a lot of different sizes of azimuth thrusters, the power can go up to 20 MW[45].

Bow thrusters

In the Arctic a lot of vessels are also equipped with a tunnel bow thruster. "In general, bow thrusters are not used in ice as the ice floes may damage the thruster blades" [46, p. 24]. Ice floes can get into the bow thruster tunnel due to suction. Grids at the tunnel entrance and ice strengthening can be applied to bow tunnel thruster, which makes it possible to operate in ice if desired. A grid, however, decreases the performance of a thruster in open water [46, p. 24]. A installed bow thruster on ice-going vessels is therefore mainly needed for open water operations.

Bow propeller Bow propellers have been installed because they have some beneficial effects. The first is the ability to mill the broken ice into smaller pieces. Second, this ice is flushed away by the flow generated by these bow propellers, decreasing friction between the ice and the hull. The ice may break in front of the hull, because of the flow. Last, the ship can maneuver easier and is able to free itsself when trapped[47].

9-2-3 Machinery

Diesel Electric propulsion When a diesel engine drives a generator and the power from this generator is used to propel the ship with an electric motor, then the propulsion is called diesel electric. The benefit for an icebreakers and tugs alike is the high torque at a low speed, contrary to diesel engines which deliver low torque on low speeds. There is also a lot of flexibility with the several generators[38].

Nuclear powerplant On ships, nuclear power is quite unusual, but the largest of vessels use it, some icebreakers among them. The nuclear plant generates high pressure steam. The steam is led through turbines, converting the heat to electricity. This electricity is used to drive the electrical motors, which in turn, drive the propellers[38]. Nuclear propulsion is especially suitable for the Arctic, because of the energy density of the fuel.

9-2-4 Additional measures

Air bubbling Friction between the hull and ice can be decreased by using an air bubbler. This system injects air, or an air water mixture, at approximately 50% of the draft at small overpressure. The bubbles expand while floating to the surface, effectively pushing ice blocks away from the hull to the side of the channel[48].

Polymer coating Another way to decrease the friction is to apply a low friction paint on the hull. With an unpainted hull the friction coefficient is between 0.2 and 0.3. A low friction paint can reduce this to 0.05 to 0.17. This paint does not only reduce friction, but also prevents corrosion and wear[49].

Ice knife An ice knife is a steel structure used to cut through ice at certain parts of the hull. This can be used at the bottom of a ship, to prevent ice from reaching the propeller. Another place for an ice knife is between the bulb and the bow of the ship or between the rudder and the ster[50].

Multi functionalism Starting with the Fennica, icebreakers have more functions than just breaking ice. The missions of icebreakers are expanded with offshore supply / support vessels. This allows shipowners to use their vessels in a broader manner as stated in chapter 12.

9-3 Materials

In this section the use of materials in the arctic will be dealt with, there are factors that are of influence on the ductility. The first section will explain the factors that have to be taken into account after which some researches are discussed with their application and usage.

The strength of materials is going to be challenged in the arctic environment due to the low ambient temperature. A table made by ABS shows the design temperatures of the standard steel grades, see appendix D Because of the Ductile-to-Brittle Transition (DBT) all BCC structural steels will suffer from reduced fracture toughness as shown in figure 9-6 where an example of the Ductile-to-Brittle Transistion Temperature (DBTT) curve is showed. This is due to limited active slip systems operating at low temperature. This reduction in fracture toughness will decrease when alloyed with nickel, this is however a very expensive solution.

9-3-1 Production effects

There are at least five factors that affect the DBTT, these will be mentioned here. Other factors are considered irrelevant for this report. According to the universities of Delft, Virginia and Suranaree the crystal structure has an effect on the DBTT. Delft and Virginia claim that FCC metals remain ductile to very low temperatures, but do not specify how low or how big the difference is for certain materials [51, 52]. While Suranaree goes as far as claiming the energy absorbed does not change at any temperature [53].

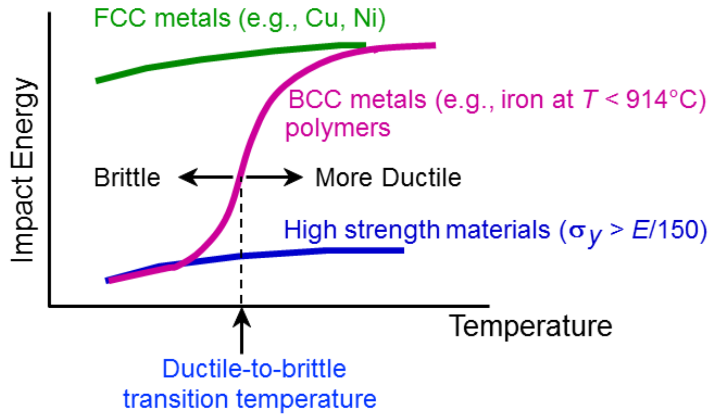

Figure 9-6: Example of a DBTT

Interstitial atoms such as carbon and manganese change the DBTT curve. When the carbon content rises the transition temperature goes up as well, this gives steel which performs worse at lower temperature [53] certain kinds of heat treatments have effect of the diffusing of these interstitial atoms.

Furthermore, the grain size has an effect on the DBTT curve. The larger the grains the further the curve shifts to the right, which gives a higher transition temperature. Heat treatments can provide the grain refinement required for this problem.

9-3-2 Practical effects

In rolled or forged products there is always a certain measure of anisotropy as can be found with the Lankford coefficient. This gives different DBTT in the direction of loading. In longitudinal loading the energy absorption at a certain temperature will be higher then transverse as the crack propagation will be across respectively parallel to the fiber alignment.

Another effect on the DBTT is the specimen size. Tests have shown that the size of the specimen brings the transition temperature down e.g. a thick structure is less ductile at low temperature.

One of the existing solutions is to stretch the existing technology by fine tuning the chemical composition by advanced thermo-mechanical treatment and reducing the carbon content. The steel for Shell's Sakhalin II project is a by Dillinger Hütte developed improved grade of their S450 grade steel. This steel has a design temperature in the range of $-30-35°$ [54]. Through the last 25 years there was a lot of research, new steel qualities with low alloying content and high weldability were developed. Despite the increased strength level a high level of safety has been maintained. During the last 10 years FE calculations and mathematical modeling have been used in practice. Because of the research over these years the predictive capacity has improved as new material qualities and strength levels were introduced. The development continues in various directions, for example in the research project PRESS steel grade 700 was examined. This steel grade is used in DONG Energy's platform Siri [55].

There is still a lot of research going on in this area and improvements in technology, but good solutions can be found by looking at the right parameters instead of using conventional solutions.

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Chapter 10

Market Research

A great amount of companies are involved in Arctic activities, the length of this chapter endorses this statement. The companies cooperate in projects, which are currently aimed at oil and gas exploration and extraction. Any companies involved in (deep) sea mining, such as Nautilus Minerals, are therefore omitted from this chapter. In the future mining activities may increase, as does the need for support vessels for such operations.

As the name of the chapter suggests, a market research has been done. The point of view of an AOSV builder was chosen. The possible customers are mentioned, as are the projects which require an AOSV and subcontractors which supply parts that require extra attention for an AOSV. A technical explanation of the requirements of these parts are given in Section 12-4.

The chapter contains sections about oil companies, projects, OSV operators, shipbuilders and -designers, sub contractors, class societies, transporters, gouvernments and non governmental organizations. All te sections are composed of tables, which gives a schematic overview of key information on any of the chosen companies. Along with the table an explanation is given about the general subject.

10-1 Oil companies

A list of major oil and gas companies is presented in table 10-1. These companies were selected on their status as 'supermajor' oil company and geographical location. All of these companies are publicly held, although Norway has a major influence in Statoil.

Not all of these companies are interested in the Arctic. Total is abandoning their oil drilling plans, by warning for the environmental consequences imposed by arctic drilling[1]. Statoil is retreating from the Stockman project, while Gazprom is also in doubt[2].

In the summer of 2012 Shell started drilling north of Alaska. The drilling should have yielded test wells, but Shell was unable to start drilling within the time window given by the United States government. This was not the only setback for Shell, earlier there were problems obtaining permits. Nonetheless, the US government has encouraged Shell to continue with their efforts[3].

Table 10-1: View on various oil companies

Name	Activities	Employees	Ownership	Turnover (bln $)
BP plc[4]	extraction	83,000	publicly held	135.2
Royal Dutch Shell plc[5]	extraction	90,000	publicly held	470
A.P. Moller - Maersk Group[6]	extraction, shipping	117,080	publicly held	322.5
ConocoPhillips[7]	extraction	29,200	publicly held	251
Statoil ASA[8]	extraction	21,330	publicly held, state owned	87.6
GDF Suez S.A.[9]	energy, extraction	11,658	publicly held	21,2
Chevron[10]	extraction	62,000	publicly held	244.3
Total S.A. [11]	extraction	96,104	publicly held	184.7
Exxonmobil[12]	extraction	82,100	publicly held	467
OAO Gazprom[13]	extraction	404,400	publicly held	152
OAO Lukoil[14]	extraction	120,300	publicly held	133.7

10-2 Projects

Only few projects are going on in the Arctic. One project in Russia that still has to start, is the Stockman project. At the moment of writing this project has been suspended because the costs were to high to proceed. The project will be resumed when the natural gas market has stabilized[15].

One of the projects with high potential is the 'Baffin Bay' project. In figure 10-1 is the licence grow displayed. It will take some years before the drilling can start in Greenland because the infrastructure needs to be made, but that is why there are a lot of opportunities.

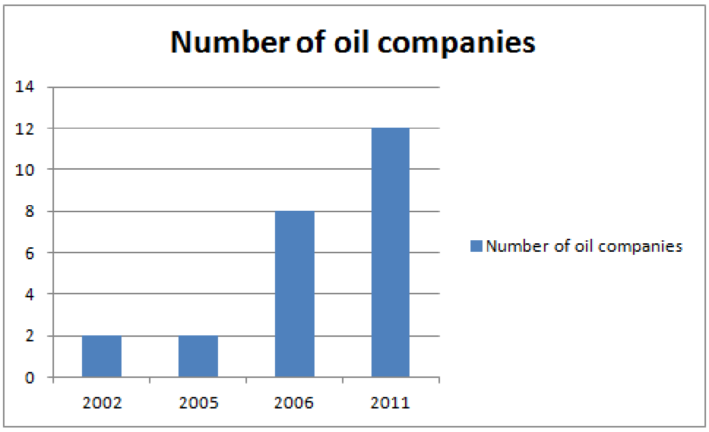

Figure 10-1: Number of oil companies with licenses in Greenland[16]

Table 10-2: Overview of Current and future Arctic projects (NA is Not Available

Name	Location	Result	Production start	Shareholders/Companies	Difficulties
Shtokman field	Barents Sea (Russian)[18]	37 million tonnes of gas condensate[18] 3.8 trillion cubic meters natural gas[18]	2015-2017[15]	Gazprom(51%)[17] Total(25%)[17] StatoilHydro(24%)[17]	sea depth(320-340 m)[17] gas deposits depth (1900 - 2300 m)[17]
Sakhalin-1	northeastern coast of Sakhalin island, Russian Far East[23]	324 millions ton of oil and gas condensate[22] 420 billion cubic meters natural gas[22]	2005[19]	ExxonMobil(30%)[20] SODECO(30%)[20] ONGC Videsh(20%)[20] Rosneft(20%)[20]	Pack ice(1-1.5 m)[21] Severe wave and earthquake activity[21]
Sakhalin-2	northeastern coast of Sakhalin island, Russian far East[26]	433 millions tons of oil and gas condensate[22] 521 billion cubic meters natural gas[22]	1999[24]	Gazprom Sakhalin Holdings B.V.(50%) (plus one share)[25] Shell Sakhalin Holdings B.V.(27.5%) (minus one share)[25] Mitsui Sakhalin Holdings B.V.(12.5%)[25] Diamond Gas Sakhalin B.V.(10%)[25]	Pack ice(1-1.5 m)[21] Severe wave and earthquake activity[21]
Varandey	Pechora Sea[27] (coast)	12 million tons oil[28] annually	2008[29]	Lukoil[30] ConocoPhilips[30]	Storm winds[31] Wave height(5 m)[31] Ice build up(1.7 m)[31]
Prirazlomnoye	Pechora Sea[32]	610 million barrels[33] of oil	2012[32]	Gazprom neft shelf[32]	Ice Thickness(1.7 m)[33] Wind strengths(40 m/s)[33] Wave height(12 m)[33]
Baffin Bay	Greenland[34]	50 billion barrels of crude oil and gas[34]		Pa Resources[16] Conocophillips[16] DONG Energy[16] Cairn Energy[16] Statoil[16] Shell[16] GDF Suez[16] Mearsk Oil[16] Chevron[16] Gazprom[16] Exxonmobil[16] Husky Energy[16]	Strong winds[35] Fog[35] Drift ice[35] Icebergs[35]
Chukchi Sea	Alaska, USA	Unknown[36]	2022[36]	Shell[36]	NA, See (5-2-5)
Hibernia	Canada[37]	1.2 billion barrels of light sweet crude oil[37]	1997 [37]	ExxonMobil Canada subsidiary(33.125%)[37] Chevron Canada Resources(26.875%)[37] Suncor(20%)[37] Canada Hibernia Holding Corporation(8.5%)[37] Murphy Oil(6.5%)[37] Norsk Hydro(5%)[37]	Icebergs[37]
Terra Nova	Canada[38]	406 million barrels[38] of oil[38]	2002 [39]	Suncor energy(37.675%)[39] ExxonMobil(19%)[39] Statoil(15%)[39] Husky Energy(13%)[39] Murply Oil(10.475%)[39] Mosbacher(3.85%)[39] Chevron Canada (1%)[39]	Sea ice(0.5-1.5 m) Icebergs
White Rose	Canada[40]	230 million barrels[40] of oil[40]	2010[40]	Hucky Energy(68.875%)[40] Petro-Canada(26.125%)[40] Province's energy corporation(5%)[40]	Icebergs[40]

10-3 OSV operators

The OSVs are intended to supply offshore installations. In table 10-3 gives an overview of OSV operators. The icebreakers and the ice class vessels are separated, all the ice class vessels have ice class A1 or higher from DNV or equivalent. Because with a lower ice class they will not be able to operate in Arctic without assistance from an icebreaker.

Table 10-3: Overview of OSV operators with ships capable of handling ice conditions

Name	Area	Fleet
Viking	Arctic and Subarctic[41]	3 Icebreaker class AHTS[42, 43] 4 ice classed AHTS[42, 43]
Wagenborg	Caspian Sea[44]	5 Ice class PSV[44, 45] 3 Ice class barges [44]
Sovcomflot	Sakhalin area[46, 47]	4 Icebreaker PSV[48] 1 Ice class research vessel[48]
Arctia	North Sea[49, 50] Beaufort[49, 50] Greenland[49, 50] Baltic Sea[49, 50]	3 icebreaker MSV[51] 3 ice class vessels[51]
GC Rieber Shipping	Sakhalin area[52] Antarctica[52]	2 research icebreakers[53, 54, 55, 56] 1 icebreaker tug[57, 58] 1 ice class research vessel[59, 60]
Dolphin Geophysical	Unknown	1 ice class research vessel[61] 1 ice class seismic vessel[61]

10-4 Shipbuilders and -designers

The companies mentioned in table 10-4 have built structures or vessels for operation in ice. For instance Keppel Singapore, part of the Keppel Group, has built multiple icebreakers, AHTS and an FPSO[62]. Arctech has a major market share of 60% of the icebreakers[63]. The companies building ships are not necessarily the designers or operators.

Bluewater has built a custom Tower Loading Unit for the Sakhalin-I field, which had to withstand earthquakes, once in a hundred year ice loads and has improved fatigue capacities[64, 65]. SBM Offshore has Arctic experience with the Okha FSO at the Sakhalin Island. They have also performed studies on mooring systems and hullforms suitable for ice conditions[66].

Table 10-4: Construction and design companies of ice operating vessels

Name	Activities	Location
Arctech[67]	Design and construction of icebreakers	Finland
Bluewater[68]	Design and operation of floating platforms	The Netherlands
STX Europe[63]	Design and construction of: offshore vessels, cruise ships, ferries and specialized ships	Finland, France, Norway, Brazil, Romania, Vietnam
Havyard[69]	Design and construction of (arctic) offshore vessels	Norway
SBM Offshore[70]	Design and operation of FPSOs, design of TLPs	The Netherlands, worldwide
Keppel Offshore & Marine[71]	Construction and reparation of various vessel types	Worldwide
Edison Chouest[72]	Design, build and operation of offshore support vessels	United States of America
Ulstein[73]	Ship design and building	Norway
Samsung Heavy Industries	Ship building	South Korea

10-5 Sub contractors

In table 10-5 parts of a ship are mentioned. These parts have to be chosen with care, when the ship is operating in a cold environment. The propulsor is subjected to heavy loads, so these are most specially designed. ABB, Rolls Royce and Wärtsilä all have their own specialty. ABB has the Azipod, Rolls Royce has azimuthing propulsors and Wärtsilä has a can mounted propulsor, which is easy to replace in case it fails[74, 75].

In the third column the companies are mentioned that have specific products for the Arctic region. When this is not mentioned, there are no special recommendations for any company.

10-6 Class Societies

All major class societies have an own ice class, which are often depending on each other. Different ice classes and the role of class societies are discussed in chapter 8-3. A overview of current ice classes and their Finnish- Swedish equivalent can be found in appendix C.

Table 10-6 shows major class societies with their general market share based on gross tonnage and ships under class. No figures of the market share related to the ice classes could be found, but DNV states that they have been the leading class for vessels working in ice[76].

Table 10-5: Parts of a ship and subcontractors associated with them

Part	Company	Recommended for Arctic
Prime mover	Caterpillar, Rolls Royce, MAN	NS, engine room has climate of its own
Gearbox	Reintjes, Schottel, Wärtsilä	NS, DE is commonly used
Propeller	Wärtsilä, Van Voorden, Promarin	When used for milling and flushing, loads can become higher than regular. This must be taken into account.
Deck Crane	Heila, Liebherr, Hydralift	Hydralift is used on an AOSV[77]
Life Rafts	RFD, Viking, Zodiac	Viking has a special polar line[78]
Man Over Board and Fast Rescue Boat	Zodiac, Narwhal, Fast RSQ, Ned Deck Marine	NS, operational range depends on type
Navigation	Alphatron, Maritime Technology, Imtech	General problems exist regarding arctic navigation, see chapter 6
Dynamic Positioning	Kongsberg, Rolls Royce	Currently there is no experience with DP in heavy ice[79]
Azimuthing Propulsion	ABB, Rolls Royce, Wärtsilä	NS, all are used commonly

Table 10-6: Main class societies and their market share, number of employees and total revenue

Class Society	Abbr.	Main Office	Market Share based on		Number of Employees	Revenue in M US$
			GT(2007) [80]	Ships(2012) [81]		
Nippon Kaiji Kyoki	ClassNK	Tokyo, Japan	20,0%	14,6%	no data	no data
Lloyd's Register	LR	London, UK	18,4%	15,2%	7555 [82, p. 56]	1372 [82, p. 56]
American Bureau of Shipping	ABS	Houston,TX, USA	16,9%	14,4%	no data	no data
Det Norske Veritas	DNV	Høvik, Norway	15,4%	10,2%	8453 [83, p. 1]	1802 [83, p. 4]
Germanischer Lloyd	GL	Hamburg, Germany	9,8%	9,9%	6900 [84, p. 10]	1003 [84, p. 10]
Bureau Veritas	BV	Neuilly-sur-Seine, France	8,0%	13,7%	52000 [85, p. 1]	4446 [85, p. 12]

10-7 Transporters

Table 10-7 shows the largest companies that do general cargo transportations in ice not intended to supply the offshore installations. Prisco, Sovcomflot and Stena's focus is mainly on oil and product transportation, while the focus of Wagenborg is mainly on general cargo.

In the table icebreakers and the ice class vessels are separated, all the ice class vessels have ice class A1 or higher from DNV or equivalent. Only vessels with ice class A1 or higher are mentioned, because with a lower ice class they will not be able to operate in Arctic without assistance from an icebreaker.

Table 10-7: Main Transporters and their vessels

Name	Fleet size
Primorsk	1 Ice class tug
	7 Ice classed tankers
Wagenborg[86]	1 Ice class open top container vessel
	1 Ice class muti purpose roro
	2 Ice class roro
	133 Ice class multipurpose vessels
Sovcomflot[87]	16 Ice Class oil/product tankers
Stena[88]	6 Ice Class oil tankers

10-8 Governments

These countries as mentioned in table 10-8 are chosen because they are memebers of the Arctic Council. The amount of icebreakers given in the table is the amount of icebreakers that the country owns and which are still in service. Countries like Finland and Sweden do not have a part of the Arctic. But they want to help the other countries with knowledge they already have from working in the Baltic area.

10-9 Non governmental organizations

In table 10-9 all the non governmental organizations care about the environment a lot. For this they do different kind of things, most of them do research, Greenpeace is for example, is also taking actions to stop companies for drilling oil in the Arctic. Most of these actions are because Greenpeace thinks that the chances of an oil spill are big. Since the actions are in the media it will be extra important that there will be no oil spill, not even a little one. If an oil spill occurs the market in the Arctic will probably be demolished by the media and it will not be possible to drill oil again in the upcoming years.

Table 10-8: Overview of countries that are of great importance for the Arctic

Country	View on Arctic	Amount of icebreakers
Russia	Motivated to explore and drill oil and gas[89]. They see the opening of the Arctic as an opportunity and have recently unveiled plans to expand their Arctic infrastructure[90]. The Russian state has an estimated one-quarter of the world's untapped hydrocarbon. reserves[91]	25[90]
USA	Big interest in Arctic, but U.S. diplomats may be left on the sidelines. That is because Congress still has not ratified the 30-year-old law of the Sea Treaty that is about how nations develop resources beyond their boundaries[92]	1 [90, 93]
Canada	Enhancing military and research capacity[90].	6[90]
Norway	They are going to boost the transport and energy infrastructure but also protecting the local livelihoods and the environment[94].	1[93]
Finland	There is an extensive Arctic expertise and know-how. They want to protect the environment, do research, strengthen the Arctic Council and development of the EU's Arctic policy[95].	7[90]
Sweden	They think the Artic development is good because the people in the north need jobs en economic growth like everyone else. But the development has to be balanced with protection of the sensitive Arctic nature and engagement with local societies. Also some work needs to be done by Arctic Counsil[96]	7[90]
Denmark	Following Russia, focusing on the oil and gas opportunities[90]	2[97]
Iceland	They want to secure the Icelandic interests within the region, want to react against armament and strengthen their relations with other Arctic states and various stakeholders[98].	0

Table 10-9: Name, accomplishments and goals of various non governmental organizations

Name	Accomplishments	Goals
Arctic Council		Provide a means for promoting cooperation, coordination and interaction among the Arctic States. About for example issues of sustainable development and environmental protection[99].
IMO	Guidelines for ships operating in polar waters[100]	Safe, secure and efficient shipping on clean oceans[101].
PAME	Findings of key aspects of Arctic shipping, see [102].	Provide a local point of the Arctic Council's activities related to the protection and sustainable use of the arctic marine environment[103].
WWF	Studies on the environmental impact of oil spills focusing on Chukchi Sea an the Barents Sea[104, 105]	Preserve the Arctic's rich biodiversity. Ensure that the use of renewable natural resources is sustainable. Reduce pollution and wasteful consumption[106].
Greenpeace		Prevent melting, oil drilling, industrial fishing and conflict among Arctic nations[107]. Also they want to stop Shell from making exploration drills in the Chukchi and Beaufort Sea [108, 107, 109].

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Chapter 11

Economic feasibility

When is it economic feasible to operate in the Arctic, with all its additional costs and hazards? This chapter deals with this topic and focuses on the oil and gas industry and the coherent need for AOSVs. A short study is made on the driving factors of going into the Arctic and the extra costs of operating, taking into account the higher risks and harder conditions.

Factors that increase the costs of operating in the Arctic are among others:

- Weather and ice conditions:
  - Special equipment
  - Hull form and propulsion means
  - Longer duration
- Remoteness: long transport routes and high required redundancy levels
- Wages for personnel
- Long research and development trajectories.

The bottom line for operating in the Arctic is that high operation and development costs, high risks, and lengthy lead-times can all serve to deter their development in preference to the development of projects in other areas.

This chapter gives first the driving factors behind operating in the Arctic and emphasizes second the additional cost factors.

11-1 Driving factors industry

Oil companies are only going into the Arctic if the oil or gas price is high enough to let the operations be profitable. The commerciality of any project or technique in the oil and gas industry is based on expectations of the future market prices.

To determine the feasibility of a offshore project, many factors have to be taken into account as showed in figure 11-1 and the additional factors of the Arctic as indicated in the introduction. In the Arctic especially the oil price is important to cover the high cost of producing in the Arctic.

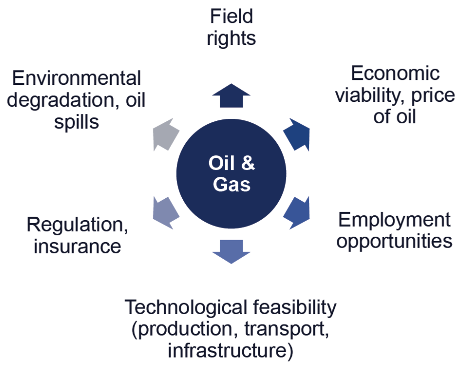

Figure 11-1: Important factors for the total costs of a project [1]

This section gives an analysis of the oil and gas prices and indicates the other driving factors of operating in the Arctic.

11-1-1 Natural resources

The US Geological Survey (USGS) produced an in-depth analysis of the anticipated oil and gas resources available for extraction in the Arctic compared to the worldwide reserves. The USGS estimates that the arctic areas contain about: [2]

- 13% oil
- 30% natural gas
- 20% natural gas liquids.

About 84% of these estimated resources are expected to occur offshore.

In 2009 the International Energy Agency expected the oil price to rise to an average level of $100 by 2020 and $115 by 2030. Based on this scenario a study performed by the research department of Statistics Norway indicates the estimated future oil production in the Arctic, see figure 11-2. If the oil price will be higher than estimated, more production will occur in the Arctic. The same occurs if the undiscovered resources prove to be higher than the estimates by the USGS. The opposite scenario can also happen, and the oil production will be lower than expected. [3]

Because only a few exploratory drills are performed, operating in the Arctic logically gives the chance to discover new large profitable fields [4].

The Chatham House report of 2012 states that the cost per barrel are for conventional oil averaged $22 and for the Arctic three times higher with an average of $68 a barrel. "Expectations that the price of oil will remain in the $80 to $120 range provide a strong incentive for exploration despite the high costs of arctic development" [5].

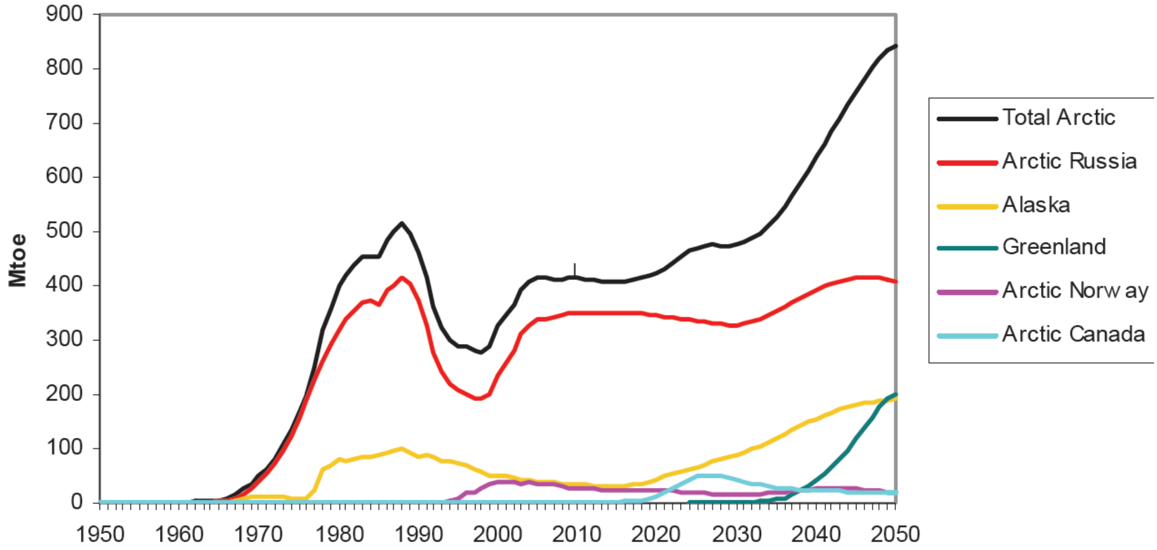

Figure 11-2: Arctic oil production [3]

Figures 11-3 and 11-4 show the oil and gas price over the last years:

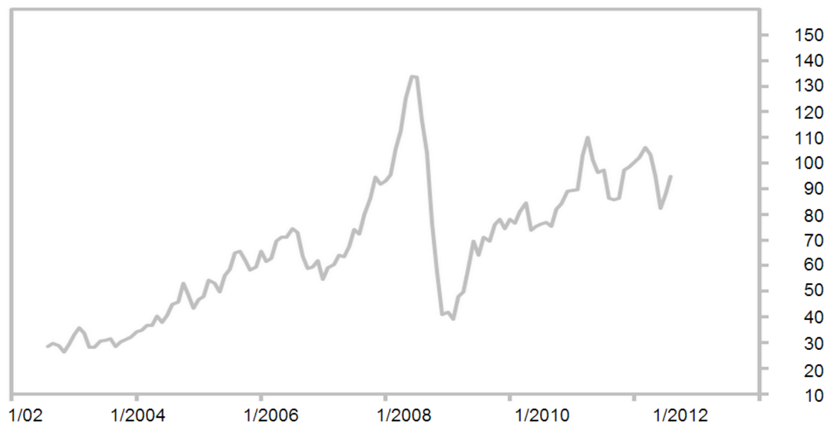

Figure 11-3: Oil price (in $ per barrel) [6]

Figure 11-3 shows that at this moment the oil price is in the $80 to $110 range and companies are indeed interested to go into the Arctic.

The Arctic is also particularly rich in gas, but oil companies are mainly focusing on oil, because the long-distance transportation of gas is not profitable with the current prices [7, 8]. For instance, the Stockman project is suspended, although the field contains also significant condensate reserves, see table 10-2 [9].

11-1-2 Changing environmental conditions

The National Snow and Ice Data Center has observed changes in the Arctic regarding the sea ice cover. The Arctic used to be dominated by multi-year ice features. Lately, the Arctic is

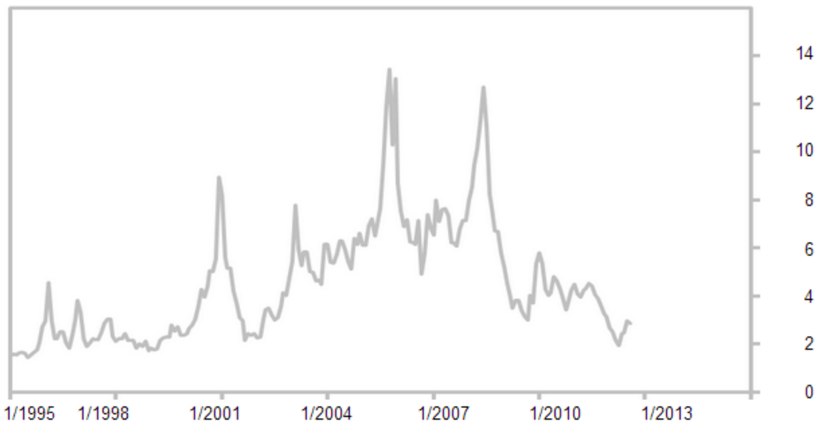

Figure 11-4: Gas price (in $ per MMBTU) [6]

increasingly characterized by seasonal ice cover and large areas are now prone to completely melt away in summer. [10]

For the oil companies this melt is serving to set up drilling operations and production platforms, a longer open water season is available in the summer and there are less severe ice conditions in the winter. This means that operations can last longer and it gives easier transport and supply possibilities.

Also the sea transport means for land based industries, as mineral mining and land based gas and oil projects, will increase so that they contribute to the development of infrastructure and navigation means.

11-1-3 Development and investments

As shown in the market research, chapter 10, companies are interested in the Arctic and want to be prepared for future developments. Not only the oil companies, but also the subcontractors and research institutes invest in arctic research and development. They are driven by the economic view to be prepared when the oil companies decide to produce in the Arctic, to have the best suitable solution to enter a new economic feasible market. With the installation of an arctic offshore platform other activities are involved and need to be done with special equipment designed for the Arctic.

The Chatham House report shows the arctic investments already done by the oil and gas sector. The report also states that the investments in the Arctic are relatively small compared to the expected overall investments in the oil and gas industry. These will reach $20,000bn between 2011 and 2035 according to the International Energy Agency [5, p. 24, 25]

The development and improvement of exploration, drilling and production technologies has increased the likelihood of finding oil and gas in any given location, and allows larger areas to be developed with fewer oil and gas installations [5, 11].

11-1-4 Infrastructure

Arctic developments, such as offshore Greenland and the Beaufort Sea, have more severe ice conditions and are more remote than for example the Barents Sea, which means:

- Potentially higher production costs
- Requirement for major infrastructure investment before development.
- Higher price or a larger oil field to be profitable compared to other areas [5]

These high investments are usable in the future as stated in a report of the United States Energy Information Administration: "The development of new fields near existing fields is economically benefited by the ability to use whatever infrastructure already exists, for example, roads, railroads, harbor facilities, air fields, electric power generation, and living quarters." [8]

11-2 Development of Arctic Offshore Support Vessels

In the previous section is explained why the oil companies are going to concentrate on the Arctic. To perform these activities production platforms and drilling ships are needed, but also support and supply vessels. This section focuses on the development and operational need of AOSVs.

11-2-1 Operational need

The operational need of an AOSV is dependent on the area and the type of production platform that should be supported. In section 12-1 the three main areas of interest are explained, and section 12-4 gives an overview of the possible operations the AOSV could perform. These sections show different operational needs and areas which are also effecting the economical feasibility of an AOSV.

Predictability, punctuality and economy-of-scale are important factors in modern day shipping economy. For open water operations the Estimated Time Arrival (ETA) are stated clearly in contracts and not meeting the ETA results in high financial fees for the operator as well as medium series of the same ship are produce to make use of economy-on-scale effects. In the Arctic these three factors are currently limited [12]. Predictability and punctuality are highly depended on weather and ice conditions and can result in large differences between the planned ETA and actual ETA.

While oil companies show increased interest in the Arctic, shipbuilders and their subcontractors are following. In a early stage of development shipbuilders will make AOSVs that are designed to perform all expected operations that are needed. With such concept design a company will try to enter the AOSV market, to cover all operations that might be performed. In general companies have to invest in arctic development before actual operations are carried out, and be ready when their products are needed.

11-2-2 Cost factors

The focus in this section is on the additional cost for developing and producing an AOSV compared to an OSV.

In general the complete vessel will be more expensive. Every part of the ship needs to comply with ice class standards. From hull to lifeboats and from oil tanks to accommodation needs to be reconsidered for the Arctic. A close cooperation with sub contractors is therefore a key element in developing an AOSV. In section 10-5 a market research on sub contractors can be found. Additional cost factors are shown in figure 1-1 in section 1-3 and are explained in more detail in the following itemizing:

- **R&D** There is only small research done into the Arctic. R&D is therefore an important department while developing an AOSV. Companies are aspiring to come up with new solutions to reduce costs and increase efficiency.
- **Ice strengthening** Ice strengthening means that the construction of the ship is sufficient for safe operiation in the design conditions. The shell plating is thicker and frame spacing and stiffening is different to deal with the ice loads. Therefore the ship is heavier, material, production and operational costs increase.
- **Materials** For the Arctic special materials are needed such as discussed in section 9-3. These materials are generally more expensive due to special production processes.
- **Machinery** Section 9-2 shows that a direct diesel drive is not the best solution for Arctic operations. Diesel electric propulsion is generally used with multiple ice strengthened azimuth thrusters. This propulsion system is more expensive, but it reduces also the operational cost due to the higher efficiency.
- **Environmental Regulations** As mentioned in chapter 8 and in section 6-1-3 high economic regulations such as TIER III have an effect in designing new ships. In the Arctic an spill can have severe consequences to nature, reputation of the companies involved and to Arctic operations in general
- **Open water behaviour** In general the bow and stern of a ship can only be optimized for one condition. It is impossible to have optimal open water performance and optimal ice performance at the same time. Therefore compromises have to be made and the open water behaviour will decrease compared to an OSV which increases the operational costs.
- **Equipment** To decrease the hazards of ice accretion, winterization of the vessel is needed. This results in warmed decks, more enclosed rooms and specialized equipment for operating in cold and harsh conditions. This increases the costs of the ship, because of the additional measures needed to develop and implement.

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Chapter 12

Operations in the Arctic

A operational profile of a vessel is a quantitative characterization of how a vessel will be used. This deals with the operation areas and the operation that will be performed in these. With the information gathered in the previous chapters, this is a concluding chapter that focuses of the operations of AOSVs.

First a comparison of feasible operation areas will be made. Also, three different operational scenarios are specified. Thridly a general overview of exploaration activities is given and finally several operations are explained with respect to offshore supply and support in the Arctic together with the resulting requirements.

12-1 Operation areas

With the obtained information from the previous chapters, a comparison can be made between Arctic areas that are of interest for the industry. These areas are explained in section 5-2. As follows from the market research the industry concentrates on the following areas:

- **Baffin Bay** This area of interest by the oil companies covers the EEZ of Greenland.
- **Barents Sea** The focus by the oil companies is in the south of the sea. The licenses are in the EEZs of Russia as well as Norway.
- **Beaufort Sea** Especially the area near the shore is of interest, because of the water depth. This means the Beaufort Shelf, with depths up to 200 m.

Table 12-1 gives the specifications and details about each region in a summary from the previous chapters. This table shows the range of annual maximum values of each area. For instance, in the summer period there is open water in each of the regions, while only in March the first year ice is as thick as mentioned in the table.

Table 12-1: Comparison possible operation areas.

	Baffin Bay	**Barents Sea**	**Beaufort Sea**
Water Depth (mean, max) [m]	300 to 700 ,2000	200, 600	2 to 200, >2000
Weather			
Air temperature (min, max) [°C]	-39, 18	-19, 8	-30, 20
Freezing Degree Days	5000	2500	4500
Wind speed at 10m elevation [m/s]	18 to 24	20 to 30	18 to 32
Significant wave [m]	4 to 8	2 to 9	2 to 8
Near surface current [cm/s]	20	100	40
Ice Conditions			
First Ice	Nov	Dec	Oct
Last Ice	Aug / Jul	May	Aug/Jul
First year ice floe [m]	1.5 to 2.0	0.9 to 1.1	1.5 to 2.3
Multi year ice floe [m]	2.5 to 5	2.2 to 2.8	3 to 6
Ridges first year (sail, keel) [m]	0.5 to 1.5, 5 to 8	3 to 4, 14 to 18	3 to 6, 15 to 28
Ice bergs			
Mass [million tonnes]	20	6	10
Presence	all year	Jan to Jun	-
Frequency [per year]	>2000	10 to 40	rare
Ports			
Amount	3	7	3
Facilities [grade]	2	1	3
Potentional Oil (%)	50-100	100	100
Region	shore	shore	shore
Operations by Oil Companies			
Licenses	9	4	5
Already Active	1	4	1
Future projects	2	2	2

A grading system (scale 1 to 3, where 1 is the best) is applied for the facilities which takes into account the size, hospital, airport, waterdepth and infrastructure.

A comparison of these areas bases on table 12-1 can be made with respect to the following:

1. The anticipated activities of the large oil companies, see table 10-2 in section 10-2 and appendix B
    - The Barents Sea is the area with the most activities, followed by Baffin Bay. In the Beaufort Sea are a few oil production islands near the shore, but other activities do rarely exist.
2. The estimated oil reserves, see figure A-4
    - The potential oil is in every area about the same, the oil estimate in the Baffin Bay is somewhat lower. However, research and explorations are planned in the open water seasons, see the market research in chapter 10
    - The Kara Sea has also a high estimated oil reserve, but there is currently no focus of the oil companies on that area. Additionally, the Kara Sea has harder

ice and weather conditions: the Barents Sea is easier to access and has a better infrastructure and better developed ports.

3. Existing ports, see figure A-3 and table 5-14
    - The Barents Sea has the most and the best ports in the surroundings. The Baffin Bay and the Beaufort Sea are comparable. Besides the mentioned ports in section 5-3, a few small places with or without an airstrip exist, but they are hardy accessible and do not have a hospital. Only the important ports are mentioned in table 12-1.
4. Environmental conditions, see chapter 5
    - The weather is different regarding temperature and freezing degree days. This is partly reflected in the ice thickness and the period of ice occurrence.
    - The Barents Sea has easiest first year ice and the longest open water season due to the North Atlantic Current, the Baffin Bay and Beaufort Sea are comparable with each other.
    - The Barents Sea and Beaufort Sea have the most difficult ridges. This is partly because of the fact that multi year ice drifts easier to this areas than to the Baffin Bay. Also the fact that there is a lot of pressure in the ice due to onshore drifting is a reason for the forming of ice ridges and rafted ice.
    - The Beaufort Sea has the most severe ice conditions and the smallest time window to operate. Year around operation with ships in the licensed areas is nearly impossible as result of ridges and water depth.
    - Only Baffin Bay has a significant amount of icebergs.
    - The areas have nearly the same wave and wind conditions, but the current speed differs.
    - The licensed area of the Beaufort Sea is very shallow, while the Barents Sea and Baffin Bay are deeper and therefore require floating production platforms.

12-2 Scenarios

Different operating possibilities can be used while operating in the Arctic. Parts of the arctic seas are not the whole year covered with ice. Therefore, a vessel does not especially need to be designed for year around operation. It depends on the choice of the shipowner in which part of the year the vessel has to operate. Therefore, three scenarios are described:

1. **Season** Ice Class IA
2. **Extended season** $>$ Ice Class IA
3. **Year around operation** Sufficient ice class for all year ice conditions

The ice class for the extended season scenario depends on the time window in which the offshore facility should be supported and the ice conditions in that specific area. The year around operation means a sufficient ice class for all year ice conditions described in table 12-1. Different ice classes, with its definitions, can be found in section 8-3.

The scenarios are not described in combination with one of the areas in section 12-1, but are applicable for each of them. The same open water conditions are applicable, belonging to the operational area. However, the ice conditions are different. If the ice conditions become too hard to operate in, the vessel has to go to easier ice conditions or even go to open water and can be deployed in other offshore activities.

12-3 Exploration activities

The whole interest in the Arctic is stimulated by the knowledge of the existence of natural resources in the Arctic. A map of the oil and gas resources in the Arctic are to be found in figure A-4.

This chapter gives a brief overview of the methods used in exploration and mining of these resources. The first section deals with oil and gas and the second section is about mineral mining. This chapter is not especially focused on the Arctic, but intended to give background information of offshore operations.

12-3-1 Oil and Gas

This section shortly explains how oil and gas are found, how they are extracted from the ground and how they are transported. This section is mainly focused to oil. The methods for the extraction and transportation of natural gas are different, but the basic concept is the same.

Exploration There are the steps in the process of exploration:

1. Looking at the surroundings, to find any traces of oil. These do not have to be obvious signs of oil flowing out the ocean, but are often based on the experience of the explorers.
2. Seismic exploration should give a more detailed view of the earth layers, including any oil trapped between them. Sound waves are sent through the earth or the water. Reflections of the sound are captured on microphones and give a better idea of possible resources beneath the earth [1], see also section 12-4-7.
3. Making sure there really is oil. This is done by drilling exploratory wells. The oil coming from these exploratory wells (if any), is tested, to make sure more oil is to be found [2]. If the results are positive, more wells will be drilled. These drilling operations are likely to performed in the open water seasons of the arctic regions.
4. These results of the drilling will, in combination with an economical analysis, decide whether extraction is feasible or not.

Extraction When it is feasible to drill for oil, the wells will be equipped for extraction. An oil rig will be placed, to get the oil out of the ground. On sea, this is done by an offshore oil platform or FPSO. These platforms can handle multiple wells and do not have to be on top of them. There are many different types of platforms, depending on depth of water, size of the oil field, the area and many other parameters. The operator of the platform has to decide what kind of platform should be used and in what time window of the year production is possible with respect to the ice conditions.

Transport When the oil is extracted from the ground, it can be either pumped away directly through a pipeline system, or it can be stored and transported by an oil tanker. The pipelines eliminate the need for storage, but are only used as a long-term solution, because of the economical aspects. Oil tankers have more flexibility and can also be used on small oil fields. Several solutions for ice breaking oil or LNG tankers are already used or proposed, see section 9-1.

12-3-2 Mineral mining

Other than oil and gas exploration, sea mining is a new type of resource gathering. The resources are to be found on the seabed, requiring special equipment to mine them.

Hydrothermal vents On the seabed, near the borders of the tectonic plates, there are hydrothermal vents. These vents emit hot sulfurous gases, which react with the rocks around it. As a result of the reaction, several metals, such as silver, gold, copper, manganese, cobalt, and zinc are formed. Other recourses as diamonds and polymetallic nodules are a topic of interest [3].

The Mid Atlantic Ridge continues in the arctic ocean, active hydrothermal sites are found in the arctic regions [4]. However, deep see mining is even in open water in development. The focus for the Arctic is oil and gas and industry is focusing on that.

Exploration methods The mentioned resources are to be mined with deep sea mining methods meaning that no direct mining or dredging methods can be used as in shallow waters. Deep sea mining consists of: [5, 6]

1. Locating using sonar, seismic exploration or towed video systems to locate the vents.
2. Sampling using submarines, ROVs or drilling
3. Exploration of the whole field by drilling
4. Extraction by ROVs and pumping systems in deep water.
5. Transportation

To support the ROVs or drilling ships a Mining Support Vessel (MSV) is needed. An overview of deep sea mining is given in figure 12-1. The surface vessels of sea mining could, like FPSOs, be designed for operation in the Arctic. Although the planned activities in the Arctic are focused on the oil and gas industry, an AOSV can also be equipped, if necessary to assist the MSV.

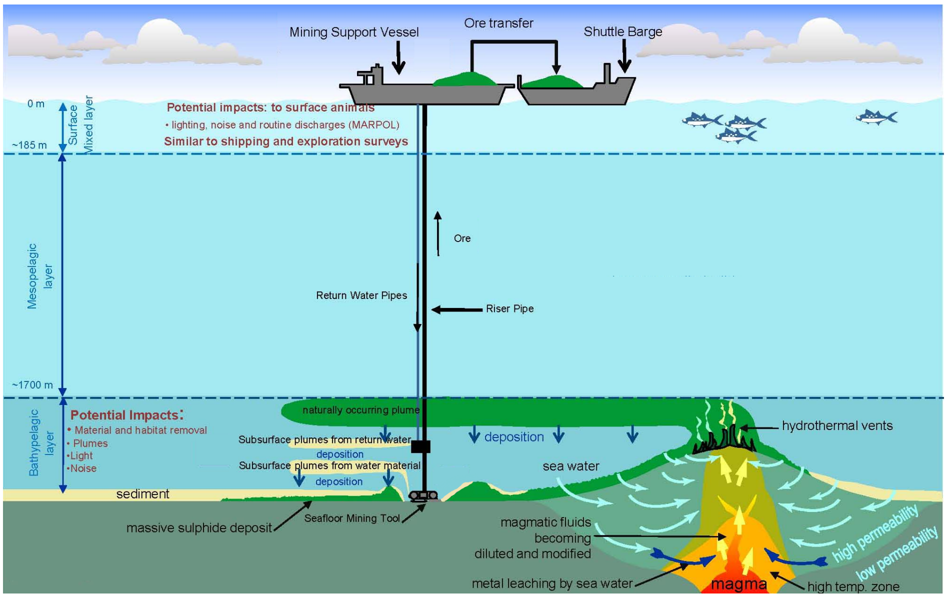

Figure 12-1: Overview of a sea floor resource production system [6].

12-4 Operations and Requirements

In this section operations are described that an Arctic Offshore Supply/Support Vessel (AOSV) must be capable of. These ships are needed by the oil companies to supply and support their facilities.

In this chapter several additional class notations are given that an AOSV might have. The operations mentioned in the following subsections are needed in the Arctic and specified with respect to that. Furthermore, the general design requirements belonging to these operations are given. The requirements given in open water do not change in the ice, what does change, is the way these requirements can be met.

Not all the operations mentioned in this section are possible to implement in one ship, a choice should be made. In general the supply and emergency opertions are nessesary and the others depend on the requirements of the shipowner.

12-4-1 Winterization and Ice Class

The requirements of a vessel depends on the operational profile of the ship, but also on the chosen class notations following from the operational profile. In general the choice of ice classes is based on: [7]

1. Environmental (ice conditions, temperatures)

2. Operational (level of operational support, time in ice, national legislation, future)

3. Ship (effiency, production)

The ice class rules give requirements with respect to the machinery and construction. But operating in the Arctic requires always the winterization of equipment. Winterization is applicable to all ships operating in sub-zero temperatures, independend of the presence of sea ice. It ensures the safe operations with respect to the design, equipment and crew operations. The winterized areas of the ship can include: navigation means, cargo, ballast tanks, mooring, life saving and fire fighting equipment, crewing, cranes, accomodation, ventilation, void spaced and the machinery and propulsions system of the ship.

The means of protection are among others: heating, ice removal equipment, covers, insulation and material, lubricants, oils, hydraulics and greases selection.

DNV has the following notations with their requirements: [8, Part 5, Chapter 1, Section 6] (the requirements are given cumulative)

1. WINTERIZED BASIC
   - Arrangements for anti-icing and deicing
   - Heating of spaces with important equipment
   - Arrangements and location of generator capacity
2. WINTERIZED COLD(t1,t2)
   - Requirements to the location of safety equipment
   - Requirements to steel grades, DAT(-xx) notation
   - Low temperature materials hull and equipment
   - Propeller material (austenitic stainless steel or equivalent)
3. WINTERIZED ARCTIC(t1,t2)
   - Requirements to Controllable Pitch Propeller(CPP) / diesel-electric azipod propulsion
   - Two separate engine rooms
   - Additional measures to take the environmental vulnerability of the Arctic regions into consideration
   - Helicopter landing facilities
   - Life saving and navigation equipment certified for low temperatures

t1 = material design temperature in °C, t2 = extreme design temperature in °C.

DAT(-xx): Design ambient air temperature for structural material properties where (-xx) designates the lowest design ambient temperature in °C.

12-4-2 Ice Management

Ice management involves various operational procedures that can be used to reduce global and local design ice action and is most commonly used to support floating systems, but it can also be used to mitigate the risk of deep draught ice features interacting with sea floor facilities. Ice management consists of active, mechanical processes. For the support vessel they include ice breaking, ice clearing and iceberg towing [9]. Many other activities are included in ice management, such as ice detection, tracking and forecasting. Figure 12-2 explains the process of ice management.

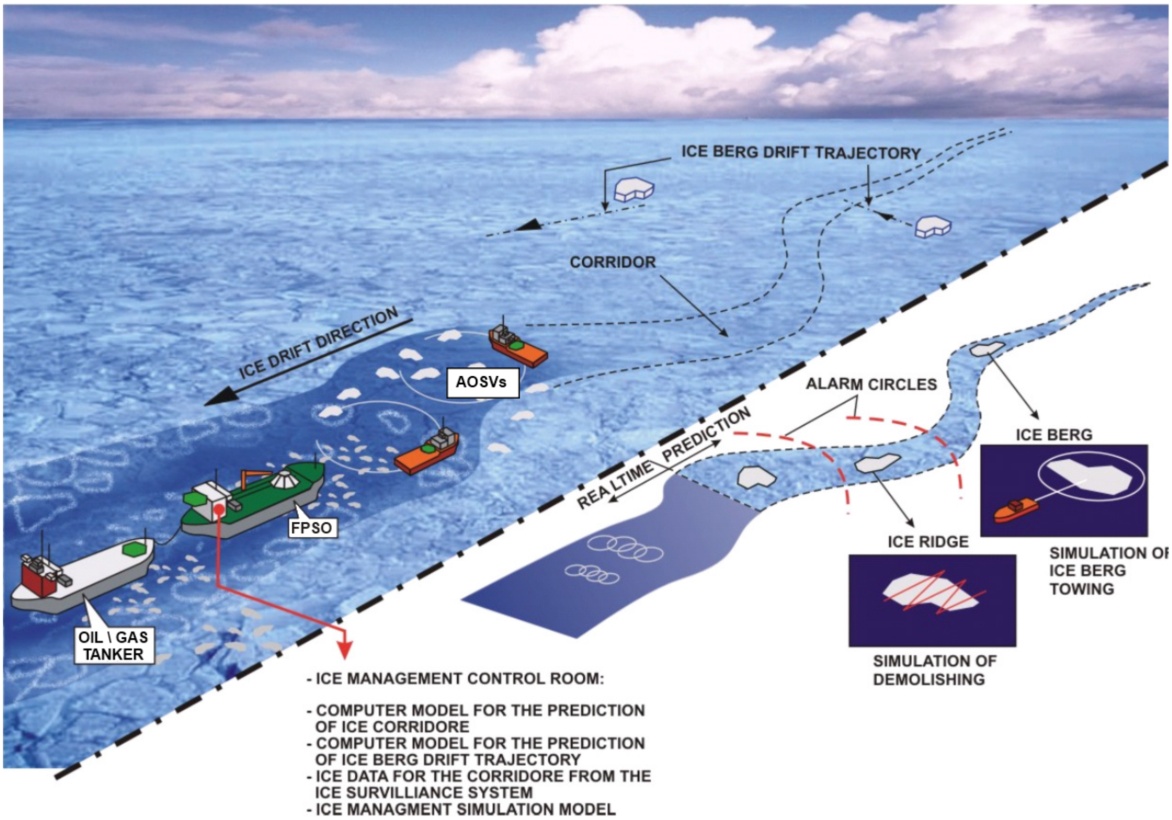

Figure 12-2: Overview of ice management [10]

More information about ice management can be found in the ISO19906 [11, chapter 17, appendix 17]. In this appendix procedures for the ice breaking vessel as well as for the coordinating management are described together with different ice management techniques.

The ISO11906 gives several requirements for a vessel with ice management capability:

- Availability on a timely basis, when the ice become to harsh or when there is danger of icebergs.
- Higher class notation than vessels that are intended for normal ice navigation in the same area, in which heavy ice and ridges can be avoided.
- Capability of iceberg / glacier ice flow towing. This requires 70 to 140 tonnes, but

preferably more, bollard pull, a towing winch, steel towing hawser, and synthetic floating line. The objective is to deflect the ice mass from its natural path.

- Qualified, experienced personnel
- Designed and registered for operations in the most severe ice regimes that can be present at the installation site.
- Equipped for assistance in case of shutting of production, disconnection of the structure, towing it off location and evacuation.

An ice management plan can differ with respect to, for instance, the number of ice management vessels and their interaction with each other, the acceptable level of managed ice and the operational time window. The precise requirements of the support vessel and its equipment depend on the chosen ice management plan, but the general requirements are mentioned above.

12-4-3 Anchor Handling, Towing and Supply

Anchor handling requires special operations aboard a ship. High tensions in chains and cables may cause the vessel to move lateral or astern. The tensions may also cause high heeling moments and therefore high angles. According to DNV there are 4 kinds of notations and missions in this area of operations in open water[12]. These can be found in table 12-2.

Table 12-2: Additional Class Notations

Additional notation	**Services**
Towing	Towing of floating objects
Anchor handling	Towing of floating objects and **objects on sea bed in addition** to subsurface deployment and lifting of anchoring equipment
Supply	Supply services to offshore units or installations
AHTS	**Combined notation** for Anchor Handling, Towing and Supply

An AOSV with anchor handling capability will therefore have the additional class description AHTS, which covers anchor handling, towing and supply capability. Figure 12-3 gives an idea of the magnitude of the bollard pull and other parameters normal anchor handling vessels work with. As seen the bollard pull is also sufficient for iceberg towing, as mentioned in section 12-4-2.

The requirements for an AHTS include but are not limited to:

1. Supply equipment
    - Great variety of bulk products including diesel fuel, drilling mud, pulverized cement and other chemicals used in drilling
    - The transport of project cargo, for example parts or components for extension or maintenance of a platform

- Personnel transfer

2. Bollard pull, equipment to hoist anchors aboard and adequate winch capability
3. Sufficient stability to perform the necessary operations
4. DP system

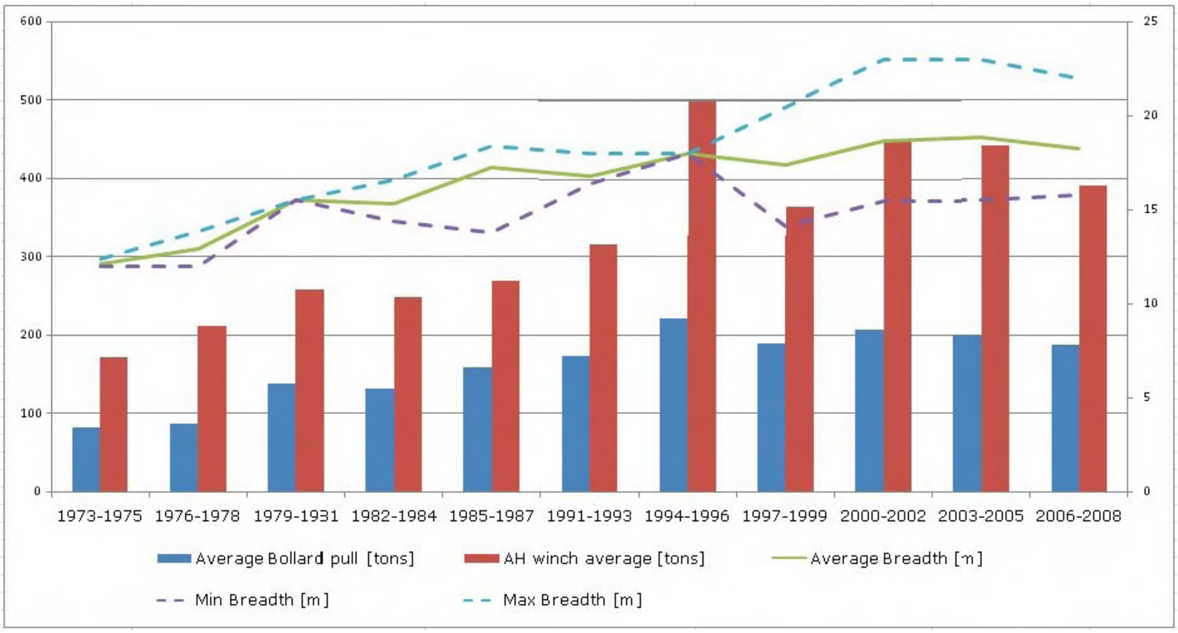

Figure 12-3: The progression of anchor handling vessels 1973-2008 [13]

To meet the requirements a AHTS utilize several tanks normally below the deck, a relatively large superstructure and a flat deck. An AHTS differs to a normal tug regarding deck space and winch locations. This can pose problems in arctic conditions, because of icing on deck, frozen winches and general lower workability. Therefore, the equipment must be fitted so that the workability is as high as possible.

12-4-4 Emergency Operations

The general requirement of a vessel in the Arctic: In case of an emergency the vessel must be capable to handle this on its own because of the remoteness of the arctic area. This means that vessels in the Arctic have to be quite self-supporting, assistance takes longer than in open water. Moreover, in case of accidents the vessel has to be able to give assistance to other platforms, such as fire fighting, oil spill recovery and rescue. The IMO guidelines give recommendations about this, but the coming Polar Code will give mandatory regulations, see section 8-4. Table 12-3 gives the additional class notations of DNV.

Escape, Evacuation and Rescue

In case of emergency the vessel must be capable of safe operations for Escape, Evacuation and Rescue (EER). Chapter 11 of the IMO guidelines indicates that life saving equipment

Table 12-3: Additional emergency class notations

Standby Vessel	Carry out rescue and standby services to offshore installations
OILREC	Oil recovery and transportation after an oil spill in emergency situations
Fire Fighter	Fighting fires onboard ships and offshore and onshore structures

is to be applied with adequate adaptations for the arctic environment [14]. The operations are hampered by the harsh weather, namely the low temperature, wind speed, snow, bad visibility, ice and snow accumulation and the effects due to the features mentioned. A master thesis by Kristian Nedrevåg is focused to requirements and concepts for arctic evacuation [15].

The vessel should also be capable of the evacuation and reception of personnel from other vessels or offshore installations and needs therefore special features. This is especially needed in the arctic conditions, but no extra requirements are available. Only the rules for open water apply. The DNV class notation is 'Standby Vessel'. These rules require for instance a rescue zone in the sides, equipment for recovery out of the sea, accommodation and facilities for survivors and extra rescue and safety equipment. [16].

Oil Spill Recovery

The requirements according to the DNV class notation 'OILREC' should be applied if the vessel must be capable of oil spill recovery. The system aboard the vessel used for open water oil recovery can be used in the Arctic, but there is a problem with the cleaning of the sea. Conventional methods with booms and skimmers cannot effectively be used in combination with ice. The ice hampers the sliding of the booms and skimmers trough the water and the recovery process is not effective anymore. Research is going on to develop methods for recovery of oil from arctic waters and is funded by the oil industry [17]. Furthermore, DNV indicates among others the importance of an oil spill response system that is designed for a complete coverage of the Arctic [18].

Fire Fighting

In open water DNV has the additional class notation 'Fire Fighter', intended for fighting fires on board ships and on offshore and onshore structures. There are three notations, that differ with respect to duration and capacity of the fire fighting [16]. Experience of DNV carried out that "the rules have become the first choice of the safety conscious operators due to protecting offshore oil exploration and production units, safeguarding the environment and ensuring safety for personnel" [19].

Problems that occur in arctic conditions are icing on the fire fighting vessel in operation and otherwise freezing of for instance the pipe systems. Chapter 10 of the IMO guidelines emphasizes the importance of adequate protection of the equipment by heating and isolation [14]. Also the DNV rules 'Ships for Navigation in Ice' give extra regulations about the equipment needed for firefighting in arctic conditions in the winterization rules [8, Part 5, Chapter 1, Section 6]

Other advantages of fire fighting equipment are proposed, such as using water beams to deflect an iceberg or glacier flow of their natural part. Therefore, the water cannon is located on the bow of the vessel, this gives also less hazard to icing on the deck. However, this is only feasible for icebergs up to 60,000 tonnes. Based on a capacity of 3600 m^3/hr and a velocity of 54 m/s (Fire Fighter II requirements), a pushing force of five tonnes can be reached. Small icebergs can be controlled in this way, without towing them. [20, p. 39]

An AOSV should have this class notation, especially in the Arctic because of the remoteness.

Medical Treatment No prescriptive requirements about medical treatment are available at the moment. But additional measures should be considered when planning voyages [21]. The IMO guidelines are also give some recommendations about this subject indicating that appropriate equipment and training are needed, depending on the sort of voyage and operations [14, articles 15.1.2/3].

Helicopter facilities If the vessel is 'WINTERIZED ARCTIC' a helicopter landing facility must be provided. This is a helideck including refuelling and hangar facilities. Rules about ice accreditation of the helideck are also provided by the DNV winterization rules [8]. If a helideck is required it also has to be part of the EER equipment.

12-4-5 Dynamic Positioning

The IMO defines three classes of dynamic positioning (DP) under specified maximum environmental conditions in their rules. DNV has similar notations that comply with the ones given by the IMO. This can be seen, together with the descriptions, in table 12-4.

Table 12-4: DP classes by society

Description	IMO Equipment Class[22]	DNV Equipment Class[23]
Manual position and **automatic** heading control	-	DYNPOS AUTS
Automatic and manual position and heading control	Class 1	DYNPOS AUT&DPS1
Automatic and manual position and heading control, during and following any single fault **excluding** loss of a compartment. (Two independent computer systems)	Class 2	DYNPOS AUTR & DPS2
Automatic and manual position and heading control, during and following any single fault **including** loss of a compartment. (At least two independent computer systems with a separate backup system)	Class 3	DYNPOS AUTRO & DPS3

DP in arctic conditions formed the central focus of a study by the Dynamic Positioning Committee[24]: "Different from open water DP, qualification of DP control in such environments is difficult since there are no well established methods for doing so". The paper shows that there is a need to make a DP control system more reactive to cope with the highly varying ice loads acting on a DP vessel. Assuming such a measure is taken, DP operations should be feasible.

12-4-6 Underwater Operations

Diving operations are needed for instance, for research purposes or support services to platforms because of maintenance or exploration motives. However, Remotely Operated underwater Vehicles (ROV) will can be used instead of human divers.

Ships that perform diving operations often utilize moon pools. DNV has requirements in their rules regarding operations in moon pools [25].

Moon Pool Moon pools come in different types, open and closed. Open moon pools are in contact with the atmosphere and are essentially a big hole through the ship. The sides of an open moon pool are high because they need to be greater than the draft of the ship plus a safety margin. Closed pools are airtight and pressurized to keep the water out, and are commonly used for diving operations. Moon pools in ships that operate in ice infested waters require a vessel that is designed to have no ice beneath the hull or to have a moon pool that can be closed. Additionally the moon pool is recommended to be ice strengthened [21].

Diving If diving operations are performed, there should be adequate equipment on board the vessel to perform this. This includes but is not limited to decompression/re-compression chambers, diving bell, air compressor system and compressed gas cylinders. The problems with diving operations in arctic waters include frostbite, hypothermia and entrapment by moving ice [26].

ROV ROVs are operated from a comfortable environment as opposed to divers that would have to get in arctic waters. This gives the possibility of underwater surveys and maintenance services for sustained periods of time. However, to operate the ROV a advanced control system is required including people capable of working with it.

Both of these operations involve a tether or umbilical for data transfer, air supply, welding equipment and other supplies. Therefore the dynamic positioning system of the vessel for these operations is regulated according to the DNV rules"the class notation DYNPOSAUTR or higher is mandatory, alarms shall be initiated and set accordingly."[27].

12-4-7 Seismic operations

in this section the purpose and requirements of a seismic vessel are described. First there will be a brief explanation about the methods used, after which a few words are said about class notations. Finally,the problems that these operations give in ice and the adaptations of existing seismic vessels will be discussed as well.

Purpose and requirements

Seismic vessels are used to do marine survey acquisition, a form of reflection seismology and utilise streamers and ocean-bottom technologies for this. This is used to get an estimate of the properties of the subsurface or the earth and is therefore widely used in the search for oil. These vessels can also be considered research vessels because they 'research' the geology of the sea bottom. There are two ways a seismic vessel can get geological information using reflective technology. Either by using streamers or ocean-bottom methods. A streamer is a cable with a series of hydrophones spaced evenly over the length as seen in figure 12-4. a

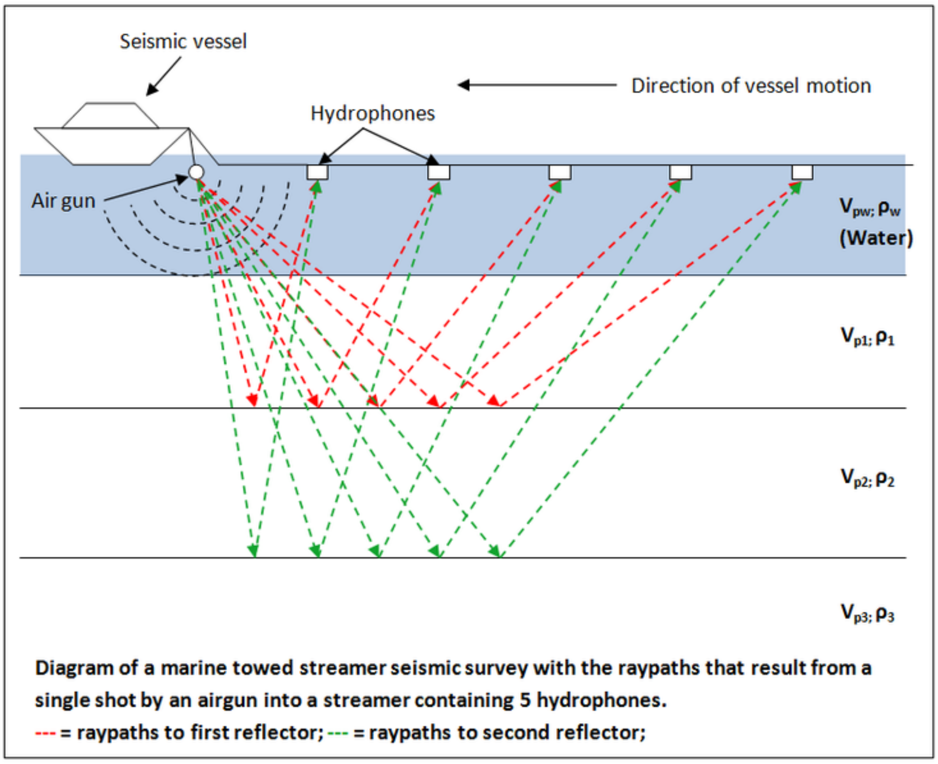

Figure 12-4: Marine seismic survey using a towed streamer [28]

seismic source is then used to generated seismic waves of which the reflection is caught by the hydrophones. This gives information on the shape and subsurface composition of the earth. Multiple of these can be employed behind one vessel to obtain 3D information [28]. A different method is laying the streamers on the ocean-bottom. This requires a separate source vessel as seen in figure 12-5.

The requirements of a seismic vessel then are:

- Being able to handle the equipment necessary for performing seismic operations.
- Have sufficient power and redundancy to perform these operations safely in all encountered weather conditions.

Last summer DNV developed rules about seismic vessels with "a particular focus on the robust design of the seismic equipment hangar and the continuous ability to maintain propulsion power" [30].

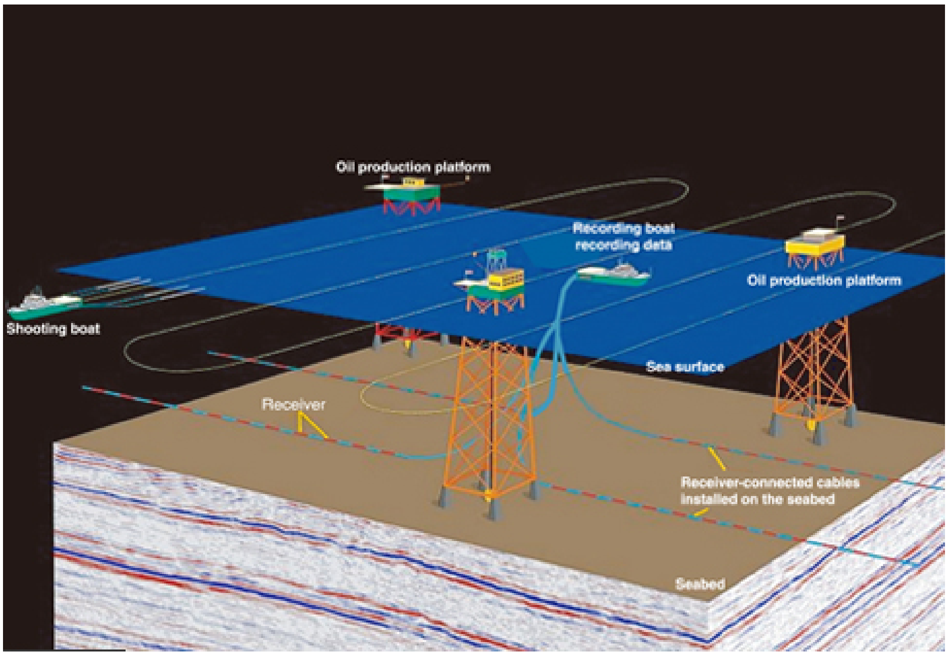

Figure 12-5: 3D ocean-bottom seismic survey in 2003 [29]

Problems in ice According to "The Arctic Icebreaker Coordinating Committee" from UNOLS, seismic operations are stil possible in ice covered water. However they do not specify what they mean by 'ice covered' [31]. Yngve Kristoffersen says that "Seismic operations will use small airguns and short streamers". The problem is that when the equipment is towed at the surface it will be in danger of ice collisions. If the ocean-bottom method is used, the cables must be put down on the bottom in ice condition after which the vessel will need to gather all the data using an ice resistant buoy or connecting directly to the cables.

To overcome these problems there has been an "Ice Pack Project". The aim of this was to "investigate methods for seismic data acquisition in arctic waters with dense ice concentrations"[32]. The outcome of this project is a concept were the seismic vessel is towing a barge which contains the streamer equipment. This barge has a wide slot in the center with a specially shaped tube that ensures the streamers are some meters below the sea surface, thus avoiding the ice floes [33].

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Chapter 13

Conclusion

The main question of this report was stated as: "What are the design requirements and operational profile of an Arctic Offshore Support Vessel?" The answer is given a broad overview of the topics that should be taken into account when operating in and designing for the Arctic. For the development of an AOSV this conclusion gives the initial design requirements and operational profile. The operational profile of the AOSV will be fully determined in the third stage of this research.

The discussion in section 12-1 suggest to focus on three areas to design the AOSV: the Barents Sea, Beaufort Sea and the Baffin Bay. Current projects are going on for these areas and is to be expected that there will be a need for AOSVs in about five years. Other regions as for instance the Chukchi Sea are still in an earlier stage development.

Therefore the design areas of the AOSV is set to the South of the Barents Sea (Norway and Russian EEZ), shore region in the Beaufort Sea (Canada and USA EEZ) and the Baffin Bay (Greenland EEZ).

Season, extended season and year round operations were discussed in section 12-2. The most interesting scenario to choose would be an extended season operation. Offshore platforms will be designed to operate as long as possible in a certain area.

The design requirements will be set according to the heaviest conditions of each of the areas according to the operating time window. When the ice conditions in a certain area become too harsh and dangerous, the ship has to leave the area. The estimated time windows are given below. They are based on the ice conditions and open water seasons for each area, see table 12-1.

1. Barents Sea: March - January

2. Beaufort Sea: April - November

3. Baffin Bay: May - December

The time windows depend naturally on the location in the areas and the specific weather conditions of a year and are only meant to give a global indication.

The ice class has to be sufficient to operate in those three areas. The ship will be designed for the Barents Sea because it is expected that the operations will start in the near future. Because she is also sufficient for the Baffin Bay, she will also be able to operate there when the operations start. The choice of sufficient ice classes can be based on the scenario, areas, reference ships and in general section 12-4-1. The following ice classes are chosen and will be used for further development:

- **PC4** of the PC-rules: "Year-round operation in thick first-year ice which may include old ice inclusions", see section 8-3. This ice class is comparable to the ICE-15 class of DNV which is intented for ice breaking with a nominal ice thickness of 1.5 m.
- **Icebreaker** of DNV: Ramming requirements for ice ridges and other ice features.

An overview of class notations the vessel should have is given below: (section 12-4 gives more information about these notations)

- PC4
- Icebreaker
- Winterized Arctic
- DAT
- AHTS
- DYNPOS AUTR
- Standby Vessel
- OILREC
- Fire Fighter II

The class notation is not complete or specified. As shown in section 12-4 there are more operations that the vessel can perform, if sufficiently equipped. AHTS and emergency operations will set the main design requirements. In the design process more classes will probably be given to the ship. The mentioned classes give, however, a good indication of the operations and requirements of the vessel. Also, in a next stage of the research the design requirements and class notations will be defined further as more insight is gained by a in depth study of existing OSVs.

The vessel will be designed for world wide operations in areas where offshore platforms are located, in open, preferably in ice infested waters, but excluding multi year ice areas with ice thicknesses higher than what the vessel is designed for.

Appendix A

Charts

Figure A-1: General map defining arctic areas[1]

Figure A-2: General map defining national waters[1]

Figure A-3: General map showing ports[1]

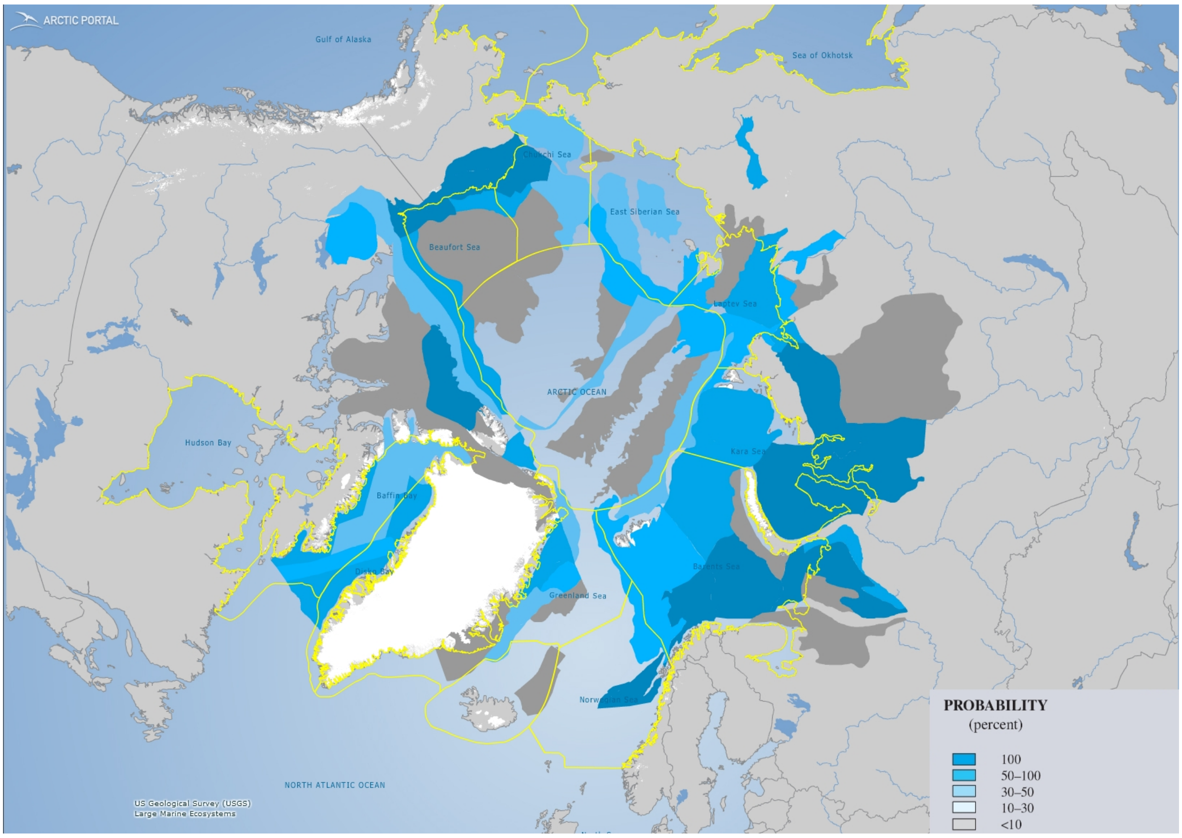
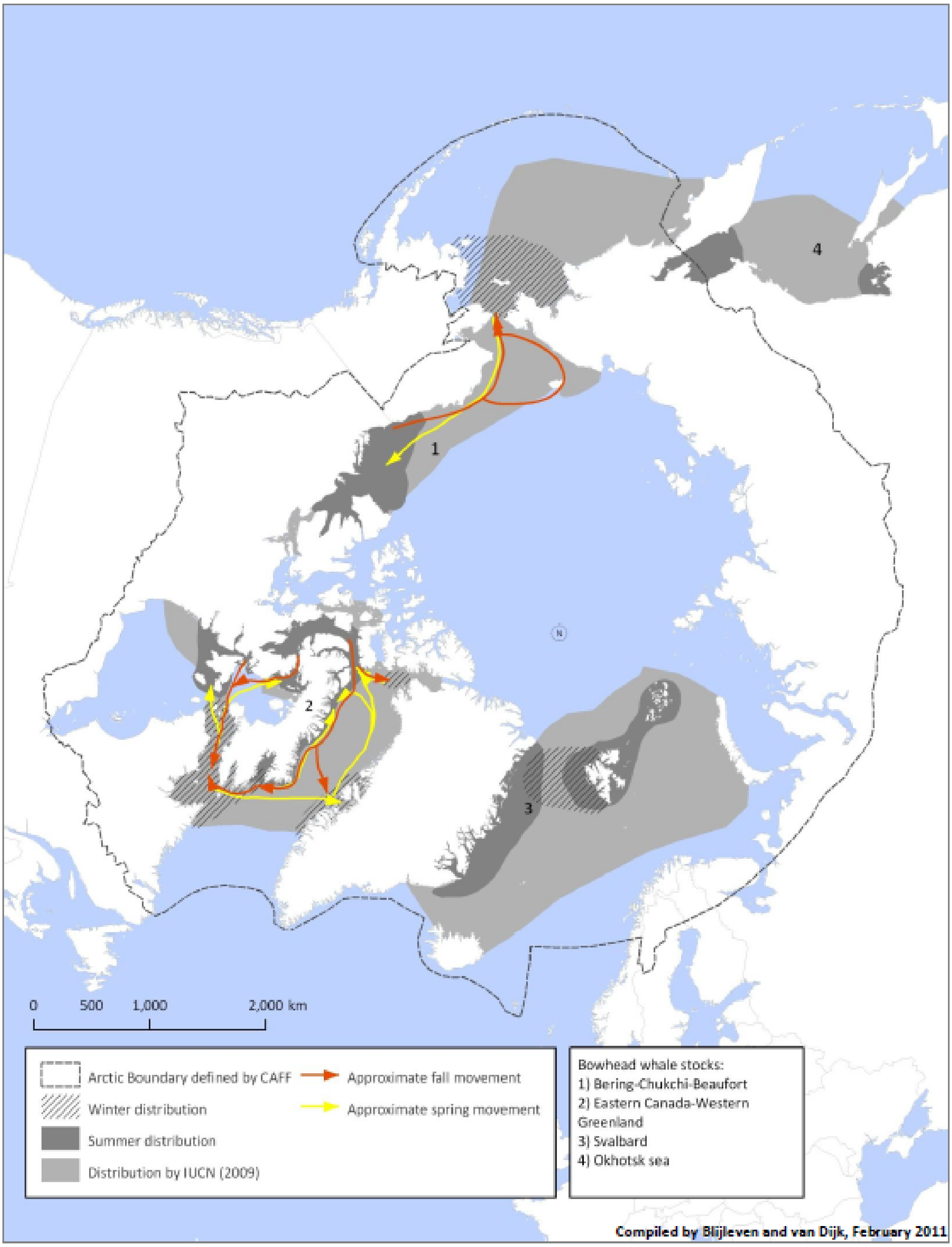


Figure A-4: Resource map, showing probability of oil/gas in arctic areas[1] [2]



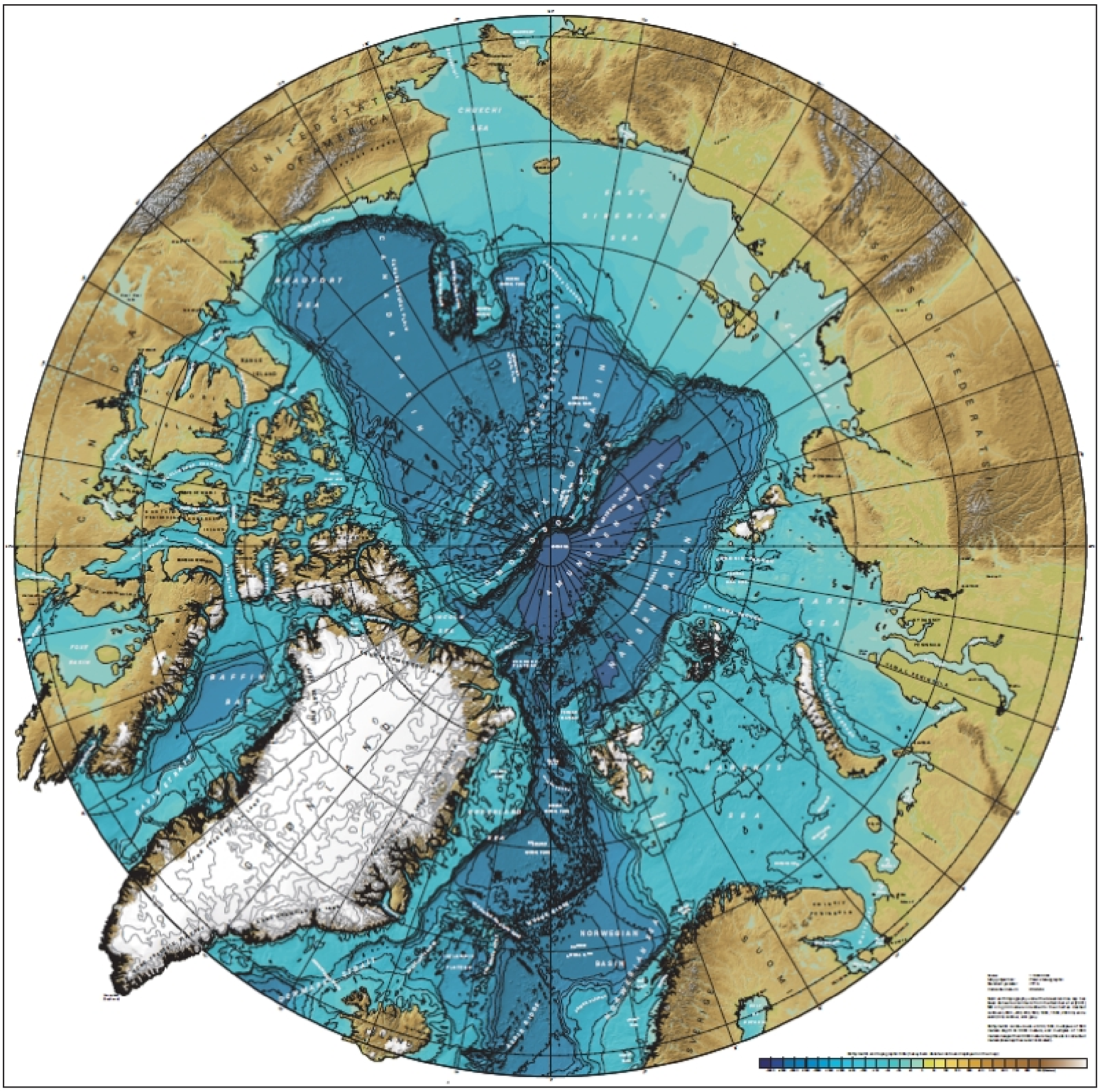
Map 4 Seasonal distribution of the Bowhead whale

This map presents the approximate currently known summer and winter habitats of the Bowhead whale, based on the astronomical seasons. The distribution and movement patterns are narrowed down to a general range, thus events of Bowhead whales occurring outside this range is therefore not excluded.

References: Bradford, 2010; Gavrilo and Ershov, 2010; Heide-Jørgensen *et al.*, 2010b; Ivashchenko and Clapham, 2010; Olson and Dinerstein, 2010; Stephenson and Hartwig, 2010; Vedenev, 2010; Wiig *et al.*, 2010a; Boertmann *et al.*, 2009; CAFF, 2009; Clarke and Ferguson, 2009; COSEWIC, 2009; IUCN, 2009; Koski and Miller, 2009; Quakenbush, 2009b; Gavrilo and Tretiakov, 2008; Melnikov, 2008; Wiig *et al.*, 2008; Wiig *et al.*, 2007; Moore and Laidre, 2006; Gilg and Born, 2005; Heide-Jørgensen and Laidre, 2004; Heide-Jørgensen *et al.*, 2003; Cosens and Innes, 2000; IWC, 1999; Richard *et al.*, 1998.

Reviewed by and feedback received from: P.J. Ewins; I. Gjertz; M.P. Heide-Jørgensen; L. Hughes; K.L. Laidre; C. Lydersen; R.R. Reeves; Ø. Wiig.

Figure A-5: Environmental map, defining areas with endangered species[3]



THE INTERNATIONAL BATHYMETRIC CHART OF THE ARCTIC OCEAN (IBCAO)

Figure A-6: Depth chart, showing depth lines in arctic areas[4]

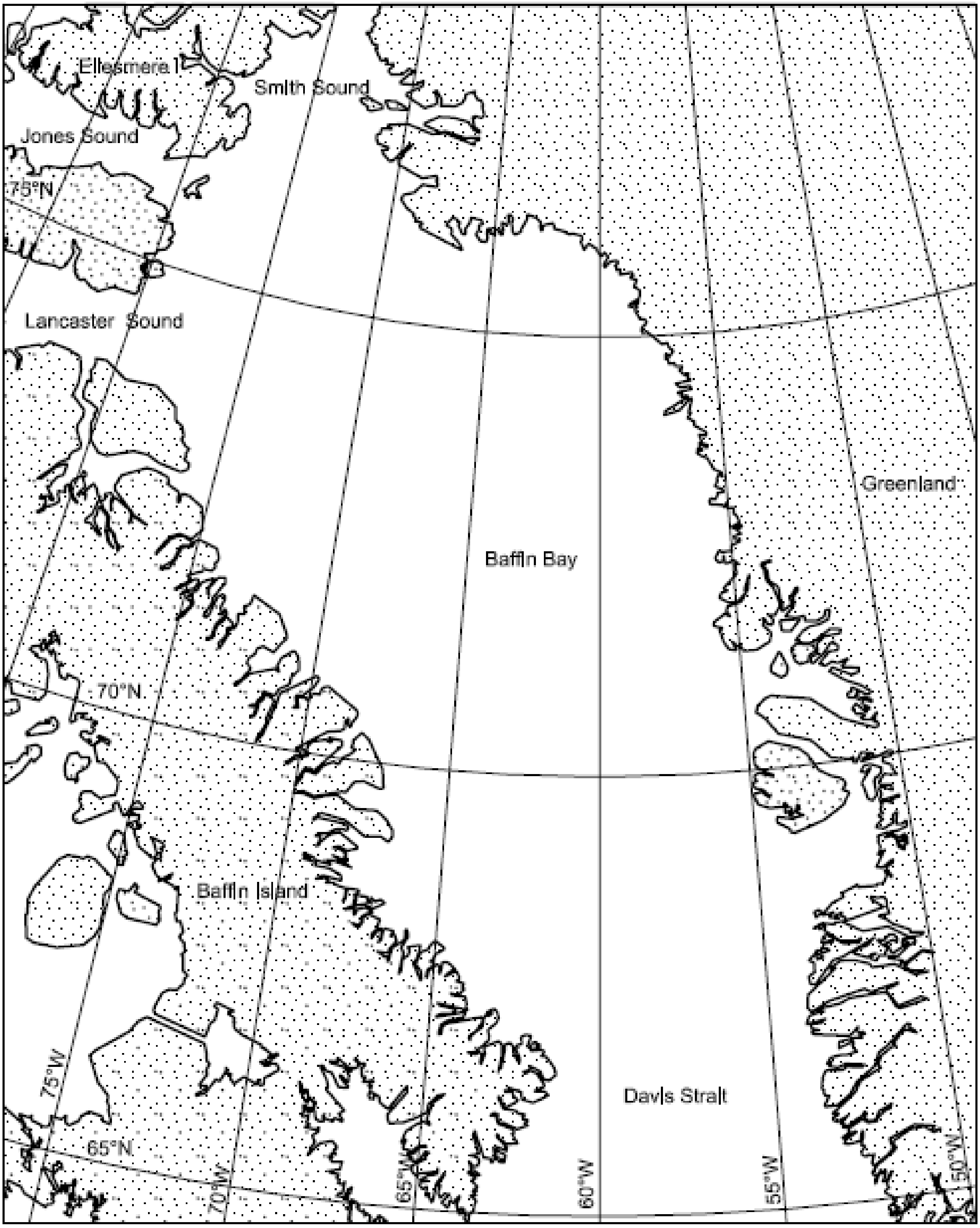


Figure A-7: Map of the Baffin Bay and David Strait region [5]

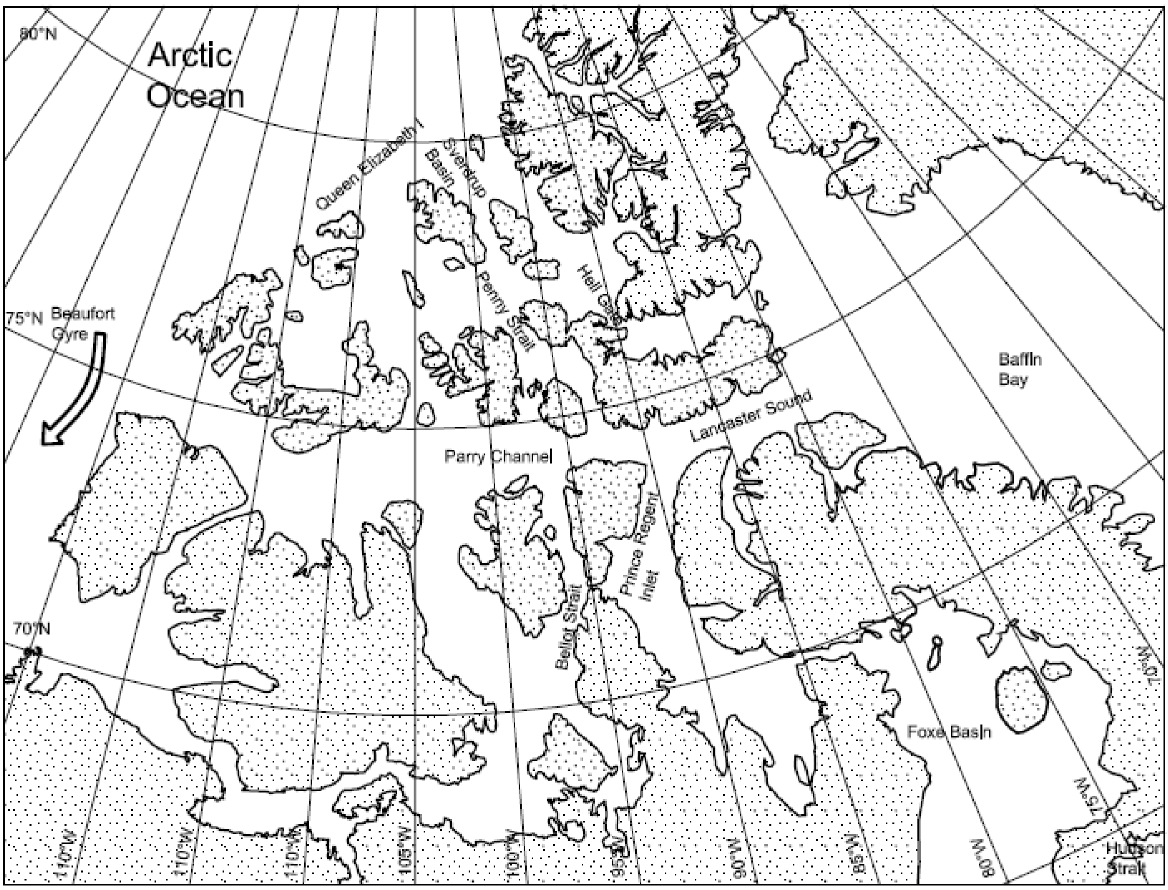


Figure A-8: Map of the Canadian Arctic Archipelago [5]

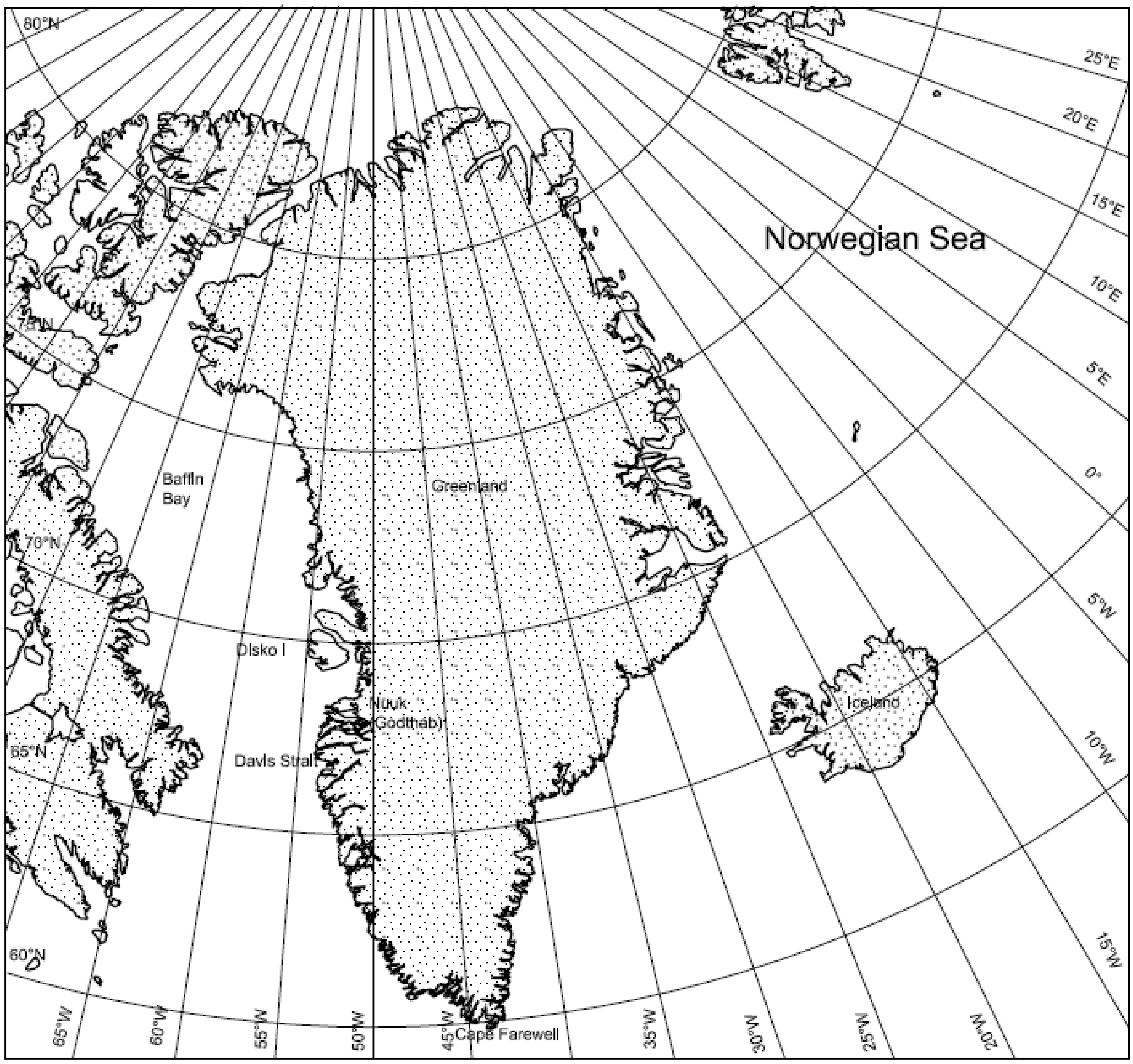


Figure A-9: Map of the Greenland [5]

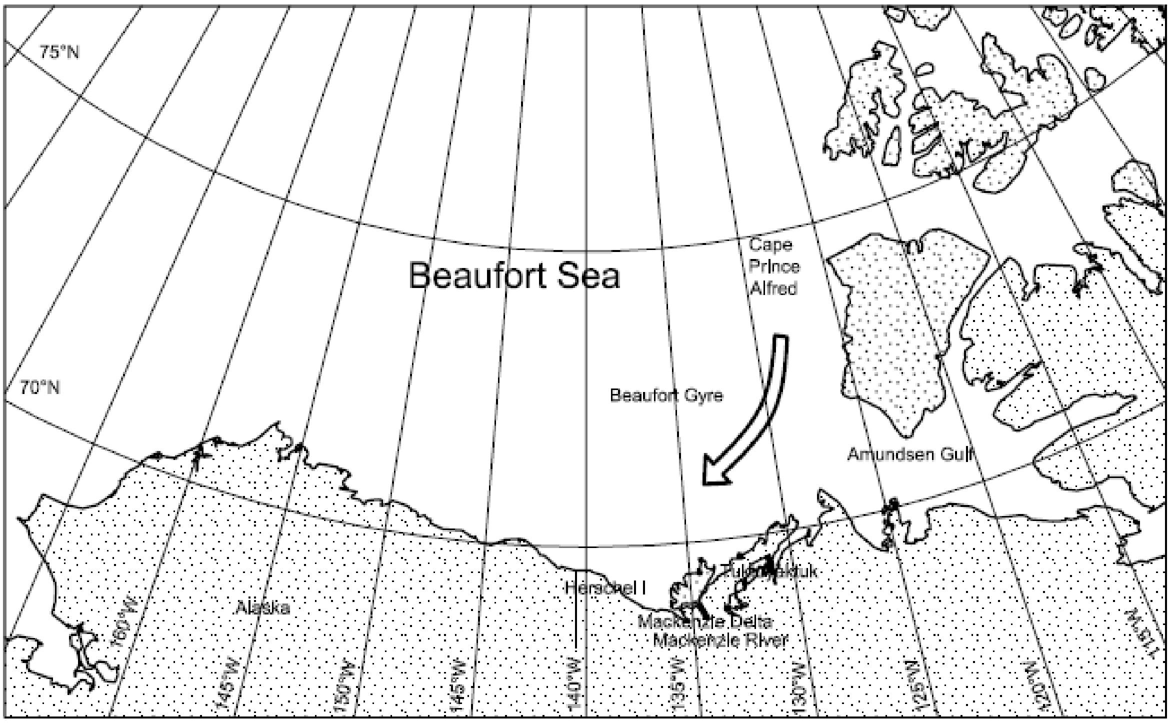


Figure A-10: Map of the Beafort Sea[5]

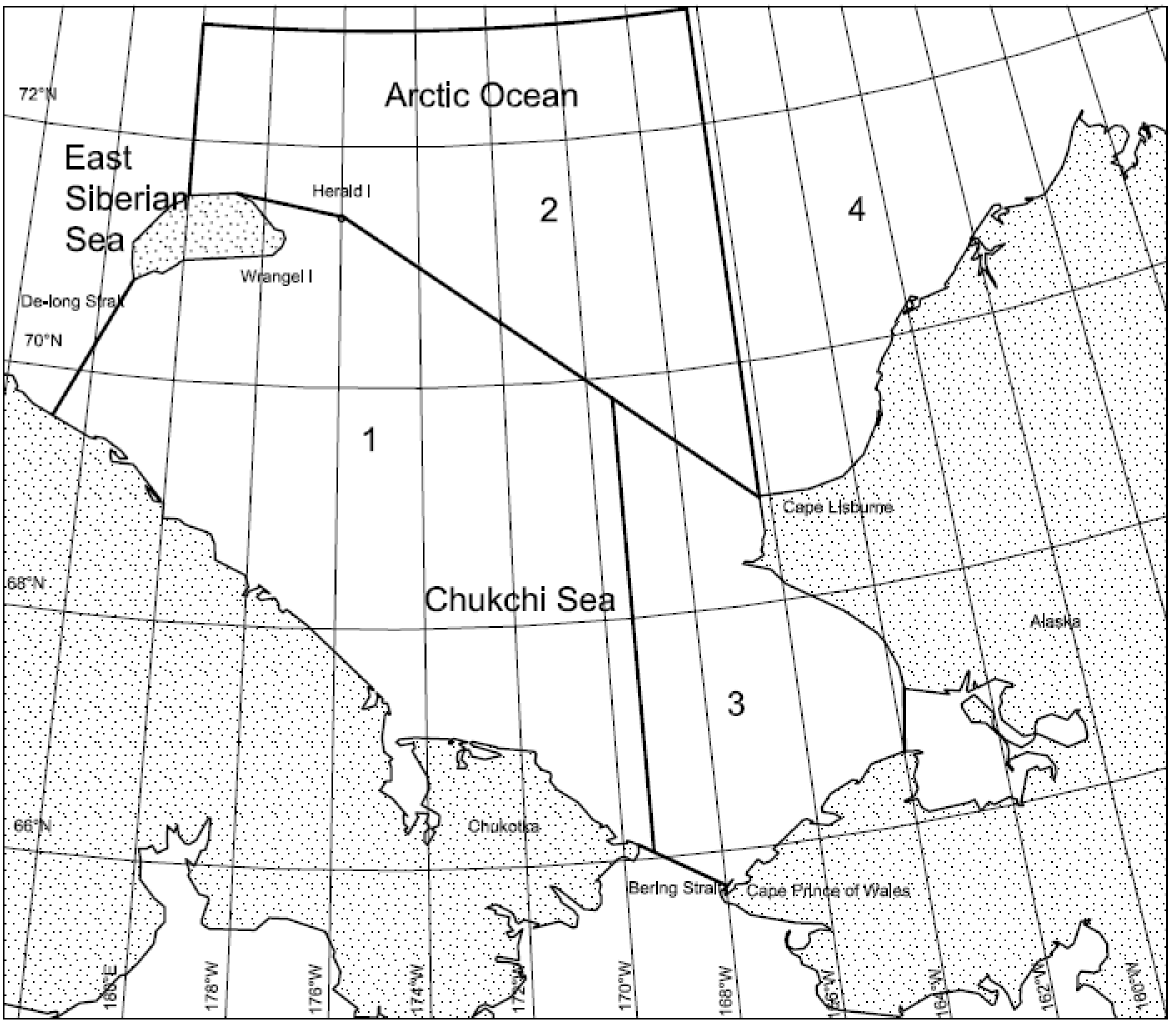


Figure A-11: Map of the Chukchi Sea [5]

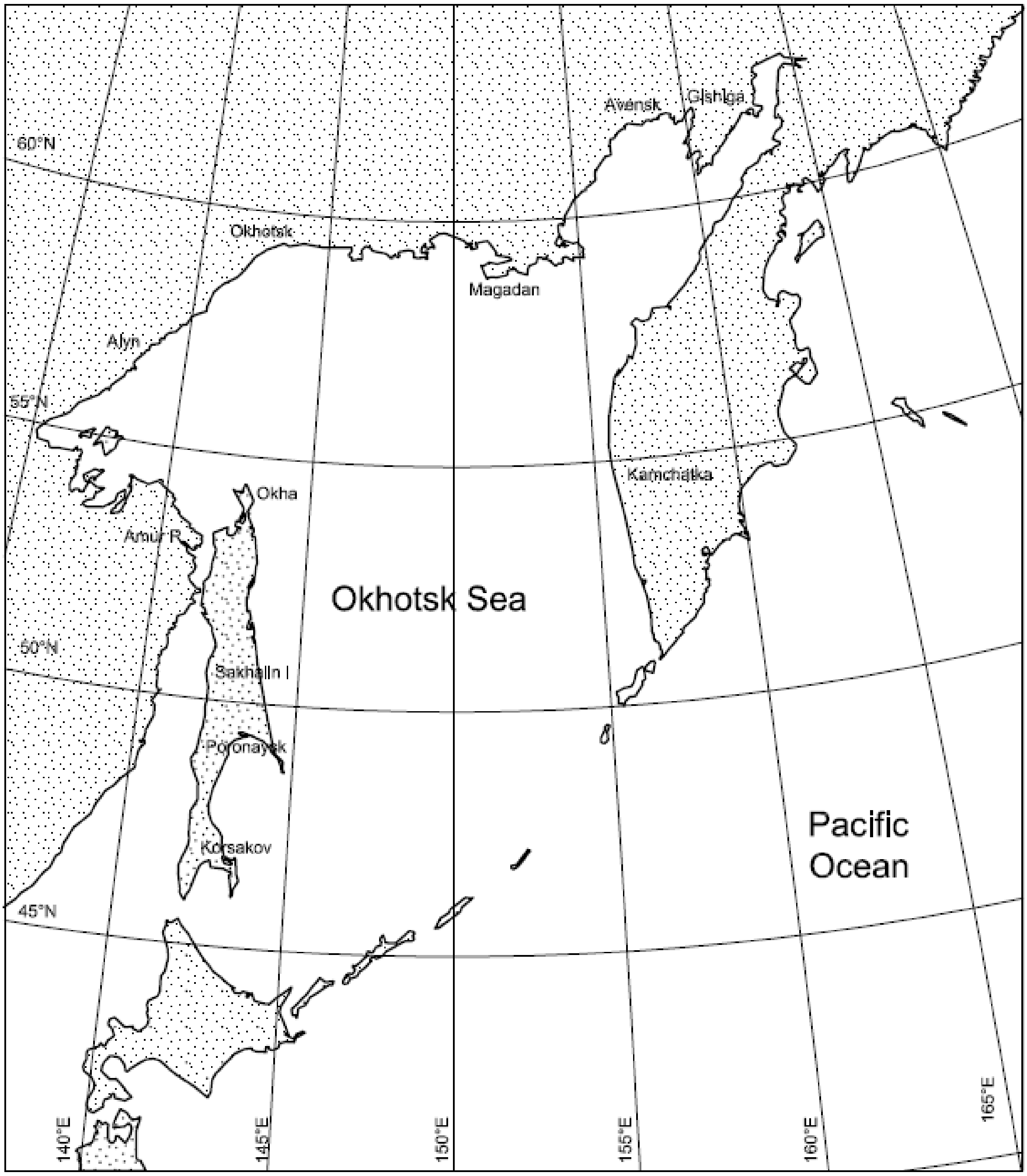


Figure A-12: Map of the Okhotsk Sea [5]

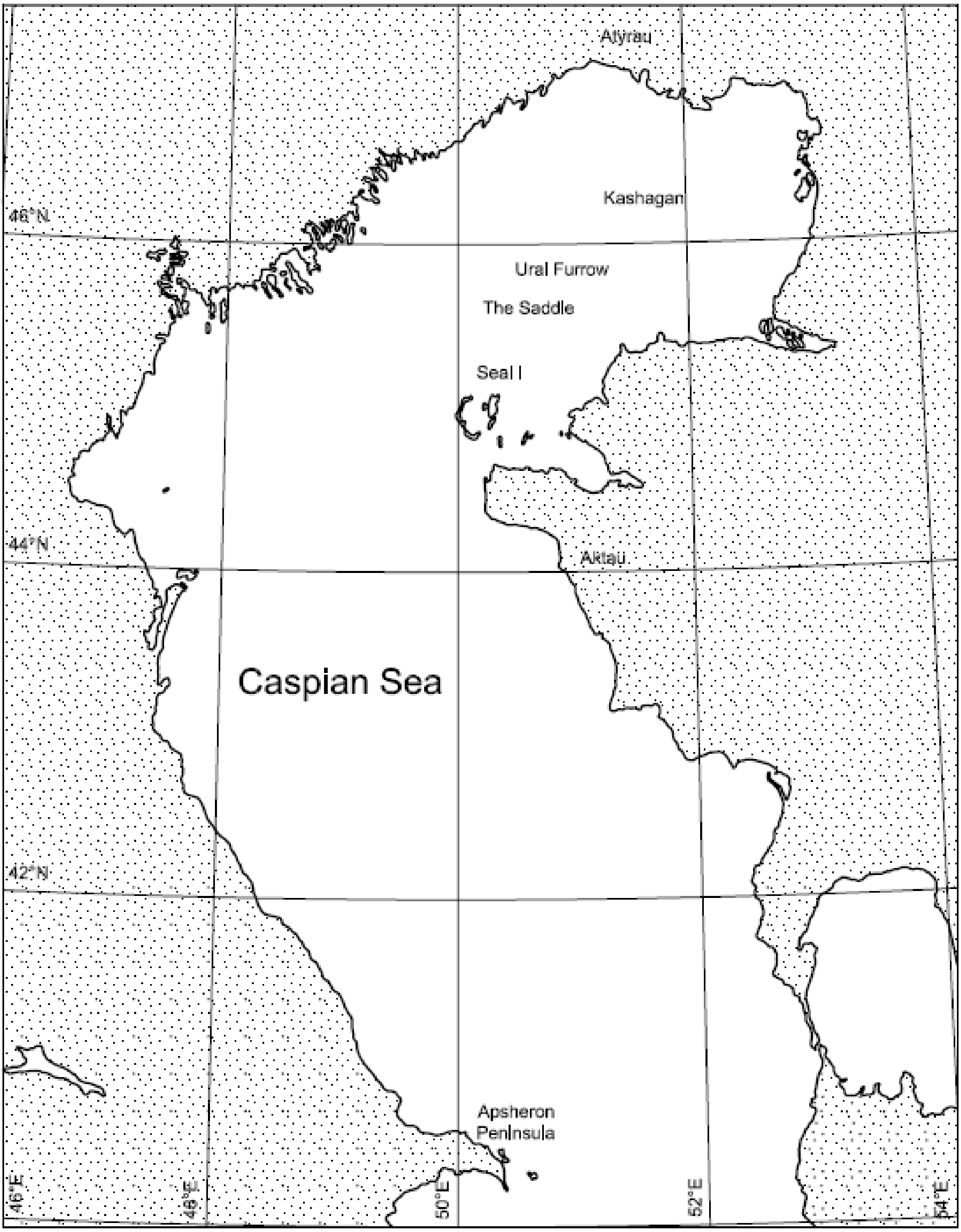


Figure A-13: Map of the Caspian Sea [5]

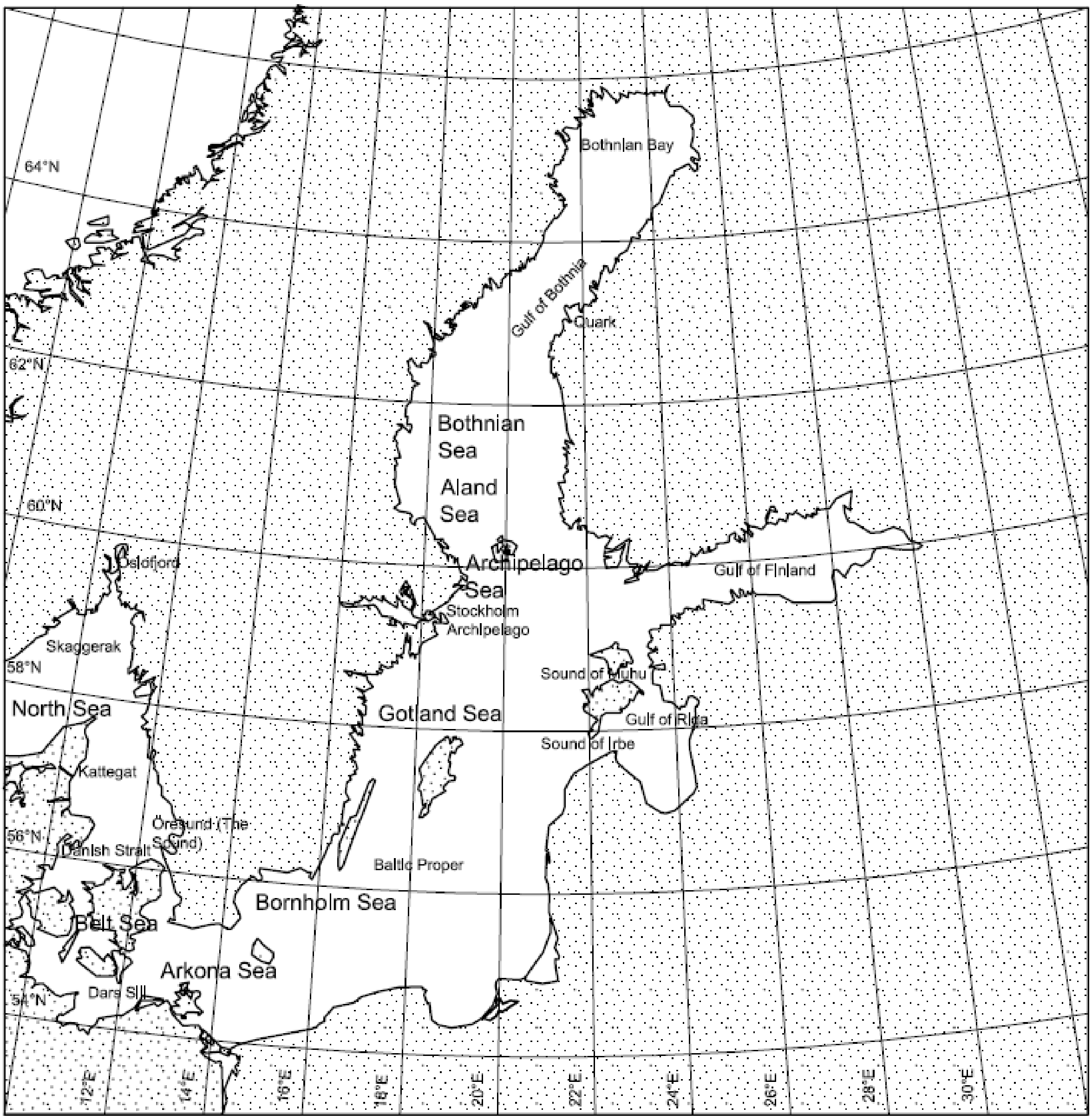


Figure A-14: Map of the Baltic Sea [5]

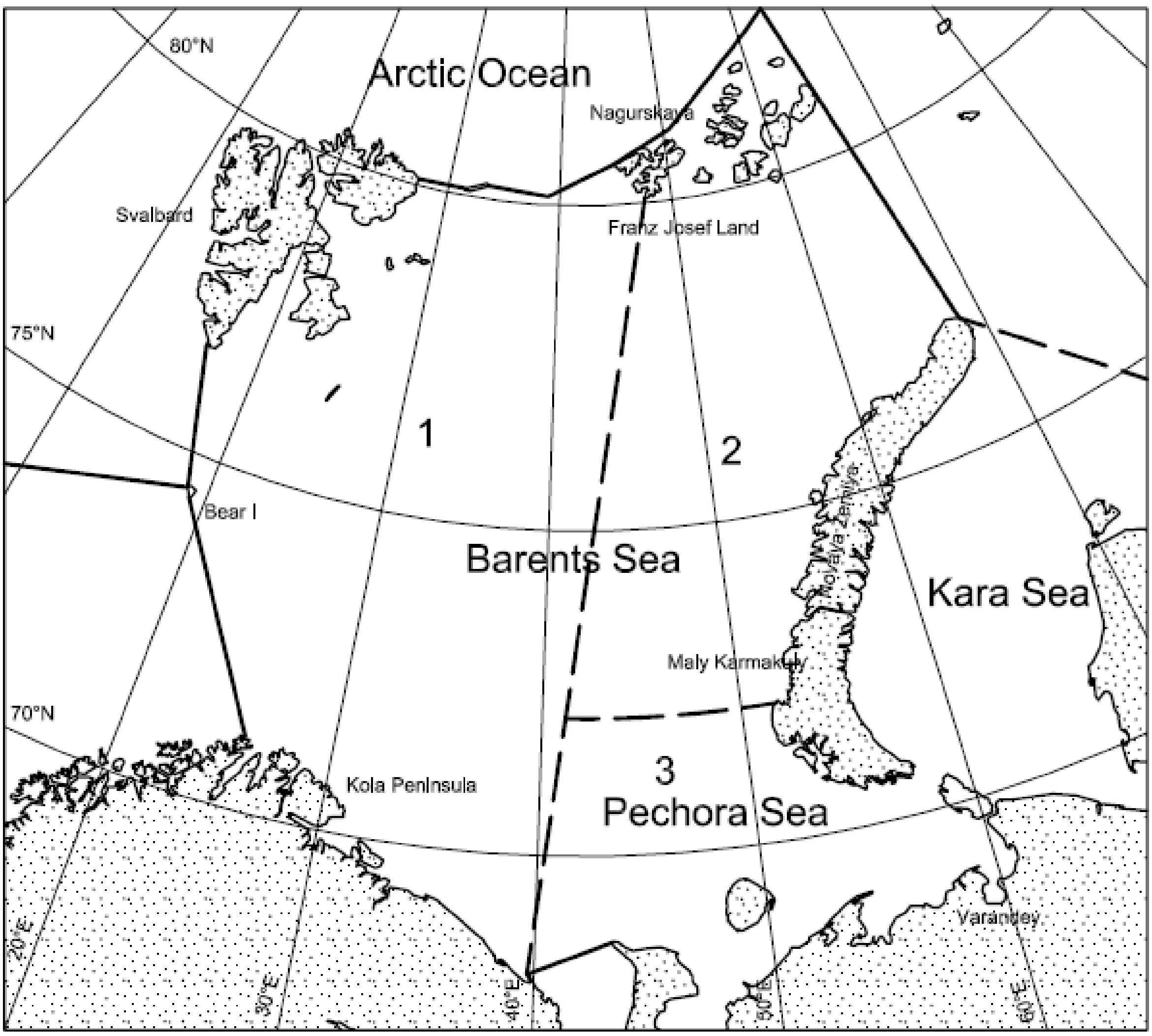


Figure A-15: Map of the Barents sea [5]

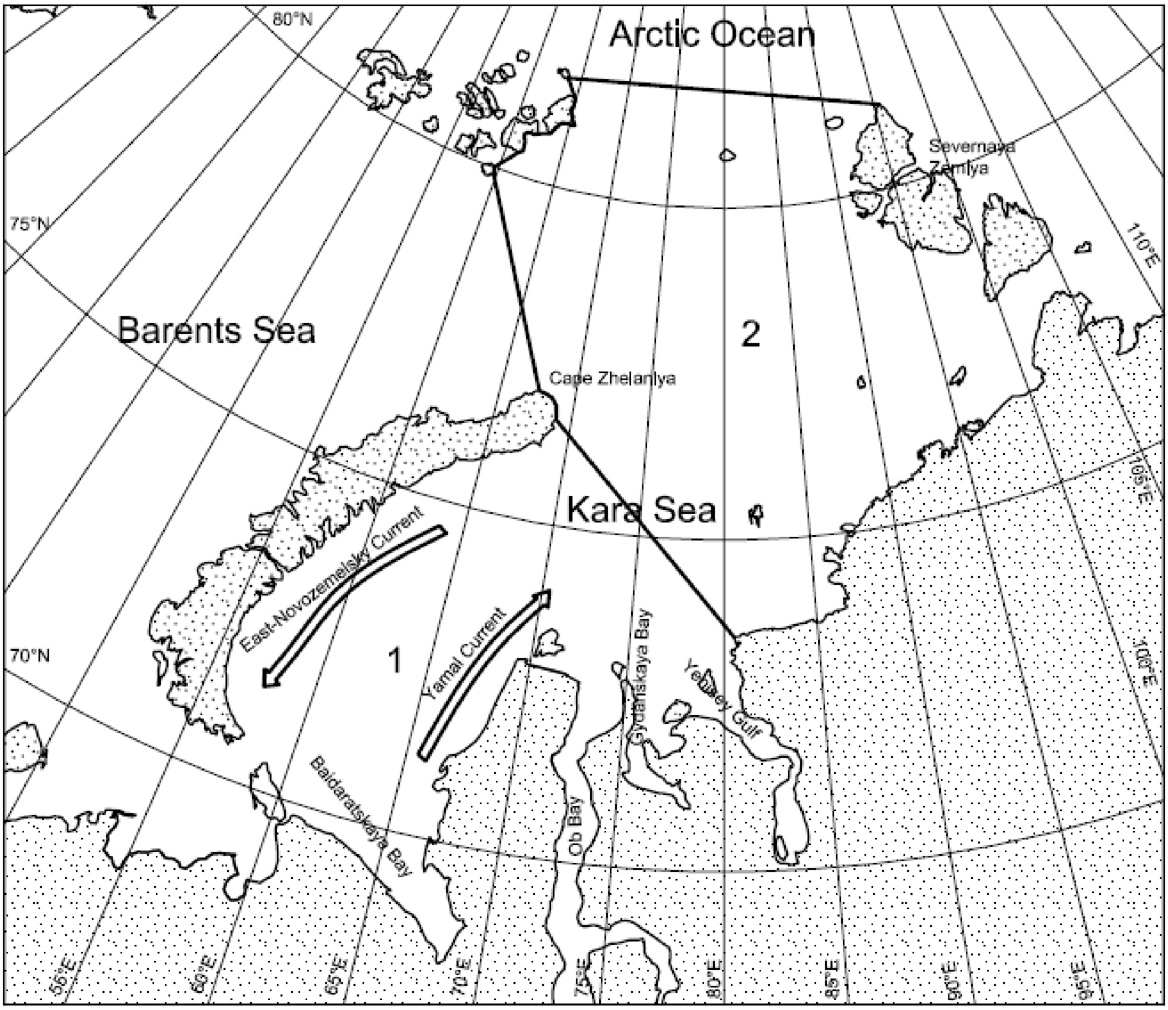


Figure A-16: Map of the Kara Sea[5]

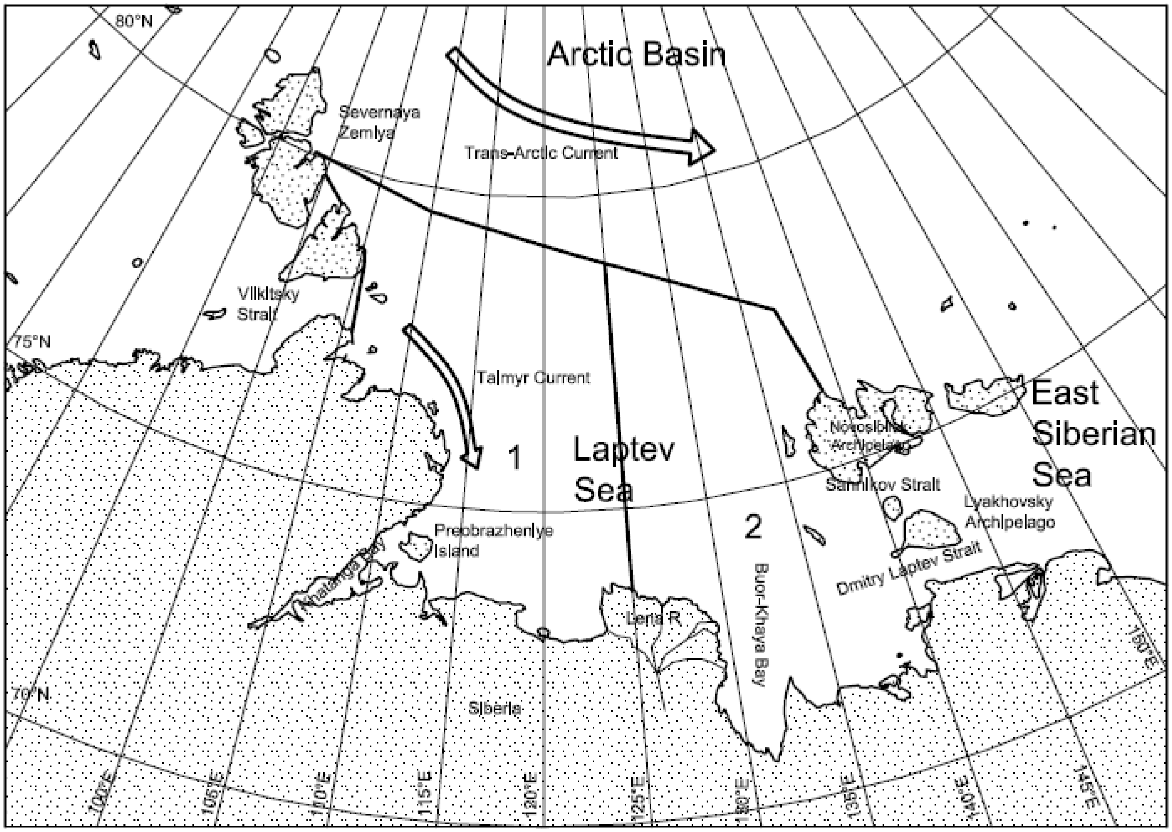


Figure A-17: Map of the Laptev Sea[5]

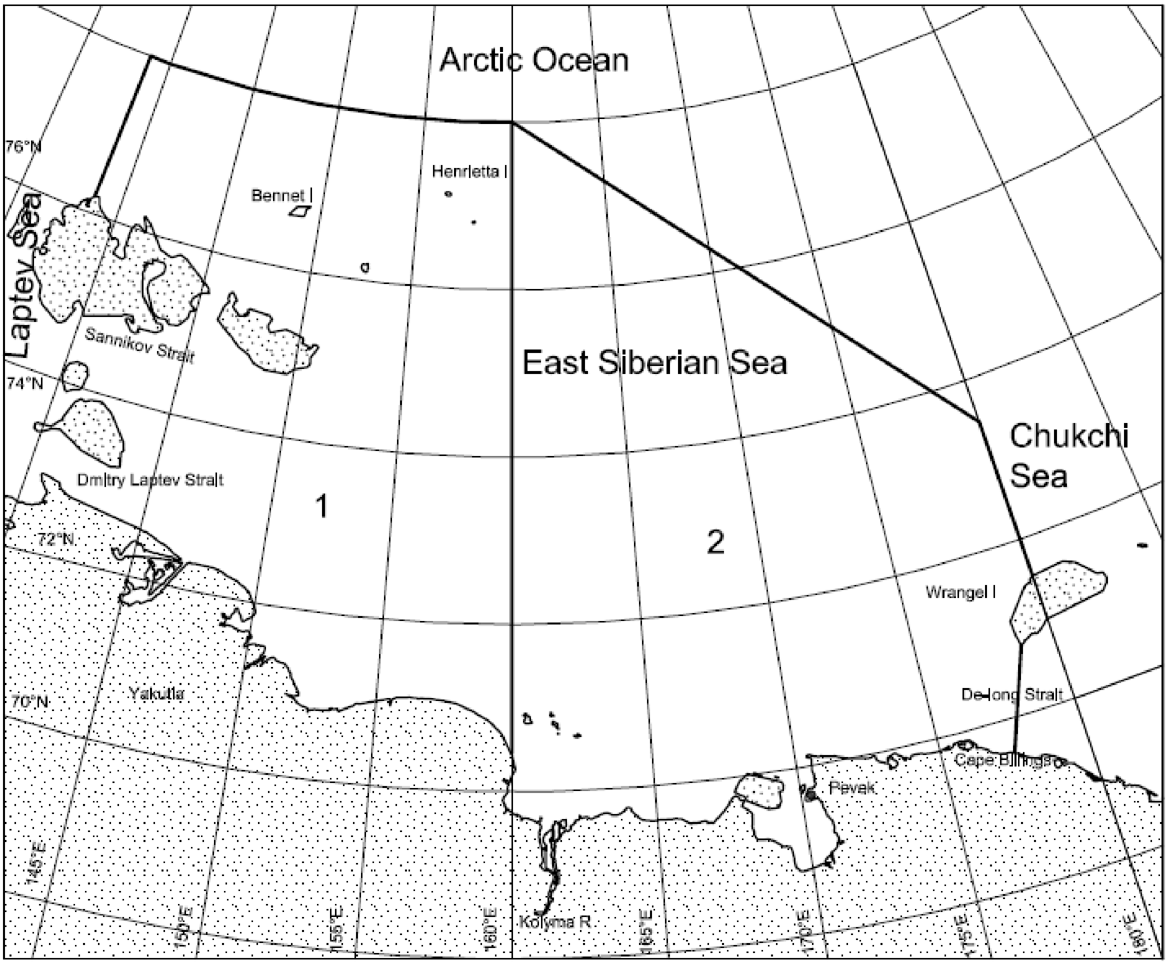


Figure A-18: Map of the East Siberian Sea[5]

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Appendix B

Locations oil companies

In this appendix two hydrocarbons maps are shown figure B-1 and figure B-2. They show the current and future gas and oil fields in the Arctic region. The focus lays on the Beaufort Sea, Baffin Bay, Barents Sea and the cost of Norway.

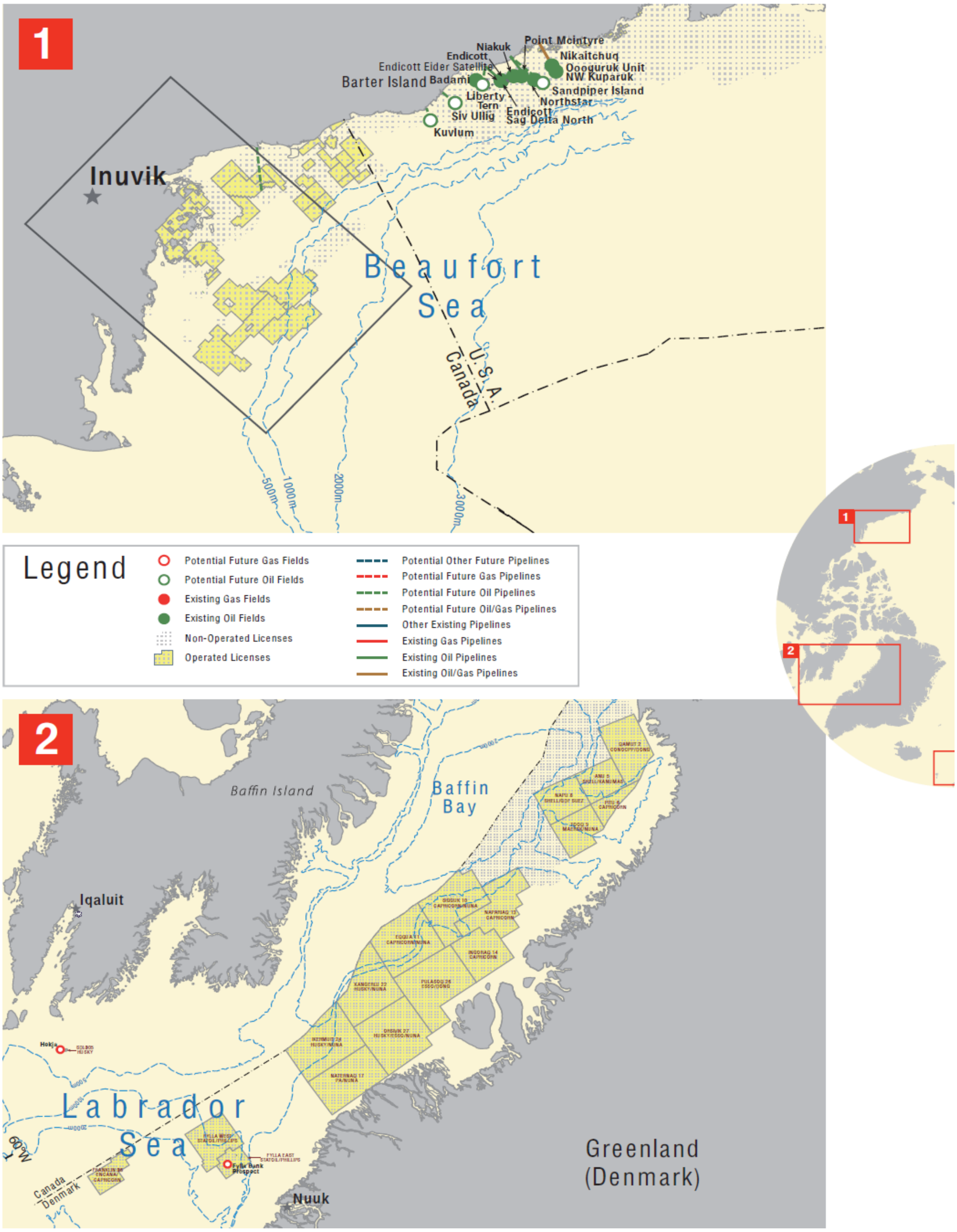

Figure B-1: Current and potential future Arctic offshore hydrocarbons map adapted from [1, p. 20]

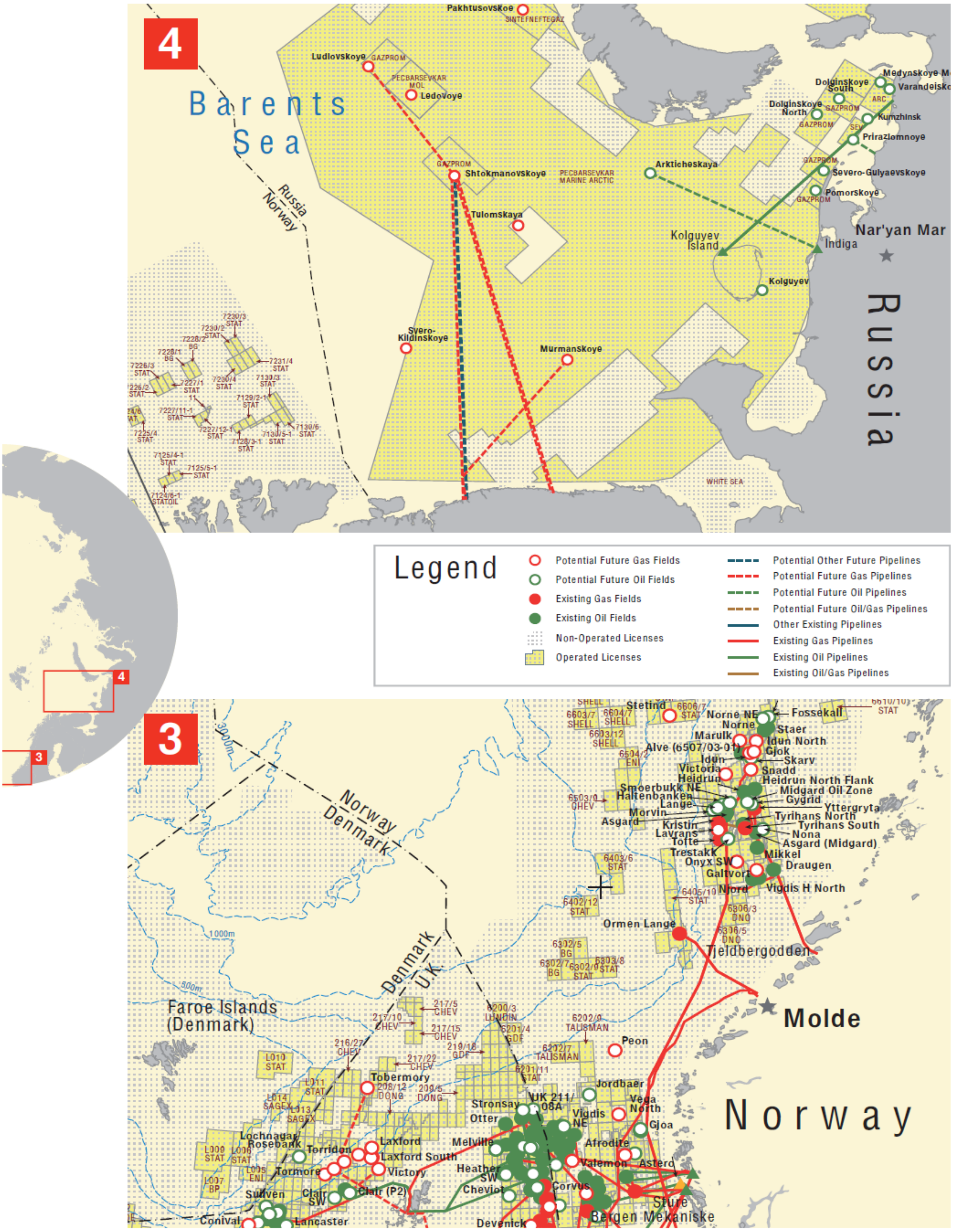

Figure B-2: Current and potential future Arctic offshore hydrocarbons map adapted from [1, p. 21]

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Appendix C

Equivalent ice classes

In table C-1 the current ice class rules and there equivalent to the Finnish- Swedish Ice class rules are shown. The table only includes the naming of 2010 of the classes, for a complete list please see [1, Appendix]. The equivalency of the ice classes is based on the operational conditions and depends on ship type and size and does not include equivalency of resistance calculations and machinery requirements.

Furthermore, figure C-1 shows the different ice class rules of LR, DNV and the Russian ice class rules.

Ice									
LR	DNV	RS (old)	LR	DNV	RS (old)	IACS (LR old)	DNV (old) Icebreakers	RS (old)	RS (old) Icebreakers
Light ice conditions			First-year ice (Finnish-Swedish)			Multi-year ice / Polar			
1E									
1D	Ice C	LU1 (L4)							
			1C FS	1C	LU2 (L3)				
			1B FS	1B	LU3 (L2)				
			1A FS	1A	LU4 (L1)	PC7	Ice 05		
			1AS FS	1A*	LU5 (UL)	PC6	Ice 10		
				1A*F		PC5			
						PC4 (AC1)	Ice 15 (polar 10)	LU6	LL6 (LL4)
						PC3 (AC1.5)		LU7 (ULA)	LL7 (LL3)
						PC2 (AC2)	(polar 20)	LU8	LL8 (LL2)
						PC1 (AC3)	(polar 30)	LU9	LL9 (LL1)

Figure C-1: Ice class equivalency [2].

Table C-1: Ice classes by class societies and there equivalent Finnish-Swedish ice class. Based on [1, Appendix]

Class society	Equivalent Finnish- Swedish ice class			
	IA Super	IA	IB	IC
ABS	Ice Class I AA	Ice Class I A	Ice Class I B	Ice Class I C
BV	ICE CLASS IA SUPER	ICE CLASS IA	ICE CLASS IB	ICE CLASS IC
CCS	Ice class B1*	Ice class B1	Ice class B2	Ice class B3
DNV	ICE-1A*	ICE-1A	ICE-1B	ICE-1C
GL	E4	E3	E2	E1
IACS Polar Rules	PC6	PC7		
KR	IA Super	IA	IB	IC
LR	100 A1 Ice Class 1AS FS(+) 100 A1 Ice Class 1AS FS	100 A1 Ice Class 1A FS(+) 100 A1 Ice Class 1A FS	100 A1 Ice Class 1B FS(+) 100 A1 Ice Class 1B FS	100 A1 Ice Class 1C FS(+) 100 A1 Ice Class 1C FS
ClassNK	NS* (Class IA Super Ice Str.) NS (Class IA Super Ice Str.)	NS* (Class IA Ice Str.) NS (Class IA Ice Str.)	NS* (Class IB Ice Str.) NS (Class IB Ice Str.)	NS* (Class IC Ice Str.) NS (Class IC Ice Str.)
PRS	L1A	L1	L2	L3
RINA	ICE CLASS IA SUPER	ICE CLASS IA	ICE CLASS IB	ICE CLASS IC
RS	Arc7 Arc6 Arc5	Arc4	Ice3	Ice2

Bibliography

[1] “Finnish ice classes equivalent to class notations of recognized classification societies and documentation required for the determination of the ice classes of ships,” tech. rep., Transport Safety Agency, Helsinki, Finland, Nov. 2010.

[2] Lloyd’s Register, Des Upcraft, “Technical implications of choosing ice class and development of winterisation options.” presentation, seminar Lloyd’s Maritime Academy, November 2008.

Appendix D

Material Table

Material Grade	A	AH	B	D	DH	E	EH	FH(1)
Design Service Temperature (°C)	0 to -15	0 to -45	0 to -45	0 to -40	0 to -45	-16 to -45	-16 to -45	-36 to -45
Material Test Temperature (°C) Class I Class II Class III	20	0	0	-20	-20	-40	-40	-60
Extreme Low Temperature (°C) (assume -20°C below design)	-20 to -35	-20 to -65	-20 to -65	-20 to -60	-20 to -65	-36 to -65	-36 to -65	-56 to -65

Figure D-1: Temperature ranges of materials according to ABS[1]

Bibliography

[1] D. Morgan, "Special Considerations for Deck Equipment and Machinery," Nov. 2008. Presentation.

Appendix E

Marpol Garbage Rules

Bibliography

[1] IMO, MARPOL, "Sulphur oxides (SOx) âĂŞ Regulation 14." http://www.imo.org/ourwork/environment/pollutionprevention/airpollution/pages/sulphur-oxides-(sox)-%E2%80%93-regulation-14.aspx, Nov. 2012.

Table E-1: Fuel oil sulphur limits in % m/m [1]

Garbage type	All ships except platforms outside special areas Regulation 4 (Distances are from the nearest land)	All ships except platforms within special areas Regulation 6 (Distances are from nearest land or nearest iceshelf)	Offshore platforms located more than 12 nm from nearest land and ships when alongside or within 500 metres of such platforms Regulation 5
Food waste comminuted or ground	≥3 nm, en route and as far as practicable	≥12 nm, en route and as far as practicable	Discharge permitted
Food waste not comminuted or ground	≥ 12 nm, en route and as far as practicable	Discharge prohibited	Discharge prohibited
Cargo residues not contained in washwater	≥ 12 nm, en route and as far as practicable	Discharge prohibited	Discharge prohibited
Cargo residues contained in washwater	≥ 12 nm, en route and as far as practicable	> 12 nm, en route and as far as practicable (subject to conditions in regulation 6.1.2)	Discharge prohibited
Cleaning agents and additives contained in cargo hold washwater	Discharge permitted	12 nm, en route and as far as practicable (subject to conditions in regulation 6.1.2)	Discharge prohibited
Cleaning agents and additives in deck and external surfaces washwater		Discharge permitted	
Animal Carcasses (should be split or otherwise treated to ensure the carcasses will sink immediately)	Must be en route and as far from the nearest land as possible. Should be >100 nm and maximum water depth	Discharge prohibited	Discharge prohibited
All other garbage including plastics, synthetic ropes, fishing gear, plastic garbage bags, incinerator ashes, clinkers, cooking oil, floating dunnage, lining and packing materials, paper, rags, glass, metal, bottles, crockery and similar refuse	Discharge prohibited	Discharge prohibited	Discharge prohibited