MARINE ENVIRONMENTAL RISK ASSESSMENT – CONCERNING WATERS IN AND ADJACENT TO GREENLAND AND THE ARCTIC

Marine Environmental Risk Assessment - Greenland

Defence Command Denmark

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Applicable contract(s) governing the provision of this Report:

Objective:
Quantify and describe the likelihood of marine accidents with and without pollution by spill of oil/chemical cargo products and fuels, as well as corresponding spill volumes. Perform a marine environmental risk assessment for Greenland based on probabilities for spill from ship traffic.

Prepared by:

Verified by:

Approved by:

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EXECUTIVE SUMMARY

There has been an increasing level of activity in and around Greenland, especially in the last decade. This is expected to continue in the coming years and activities such as cruise tourism, oil exploration and extraction and the general amount of traffic constitute a potential risk for the marine environment in and around Greenland.

The analyses presented in this report, quantify and describe the likelihood of marine accidents with and without pollution by spill of oil products, oil/chemical cargo products and fuels, as well as corresponding spill volumes. The analysis also includes prognoses on future ship traffic around Greenland in 2027. Further the analysis has looked at the environmental risk related to the shipping accidents.

It will form the basis of political and administrative discussions about how the Danish Defence’s future marine oil spill preparedness should be structured and dimensioned. It is important to stress that the approach in the current risk assessment is general and strategic. Local physical environment and operating conditions may be different from those reflected in the current report.

The competence in the field of the marine environment around Greenland is divided between the Danish and Greenlandic authorities. Since January 1st 1993, the competence related to the marine environment to the 3 nautical mile limit has been held by the Government of Greenland. Denmark holds the competence related to the marine environment from the 3 nautical mile limit to 200 nautical miles from the baseline (in the Exclusive Economic Zone – the EEZ). In the Danish area of responsibility, the Ministry of Defence has the responsibility for executive functions related to the marine environment. This includes pollution response and surveillance of the marine environment.

Competence in the area of mineral resources was transferred to Greenland in 2010. The area of mineral resources includes mineral resources inside as well as outside territorial waters (territorial waters and the EEZ). Issues concerning the marine environment that are related to the area of mineral resources were transferred to Greenland as a part of the mineral resources area.

As a consequence of the National Audit Office’s Report on Danish efforts in the Arctic region from September 2013 and several questions from the committees under the Danish Parliament, inter alia from the Environmental Committee, a working group was established in the fall of 2013 to clarify the issue of the authorities’ competence related to the marine environment around Greenland.

The working group tasked with scrutinizing this issue paid special attention to the delimitation between the part of the marine environment around Greenland that remains within the Danish area of competence and the area of mineral resources that was transferred to the Government of Greenland in 2010. The working group finalised its work in September 2014. In short, it was concluded that issues concerning the marine environment that are related to the area of mineral resources are to be considered as part of the mineral resource area as understood in the terms of the Act on Greenland Self-Government (Self-Government Act) – and therefore as transferred to the Government of Greenland.

In connection with the above-mentioned work, a separate issue concerning the extent of a textual remark in the Danish Finance Act was identified for subsequent separate consideration. According to textual remark no. 6 (section 12 of the Danish Finance Act concerning the Ministry of Defence), the Minister of Defence is authorized to defray all necessary expenses incurred for combating pollution caused by oil or chemicals in Danish and adjacent waters as well as Greenlandic waters in case of either extensive pollution incidents or an imminent risk hereof.
In relation to the issue of the textual remark, the Danish authorities under the leadership of the Ministry of Defence identified and compiled some of the relevant source material in late 2014 with a view to understanding the extent of the textual remark. This was done because it had come to the fore during the process that the Danish and Greenlandic authorities had different interpretations of the provision. Subsequently, the Greenlandic authorities have contributed to understanding the extent of the provision by means of additional relevant source material. The issue of the extent of the textual remark is now subject to discussions between the Greenlandic and Danish authorities in order to reach a common understanding for the future performance of the tasks related to the marine environment in Greenland.

The analysis has covered the marine environment within territorial waters and the marine environment outside territorial waters and Figure 1 shows the study area around Greenland including 15 subsegments. The sub-division into areas 1-14 is based on Danish Maritime Authority’s waters division which is the same as the Danish Meteorological Institute uses. In addition, the northern part has been defined as area 15. All 15 areas have been extended out to the Greenland Exclusive Economic Zone.

The risk has further been split into risk inside and outside the 3 nautical mile limit respectively. The 3 nautical mile limit is shown as a dotted line in Figure 1.

The analyses consist of the following main activities:

1. Processing and analysis of vessel traffic, including fuels and cargo carried – Chapter 2.1
2. Calculation of risk based on traffic analysis – Chapter 2.4
   a. Average yearly accident frequencies
   b. Average yearly spill accident frequencies
   c. Average yearly spill volumes
3. Calculation of environmental risk based on the traffic analysis – Chapter 3
Figure 1 Map showing the 10 x 10 km grid defining the study area with the 15 predefined coastal segments.
Vessel traffic data consists of Automatic Identification System (AIS) data, collected from the study area for the whole of 2013 (Chapter 2.1.1), augmented with ship particulars on type, size, fuel type, fuel volume, cargo type and cargo volume (Chapter 2.1.2, 2.1.3 and 2.1.4). Risk is subsequently calculated by combination of the vessel traffic data, historical accident data and estimations on likely spill volumes. The environmental risk analysis is based on ship traffic accident frequencies and distribution of environmental resources in the area. Figure 2 shows a flowchart of the main elements in the method used in the analysis and the present sub-chapters gives a more detailed description of the steps and elements in the method.

Figure 2 Flowchart showing the elements in the method used in the environmental risk analysis.

The first step of the analysis was to look at AIS data from 2013 based on data from LuxSpace. Using a single year of data may not capture correctly the average yearly traffic over a longer period, such as a decade. This may happen if some additional or lacking traffic has occurred in the sample period, for example exploration, special research, weather and fishing conditions, etc., or if the activity level has fundamentally changed. However, as given in the background for the project, recent climate change and the reduction of sea ice around Greenland and in the Arctic have generally led to an increased geographic availability. This means that using older traffic data will likely result in underestimating vessel activity given current realities.

Since traffic data sourced from AIS does not capture smaller vessels, all additional traffic of these vessels is not included in the analysis, potentially resulting in an underestimation of risk. However, since these vessels are by definition small (i.e. below 300GT) they will not contribute significantly to the end results in terms of spill volumes, and especially in terms of geographic locations of risk high risk areas,
i.e. areas which contributes the most to the overall risk in the Greenlandic waters. Thus it has been concluded that the total risk picture on Greenland presented in this report is not degraded by this potential exclusion of traffic. Furthermore, the results are compared to local accident statistics in Chapter 2.4.1, and causes for differences relating to the capture of actual traffic are discussed.

The AIS data was processed and the number of sailed nautical miles calculated per grid cell as presented in Figure 3. The total number of unique vessels registered by AIS satellites, within the analysis area, in 2013 was 1873. The AIS data analysis showed that no chemical tankers had been sailing in the area in 2013 and therefore all results will include oil spills only. It should be noted that chemicals can have been transported in for example containers onboard other ship, and that the model as such underestimates the risk from chemicals.
As illustrated in Figure 4, there are big differences in the sailing profile of the various vessel types with regards to distance to shore. As 100% of their operations are outside 3 nm, Ro Ro Cargo vessels, Gas Tankers and Crude Oil Tankers stand out. Thus it is clear that these vessels are not sailing to or from ports in Greenland, but rather pass through the study area in open waters. Over 80% of Passenger vessels operations are within 3 nm from the coast.
The ship risk analysis shows that the south west parts of Greenland, especially in the areas around Nuuk, are the most exposed to potential maritime accidents. Reasons for this are a substantially higher level of traffic than seen elsewhere in the area, as well as traffic routes in the region are located close to shore.

The estimated annual number of marine accidents\(^1\) for Greenland is 1.6, i.e. on average an accident approximately every 0.6 years. Figure 8 shows that grounding accidents dominate the accident statistics in the study area. The risk is about 5 times lower than in the waters of Svalbard and Jan Mayen (ref /3/) which in itself is much lower than the risk along the Norwegian coast. The main reason for the relative low risk is the relative low level of ship traffic in the Greenlandic waters compared to other areas.

The dominance of grounding accidents in Greenland is similar to the geographically comparable area around Svalbard. A DNV GL report concerning the possible reasons for the dominance of grounding in the waters around Svalbard /3/, identify among others the following factors:

- In a global perspective, the traffic density in the area is low, resulting in fewer collisions.
- Waters are not charted as well as is typically the case in mainland coastal areas.
- Fewer navigational aids.
- Cruise and passenger vessels with an operational pattern close to shore. In 2013 there was 28 cruise vessels and 34 passenger vessels operating in the study area around Greenland.

From Figure 5 we can see that the south west parts of Greenland, especially in the areas around Nuuk, are the most exposed to potential maritime accidents. This is due to a higher level of traffic than seen elsewhere in the study area, as well as traffic routes located close to shore. This contributes to increased

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\(^1\) See Chapter 2.1.5 for definition of marine accident
likelihood of both Collision and Grounding accidents, respectively, and results in a higher likelihood of accidents by a factor of approximately 100 compared to the waters further off the coast. The south east parts of Greenland also have higher traffic densities, mostly due to fishing activity, which is resulting in another high risk area for accidents.

Figure 5 Geographical representation of yearly average number of accidents per 10x10 grid cell on Greenland (see Appendix C for additional maps)
In terms of accidents with spill, the estimated annual number is estimated at 0.3, i.e. on average an accident approximately every 3 years. The estimated total average yearly spill volume from all vessels amount to 40 tons. The risk constitutes an oil spill every 3rd year of about 150 tons of oil which is regarded as a spill which potentially can be mitigated. The relative low traffic results in relative low risk of oil spill compared to say Denmark where the BRISK project showed an annual spill amount of 2 000 tons, ref /92/. Figure 6 shows the average yearly spill volumes broken down by geographical region and can be seen in relation to the aggregated sailed distance in 2013 shown in Figure 6.

![Figure 6 Geographical representation of potential oil spill volumes aggregated per the 15 areas of Greenland [tons]](image)

There are more accidents during summer and fall when the amount of open water areas is at its highest, and conversely fewer accidents during winter and spring when the amount of water areas with high ice concentrations is at its highest. The correlation seen indicates that the activity level itself is highly influenced by the seasons, but does not give conclusive evidence as to why.

Of the total spill volume, Product tankers represent 29 tons. This is the vessel category that carries the bulk of all petroleum cargo in the area in question. The remaining spill volume of almost 11 tons on average every year is the equivalent of the loss of all fuel on a fully fuelled fishing vessel in the size category 1. < 1000 GT, every 2 years, or every 6 years of similar sized cruise vessel.
Figure 7 and Figure 8 show the risk results in terms of average annual number of accidents and average annual number of spill accidents, respectively. The results are discussed further in Chapter 6.

![Average annual number of accidents, broken down by accident category and vessel type](image)

**Figure 7 Average annual number of accidents, broken down by accident category and vessel type**

Other observations from the results include that over 99.96% of the accident frequency involving vessels carrying crude oil, oil products or chemical products are from oil Product Tankers. The estimated accident frequency of spills of oil products is 0.03, or an accident on average every 33 years. The estimated annual number of accidents involving spills of fuel or cargo for Greenland is 0.3, i.e. on average an accident with release approximately every 3 years.
By measuring the distance from the centre of each grid cell to nearest land, all cells have been defined as either closer than 3 nm to land (defined as more than 50% of the cell area closer than 3 nm to land), or further than 3 nm from land. With this criterion Figure 9 shows the yearly average accident frequency of the entire study area per vessel category, divided in Outside 3 nm or Inside 3 nm. Figure 10 shows the yearly average spill frequency per vessel category, divided in Outside 3 nm and Inside 3 nm.

As can be seen from both figures the number of accidents and number of spills are highest Inside 3 nm with 77% and 62% of the total number, respectively.
Figure 9 Average annual number of accidents inside or outside 3 nm of coastline

Figure 10 Average annual number of spill accidents inside or outside 3 nm of coastline
A marine environmental risk assessment for Greenland based on probabilities for oil and chemical spills from ship traffic is performed. The environmental risk analysis is based on ship traffic accident frequencies and distribution of environmental resources in the area.

The volume categories of spilled oil is divided into 6 different consequence categories (K1 to K6) for either sea surface or water column. The environmental consequence categories are relative and indicate increasing seriousness from K1 to K6. A strict definition is therefore difficult, but the categories can be understood as:

- **K1** – low consequence with minor impact on resources/habitats in the area
- **K2** – low to moderate consequence
- **K3** – moderate consequence
- **K4** – high consequence
- **K5** – very high consequence
- **K6** – extreme consequence with major impact on resources/habitats in the area

There is a lot of information with different levels of detail regarding environmental resources in and around Greenland. Some areas are well studied and documented, while other areas lack information and adequate data. The task and aim with the analysis is to use the result of the analysis to get an overview of the risk level for all of Greenland and to use this as a basis for strategic decisions regarding oil spill contingency. This means that a lot of local and detailed information will not be included in the analysis.

When performing an environmental risk analysis covering a large area as Greenland, it is necessary to focus on environmental resources present in most parts of the area to be able to compare segments and regions. The environmental resources forming the basis for the current analyses are seabirds, marine mammals at vulnerable life stages in addition to spawning areas for fish. In the assessment of shoreline, the areas important fishing areas in vicinity to the coast are also included.

The method uses the highest sensitivity value per resource group to give the best consequence picture for each species within the resource group. The species diversity will not be included, but the consequences will not necessarily be higher if many resources with low vulnerability will be affected.

In areas where no vulnerability ranking for environmental resources is mapped and documented, the vulnerability is set to moderate for the analysis. This is done because the risk picture is divided and there is good input data on spill potential also for the areas lacking mapped and documented information on the environmental resources. It should be noted that the uncertainty of the analysis outcome is therefore higher in these areas than in the areas with more detailed vulnerability data available. This applies to all the resource groups.

The environmental risk analysis is based on a combination of probability for spill and the sensitivity for environmental resources in the area. This means that the risk is not necessary high even if vulnerable resources are present in the area, because spill probability is low in this area. In the same way there may be high risk in an area with less vulnerable resources because there is higher ship traffic and spill probability in the area.

The analysis shows that the south and western part (segment 6-13) and some parts on the east coast (segment 3-5) of Greenland have the highest probability for risk both seasonally and annually for the resources included in the analysis. These results corresponds to areas were environmental resources are

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2 As there have been no chemical tankers sailing in the area in 2013, the analysis shows no risk for chemical spills and therefore no environmental consequences
mapped and documented. The analysis concludes with relatively low probabilities for environmental risk. The highest annual risk is calculated for marine mammals with about 4.1% probability per year (Figure 11). All other environmental resource groups show lower risk. Fish has lower probability for risk than the other resources, mainly because it has to be a large spill of oil to give consequences in the water column compared to on the sea surface and shoreline.

The environmental risk is also presented inside and outside of the 3 nautical mile (nm) limit around Greenland. Figure 12 shows the contribution to the environmental risk inside of 3 nm and Figure 13 shows the contribution outside of 3 nm and out to the economic zone border. The results show a higher risk inside of 3 nm for the segments on the south and western part of Greenland, and also in a higher consequence class than for outside of 3 nm.
Figure 11 Annual environmental risk based on accidental spills from ship traffic around Greenland grouped for the different resource groups per segment shown as probability.
Figure 12 Annual environmental risk based on accidental spills from ship traffic around Greenland inside of 3 nm, grouped with the different resource groups per segment shown as probability.
Figure 13 Annual environmental risk based on accidental spills from ship traffic around Greenland outside of 3 nm, grouped with the different resource groups per segment shown as probability.
A study to look at the prognoses for ship traffic for 2027 indicates that traffic for most vessels types around Greenland is unlikely to change. This is due to the fact that little growth in industry or population is expected. There are possible petroleum and mining projects, but none are certain enough to serve as a basis for predicting an increase in shipping traffic. The exception is an iron ore mine on the west coast, which is likely to be in production by 2027, necessitating the need for a large increase in bulk carrier traffic. The other source of growth in shipping traffic around Greenland will result from the tourism sector.

The total growth in sailed distance around Greenland is expected to be 24%, 70% of this growth due to new bulk carrier traffic. Table 1 gives the growth of shipping and the sailed distances per vessel type in 2027.

Note that for traffic prognoses more than 10 years in the future, there will naturally be a significant amount of uncertainty. In the case of Greenland, shipping activities serve a very small population which is not expected to grow. Greenland lacks major economic activities which necessitate shipping traffic, but the appearance of new industry can change the picture dramatically. The large increase in bulk carrier traffic illustrates how the landscape of shipping in Greenland is very sensitive to individual changes to the economic landscape. Similarly, if petroleum activity starts up more quickly than estimated in this analysis, a large amount of shipping activity can take place.

Table 1  Total sailed distance by vessel type in 2013 & 2027, relative growth in sailed distance

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Distance sailed 2013 (nm)</th>
<th>Distance sailed 2027 (nm)</th>
<th>Relative growth (%)</th>
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<tr>
<td>Bulk carriers</td>
<td>5670</td>
<td>149880</td>
<td>2543 %</td>
</tr>
<tr>
<td>Container Ship</td>
<td>109997</td>
<td>109997</td>
<td>0 %</td>
</tr>
<tr>
<td>Crude Oil Tankers</td>
<td>116</td>
<td>116</td>
<td>0 %</td>
</tr>
<tr>
<td>Cruise</td>
<td>52402</td>
<td>104804</td>
<td>100 %</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>391341</td>
<td>391341</td>
<td>0 %</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>0</td>
<td>0</td>
<td>0 %</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>25978</td>
<td>25978</td>
<td>0 %</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>5101</td>
<td>5101</td>
<td>0 %</td>
</tr>
<tr>
<td>Other Activities</td>
<td>74387</td>
<td>74387</td>
<td>0 %</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>6507</td>
<td>6507</td>
<td>0 %</td>
</tr>
<tr>
<td>Passenger</td>
<td>46642</td>
<td>55970</td>
<td>20 %</td>
</tr>
<tr>
<td>Product tankers</td>
<td>55480</td>
<td>55480</td>
<td>0 %</td>
</tr>
<tr>
<td>Reefers</td>
<td>16325</td>
<td>16325</td>
<td>0 %</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>176</td>
<td>176</td>
<td>0 %</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>56684</td>
<td>56684</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>846805</strong></td>
<td><strong>1052745</strong></td>
<td><strong>24 %</strong></td>
</tr>
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</table>
### DEFINITIONS AND ABBREVIATIONS

| **AIS** | AIS (Automatic Identification System) is an automatic identification system for ships. AIS has been introduced internationally to enhance the security of ships and the environment, improve traffic surveillance and vessel traffic services. The AIS signals provide information from the ship, such as position, course, speed, identity, vessel type, dimensions and destination. |
| **AMSR2** | Advanced Microwave Scanning Radiometers, version 2. The satellite instrumentation registering ice concentration. |
| **Asphaltenes** | Asphaltenes are molecular substances that are found in crude oil, along with resins, aromatic hydrocarbons, and saturates |
| **Bunker oil** | Bunker fuel or bunker oil is technically any type of fuel oil used aboard vessels. Bunkers include Marine Gas Oil, Intermediate Fuel Oil and Heavy Fuel Oil. |
| **Chemical** | Different types of chemical products carried by vessels categorized as chemical tankers by Lloyds vessel categorization. Includes such products as wines, vegetable oils, edible oils, beers, fruit juice, latex, molten sulphur, etc. |
| **Coastal segment** | A predefined subdivision of the coast |
| **Consequence class** | Determined by oil volume and species vulnerability |
| **Crude oil** | Naturally occurring liquid mixture of hydrocarbons found in reservoirs in the bedrock and extracted as raw materials in the petroleum industry. |
| **Danish Maritime Authority (DMA)** | The Danish Maritime Authority is a Danish government agency under the Ministry of Business and Growth. Its field of responsibility is based on the shipping industry and its framework conditions, the ship and its crew. In addition, they are responsible for aids to navigation in the waters surrounding Denmark and ashore. |
| **The Danish Meteorological Institute (DMI)** | DMI provides meteorological services in the Commonwealth of the Realm of Denmark, the Faroe Islands, Greenland, and surrounding waters and airspace. Meteorological services include forecasting and warnings and monitoring of weather, climate and related environmental conditions in the atmosphere, on land and at sea. DMI is an institution under the Danish Ministry of Climate, Energy and Building. |
| **Dispersion** | A dispersion is a system in which particles are dispersed in a continuous phase of a different composition (or state) |
| **Emulsion** | An emulsion is a mixture of two or more liquids that are normally immiscible (non-mixable or un-blendable) |
| **Environmental consequences** | The impact caused to the environment in terms of the extent of damage to seabirds, marine mammals, fish and beach habitats as a result of exposure to impact (in this case cargo or fuel). |
| **Environmental resources** | Seabirds, marine mammals, fish and shoreline habitats |
| **Environmental risk** | Refers to a product of the probability of an accident to occur and the environmental consequences expressed as restitution time |
| **Environmental vulnerability** | The capacity of an environmental resource to cope with different pressures |
| **Frequency** | The expected average frequency of an event. Usually expressed either as average number of accidents per nautical mile or per year. |
| **GIS** | Geographical Information System |
| **Gross Tons (GT) and Dead Weight Tons (DWT)** | The International Convention on Tonnage Measurement of Ships of 1969 has been applied to new ships since 1986 and applies to all ships from 1994. This implies a transition from gross register tons (GRT) and net register tons (NRT) to gross tons (GT) and net tons (NT). GT is calculated based on the volume of the ship in enclosed spaces, while NT is based on volume of cargo holds. Approximate conversion numbers between net tonnage, gross tonnage and deadweight: 1 NT = 1.7 GT, 1 GT = 1.5 DWT. |
This applies to tankers and bulk carriers up to approx. 25,000 DWT, but not reefer, ro-ro ships, passenger ships, etc. For large tankers and bulk carriers (approximately 100,000 DWT and over) 1 GT equals approx. 2 DWT.

DWT is the largest weight the vessel can safely carry, and is expressed in metric tons (1,000 kg) or long tons (1016 kg). The dead weight is the most important commercial target. The maximum payload is usually 3-10 percent lower than the deadweight due to the weight of fuel, water, provisions, etc.

<table>
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<th>Habitat</th>
<th>An ecological or environmental area that is inhabited by a particular species</th>
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<tbody>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil (Residual marine fuels with viscosity &gt;180 cSt)</td>
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<tr>
<td>IFO</td>
<td>Intermediate Fuel Oil (Residual marine fuels with viscosity 11-180 cSt)</td>
</tr>
</tbody>
</table>

**IHS-Fairplay**

IHS-Fairplay Limited, is a fully owned subsidiary of American Corporation, IHS Global Inc. The IHS-Fairplay Database contains accurate and comprehensive details of all reported serious casualties, including total losses, (as defined) to all propelled sea-going merchant ships in the world of 100 GT and over from 1 January 1978 and all reported incidents (i.e. serious and non-serious) to tankers, including combination carriers and gas carriers/tankers, since 1 January 1975 and bulk carriers since 1 January 1997. In the last five years (since 1 January 2006) non-serious incidents have also been collected for bulk carriers.

**IHS Seaweb**

Sea-web combines comprehensive ships, owners, shipbuilders, fixtures, casualties, port state control, ISM and real-time ship movements data and ports information into a single application. Sea-web Ports, Sea-web Insight, and Sea-web Directory can be integrated with Sea-web Ships or available as stand alone solutions.

**IMO Number**

IMO is short for International Maritime Organization – UN’s agency for shipping. IMO numbers are a unique reference for ships and for registered ship owners and management companies. For ships, the IMO number remains linked to the hull for its lifetime, regardless of a change in name, flag, or owner.

**Influence area**

Oil/chemical affected area (a number of grid cells) which the radius of the area is defined from the relevant product and mass category

**Ice-concentration**

Defined according to the WMO nomenclature; i.e. as the percentage of the sea surface covered by ice.

**Key species**

A species that is critical for maintaining the relationship of an ecosystem

**LuxSpace**

The Luxembourg System Integrator for Aerospace & Defence Systems. LuxSpace is a daughter company of OHB AG (Bremen, Germany). Although belonging to the international network of companies within the OHB group, LuxSpace acts fully independent and provides know-how, expertise as well as products and services to the European and global institutional and industrial market in the fields of space and defence system engineering and application development.

**Marine Diesel**

Marine Diesel Oil (MDO) is a blend of heavy fuel oil and marine gas oil.

**OW Tankers³**

O.W. Tankers A/S is a limited company established January 1st, 2008 as a subsidiary Company of O.W. Bunker & Trading A/S. The company is committed to maintaining commercial and technical management of owned & chartered tonnage by O.W. Bunker Group. The commercial department is also acting as in house tanker broker for the O.W. Bunker Group cargo requirements.

**Polaroil**

Polaroil is KNI’s energy division, and the largest oil supply company in Greenland. The company’s headquarters is located in Sisimiut. KNI A/S consists of four business units. The four units are the energy company Polaroil, the retail chain Pilersuisoq, the slaughterhouse Neqi and the

³ It is noted that OW Tankers was part of the liquidation of OW Bunker & Trading which is continued under a new company
| **Product** | Different types of petroleum products including lighter distillates and heavy residual fractions such as heavy oil. Will typically include various types of marine fuel, fuel oils to land use, tar, bitumen, kerosene, naphtha, gasoline and diesel, etc. Does not include crude oil. |
| **Return period** | The average number of years between each accident or each spill if they were evenly distributed in time. The rate is calculated as the inverse of the frequency (i.e., 1 divided by the frequency). |
| **Sailed distance** | Used as a measure of shipping activity in an area. The distance travelled is calculated for a ship based on the registered positions in the AIS system. 1 nautical mile (nm) is equal to 1852 meters. |
| **Serious accident/casualty/incident** | A marine casualty to a ship, as defined in /1/, which results in:  
  a) Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilisation of main engines, extensive damage, etc.  
  b) Breakdown.  
  c) Actual Total Loss  
Any other undefined situation resulting in damage or financial loss which is considered to be serious. |
| **Spill frequency** | The number of spills per time unit |
| **Statistics Norway (SSB)** | Statistics Norway has overall responsibility for official statistics in Norway, and carries out extensive research and analysis activities. |
| **Vessel** | d) The vessel means any transport by sea. Removable installations in the petroleum activities are included, but fixed installations fall outside the definition. |
| **Viscosity** | Resistance of a fluid to a change in shape, or movement of neighbouring portions relative to one another. Viscosity denotes opposition to flow. It may also be thought of as internal friction between the molecules. |
| **Vulnerability** | The capacity of an environmental resource to cope with different pressures |
| **Vulnerability for oil** | The capacity of an environmental resource to cope with oil pollution |
| **Vulnerability value** | Relative ranking of resource vulnerability |
| **WMO** | World Meteorological Organization is the UN system’s authoritative voice on the state and behaviour of the Earth’s atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. |
1 INTRODUCTION

1.1 Background
Recent climate change and the reduction of sea ice around Greenland and in the Arctic have generally led to an increased geographic availability. The Kingdom of Denmark’s Arctic strategy makes clear that "It is our common goal that the Arctic and its existing potential be developed in order to promote self-supporting growth and societal sustainability. This development must first and foremost benefit the inhabitants of the Arctic, and it must go hand in hand with the protection of the Arctic environment".

There has been an increasing level of activity in and around Greenland, especially in the last decade. This is expected to continue in the coming years and activities such as cruise tourism, oil exploration and extraction and the general amount of traffic constitutes a potential risk for the marine environment.

On the basis of the above factors, it was agreed in the Danish Defence Agreement 2013–2017 that a risk assessment would be prepared for the marine environment in and around Greenland. The risk assessment must contribute to the assessment work concerning the Danish Defence’s consolidation of assignments in the Arctic.

Prognoses for shipping traffic around Greenland are also developed in order to comment on how environmental risk due to shipping will change in the future.

Both the Greenlandic and Danish Authorities have a responsibility concerning the marine environment in the waters around Greenland and are therefore stakeholders in terms of a marine environment risk assessment.

The assessment will form the basis of political and administrative discussions about how the Danish Defence’s future marine environmental preparedness should be structured and dimensioned.

It is important to stress that the approach in the current risk assessment is general and strategic. Local physical environment and operating conditions may be different from those reflected in the current report. This as an example applies for the distribution of sea ice and icebergs including debris ice which pose a hazard to marine operations and at all times must be addressed accordingly. This is normally handled safely by well-prepared and experienced Arctic marine users, even by those operating in the harsh ice-infested waters near the southern tip of Greenland as well as on higher latitudes.

1.2 Scope of work
The analysis shall quantify and describe the likelihood of marine accidents with and without pollution by spill of oil/chemical cargo products and fuels, as well as corresponding spill volumes.

Additionally, prognoses for shipping traffic in 2027 around Greenland will be prepared. The prognoses will describe the drivers for the Greenlandic shipping industry, and result in growth of sailed distance for each vessel type around Greenland.

The environmental risk analysis will be based on ship traffic accident frequencies and distribution of environmental resources in the area. The analysis will be performed in 10 x 10 km grid cells, and will be presented in 15 predefined coastal segments around Greenland.
1.3 Geographical

Figure 14 shows the study area around Greenland including 15 sub segments. The sub-division into areas 1-14 is based on Danish Maritime Authority’s waters division which is the same as the Danish Meteorological Institute uses. In addition, the northern part has been defined as area 15. All 15 areas have been extended out to the Greenland Exclusive Economic Zone.

The competence in the field of the marine environment around Greenland is divided between the Danish and Greenlandic authorities. Since January 1st 1993, the competence related to the marine environment to the 3 nautical mile limit has been held by the Government of Greenland. Denmark holds the competence related to the marine environment from the 3 nautical mile limit to 200 nautical miles from the baseline (in the Exclusive Economic Zone – the EEZ). In the Danish area of responsibility, the Ministry of Defence has the responsibility for executive functions related to the marine environment. This includes pollution response and surveillance of the marine environment.

Competence in the area of mineral resources was transferred to Greenland in 2010. The area of mineral resources includes mineral resources inside as well as outside territorial waters (territorial waters and the EEZ). Issues concerning the marine environment that are related to the area of mineral resources were transferred to Greenland as a part of the mineral resources area.

As a consequence of the National Audit Office’s Report on Danish efforts in the Arctic region from September 2013 and several questions from the committees under the Danish Parliament, inter alia from the Environmental Committee, a working group was established in the fall of 2013 to clarify the issue of the authorities’ competence related to the marine environment around Greenland.

The working group tasked with scrutinizing this issue paid special attention to the delimitation between the part of the marine environment around Greenland that remains within the Danish area of competence and the area of mineral resources that was transferred to the Government of Greenland in 2010. The working group finalised its work in September 2014. In short, it was concluded that issues concerning the marine environment that are related to the area of mineral resources are to be considered as part of the mineral resource area as understood in the terms of the Act on Greenland Self-Government (Self-Government Act) – and therefore as transferred to the Government of Greenland.

In connection with the above-mentioned work, a separate issue concerning the extent of a textual remark in the Danish Finance Act was identified for subsequent separate consideration. According to textual remark no. 6 (section 12 of the Danish Finance Act concerning the Ministry of Defence), the Minister of Defence is authorized to defray all necessary expenses incurred for combating pollution caused by oil or chemicals in Danish and adjacent waters as well as Greenlandic waters in case of either extensive pollution incidents or an imminent risk hereof.

In relation to the issue of the textual remark, the Danish authorities under the leadership of the Ministry of Defence identified and compiled some of the relevant source material in late 2014 with a view to understanding the extent of the textual remark. This was done because it had come to the fore during the process that the Danish and Greenlandic authorities had different interpretations of the provision. Subsequently, the Greenlandic authorities have contributed to understanding the extent of the provision by means of additional relevant source material. The issue of the extent of the textual remark is now subject to discussions between the Greenlandic and Danish authorities in order to reach a common understanding for the future performance of the tasks related to the marine environment in Greenland.

The 3 nm limit is shown in Figure 14 as a dotted line.
Figure 14 Map showing the 10 x 10 km grid defining the study area with the 15 predefined coastal segments.
1.4 High level description of approach

The analysis consists of three main activities:

4. Processing and analysis of vessel traffic, including fuels and cargo carried – Chapter 2.1
5. Calculation of risk based on traffic analysis – Chapter 2.4
   a. Average yearly accident frequencies
   b. Average yearly spill accident frequencies
   c. Average yearly spill volumes
6. Calculation of environmental risk based on the traffic analysis – Chapter 3

Vessel traffic data consists of Automatic Identification System (AIS) data, collected from the study area for the whole of 2013 (Chapter 2.1.1), augmented with ship particulars on type, size, fuel type, fuel volume, cargo type and cargo volume (Chapter 2.1.2, 2.1.3 and 2.1.4). Risk is subsequently calculated by combination of the vessel traffic data, historical accident data and estimations on likely spill volumes. The environmental risk analysis will be based on ship traffic accident frequencies and distribution of environmental resources in the area.

1.5 Similar studies

To benefit from the experience gained in previous work, the following studies have been used as basis:

- Analysis of fuel types and distribution of vessel traffic along the coast of Norway /5/ (Report is in Norwegian: Analyse av drivstofftyper og fordeling av skipstrafikk langs norskekysten)
- Probability analysis of vessel traffic around Jan Mayen /6/ (Report is in Norwegian: Sannsynlighetsanalyse for skipstrafikk ved Jan Mayen)
- Analysis of the likelihood of acute oil spills from shipping – Svalbard and Jan Mayen /3/ (Report is in Norwegian: Analyse av sannsynligheten for akutt oljeutslipp fra skipstrafikk – Svalbard og Jan Mayen)
- Analysis of environmental risk based on vessel traffic along the coast of Norway. (Report is in Norwegian: Miljørisiko ved akutt oljeforurensning fra skipstrafikk langs kysten av Fastlands-Norge for 2008 og prognoser for 2025; DNV report 2011-0850) /88/
- Analysis of environmental risk based on vessel traffic around Svalbard and Jan Mayen. (Report is in Norwegian: Miljørisiko knyttet til potensiell akutt oljedødselig fra skipstrafikk i havområdene omkring Svalbard og Jan Mayen; DNV GL report 2014-0765) /89/
2 SHIP RISK ANALYSIS

2.1 Input Data

The following describes the input data used in the analysis of marine risk.

2.1.1 Ship traffic – AIS data

AIS is an international aid to avert ship collisions and identify and monitor ships. AIS is required for vessels over 300 Gross Tons (GT) in international traffic, over 500 GT engaged on domestic voyages, and all tankers and passenger ships irrespective of size. As of May 31\textsuperscript{st} 2014, there are new rules for AIS on fishing vessels. All ships over 300 gross tons must have AIS on board. All fishing vessels over 15 meters, built after November 30\textsuperscript{th} 2010 must have AIS on board, and fishing vessels over 15 meters, built before, have to be equipped with AIS. Exempt from the requirement to be equipped with AIS are special categories warships, naval auxiliaries and state-owned or state-operated vessels and small craft yacht. There is, however, far more ships carrying AIS than those that are required, which is considered beneficial to the analysis as this gives a more comprehensive traffic picture.

AIS signals are generally collected by satellites and/or land based stations and subsequently stored/aggregated in databases, both operated by various commercial or state owned parties.

Only satellite AIS data from the provider LuxSpace has been used. Due to the orbital periods of these, the data does not provide a continuous recording of all ship movements (when a satellite has been in range, the sampling rate used is every 10 minutes). However, in order to form a representative picture of the ship traffic in the entire study area, this is considered the most suited approach.

Based on the recorded position of AIS messages a Geographic Information System (GIS) is used to draw ship tracks illustrating traffic patterns. Ship tracks are lines drawn between AIS points recorded for each vessel based on the route the vessel has sailed, as shown in Figure 15, and later aggregated within the 10x10 km grid cells for use in the risk calculations.

\textbf{Figure 15 AIS points to tracks}
The risk analysis is based on AIS data for the period 1 January 2013 to 31 December 2013. Using a single year of data may not capture correctly the average yearly traffic over a longer period, such as a decade. This may happen if some additional or lacking traffic has occurred in the sample period, for example exploration, special research, weather and fishing conditions, etc., or if the activity level has fundamentally changed. However, as given in the background for the project, recent climate change and the reduction of sea ice around Greenland and in the Arctic have generally led to an increased geographic availability. This means that using older traffic data will likely result in underestimating vessel activity given current realities.

Since traffic data sourced from AIS does not capture smaller vessels, all additional traffic of these vessels is not included in the analysis, potentially resulting in an underestimation of risk. However, since these vessels are by definition small (i.e. below 300GT) they will not contribute significantly to the end results in terms of spill volumes, and especially in terms of geographic locations of high risk areas, i.e. areas which contributes most to the overall risk in the Greenlandic waters. Thus it has been concluded that the total risk picture on Greenland presented in this report is not degraded by this potential exclusion of traffic. Furthermore, the results are compared to local accident statistics in Chapter 2.4.1, and causes for differences relating to the capture of actual traffic are discussed.

2.1.2 Ship traffic – Meta data mapping

AIS data makes it possible to identify vessel traffic at a granular level. This data is used in combination with vessel databases (primarily IHS Seaweb) to determine the ship's identity and position, as well as other ship specific information such as vessel type, installed machinery power, tonnage, fuel type etc. See Appendix Table 11 in Appendix B for details on the vessel categorisation and the main spill products associated with the traffic data. The mapping of vessel category, size category, fuel type and cargo type is thus done on an individual vessel level and subsequently aggregated to the level of vessel category for the risk calculations.

Vessels in the AIS data that are not recorded with an IMO number, MMSI number or call sign are difficult to categorise as well as link with data on fuel / cargo type. According to the method in the DNVG GL report “Svalbard og Jan Mayen” /3/ these vessels have been categorised as "Unknown vessel type" under the smallest size category «<1000 GT» and the fuel Marine Gas Oil (Distillate marine fuels with viscosity <11 cSt). See Chapter 2.1.3 for details on fuel.

2.1.3 Type and amount of fuel

DNV GL has conducted several studies regarding fuels used on vessels in Norwegian waters /4/ and /5/. Based on this work, a table indicating the likely kind of fuel that can be expected on board vessels of different vessel and size categories has been created. The data is presented in Table 2 and is divided into the following three fuel categories:

- A: Marine Gas Oil (Distillate marine fuels with viscosity <11 cSt)
- B: Intermediate Fuel Oil (Residual marine fuels with viscosity 11-180 cSt)
- C: Heavy Fuel Oil (Residual marine fuels with viscosity >180 cSt)
Table 2 Fuel type onboard ships in each ship category and size category

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Tankers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Product tankers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C*</td>
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<td>B</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Container ship</td>
<td>A*</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>A*</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Reefers</td>
<td>A*</td>
<td>B</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Cruise</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Passenger</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
</tr>
<tr>
<td>Other Activities</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
</tr>
</tbody>
</table>

* The combinations of vessel category and size that did not have data in the studies (/4/ and /5/) have been assigned fuel kind based on judgements by the project team.

Fishing vessels as a category are all assigned MGO fuel.

Amount of fuel on board the ship is a parameter often poorly represented in ship databases. Therefore, this is based on the same methodology as in previous studies for the Norwegian Coastal Administration /6/.

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4 It is noted that fishing vessels in the area have been known to run on HFO
### Table 3 Fuel volume onboard ships in each ship category and size category [tons]

<table>
<thead>
<tr>
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<tr>
<td>Crude Oil Tankers</td>
<td>25</td>
<td>56</td>
<td>119</td>
<td>206</td>
<td>496</td>
<td>801</td>
<td>998</td>
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<tr>
<td>Product tankers</td>
<td>22</td>
<td>58</td>
<td>106</td>
<td>106</td>
<td>295</td>
<td>624</td>
<td>810</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>22</td>
<td>58</td>
<td>106</td>
<td>106</td>
<td>295</td>
<td>624</td>
<td>810</td>
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<tr>
<td>Gas tankers</td>
<td>25</td>
<td>56</td>
<td>119</td>
<td>206</td>
<td>816</td>
<td>1453</td>
<td>2010</td>
</tr>
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<td>Bulk carriers</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Container Ship</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Reefers</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Cruise</td>
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<td>439</td>
<td>612</td>
<td>1566</td>
<td>2576</td>
<td>3934</td>
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<tr>
<td>Passenger</td>
<td>65</td>
<td>160</td>
<td>439</td>
<td>612</td>
<td>1566</td>
<td>2576</td>
<td>3934</td>
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<tr>
<td>Offshore supply vessels</td>
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<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
<td>1223</td>
<td>1688</td>
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<tr>
<td>Other offshore service vessels</td>
<td>32</td>
<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
<td>1223</td>
<td>1688</td>
</tr>
<tr>
<td>Other Activities</td>
<td>32</td>
<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
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<td>Fishing vessels</td>
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<td>Unknown vessel type</td>
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<td>100</td>
<td>200</td>
<td>300</td>
<td>850</td>
<td>1300</td>
<td>1800</td>
</tr>
</tbody>
</table>

### 2.1.4 Type and amount of cargo

Three categories of cargo are covered by the calculations: crude oil, oil products and chemicals. Only the ship categories "Crude Oil Tankers", "Product tankers" and "Chemical tankers", respectively, are considered to carry this cargo.

The volume of cargo on board tankers, i.e. the number of tons of crude oil, petroleum products or chemicals depending on the type of ship, are set equal to the value of the vessels Dead Weight Tons (Dwt). Half the sailed distance is assumed with ships fully loaded, i.e. 100% of the load capacity, and the other half is represented by no cargo, i.e. 0% of the load capacity.

This is based on the same methodology as in previous studies for the Norwegian Coastal Administration /6/, and further details on the calculations can be found in Appendix A.

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5 As the traffic analysis presented in this report shows that no chemical tanker trade in the area the risk for chemicals spills is negligible. However it should be noted that chemicals might have been transported on container vessels or other ships and as such the risk might have been underestimated. See note at start of Chapter 2.4
2.1.5 Accident statistics

The IHS-Fairplay casualty database is considered the most complete and reliable maritime casualty data source in the world. For this reason, base accident frequencies are based on the IHS-Fairplay casualty database /1/. A marine casualty is defined as any incident occurring to a propelled, sea-going merchant ship of 100 gross tons and above in which the condition of the ship suffers adversely. The database contains comprehensive details of all reported serious casualties to all propelled sea-going merchant ships in the world of 100 gross tons and above from 1 January 1978. These general basis data have been considered in relation to the Norwegian Maritime Directorate accident database to be more representative for conditions around Svalbard, which in turn are considered similar to Greenland.

2.1.6 Ice coverage

It is important to stress that the approach in the current risk assessment is general and strategic. Local physical environment and operating conditions may be different from those reflected in the current report. This also implies for the distribution of sea ice and icebergs including debris ice which pose a hazard to marine operations and at all times must be addressed accordingly. This is normally handled safely by well-prepared and experienced Arctic marine users, even by those operating in the harsh ice-infested waters near the southern tip of Greenland as well as on higher latitudes. It is beyond the scope of the current risk assessment to include local and tactical scales which would add another analysis level.

The seasonal sea ice regimes and variability should be noticed at all times. Deteriorating icebergs occur year-round in Greenland, but with seasonal and geographical variability. At safe distance infrequent icebergs are normally not considered as a major risk as they can circumnavigated however iceberg clusters, grounded icebergs or debris ice (small icebergs, bergy bits and growlers) may challenges local operating conditions and emergency response in combination with remoteness, lack of infrastructure / fully updated navigation maps, cold environment etc.

Ice concentration is defined according to the WMO nomenclature; i.e. as the percentage of the sea surface covered by ice. E.g. 70% concentration indicates that 70% of the area is covered by ice. As the value of ice concentration serves as the basis to determine if a ship has sailed in ice or not, it is central to the results of ice risk.

Data on ice concentration for the study area is sourced from the University of Bremen AMSR2 sea ice concentration dataset /7/. This source has been chosen since DNV GL had it readily available and on the format need for the risk model.

In reality, ice concentration will vary each year as illustrated in Greenland ice charts shown in Figure 16. Rather than using average values for several years it is considered most appropriate to use ice data for the latest full year (2013) which is the same period as AIS traffic data used in the analysis. This is also useful when comparing variability in ice conditions with variability in ship traffic, i.e. how shipping routes and levels change per month in relation to changing ice conditions per month. The data is placed in the same 10 x 10 km grid and extracted per month from the same time period as AIS data (i.e. 2013). Details on the modelling of ice-related risks are given in Appendix A.
Ice concentration will be under continuous change. With a temporal resolution of one month in the risk calculations, monthly ice concentration is extracted from the 15th of every month. Figure 17 shows the ice concentration around Greenland in January, April, July and October. Of these four months the ice concentration is at its maximum in April where it covers the entire coast of Greenland except the south west, including the waters around Nuuk.
Figure 17 Ice concentration on the 15th of given month in 2013, ref /7/
2.2 Risk Modelling

This section of the report illustrates in brief the risk modelling methodology. For further details, see Appendix A.

Risk calculations are done on a grid with cells of 10x10 km size within this area. The grid system is based on a similar system used by Statistics Norway (SSB) for areas around mainland Norway. Given the resolution of the traffic data (based on satellite coverage, as explained in Chapter 2.1.1) smaller grid cells would not give a result of higher resolution. On this level it is not possible to distinguish traffic inshore sailing routes from other traffic within the same 10x10 km grid cell.

The risk model estimates risk related to ship accidents at sea. Figure 18 illustrates graphically the structure of the calculations. Risk is defined as the product of frequency and consequence, as shown in Equation 1. The calculations are made for each unique combination of accident category, geographic cell, vessel category and vessel size category.

\[
R = F_a \times C
\]

Where,

- **R**: Risk in terms of yearly average spill in tons
- **\(F_a\)**: Frequency of yearly number of accidents
- **C**: Consequence in terms of spill in tons per accident

The accident categories covered are:\(^6\):

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\(^6\) Bunkering operations and potential corresponding risk is not covered by this study.
In addition, an accident category for ice-related events is calculated (illustrated graphically in Figure 19). In this context sailing in ice is defined as sailing in more than 70% ice concentration. Ice concentration is defined according to the WMO nomenclature; i.e. as the percentage of the sea surface covered by ice. The value 70% is selected based on a qualitative assessment carried out in a workshop with the participation of experts in risk modeling and individuals with experience in sailing in icy waters.

It should be noted that risks related to ice bergs are not covered in this approach.

**Figure 19 Overview of the risk calculations for ice-related incidents**
2.3 Traffic Analysis

The traffic analysis presents the number of unique vessels and vessel distribution per vessel type\(^7\), size category and fuel type, as described in Chapter 2.1.2. Also shown is the total traffic pattern and sailed distances. The results are presented on an annual basis.

2.3.1 Vessel activity

The total number of unique vessels registered by AIS satellites, within the analysis area, in 2013 was 1873.

The distribution of number of vessels within the vessel categories in Figure 20 and Figure 21, shows a relatively large portion of the total vessels is unknown vessels (738 or 39% of the total number of vessels). Vessels that show up in AIS data that are not associated with any vessel specific information (i.e. vessel type, vessel size, IMO number, name, etc) are most likely small vessels that are not required to have AIS transponders, typically smaller pleasure craft, but that carry AIS for safety reasons (military vessels may also carry AIS transponders without being identified by type etc.). As seen in Chapter 7 there is a number of smaller fishing vessels and these might also have AIS transponders and be classified as unknown in the AIS database.

Although there are many vessels in the Unknown category, they represent a moderate share (7%) of the total distance sailed, as seen in Figure 22. These unknown vessels have a moderate effect on the overall risk picture, as seen in Chapter 2.4.

For a better view of the size distribution within the known vessel categories, Figure 21 shows the same data excluding the unknown vessel category. See Chapter 2.3.2 regarding how the spill potential of the unknown vessel category is handled in terms of their estimated fuel volumes.

After unknown vessels, the most common vessel categories are Bulk carriers (11 %). Bulk carriers’ traffic pattern is characterized by sailing directly in and out of the study area, without visiting Greenland), Other activities (9 %) and Product tankers (9 %). Fishing vessels represent 8 % of all vessels in the data. However, as mentioned in Chapter 2.1.1, a lot of vessels carry AIS even though they have not been required to. Since this is especially common on fishing vessels it is fair to assume that a substantial share of the vessels in the category “Unknown vessel type” is fishing vessels. As shown in Chapter 2.1.3, Table 2 and Table 3, all unknown vessels are given a fuel type and volume as to include a rough estimate on their contribution to risks related to spills.

The vessel category “Other Activities” include all vessels that are identified by kind, but do not fit into any of the other categories. This includes such vessels as patrol vessels, icebreakers, tugboats, dredging vessels, research vessels, search and rescue vessels, pilot boats, etc.

\(^7\) All vessel types are defined based on the Lloyds categorization, as given in Appendix B.
Figure 20 Number of unique vessels in the study area during 2013, per ship type and size segment

Figure 21 Number of unique vessels in the study area during 2013, per ship type and size segment (excluding unknown vessels)
Figure 22 Distance sailed in 2013 per ship type

Figure 22, showing the total sailed distances by vessel type, is sorted in the same order as Figure 20. When comparing the two charts it gives an impression of the activity level per vessel. In terms sailed distances per year, Fishing vessels are the most active with 46% of the total and an average of 2700 nm sailed per vessel. Although there are many vessels in the Unknown category, they represent a moderate share (7%) of the total distance sailed.
Figure 23 gives a graphical representation of the traffic pattern seen in the study area in 2013, based on AIS data as described in Chapter 2.1.1. When reading the map, it is important to note that the color scale is not linear. E.g. the span of the highest category (red) is 2700 nm, as opposed to the span of the lowest category (dark green) which is 1.5 nm. The scale has been created in order to give the most legible illustration of the traffic patterns around Greenland in 2013. Any grid cells in white have had zero distance sailed in them in this period.
The areas close to shore in the south west parts of Greenland clearly have the highest density of traffic, and dominate the picture. Additionally, an area off the coast of south east Greenland represents an area with relative high traffic density.

![Figure 24 Share of sailed distance in 2013 within four distance to shore categories](image)

As illustrated in Figure 24, there are big differences in the sailing profile of the various vessel types with regards to distance to shore. As 100% of their operations are outside 3 nm, Ro Ro Cargo vessels, Gas Tankers and Crude Oil Tankers stand out. Thus it is clear that these vessels are not sailing to or from ports in Greenland, but rather pass through the study area in open waters. Over 80% of Passenger vessels operations are within 3 nm from the coast.

### 2.3.2 Fuel and cargo

The method for assigning fuel type and volume to the data from AIS is described in Chapter 2.1.3. Figure 25 shows the number of vessels within each vessel category grouped by fuel type.
Figure 25 Number of unique vessels in the study area during 2013 by fuel type

Excluded in Figure 25 are vessels in the Unknown vessel category. As seen in Figure 20 this vessel category consists of 738 unique vessels. The number of vessels by fuel type within the known vessel types is given in Figure 25.

Per definition of the Unknown vessel category the amount and kind of fuel carried is unknown. As described in Chapter 2.1.3 these vessels are assigned Marine Gas Oil as an estimate, and is therefore associated with some degree of uncertainty. Vessels that show up in AIS data that are not associated with any vessel specific information (i.e. vessel type, vessel size, IMO number, name, etc) are most likely small vessels that are not required to have AIS transponders, typically smaller pleasure craft, but that carry AIS for safety reasons (military vessels may also carry AIS transponders without being identified by type etc.). However, since the vessels are not known, the assumption used is that these vessels carry the amount given in Table 3 (i.e. 30 tons), which should be considered a very conservative estimate. As seen in Chapter 2.3.1, the activity of unknown vessels in terms of sailed distances is very low on a per vessel basis, also supporting the characteristics of pleasure craft and similar. When interpreting the results in Chapter 6 the conservative assumption on fuel volume needs to be taken into account.

Based on the assumptions presented in Chapter 2.1.3, Figure 26 presents the shares of the total fuel volumes carried by vessels in the study area, sorted by fuel type. 77% of the carried fuel is Heavy fuel oil. Total volume of Heavy fuel oil is mostly carried by Bulk carriers (39%), Container ships (16%) and Cruise vessel (12%).

---

As given in Table 2, Fishing vessels as a category are all assigned MGO fuel. However, it is recognized that there might exist fishing vessels sailing with Heavy Fuel Oil in the Greenlandic waters.
The number of vessels carrying a particular fuel type does not give a complete picture since the volume carried and the distance sailed varies widely with vessel size and category. Percentage volume carried and distance sailed with the three fuel types is visualized in Figure 26 and Figure 27 respectively.

The reason for the big differences between Figure 26 and Figure 27 is that heavy fuel oil is mostly carried by large vessels and marine gas oil mostly by smaller vessels. The large vessels are few compared to smaller category vessels and the total sailed distance is therefore smaller for vessels carrying heavy fuel oil. The aggregate distance sailed by smaller vessels is great due to the number of vessels as well as their operational profile within the study area. The spill potentials presented in Chapter 2.4.2 take these effects into account, giving the risk picture from the 2013 traffic picture.

Figure 26 Percentage of total fuel volumes carried, by fuel type
Figure 27 Percentage of sailed distances by fuel type

Figure 28 Volume of fuel and petroleum cargo sold in Greenland in 2013 per month on the left axis [Million litres] and monthly number of transfers on the right axis
Figure 29 and Figure 28 have been made based on data received from Polaroil and OW Tankers via Defence Command Denmark /12/. The figures show the amount, in litres, of fuel and oil products sold by Polaroil in 2013. It gives an impression of the types and volumes of fuel and petroleum cargo used and transported in Greenland.

Estimates of carried fuel in the study area, presented above in Figure 26 and Figure 29, are fundamentally different. The numbers are derived by two different methods and sources; the former by generalizations and estimations by methods described in Chapters 2.1.3 and 2.1.4, and the latter by aggregating sales numbers from Polaroil and OW Tankers on Greenland. The statistics show that 92 million liters of fuel and 18 million liters of cargo where sold in 2013, while in comparison, 280 million liters of fuel is the estimated total capacity on vessels in the study area.

While these numbers are not directly comparable, they are assessed to indicate that only a fraction of the fuel used in the study area is purchased within it. Further it is assumed that vessels engaged in domestic activity on Greenland constitute the majority of local fuel demand. These vessels are also likely to be of smaller size categories, i.e. normally running on lighter fuels as Marine Gas Oil (MGO), hence the large amount of Marine Gas Oil compared to the other fuel types presented in Figure 29.

The distribution of carried amount of fuel per fuel type presented in Figure 26 is based on AIS data, which lacks vessels in the smaller vessel categories, as discussed in Chapter 2.1.1. The larger vessels that are captured by AIS are normally running on heavier fuels, and also to a larger extent assumed to engage in international voyages and refuelling elsewhere than Greenland. These volumes are therefore not captured in the statistics presented in Figure 29, and thus supporting the large difference between the figures.
2.4 Risk Analysis

It should be noted that the traffic analysis presented in Chapter 2.3.1 and 2.3.2 shows that no chemical tankers traded in the area in 2013 and therefore the risk of chemical spills will be zero. Chemicals could have been shipped in containers onboard other types of ships and therefore the risk can have been underestimated.

2.4.1 Frequencies – All accidents

The traffic situation presented in Chapter 2.3.1 and 2.3.2 is the starting point for the modelling of the accident and spill probability of ship traffic around Greenland. The method of calculations is described in Chapter 1.4 and in more detail in Appendix A.

![Graph showing average annual number of accidents by accident category and vessel type](image_url)

**Figure 30 Average annual number of accidents, broken down by accident category and vessel type**

The estimated annual number of accidents for Greenland is 1.6, i.e. on average an accident approximately every 0.6 years. Figure 30 shows that grounding accidents dominate the accident statistics in the study area.

The dominance of grounding accidents in Greenland is similar to the geographically comparable area around Svalbard. A DNV GL report concerning the possible reasons for the dominance of grounding in the waters around Svalbard /3/, identify among others the following factors:

- In a global perspective, the traffic density in the area is low, resulting in fewer collisions.
Waters are not charted as well as is typically the case in mainland coastal areas.

Fewer navigational aids.

Cruise and passenger vessels with an operational pattern close to shore. In 2013 there was 28 cruise vessels and 34 passenger vessels operating in the study area around Greenland.

Traffic patterns as discussed in Chapter 2.3.1 are highly influential on the risk results. As an example, bulk carriers are the second most common vessel category in terms of number of vessels in the study area (only behind the Unknown vessel type, as seen in Figure 20), but is expected to have one of the lowest accident rates. Bulk carriers’ traffic pattern is characterized by sailing directly in and out of the study area, i.e. low sailed distance as seen in Figure 22, as well as far from shore. The adjustment factors used in the risk calculations are such that the risk of grounding is directly dependent on distance to shore (see Appendix Table 4), and estimated as zero so long as sailing occurs over 35 nm from shore.

As with all accident categories, Ice-related accidents are modelled with a temporal resolution of one month (see Appendix A for details). In effect this means that if during a particular month the ice concentration within a 10x10 km grid cell was over 70% on the 15th day of that month, then the sailed distances in that cell during the month in question, will be associated with an Ice-related risk. Thus if the activity level that satisfies this criteria is high, the calculated Ice-related risk will follow. With the spatial resolution of 10x10 km it is not possible to say if the vessel where sailing in ice or simply close by areas with ice. However, the results for Ice-related accidents give an indication as to which vessel types have the relatively highest exposure to ice conditions. It is worth noting that the vessel categories Cruise and Passenger are higher on the list of Ice-related risk than they are for the other four accident categories.

<table>
<thead>
<tr>
<th>Colour code</th>
<th>Likelihood</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very rare</td>
<td>Indicates an accident is expected less than once in every 1 000 000 years, on average.</td>
</tr>
<tr>
<td></td>
<td>Rare</td>
<td>Indicates an accident is expected less than once in every 1 000 000 to 100 000 years, on average.</td>
</tr>
<tr>
<td></td>
<td>Infrequent</td>
<td>Indicates an accident is expected less than once in every 100 000 to 10 000 years, on average.</td>
</tr>
<tr>
<td></td>
<td>Less frequent</td>
<td>Indicates an accident is expected less than once in every 10 000 to 1 000 years, on average.</td>
</tr>
<tr>
<td></td>
<td>Moderately frequent</td>
<td>Indicates an accident is expected less than once in every 1 000 to 100 years, on average.</td>
</tr>
<tr>
<td></td>
<td>Frequent</td>
<td>Indicates an accident is expected less than once in every 100 to 10 years, on average.</td>
</tr>
</tbody>
</table>

Figure 31 shows the same results as Figure 30 geographically in a map. The accident frequencies are given with 6 different colour indicators as defined in Table 4. The total sum of all frequencies of 10x10
km cells amount to the total expected average annual accident rate for the study area including ice-related accidents, i.e. 1.6.

From Figure 31 we can see that the south west parts of Greenland, especially in the areas around Nuuk, are the most exposed to potential maritime accidents. This is due to a higher level of traffic than seen elsewhere in the study area, as well as traffic routes located close to shore. This contributes to increased likelihood of both Collision and Grounding accidents, respectively, and results in a higher likelihood of accidents by a factor of approximately 100 compared to the waters further off the coast.

The south east parts of Greenland also have higher traffic densities, mostly due to fishing activity, which is resulting in another high risk area for accidents. Traffic density in the study area decreases significantly further north, which may partly be explained by the presence of ice, as illustrated in Figure 17.
Figure 31 Geographical representation of yearly average number of accidents per 10x10 grid cell on Greenland (see Appendix C for additional maps)
Return period of an accident is the inverse of the accident frequency, representing the statistical average period of time, the number of years, in between each accident. A large number is therefore perceived as positive, meaning that there are a large number of years in between. The numbers in Figure 32 represent the return period of all accidents, broken down by geographical region. As observed in the figure, region 10 has the lowest return period, with an expected accident every 2 years. This is due to a large amount of traffic close to shore in this region. In comparison region 7 has an expected accident every 525 years. The main reason for this is the lack area close to shore in region 10, which leads to few grounding accidents within it. The same logic applies for region 6.
Figure 33 Navigational accidents around Greenland, all flags /9/

Data from the Danish Maritime Authority show that the actual reported number of navigational accidents (i.e. Groundings, collisions and contacts) in the study area for the period 2001 to 2009 averages at almost 6 per year /9/. In the period 2010 to 2013 the average was 2.5 serious accidents per year /10/ (the numbers for 2001 to 2009 are not differentiated by accident severity). 2010 to 2013 serve as the most worthwhile comparison with the risk model, as both cover “serious accidents” even though the sources and definition of “serious” is not known to be identical. The number of 2.5 accidents per year is about 1.5 times the yearly frequency predicted from the risk model.

From these results it seems the risk model underestimates the likelihood of serious accidents. The same methodology used in this study has been found to be accurate and usually on the conservative side when applied in Svalbard and the along the Norwegian coast. There might be operational and/or material differences between Svalbard/Norway and Greenland, but another reason is explored in the following.

All passenger vessels are required to carry AIS, but only vessels over 300 GT in international traffic or over 500 GT engaged on domestic voyages are required to do so. The accident statistics for all Danish waters from the Danish Maritime Authority (/9/ and /10/) do not state specifically which vessel size categories are included in the accident statistics. However, the numbers of occupational accidents are given based on size and vessel category. Cargo vessels and passenger vessels are presented within the four size categories <300 GT, 300-3000 GT, 3000-10000 GT and >10000. Fishing vessels are presented

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9 “Serious accident” here is per /10/. The document does not explicitly define “Serious accident”.
based on length within the four categories <15 meters, 15-24 meters, 24-45 meters and >45 meters. Assessments done on data from the ship registry database IHS-Fairplay Seaweb /11/, indicate that fishing vessels of 300 GT on average translates to a length of 40m and 500 GT to a length of 52m. Thus, if all accidents involving fishing vessels shorter than 45 meters are categorized as below 300 GT, the distribution of occupational accidents from the Danish Maritime Authority statistics look like Figure 34. As explained, this is only the distribution of number of occupational accidents, not number of vessels. However, under the assumption that the number of occupational accidents gives an indication of fleet size, Figure 34 tells us that the majority of cargo and passenger vessels are over 300 GT, but the majority of fishing vessels are below 300 GT.

Figure 34 shows that most cargo vessels in Danish waters will carry AIS due to their gross tonnage. Since the majority of fishing vessels seem to fall outside the AIS requirements\(^\text{10}\), these will not be included in the input data used for the risk calculations in this study. Figure 33 shows accidents involving fishing vessels in green – i.e. vessels most likely not in the risk model input data – account for a substantial share of all reported accidents. This may indicate a possible reason for the apparent underestimation by the risk model of average accident frequency.

\(^{10}\) Not taking into account the changes as of May 2014 (see Chapter 2.1.1) since the traffic data is from 2013.

Figure 34 Vessel size categories in occupational accident statistics from Danish Maritime Authority /9/
2.4.2 Frequencies – Accidents with spill

In this chapter the expected frequencies of spill accidents are calculated, given the traffic patterns and volumes recorded in 2013. The frequencies are stated in terms of expected number of spill events per year.

![Figure 35 Average annual number of spill accidents, broken down by accident category and vessel category](image)

The estimated annual number of spill accidents for Greenland, shown in Figure 35, is 0.3 i.e. on average an accident approximately every 3 years. When interpreting Figure 35 and Figure 36 with regards to the Unknown vessel type, the conservative assumption on fuel volume presented in Chapter 2.3.2 needs to be taken into account.
Figure 36 shows the same accident statistics as shown Figure 35, but with the breakdown on fuel type on board instead of accident type. Since this reflects the accident rate corresponding to the various fuel types carried, it provides a different picture of the fuel data presented in Chapter 2.1.3. The fuel type that is carried by the highest number of vessels might not be the same that is used on those vessels sailing the furthest, thus having the highest accident risk associated with them.

Other observations from the results include that over 99.96% of the accident frequency involving vessels carrying crude oil, oil products or chemical products are from oil Product Tankers. The estimated accident frequency of spills of oil products is 0.03, or an accident on average every 33 years. The estimated annual number of accidents involving spills of fuel or cargo for Greenland is 0.3, i.e. on average an accident with release approximately every 3 years.
Figure 37 Average annual number of spill accidents, broken down by accident category and season

As with Figure 35, Figure 37 shows the average annual number of spill accidents, but divided within the four seasons as opposed to vessel categories. Seasonal ice coverage given in Figure 17 indicates that accident frequencies correlate well with ice coverage. That is, there are more accidents during summer and fall when the amount of open water areas is at its highest, and conversely fewer accidents during winter and spring when the amount of water areas with high ice concentrations is at its highest. The correlation seen indicates that the activity level itself is highly influenced by the seasons. As the model calculates the accident frequencies based on sailed distances, higher accident frequencies are almost directly analogous with a higher level sailing activity, which itself may be linked with the extent of waters open to sail in. However, it is important to note that this does not provide conclusive evidence as to whether activity level is directly dictated by ice coverage at sea or if there are other factors that contribute to these seasonal characteristics.

Figure 38 shows all spill accident frequencies combined geographically in a map. The 6 different colour indicators are the same as for previous Figure 31, defined in Table 4. The total sum of all frequencies of 10x10 km cells amount to the total expected average annual spill accident rate for the study area, i.e. 0.3. That is about 19% of the total accident rate presented in Chapter 2.4.1.

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11 Winter: December to February  
Spring: March to May  
Summer: June to August  
Fall: September to November
Figure 38 Geographical representation of yearly average number of spill accidents per 10x10 grid cell on Greenland (see Appendix C for additional maps).
Figure 39 Geographical representation of spill accident return periods within the 15 areas of Greenland [years]. Bubble size represents likelihood of accident. Smaller is better.

The numbers in Figure 39 represent the return period of all accidents with spill, broken down by geographical region. The same observation as in Figure 32 is seen in this figure. Region 10 with the lowest return period of about 11 years between each accident and region 7 with the highest return period of about 1257 years in between each accident. This is due to the same reason as discussed in relation to Figure 32.
2.4.3 Risk – Spill potential

In this chapter the estimated spill potential of accidents are calculated, given the traffic patterns and volumes recorded in 2013. In the context of this study, this is what is termed risk, as it is the combination of both rate of accidents occurring and the consequence of these accidents in terms of spill volumes. The result is stated in terms of average yearly tons spilt, and is the result of the spill frequencies multiplied by the corresponding quantity per accident.

The estimated average yearly spill volumes from all vessels except Product tankers amount to 10.6 tons. Of this Crude tankers have an estimated spill of 0.08 tons (0.2% of total). As this is the only vessel type in the study area carrying petroleum cargo besides Product tankers, most of the 10.6 tons will be fuel. 10.6 tons of fuel on average every year is the equivalent of the loss of all fuel on a fully fuelled fishing vessel in the size category 1. < 1000 GT, every 2 years, or every 6 years of similar sized cruise vessel (using estimates of carried fuel as given in Table 3). The relative low traffic results in relative low risk of oil spill compared to say Denmark where the BRISK project showed an annual average spill amount of 2 000 tons, ref /92/

![Figure 40 Average annual spill volume from Product tankers, broken down by accident category](image)

The accidents mix for Product tankers causing the 29 tons, or 73%, of the total estimated yearly spill volume is shown in Figure 40. Grounding accidents are by far the most prominent category within these spill volume results. This will be mainly due to the high accident frequency itself, and not to high differences in the estimated likelihoods and volumes associated with Groundings compared to the other accident categories. Details on the numbers used in the calculations are given in Appendix A.
In Figure 41 the picture is similar to that of Figure 40 with regards to Grounding accidents representing the bulk of the spill volumes. The exception is Crude oil tankers which, as seen earlier in Figure 24 Share of sailed distance in 2013 within four distance to shore categories, does not sail much of its voyages in the study area close to shore.

Due to the generally high volumes of petroleum cargo carried by Crude oil tankers mean that even though they are the second least active in terms of sailed distance with 120 nm in 2013 (0.01% of the total) the associated spill potential is above General cargo vessels sailing some 200 times the distance of Crude oil tankers.
Of the total estimated volume of nearly 40 tons spill on a yearly average, the distribution in Figure 42 shows that 72% of the estimated spill volume is cargo.

Figure 43 shows all spill accident frequencies combined geographically in a map. The 6 different colour indicators are the same as for previous Figure 31 and Figure 38, defined in Table 4, except the unit is in terms on average tons spill volumes on average per year. The total sum of the spill volumes within the 10x10 km cells amount to the total expected average annual spill volume for the study area i.e. 40 tons. The high traffic density close to shore on the south west area of Greenland in Figure 23 is even more apparent in this figure, as these sailing routes give a high risk of grounding of tankers with the potential of high volume spills.

**Figure 42 Share of total spill volumes by type**
Figure 43 Geographical representation of yearly average spill volumes per 10x10 grid cell on Greenland [tons] (see Appendix C for additional maps)
The numbers in Figure 44 represent the amount of expected average annual oil spill (in tons), broken down by geographical region. In this assessment a large number is perceived as negative, with a corresponding large amount of spill measured in tons. The same observation as in Figure 39 is seen in this figure. Region 10 with the lowest return period has a large corresponding expected amount of annual average spill, of about 21.6 tons. Conversely, region 1, 2, 3, 4 and 7 all have small expected annual average spill volumes, of about 0.2 tons.

2.4.4 Risk – inside and outside of 3 nm
By measuring the distance from the centre of each grid cell to nearest land, all cells have been defined as either closer than 3 nm to land (defined as more than 50% of the cell area closer than 3 nm to land), or further than 3 nm from land. With this criterion Figure 45 shows the yearly average accident
frequency of the entire study area per vessel category, divided in Outside 3 nm or Inside 3 nm. Figure 46 shows the same data as percentage distributions. As is seen in both charts, most accidents are estimated to occur within the 3 nm zone.

**Figure 45 Average annual number of accidents inside or outside 3 nm of coastline**

**Figure 46 Distribution of accidents inside or outside 3 nm of coastline**
According to the method of risk modeling presented in Appendix A, all traffic out to 30 nm will have grounding accident probabilities associated with them. Thus, the risk results will give grounding accidents outside 3 nm that in reality will occur within 3 nm of land, as land is required to have a grounding in the first place. This is due to the fact that vessels may for instance lose propulsion a certain distance from land and subsequently drift onto shore. In the context of dividing accidents in categories based on distance to land as described above, this means that the location experiencing the actual consequences of grounding accidents, such as oil spill, will differ from that which is given in this chapter.

Figure 47 and Figure 48 are similar to Figure 45 and Figure 46. Rather than all accidents, they present the yearly frequency of spill accidents, and the picture has therefore changed slightly. When looking at all accidents, 23% are estimated to occur outside the 3 nm zone. When looking at spill accidents, this number has risen to 38%. To understand the reasons for this it is important to have the model assumptions in mind. As presented in Appendix A, 88% of Fire/explosion accidents are assumed to result in a spill. For the other three accident categories roughly 25% of accidents are assumed to result in a spill.

Figure 47  Average annual number of spill accidents inside or outside 3 nm of coastline
Figure 48  Distribution of spill accidents inside or outside 3 nm of coastline

Figure 49 and Figure 50 show "Accident category share outside vs inside 3 nm of the coastline" and "Frequency of accidents outside vs inside 3 nm of the coastline", respectively. From these charts it is clear that there are estimated to be more fire/explosion accidents outside the 3 nm limit than inside, both in absolute terms and in terms of share of accidents within each zone. Therefore, since the share of Fire/explosion accidents outside 3 nm is greater than inside, the total share of spill accidents (all accidents included) will be skewed towards Outside 3 nm when compared with the distribution of all accidents shown in Figure 2.
Figure 49 Accident category share outside vs inside 3 nm of the coastline

Figure 50 Frequency of accidents outside vs inside 3 nm of the coastline
Figure 51 and Figure 52 are similar to Figure 45, Figure 46, Figure 47 and Figure 48, but show the estimated yearly spilled volume to. These numbers should be read with the limitation described above regarding grounding accidents estimated in cells some distance from land, in mind.

Figure 51  Average yearly spill volume inside or outside 3 nm of coastline

Figure 52 Distribution of spill volumes inside or outside 3 nm of coastline
2.5 Forecast for ship traffic in 2027

This chapter includes a forecast for ship traffic in Greenland around 2027. The forecast is developed combining two ways in which ship traffic will develop: development of new traffic, and future changes to existing traffic.

First, we consider the possible emergence of new traffic around Greenland. By new traffic we mean traffic patterns which do not occur around Greenland today, but which can possibly start up between now and 2027. We consider three potential activities which could induce such new ship traffic in Greenland. These are production of offshore oil and gas, mining activities onshore and trans-arctic shipping between Asia and the North Atlantic resulting from decreased ice cover. These developments are described in chapter 2.5.1.

Second, we consider traffic around Greenland which exists today and determine how this traffic will change based on economic and demographic drivers. This development is described in chapter 2.5.2. The resulting forecasts, covering the above mentioned future developments, are finally presented in chapter 2.5.4.

2.5.1 Future development of new traffic

2.5.1.1 Offshore oil and gas production

There is presently no production of offshore oil and gas in Greenland. AIS data shows that there is currently some shipping activity related to exploratory work around Greenland, with 24 exploration and exploitation licenses granted /61/. Future development of exploration activity is covered in chapter 2.5.2.4. This section considers the possible development of shipping activity linked to production of oil and gas; including tankers to transport oil and gas and support activities by offshore service ships that will serve possible new activities.

In recent years, hydrocarbon exploration in Greenland has received increasing attention. In 2008, the U.S. Geological Survey ranked the East Greenland region 4th out of 25 oil and gas provinces in the Arctic in terms of hydrocarbon potential, estimating that the region contained up to 31.387 billion barrels of oil equivalents in oil, gas and natural gas liquids.

Interest in Greenland’s oil and gas potential has experienced many ups and downs over the past fifty years. Price spikes in the 1970s spurred exploration, though subsequent price declines and the lack of any significant finds caused international oil companies to lose interest. Additional licenses in western Greenland were offered in the early 2000s, but no major companies applied. In the face of tepid interest from the oil and gas industry, Denmark and Greenland sought to more actively promote the region’s potential and encourage investment by directly funding extensive seismic exploration in promising areas. Rising oil prices in the middle 2000s helped to increase interest in Greenland’s oil again, and in 2006 several major oil companies bid on licenses in Western Greenland although exploration there to date has not revealed any promising prospects /25/.

While development of oil and gas in Greenland has historically focused on offshore areas west of Greenland, the Mineral Licence and Safety Authority of the Government of Greenland (formerly the Bureau of Minerals and Petroleum) awarded the first oil and gas exploration and exploitation licenses for eastern Greenland on 20 December 2013. Figure 53 shows an overview of current licences and exploration wells in Greenland.
The licenses in the Greenland Sea represent the greatest potential for oil and gas discoveries; however, the prevailing ice conditions in these areas will present extreme challenges to exploration activities. The entire region is ice covered for most of the year. Only in exceptional years has open water appeared throughout the license areas in August and September. Coincidentally, several exceptionally low ice years occurred in the early 1990s, facilitating the Kanumas seismic surveys that have been instrumental in describing the resource potential of the region and driving the push for more exploration.

Exploration and drilling must firstly lead to the discovery of commercially attractive hydrocarbon fields. Exploration wells in areas of harsh sea ice conditions (short open water seasons and the presence of multi-year ice) will require multiple summer seasons to drill and test. These wells can only be undertaken provided there is high confidence that costs will not rise intolerably due to the need for unanticipated additional seasons. Hence, high reliability ice management capability will be essential for exploration drilling. This includes careful icebreaker fleet selection and control, as well as capabilities to monitor and detect unmanageable multi-year ice features and to forecast ice drift. The key is to manage the interruptions to a frequency that is economically tolerable. While these conditions make exploration challenging, they will also place additional challenges and costs during the production phase.

Current global petroleum markets may make exploitation of oil and gas deposits in the Greenland Sea commercially unattractive in the near and medium-term future. Due to the remote location, lack of oil and gas support infrastructure and challenging operating conditions, exploration and development of any...
oil and gas fields in the Greenland Sea will require extensive investments /25/. The reluctance to develop challenging Arctic fields became evident when Norwegian oil major Statoil recently decided to delay production of the Johan Castberg field in the Norwegian Barents Sea due to high development costs. The Castberg field is expected to contain 600 million barrels of oil, is in an ice-free region of the Barents Sea and is relatively close to existing oil and gas infrastructure in Norway. The lesson here is that even large proven reserves of oil are not enough to make Arctic oil and gas developments economically feasible, even in less remote regions such as Norway’s Barents Sea /25/.

While the assessments of Greenland’s geology are promising, exploratory drilling will need to identify oil in sufficient quantities to warrant the extraordinary investment that will be required to bring it to market. Second, while global warming continues to improve conditions for oil and gas exploration in the Arctic, the peculiar geography of northeast Greenland means that ice conditions will continue to be challenging for the foreseeable future. Operations in northeast Greenland will thus remain expensive and technically challenging.

Even provided that a decision is made to develop a commercially attractive deposit of hydrocarbons in Greenland in the near future, the question becomes if the development of the field can be done in time for production to commence before 2027. The timeline from exploration and possible discovery of oil and gas to production can be long, referred to as lead-time. From experience on the Norwegian continental shelf, it takes on average 12 years from the discovery is made to the production is started /26/.

In sum, we find there will most likely be no petroleum production in Greenland by 2027. However, there may be significant activity related to exploration and development before 2027 (see section 2.5.2.4).

### 2.5.1.2 Mining activities

There is currently no significant mining activity in Greenland. However, minerals and mineral resources could potentially be a cornerstone of Greenland’s economic development and many initiatives have been implemented to accelerate the establishment of the mineral industry. Since 2004 there has been great activity in both the exploration for new deposits and surveys of existing finds. Global warming is causing Greenland’s ice cover to melt, increasing access to Greenland’s mineral resources, which could provide the territory with a promising source of income. Many initiatives have been implemented to accelerate the establishment of the mineral industry.

Known mineral deposits in Greenland include gold, platinum group elements (PGE), molybdenum, nickel, specialty metals such as rare earth elements (REE), tantalum and niobium (in the mineral pyrochlore), as well as several forms of industrial minerals.

There are currently six mine locations for which exploration licenses have been granted /61/. Of these, three prospects are considered to be at such an advanced stage that production before 2027 is likely.

The first is the Isukasia (Isua) iron deposit. The Government of Greenland and London Mining signed a mining permit on 24 October 2013 for an exploitation license covering the Isukasia (Isua) iron-ore deposit (see Figure 36 a). London Mining has applied for a construction license, and are waiting to receive the decision from the Government of Greenland /52/. This is the most well-known and investigated deposit, and is located 150 km north-east of the capital Nuuk /27/. The mine is known to be commercially viable if the price of iron ore remains. The resource contains more than 1.1 billion tons of ore, and the mine is expected to produce 15 million tons of high-quality iron-ore concentrate per annum.
The second prospect likely to result in production before 2027 is the True North Gems project to mine ruby and sapphire gemstones. They plan to start building an open-pit mine that will produce ruby and pink sapphire gemstones by the end of 2015. Mining of ruby and pink sapphire will result in much smaller volumes compared to, for example, iron ore, and is not likely to generate any ship traffic, as the gemstones are separated at the site, and could be transported e.g. by plane, and is thus not discussed further.

A third prospect likely to produce before 2027 is a gold mine at Napasorsuaq, run by Angel Mining (Gold A/S) in the Southwest. There is a functioning processing plant already in place, and the company expects a production of 24,000 ounces (3 tons) of gold per year. Given that the volumes produced will be so small and that the mining facilities are already constructed, this is not likely to generate significant shipping traffic.

None of the companies who have obtained licenses to exploit the remaining three possible mine locations, have indicated that they are not past the research stage. Of the three remaining locations: Seqinnersuusaq, Maarmorilik, and Malmberget, it is the molybdenum deposit, Malmberget in East Greenland that could possibly generate shipping traffic, but activities around this mine are still centered around mapping and sampling, leading to the conclusion that significant traffic will not be generated in 13 years’ time.

Greenland does have other deposits of interest. The area near Citronen Fjord has globally significant deposits of Zinc. However, the feasibility study for this deposit was only published in 2013, leading to the conclusion that production will not occur by 2027. Kvanefjeld (Kuannersuit) contains a large deposit of rare earth metals, with the discussion still ongoing as to how to safely mine the radioactive materials found there. Another promising deposit, the Naajat Calcium Feldspar Project, could come online in the future, but it was only in the process of applying for an exploration licence as of 2014. None of these three areas are expected to come into production by 2027.

Thus, the mining activity that is most likely to have the greatest impact on shipping is the Isukasia (Isua) iron deposit. The mine will comprise an open pit, a processing plant, a slurry pipeline, a port, and connecting infrastructure. It is expected that 700–800 workers will work at the mine site in the production phase, whereas as many as 3,000 will be employed during construction. During the construction phase, some extra ship traffic is anticipated, but only for a limited period. Iron ore will be shipped from a deep water port to the world markets. Like the Baffinland Iron Mine on Baffin Island (Canada), the costs of placing a mine in a remote area will be compensated by the high quality of the ore. The ore holds 70 percent iron, and requires minimal processing before being shipped. The iron ore will be shipped to world markets by bulk carriers. London Mining has estimated that 15 million tons of high-quality iron-ore concentrate per annum will be shipped from Isukasia (Isua). To determine the resulting shipping activity, the ship size to transport the cargo must be determined, as well as the likely route the ships will follow.

Firstly the ship size must be determined. The majority of observed bulk carriers in Arctic waters today are Handymax or Supramax, ranging from 40,000 to 60,000 DWT. Capesize or Very Large Bulk Carriers have not been observed in the AIS material covering Arctic waters so far. However, a Montreal-based bulk shipping company has ordered several ice-class 130,000 DWT Capesize carriers to ship high-grade iron ore from Baffinland Iron Mine on Baffin Island to Europe. It is considered likely that the same ship size will be used. In the estimation of future ship traffic it is anticipated that iron ore from Isukasia (Isua) will be transported by Capesize vessels with ice-class, with an average of typically 130,000 DWT. For one year, transporting 15 million tons of high-quality iron-ore concentrate by 130,000 DWT capsize vessels,
we estimate that 115 ship transports are required per year. 115 transports constitute 230 trips in and out of Greenland waters.

London Mining Association submitted a Navigational Safety Investigation as part of the application materials. Here they estimate 102 transports per year, well in line with the above estimation /70/.

To determine the sailed distance in Greenland waters, the route for the 115 transports must be determined. The most likely destination for the iron ore is Europe or Asian markets, however we will assume that the same considerations made for Baffin Island, will apply to Greenland, and hence we assume that the ore will be exported to Europe. Note also that in the future it is possible that the North West Passage route can be used (see chapter 2.5.1.3) to transport the ore to Asia. However, both due to depth restraints /47/ and ice conditions we do not consider this to be the most likely option. One trip from Isukasia (Isua) to Europe will cover 627 nm through Greenland waters. The 230 trips will thus result in a distance sailed of 144 210 nm into and out of Greenland waters by bulk ships in 2027.

It is recognized that additional mines to the ones described above may be in production by 2027. However, it is also possible that no new mines (including Isukasia) will be in production. For example, if there is a new drop in the price of iron ore, development of the mine may be stalled as it has been before. The presented forecast should thus be treated with the appropriate caution given the large uncertainty.

### 2.5.1.3 Transpolar ship traffic in Greenland waters

New cargo ship activity in the Arctic is expected as a result of Europe-Asia transit shipping. This traffic is expected because of the potential savings in time and cost resulting from the reduced distance between ports in Asia and ports in North America and Europe, either through the Northern Sea Route – NSR - (Russia), the North West Passage – NWP - (Canada) or across the Arctic ocean high seas (the Pole). In 2013 one ship travelled the NWP and 40 ships travelled the NSR.

We have reviewed the available literature on future Arctic shipping activity. Broadly speaking, two types of studies have been identified; some studies make assessments on the ice cover, the navigation season and the accessibility for different ship types, without making explicit estimates for future ship traffic volumes (Serreze et al. 2007 /36/; Wang and Overland, 2009 /39/; Boe et al., 2009 /30/; ACIA, 2005 /41/; Smith and Stevenson, 2013 /37/; Khon et al. 2010 /40/; Overland and Wang, 2013 /33/). A few studies explicitly assess the potential for future traffic volumes (Paxian et al., 2010 /34/; Corbett et al., 2010 /31/; Peters et al. 2011 /35/).

In this section we first present a brief overview of the findings in the above studies. Then we present an argument for the likely traffic volumes in Greenland waters resulting from new cargo ship activity in the Arctic as expected from Europe-Asia transit shipping, based on the above mentioned literature.

### Literature overview

Several studies exist which assess how ice over the polar caps can thin due to global warming and how this will affect shipping. Several studies are presented here to illustrate current understanding of the topic.

With regards to ice cover, recent trends indicate longer seasons with less sea-ice cover and reduced thickness (Serreze et al., 2007 /36/; Boe et al., 2009 /30/), implying improved ship accessibility around the margins of the Arctic Basin. Climate models project an acceleration of this trend and opening of new
shipping routes and extension of the period during which shipping is feasible (ACIA, 2005 /41/; Boe et al., 2009 /30/). Some analysts have suggested that the Arctic may be ice free in September as early as 2030 (Wang and Overland, 2009 /39/), though others suggested 2066–2085 (Boe et al., 2009 /30/). Overland and Wang (2013) /33/ estimate nearly ice free summers in the Arctic by 2060 at the latest, and possibly as early as 2020 using three different approaches.

Smith and Stephenson (2013) /37/ find that by mid-century, the trans-polar route across the pole is navigable by moderately ice-strengthened vessels (PC6) (Figure 54). By mid-century the NSR is navigable by open water vessels in any given year with 94% probability (compared to 40% in the past few decades). The NWP will be navigable by vessels without ice strengthening with a probability of 53%. This study clearly shows the technical potential for transiting the Arctic, but makes no assessment of the magnitude of the traffic.

Khon et al. (2010) /40/ found that models predict that at the end of this century there will be free passage through the NSR for 3–6 months of the year and the NWP for 2–4 months. This may make the NSR up to 15% more profitable than the Suez Canal route (Khon et al., 2010 /40/), but they did not estimate future ship traffic in the Arctic.

Several studies estimate how shipping traffic will change based on changes in ice cover predicted by climate change models. Paxian et al. (2010) /34/ estimated present-day and future emission inventories that included polar routes. The ship traffic along the polar routes was estimated using an algorithm that calculates the shortest path for all global shipping movements, considering land masses, sea ice, shipping canal sizes, and climatological mean wave heights. Ship performance or cost considerations are not included. They estimated fuel consumption along the NSR and NWP to increase by a factor of 9 and 13, respectively, from 2006 to 2050 (Paxian et al., 2010 /34/).

12 Note that that Figure 54 only shows the simulated fastest line from Bering to the North Atlantic (both America and Europe) – and does not compare the arctic routes to the traditional Suez or Panama options.
Another study, Peters et al. (2011) /35/ present results from a techno-economic model from DNV GL which accounts for the most relevant factors. This model estimates the future shipping due changing ice conditions by calculating the costs of a selected Arctic sea route versus the Suez Canal route, enabling a comparison of the alternatives. Costs are calculated by utilizing detailed projected ice data, by modelling speed and fuel consumption of ships in ice, and by adding additional costs from building and operating ships suitable for Arctic operation (e.g. ice class). The comparison is made for routes originating in different Asian ports. If the Arctic route from a given port is favourable in economic terms, the model estimates the number of passages based on the projected amount of cargo to be transported and the selected ship concept (i.e. cargo capacity and sailing season).

Peters et al. (2011) /35/ found that part-year Arctic transit will be commercially attractive for container traffic from the Tokyo hub in 2030 and 2050. The predicted amount of containers that will be transported through the Arctic equals 1.4 million TEU\(^{13}\) in 2030 (36% of the potential for the Tokyo hub) and 2.5 million TEU in 2050 (45% of the potential for the Tokyo hub). This corresponds to 480 transit voyages, or about 8% of the total container trade between Asia and Europe, in 2030 and 850 transits voyages, or about 10% of all container traffic between Asia and Europe, in 2050. Shipping activity related to petroleum extraction has been estimated based on projected production data (described in the previous section). This traffic is unlikely to impact on high seas traffic. Note that Peters et al. (2011) predict traffic outside the Russian EEZ, but not across the pole.

A third study, Corbett et al. (2010) /31/ constructed detailed inventories of all Arctic shipping activities, including transits of the NSR, NWP and other polar routes with reduced sea-ice extent. They assume a diversion of global traffic to the arctic at 1% of global shipping in 2020, increasing to 2% in 2030, and to 5% in 2050. Transits were estimated using a fixed percentage diversion of global traffic (1–5 %) and were found to be 2–4 times greater than reported by Paxian et al. (2010) /34/. In terms of polar transits these studies, however, do not explicitly model ship performance and economic costs of shipping in Arctic conditions.

We consider the numbers presented by Peters et al. (2011) /35/ to be the most reliable, with support from the findings of Paxian et al. (2010) /34/. However, we recognize high uncertainty in this estimate. The finding from Valkonen and Eide (2012) /38/ that not all ice scenarios allow for transit along the route selected by Peters et al. (2011) /35/ indicates that the number of transits is overestimated. However, the number of transits may also be underestimated, as inferred by the recent publications by Smith and Stephenson (2013) /37/ and Overland and Wang (2013) /33/ which indicate that the ice conditions may be more benign than assumed by Peters et al. (2011) /35/.

The above review of studies presenting projections for future Arctic shipping activity reveals that there is considerable uncertainty in the estimates.

### 2.5.1.4 Expected traffic in Greenland waters

As shown in Figure 54 potential new transpolar traffic may affect Greenland both on the east and west coast. On the west coast, traffic from Asia through the NWP of the Canadian Archipelago, may come into Greenland waters.

Passages through the NWP will shorten the travel distance between Asia and the North American Eastern seaboard compared to the traditional route through the Panama Canal (Table 5). However, ice conditions in the NWP are known to be harsh, and this limits the commercial attractiveness of large scale traffic. Although Figure 54 indicates that the NWP will be the fastest route across the arctic by mid century –

\(^{13}\) Twenty-foot equivalent unit (TEU) is a unit of cargo capacity commonly used to describe the capacity of container ships.
this only show that the NWP will be faster than the NSR. No study to date has found that the NWP will outperform the Panama – certainly not by 2027 which is the time horizon for this study.

Furthermore, even if traffic should transit the NWP by 2027, both Baffin Bay and the Labrador Sea is split between Canadian and Greenland waters, and as indicated in Figure 54, traffic will most likely be limited to the Canadian side. Hence, we expect no transpolar traffic of substance on the Greenland West coast by 2027.

On the east coast traffic could potentially be affected by traffic from Asia to North America through the NSR, as well as by traffic from Asia and Europe across the pole. However, the distance from Asia to North America through the NSR or across the pole, is not shorter than the Panama alternative (Table 5), and hence is not a commercial option – regardless of ice conditions.

Passages across the pole will shorten the distance between Asia and Northern European ports compared to Suez (Table 5). Figure 54 indicates that this route may be the fastest for ice-strengthened vessels by mid-century. However, by 2027 we do not consider that the route across the pole will be preferred to the NSR. Hence, we expect no transpolar traffic of substance on the Greenland East coast by 2027.

In conclusion, we do not find it likely that transpolar traffic of substance will exist in Greenland waters by 2027.

### Table 5 Distances (in kilometres) between selected ports.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Rotterdam via Suez</th>
<th>Rotterdam via NSR</th>
<th>New York via Panama</th>
<th>New York via Arctic&lt;sup&gt;14&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo</td>
<td></td>
<td>20708</td>
<td>12994</td>
<td>17992</td>
<td>18574</td>
</tr>
<tr>
<td>Hong Kong</td>
<td></td>
<td>17966</td>
<td>14510</td>
<td>20802</td>
<td>20855</td>
</tr>
<tr>
<td>Singapore</td>
<td></td>
<td>15357</td>
<td>18199</td>
<td>23138</td>
<td>23001</td>
</tr>
</tbody>
</table>

### 2.5.2 Future development of existing traffic

This chapter discusses changes in the shipping traffic which currently exists around Greenland. The changes are expected to follow from changes in the different activities which exist on Greenland today. In this analysis, an expected relative increase in sailed distance from 2013 to 2027 per vessel type is established. The new sailed distance per vessel type is then calculated based on the total sailed distances given in the AIS data available for 2013, as is described in chapter 2.1.1.

The activities of each vessel type are governed by a certain activity, and each activity is in turn governed by economic drivers. These drivers are used in the analysis to estimate changes in activities. Table 6 shows the relationships between vessel types, activities, and economic drivers.

<sup>14</sup> Along a route passing east and north of Greenland
The drivers of current vessel activity on Greenland can be summarized into five main activities: fishing, mining, tourism, exploratory and research activities, and transport of goods. Determining the development of existing traffic is performed by estimating changes in the economic drivers.

Fishing vessels and reefers are discussed in section 2.5.2.1. In section 2.5.2.2 cruise ship traffic is discussed. Passenger ships are discussed in section 2.5.2.3, and in section 2.5.2.4 offshore supply ships and "other vessels" are discussed. General cargo ships, container ships and product tankers are discussed in section 2.5.2.5, while bulk carriers are found in section 2.5.2.6. Finally, ships of "Unknown vessel type" are discussed in section 2.5.2.7, before the results are summarized in section 2.5.4. As fishing is the primary industry of the Greenland economy, the sub-chapter on fishing vessels is more extensive than the other sub-chapters.

Note that growth in crude oil tankers, gas tankers and ro-ro cargo is not discussed, as they are non-existent or negligible in Greenland today.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Economic activity</th>
<th>Economic drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing vessels, Reefers</td>
<td>Fishing</td>
<td>Fishing</td>
</tr>
<tr>
<td>Cruise</td>
<td>Arctic cruises</td>
<td>Tourism industry</td>
</tr>
<tr>
<td>Passenger</td>
<td>Arctic cruises and local transportation</td>
<td>Tourism industry + population size</td>
</tr>
<tr>
<td>Container ships, Product tankers, General cargo</td>
<td>Supplying population with goods</td>
<td>Population size + GDP</td>
</tr>
<tr>
<td>Other activities, Other offshore service vessels</td>
<td>Related to petroleum exploration</td>
<td>Continued exploration</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>Bulk ships sailing between in and out of Hudson Bay.</td>
<td>Mining in Hudson Bay</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>Fishing</td>
<td>Fishing</td>
</tr>
<tr>
<td>Crude Oil Tankers, Gas tankers, Ro Ro Cargo</td>
<td>Negligible presence in Greenland</td>
<td>-</td>
</tr>
</tbody>
</table>

### 2.5.2.1 Fishing

Vessels which depend on the fishing industry include fishing vessels and reefers, which carry the catch. Unknown vessel types (in the AIS material) also tend to be involved in fishing, but on a smaller scale. These vessel types are considered separately in chapter 2.5.2.7.

The fishing industry is mainly regulated by quotas and license regulations to ensure a sustainable use of the natural resources. A number of factors can influence this mechanism, including national and international fisheries' policies, as well as possible changes in ecosystems.

Fishing vessel activity is not only influenced by fish availability and location. Also the size, technology and efficiency of fishing vessels, number of quotas, and size of quotas affect the number of ships and the distance travelled. Below, the current situation and projections for future activity will be presented.
Fishing fleet in Greenland today

The Greenland marine environment is cold, with few commercially exploitable species compared to other areas in the North Atlantic, such as Norway and Iceland. Present-day catches from Greenland mostly comprise of shrimp, Greenland halibut, Atlantic cod, capelin, and mackerel /59/. There are currently small amounts of Atlantic cod around Greenland. For Greenland, several species of marine mammals and seabirds are listed in catch statistics. Catches of marine mammals and seabirds are important in Greenland as a form of subsistence hunting and fishing /48/.

Fishing is the primary industry of the Greenland economy. The most commercially important resources are shrimps and Greenland halibut. The fleet consists of about 850 vessels of various sizes and there is an estimated figure of 5000 smaller dinghies /49/. Of these, about 300 vessels are longer than 10 meters /60/. There is uncertainty regarding the size of the fishing fleet because not all vessels which are used for fishing are registered as fishing vessels. The larger vessels are more likely to registered and engaged in fishing as a commercial activity, while smaller vessels may be partially used for personal fishing purposes, and partially used for personal transportation. Note that the AIS material used to calculate the sailed distance for fishing vessels in 2013 only includes around 150 fishing vessels (see section 2.3.1). These are mostly large vessels, and are likely to cover all vessels above 20 GT (see table below). AIS data is used here in order to stay consistent with the basis for calculations used otherwise in this report.

The ocean-going fleet includes a number of large vessels which fish outside the limit of three nautical miles. Most large vessels have the capacity to process the catch on board. As shown in the table below, the seagoing fleet is concentrated in central Greenland. The coastal fleet fishes within the limit of three nautical miles of the coast. The small vessels under 10 GRT are found mainly in northern Greenland where they primarily partake in fishing for Greenland halibut /49/.

Table 7  Fishing vessels by District, year and size /49/

<table>
<thead>
<tr>
<th>Districts</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>0-10</th>
<th>11-20</th>
<th>21-50</th>
<th>51-80</th>
<th>81-120</th>
<th>121-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>572</td>
<td>788</td>
<td>863</td>
<td>757</td>
<td>491</td>
<td>148</td>
<td>32</td>
<td>22</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>Nanortalik</td>
<td>19</td>
<td>32</td>
<td>28</td>
<td>29</td>
<td>25</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Qaqortoq</td>
<td>26</td>
<td>55</td>
<td>58</td>
<td>56</td>
<td>37</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Narsaq</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Paamiut</td>
<td>35</td>
<td>45</td>
<td>44</td>
<td>38</td>
<td>20</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Nuuk</td>
<td>66</td>
<td>106</td>
<td>117</td>
<td>102</td>
<td>38</td>
<td>25</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>Manitisq</td>
<td>34</td>
<td>65</td>
<td>72</td>
<td>57</td>
<td>39</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sisimiut</td>
<td>41</td>
<td>56</td>
<td>66</td>
<td>53</td>
<td>29</td>
<td>13</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Kangaatsiaq</td>
<td>18</td>
<td>21</td>
<td>19</td>
<td>19</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Aasiaat</td>
<td>15</td>
<td>29</td>
<td>42</td>
<td>24</td>
<td>12</td>
<td>6</td>
<td>3</td>
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<td>11</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Ilulissat</td>
<td>90</td>
<td>119</td>
<td>137</td>
<td>129</td>
<td>85</td>
<td>33</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Qeqertasuaq</td>
<td>21</td>
<td>22</td>
<td>30</td>
<td>24</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Uummannaq</td>
<td>74</td>
<td>84</td>
<td>85</td>
<td>94</td>
<td>82</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upernavik</td>
<td>70</td>
<td>83</td>
<td>82</td>
<td>71</td>
<td>65</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Qanaaq</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Illoqqortormiut</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tasiilaq</td>
<td>14</td>
<td>26</td>
<td>28</td>
<td>15</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Predicted situation 2027
In estimating the future activities of fishing vessels, the International Arctic Science Committee’s *Arctic Climate Impact Assessment (ACIA)* forms the basis for the analysis. Three different scenarios have been described for Greenland in the ACIA to analyse how ecological changes due to climate change will affect fish stock in Greenland, and thus the region’s Gross Domestic Product (GDP). The 3 scenarios are termed “pessimistic”, “moderate” and “optimistic” scenario /48/.

Available long term projections suggest that climate change over the next 100 years is very likely to lead to an increase in the most commercially important fish stocks at Greenland. Cod stock in particular may experience a revival. According to ACIA’s optimistic scenario, the cod stock could yield a maximum of 300,000 tons on a sustainable basis /48/. The optimistic scenario also estimates climate change and increased predation by cod could lead to a dramatic fall in the sustainable harvest of shrimp by a maximum of 70,000 tons. According to today’s export prices, the value of increased cod stock would make up for the loss of shrimp /59/. In fact, this change could lead to doubling or even tripling of the total production value of the Greenland fishing industry. Thus, the projected climate change could have a major positive impact on the Greenland fishing industry on an economic level.

The pessimistic scenario assumes an insubstantial change in overall average fish stock availability. However, due to the occasional large-scale influx and survival of Icelandic cod larvae, periodic bursts in cod availability may occur. This situation results in fluctuating fish production rates and GDP impacts over time with a small average increase. The average increase in GDP after 50 years is about 2% higher than would otherwise have been the case /48/.

In the moderate scenario, fish stock availability is assumed to increase gradually by about 20% over the next 100 years. The impact of this scenario on GDP relative to a benchmark GDP of unity is shown by the middle curve in Figure 55. This increase in the availability of fish leads to a moderate long-term increase in GDP of 6% (compared to the initial level). However, as most of this increase is projected to occur over the first ten years (in fact the initial impact is projected to be greater than the long-term impact) there would be a significant addition to GDP of 1% per year during this initial period /48/.

In the optimistic scenario, fish stock availability is assumed to increase gradually, but in a fluctuating manner, by about 100% over the next 50 years. The projected relationship between the value of fish exports and GDP suggests that this will lead to an ultimate increase in GDP of 28% compared what would otherwise have been the case. This impact relative to a benchmark GDP of unity is illustrated in Figure 55. Such an impact would be very noticeable. The additional economic growth would be close to 0.8% per year over the first 30 years but would then decrease, stopping after 40 years /48/.
Figure 55 shows that in 2027 (13 years in the future), the change in GDP can be from -4% to 8%. Thus, the volume of production from the fleet in 2027 is uncertain. Also, it is unclear whether an increase in the value of production in the fishing industry would lead to an increase in distance sailed by fishing vessels. Both shrimp and cod are fished off the East coast, meaning the vessels are subject to similar weather conditions. Given that the maximum increase in cod in the ACIA is estimated to be 300 000 tons per year, and the maximum decrease in shrimp is 70 000 tons per year, it is feasible that the total tonnage of seafood fished remains the same. Although the species are different, if the tonnage of product and weather conditions remain the same, sailed distance of the fishing fleet may not change much, even if the ecology of Greenland’s waters does. As stated in the assessment, there is great uncertainty in the numbers for shrimp and cod increase. They are given here not as absolute statements about future fish stocks around Greenland, but rather to illustrate that climate change can result in changes in fish stocks which pull the industry in both directions. Some changes can lead to an increase in fishing activities; some can lead to a decrease.

There are many factors that influence the development of the fishing fleet, some may result in an increase in sailed distance, and some may result in a decrease. The fishing fleet is constantly changing, with a trend towards fewer vessels and efficiency of the fishery. A shift towards larger vessels may have the consequence that fewer vessels perform the same amount of work, and that distance sailed decreases. On the other hand, prognoses indicate that climate change can increase the available fish stock which would lead to increased activity and an increase in distance sailed. However, the extent to which a change in fish stock availability will change the sailed distance remains uncertain, and whether or not there will be a positive or negative correlation between sailed distance and fish stock is unknown.

The amount of uncertainty, and the fact that the drivers at work can lead to both an increase and a decrease in sailed distance, necessitates that the most reasonable estimation of future fishing activity is a 0 % change. This applies to both fishing vessels and reefers serving the fishing industry.
2.5.2.2 Cruise ships

Today, Greenland is an established destination in the niche cruise market. Tourism in remote places has increased dramatically in recent years, a consequence of increased focus on variation in offerings to tourists. 25 cruise vessels sailed in Greenland waters in 2013, carrying more than 20,000 cruise passengers. The vessels sailed in total a distance of more than 60,000 nm, primarily along the west coast of Greenland.

Over the next decade, the global tourist industry is expected to grow considerably, particularly within the cruise sector. This is mostly the result of an increase in affluence. The United Nations report *Tourism Towards 2030*, states that tourist activities globally will increase by 80% up to 2030 /22/. This development indicates that the cruise activities will increase globally and it is expected that Greenland’s cruise industry will follow this trend.

An increase for Greenland can be expected in the coming years, particularly due to the fact that tourism in Greenland is a young industry which has experienced significant growth in the past 15 years. From 2000 to 2010, sales of hotel accommodations in Greenland increased by 211% /40/. The same statistics show that travel to Iceland, the Faroe Islands, and Greenland has increased at a higher rate than for mainland Nordic countries, reinforcing the idea that growth in cruise activity in places such as Greenland will account for a large part of growth in the industry as a whole. Since 2003, the number of cruise passengers in Greenland has more than doubled, although fluctuations from year to year are apparent.

![Figure 56 Number of cruise passengers to Greenland from 2003 to 2013](0)

![Figure 57 Number of cruise ships to Greenland from 1998 to 2008](0)
These statistics show in a few different ways that there has been a doubling of cruise ship activity per decade. These trends coupled with the global growth of cruise activity in remote places indicate that it is reasonable to assume a doubling of the amount of cruise passengers coming to Greenland in the next 10 years.

The current development in the cruise industry is to have larger ships with more passengers. There is also a trend towards a longer cruise ship season, meaning the season can start earlier and end later. However, the fluctuation in passengers coming to Greenland indicates that even though cruise traffic is likely to increase, a significant shift in ship size towards larger ships is not expected by 2027. A fluctuation in the cruise market means that there is less incentive for cruise operators to invest in larger ships. This is because the return on their investment is less certain if the number of passengers varies from year to year. Additionally, larger ships can require an increase in infrastructure. These two facts combined indicate that a trend toward larger cruise ships sailing Greenland’s waters is a long term change that will take longer than 13 years to come to fruition.

It is assumed that cruise ships will be travelling similar routes as today, given the fact the natural landmarks visited by cruise ships will not move or change from now until 2027, although the receding ice cover may give access to new areas. Based on these facts it is assumed that the relationship between tourism activity and cruise ship activity have a correlation close to 1. In estimating sailed distance by cruise ships around Greenland in 2027, we operate on the assumption that the cruise industry in Greenland will double by 2027 and that sailed distance around Greenland will also double by 2027, resulting in a 100% increase.

### 2.5.2.3 Passenger ship traffic

Passenger ferries play a significant role in domestic travel on Greenland as there are few or no roads between towns or communities. All domestic travel is conducted by ship or by plane. There are two main operators that run a range of different services. The services from one of the operators, Disko Line, are primarily used by the local population, whereas for the other operator, Arctic Umiaq Line, tourists account for one third of the customers in the high-season (three months of the year). In 2013 passenger ferries on Greenland sailed in total 50 000 nm.

In 2013, there were 13 000 independent travellers (tourists) on Greenland. For the sake of simplicity, we assume that the local population (approximately 50 000 people) travels on average one round-trip per year, and that independent travellers conduct on average one round-trip, independent travellers account for 20% of total ferry traffic. This number is aligned with the customer pattern indicated by the ferry operators. This means than 10 000 nm of the total sailed distance (47 000 nm) results from tourism.

Based on the growth in tourism discussed in section 2.5.2.2, it is reasonable to assume that there is at least a doubling of tourists coming to Greenland from now until 2027. The local population is not expected to increase on Greenland by 2027, and the local population will therefore not drive an increase in sailed distance by passenger ferries. Figure 58 shows population projections for Greenland until 2035.
Given the tourist related sailed distance (10 000 nm) and the expected doubling of the number of independent travellers, we estimate that the sailed distance increases to 20 000 nm. The sailed distance related to local traffic (40 000 nm) is expected to remain stable.

Based on this, it is found that passenger ship traffic will increase from 47 000 to 56 000 in 2027, a 20% increase.

2.5.2.4 Exploration and research

Research activities around Greenland are important activities for vessels in the “other activities”-category. In Greenland, important research activities are the search for hydrocarbon resources, although other research activities regarding climate and the environmental also take place. The level of activity related to the search for hydrocarbons is based on factors which are not possible to predict. We have concluded not to expect active oil fields by 2027. However, given the fact that previous research indicates that hydrocarbon resources exist on Greenland and that the global demand for oil and gas is expected to increase by 2027, it is reasonable to assume that exploratory research activities will continue on Greenland until 2027.

Currently there are no concrete plans to capitalize on known resources, but the opposite conclusion – that no commercially viable hydrocarbon resources exist on Greenland – has not been drawn either. It is therefore assumed that research activities on Greenland will remain at the same level until 2027, with a 0% growth in sailed distance for vessels in the other activities category.

2.5.2.5 Goods transport

Goods transport to Greenland is carried out by general cargo ships, container ships and product tankers. General cargo ships and container ships supply goods to the population, while product tankers supply gas oil which is used as fuel. Goods transport is driven by the size of the population of Greenland and the consumption level. The GDP of Greenland provides an indication of the living standard and consumption
level of Greenland’s inhabitants. The two biggest factors governing the future activities of container ships and general cargo ships are therefore the future population and the GDP of Greenland.

Little growth in population is currently expected for Greenland, and figure 41 shows that the population of Greenland is expected to remain stable, or somewhat decreasing. From 2015 to 2030, a 1% reduction is expected.

Figure 42 shows the historical development of Greenland’s GDP. The economy of Greenland is small and depends on a few key sources of income. Half of the workforce is employed by the public sector, and block grants from Denmark make up a large part of the GDP /21/. Fishing has a significant effect on GDP, with shrimp accounting for 85% of the country’s exports. Foreign investments for hydrocarbon exploration also affect GDP.

Subsidies from Denmark can vary over time. Denmark’s annual block grant has been frozen to 2007 levels since Greenland assumed self-rule in 2009 /21/. The other large contributors to Greenland’s economy – fishing and hydrocarbon exploration – can vary significantly from year to year. An analysis of the fishing industry does not indicate major changes on this front (see 2.5.2.1), and a commercial hydrocarbon source would need to be confirmed in order to expect that these activities will have a significant effect on GDP in the future.

In chapter 2.5.1.2, a new iron ore mine is discussed. While a new mine would lead to an increase in GDP it will employ less than 1000 people on a regular basis. Approximately 3000 people will be employed to construct it which will lead to a temporary increase in GDP. The temporary nature of the increase indicates that this will not be long term or significant enough to raise the consumption level of Greenland’s population such that there would be a significant increase in shipping of goods.

The other form of growth which will occur in Greenland with some certainty is that of the tourism industry, more specifically the cruise industry. Based on the discussion outlined in chapters 2.5.2.2 and 2.5.2.3 a doubling of tourists coming to Greenland is expected by 2027. This could indicate an increase in container ships, general cargo ships, and product tankers to supply goods to the new tourists. However, the majority of these passengers will be travelling with cruise ships, and though they will most
likely make some day trips on to Greenland, the majority of goods they consume will come and leave with them on the cruise ships. As a result, it is not expected that the increase in tourist will lead to a demand for goods which will have a significant impact on shipping activity. Additionally, it is assumed that passenger ferry traffic will also increase. Since passenger ferries in such remote places as Greenland act to transport goods as well as people, it is assumed that the increase in passenger ferry traffic will serve to satisfy any potential increase in goods transportation within Greenland.

It is therefore concluded that there will be no increase of significance in general cargo ships, container ships and product tankers activity from now until 2027.

### 2.5.2.6 Passing bulk carriers

There is little bulk carrier activity around Greenland today. Some bulk carrier activity occurs around the Southern tip for ships going into and out of the Hudson Bay. These ships are primarily related to mining activities in Manitoba, Canada.

Mining activities in Hudson Bay are dominated today by HudBay Minerals Inc. The corporation operates zinc, copper, gold and silver mines in the area. It currently has to mines, the 777 mine and the Reed mine, in operation and two processing facilities, the Flin Flon and the Snow lake processing facilities. The 777 mine is expected to go offline in 2020, but the new Lalor Mine is expected to reach commercial production in 2015.

It is not within the scope of this project to create projections for mining activities in Manitoba, but a quick review of the activity in Manitoba indicates that mining will continue to 2027. Additionally, the bulk carrier activity going into Hudson Bay which sails through Greenland’s water is a small amount of the total shipping traffic connected to these activities. It is therefore assumed that the sailed distance as a result of passing bulk carriers will remain the same on Greenland. Even though will there be an increase in bulk carrier traffic due to the new iron mine, as discussed in chapter 2.5.1.2, the current activity of bulk carriers will not increase.

### 2.5.2.7 Activities of unknown vessels

‘Unknown vessels’ on Greenland consist mostly of smaller fishing ships. These are smaller vessels which may have some commercial activity, but in the case of Greenland where fishing is an important food source, it is assumed that the commercial activity of smaller vessels is limited and that these vessels work primarily to catch sea animals as food for the local population.

The activities of these vessels are therefore assumed to be more closely tied to the population size as opposed to the growth of the fishing industry, which partially serves export demands. Because the population is not expected to grow, it is therefore assumed that activities of fishing vessels serving the population will not experience an increase in sailed distance.

The growth of sailed distance by unknown vessels is therefore expected to be 0% from now until 2027.

### 2.5.3 Uncertainty in forecast

The presented forecast is based on the available information at the time the report was prepared and is based on discussions and expert judgements. As with any forecast there is significant uncertainty in the numbers presented. As an example more details on the proposed new development of the mine at Baffin Island in Canada was received after the completion of the forecast and therefore not implemented
therein. A short description of the project is given in the following with the information taken from ref/93/.

The iron ore mine at Milne Port on Baffin Island is estimated to export some 4.2 million tons of iron ore per annum which in some estimates could go up to 12 million tons per annum. The iron ore is high grade and therefore the mine is seen economical viable and potentially will feature year round shipment of iron ore in bulk carriers. There are several different options for the shipment of the iron ore and as can be seen in Figure 60 one option is to tranship the cargo at Nuuk where the iron ore will be transferred from a special self-unloading bulk carrier to a standard bulk carrier for further transport to customers.

The project envisions the following shipping operation:

1. The shipping season will start in June (after the ice has degraded in quality) with the self-discharging vessels transiting to Greenland and trans-shipping into Cape vessels until late- July;

2. The open-water season will start with the ice class Supramax and Panamax vessels; then market Panamax, Post-Panamax and Cape vessels transiting direct to customer ports in Europe; and self-discharging vessels trans-shipping to Panamax or Cape vessels in Eclipse Sound; and

3. The self-discharging vessels transiting again to Greenland waters from mid-October into March where they will load into market Panamax or Cape vessels.

The transhipment site at Nuuk would mean increased traffic in Greenlandic waters above the estimates presented in this report. A total of 150 operations with cape size bulkers in the Eclipse Sound is envisioned and part of these vessel operations could a certain times of the year take place in Greenlandic waters. As part of the destinations of the iron ore would be in Europe, many of the shipments would in any case go through the study area of this report.
2.5.4 Results

Table 8 summarizes the discussions in Chapters 2.5.1 and 2.5.2 and illustrates that little change is expected to occur for shipping activities in Greenland over the next 13 years. This is due to the fact the only industrial development which is likely to come to fruition by 2027 is the iron ore mine in Isua. The cruise and tourism industries are expected to expand and this is reflected in the increase in distance sailed by cruise ships and passenger ships.
### Table 8  Summary of changes in sailed distance from 2013 to 2027

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Changes for existing traffic (%)</th>
<th>Addition of new traffic in 2027 (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reefers</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Crude oil tankers</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Cruise</td>
<td>100%</td>
<td>52 402</td>
</tr>
<tr>
<td>Ro ro cargo</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Passenger</td>
<td>20%</td>
<td>9 328</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Container ships</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>General cargo</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Product tankers</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Other activities</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>0%</td>
<td>144 210</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>0%</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 9 shows the results for sailed distance in 2027 when the results of Table 8 are applied.

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Distance sailed 2013 (nm)</th>
<th>Distance sailed 2027 (nm)</th>
<th>Relative growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk carriers</td>
<td>5 670</td>
<td>149 880</td>
<td>2543 %</td>
</tr>
<tr>
<td>Container Ship</td>
<td>109 997</td>
<td>109 997</td>
<td>0 %</td>
</tr>
<tr>
<td>Crude Oil Tankers</td>
<td>116</td>
<td>116</td>
<td>0 %</td>
</tr>
<tr>
<td>Cruise</td>
<td>52 402</td>
<td>104 804</td>
<td>100 %</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>391 341</td>
<td>391 341</td>
<td>0 %</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>0</td>
<td>0</td>
<td>0 %</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>25 978</td>
<td>25 978</td>
<td>0 %</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>5 101</td>
<td>5 101</td>
<td>0 %</td>
</tr>
<tr>
<td>Other Activities</td>
<td>74 387</td>
<td>74 387</td>
<td>0 %</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>6 507</td>
<td>6 507</td>
<td>0 %</td>
</tr>
<tr>
<td>Passenger</td>
<td>46 642</td>
<td>55 970</td>
<td>20 %</td>
</tr>
<tr>
<td>Product tankers</td>
<td>55 480</td>
<td>55 480</td>
<td>0 %</td>
</tr>
<tr>
<td>Reefers</td>
<td>16 325</td>
<td>16 325</td>
<td>0 %</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>176</td>
<td>176</td>
<td>0 %</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>56 684</td>
<td>56 684</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>846 805</strong></td>
<td><strong>1 052 745</strong></td>
<td><strong>24 %</strong></td>
</tr>
</tbody>
</table>

Sailed distance in 2013 is based on AIS data as explained in Chapter 2.1.1.

Here, since little change is expected in other vessel types, the new bulk carrier activity accounts for 70% of the additional sailed distance around Greenland in 2027. Cruise and passenger ships account for 25% and 5% of the additional sailed distance respectively.

Note that for traffic prognoses more than 10 years in the future, there will naturally be a significant amount of uncertainty. In the case of Greenland, shipping activities serve a very small population which is not expected to grow. Greenland lacks major economic activities which necessitate shipping traffic, but the appearance of new industry can change the picture dramatically. The 2543 % increase in bulk carrier traffic illustrates how the landscape of shipping in Greenland is very sensitive to individual changes to the economic landscape. Similarly, if petroleum activity starts up more quickly than estimated in this analysis, a large amount of shipping activity can take place.

Fishing differs from mining and petroleum activities in that drivers in the fishing industry such as new equipment, quota changes, or changes to fish stocks will act more slowly over time. Although there is uncertainty in the conclusion that sailed distance by fishing vessels will not change, a change to the fishing industry is less likely to result in a change as dramatic as that caused by the mining industry by 2027.

Development of new traffic around Greenland will depend on the discovery or the exploitation of resources which are hard to predict. The exploitation of such resources can have ripple effects on the population if they lead to the establishment of profitable industries.
Although there are some activities on the horizon which could spur a sudden influx of shipping activity, Greenland is currently a remote place whose population relies on subsistence activities. In this report we conclude that little change in shipping around Greenland is expected without a significant change to the economy of the island.

Note also that, in this study, it is assumed, unless otherwise noted, that the relative sizes of ships remain the same in 2027. The effect of neglecting a possible growth in ship sizes could result in an overestimation of the amount of traffic in 2027. This is because larger ships in theory will necessitate fewer trips to perform the same amount of transport work. Even if though the average size of ships in the global fleet has increased in the past decade and is expected to increase in the coming years, the traffic in Greenland is such a distinct subset of global traffic, that general global trends cannot be assumed to apply.
3 ENVIRONMENTAL RISK ANALYSIS

3.1 Method

The environmental risk analysis is based on ship traffic accident frequencies and distribution and vulnerability of environmental resources in the selected area. Figure 61 shows a flowchart of the main elements in the method used in the analysis and the present sub-chapters gives a more detailed description of the steps and elements in the method.

![Flowchart showing the elements in the method used in the environmental risk analysis.](image)

3.1.1 Background analysis

The basis for performing the environmental risk analysis is the ship traffic analysis that gives probability for different oil spills in the study area, see chapter 2. The spills are categorized with regards to spill volume and type of product spilled (bunker oil like HFO or distillates, and cargo like crude oil, chemicals and refined oil products) for each season in each 10x10 km grid cell.

3.1.2 Spill product categories

In the analysis potential spill products from ship traffic is divided into six categories. When calculating consequences from a spill it is necessary to look at potential volume spilled. The spilled volume may vary based on if it is cargo or bunker, and with the size of the vessel.
- **Crude oil** is unprocessed oil from oil production. Crude oil is only presented in the vessels as cargo. Volume categories given an accidental spill is defined as 100-2000 tons, 2000-20 000 tons, 20 000-100 000 tons and > 100 000 tons.

- **Oil products** are processed products (e.g. condensate and other refined oil products) transported as cargo in the vessels. Volume categories given an accidental spill is defined as 100-2000 tons, 2000-20 000 tons, 20 000-100 000 tons and > 100 000 tons.

- **Chemicals** are different chemical products transported as cargo in the vessels. Volume categories given an accidental spill is defined as 100-2000 tons, 2000-20 000 tons, 20 000-100 000 tons and > 100 000 tons.

- **Marine diesel** is a light distilled petroleum product used as bunker. Volume categories given an accidental spill is defined as <200 tons, 200-400 tons, 400-1000 tons and >1000 tons.

- **Intermediate fuel oil (IFO)** is used as bunker and is a residual marine fuel with viscosity 11-180 cSt. Volume categories given an accidental spill is defined as <200 tons, 200-400 tons, 400-1000 tons and >1000 tons.

- **Heavy fuel oil (HFO)** is used as bunker and is a residual marine fuel with viscosity >180 cSt. Volume categories given an accidental spill is defined as <200 tons, 200-400 tons, 400-1000 tons and >1000 tons.

### 3.1.3 Damage potential and consequences

The purpose of the analysis is to calculate environmental risk in 15 predefined segments around Greenland. The different spills will have different potential for damage in different environmental compartments like water column (fish), sea surface (seabirds and marine mammals) and shoreline (coastal habitats). The total damage on the environment is dependent on type of product and volume spilled, and will create a good basis to evaluate potential damage (consequences). The vulnerability for the environment and the environmental resources may vary both in time and space as a result of their distribution and their sensitivity for oil in different periods and life stages. The actual consequence for the environment will hence vary in time and space and potential damage is therefore adjusted with environmental vulnerability (see chapter 3.1.8).

### 3.1.4 Environmental Risk Calculations

Environmental risk is defined as the probability of environmental consequences (given by different consequence classes), and is given per year (i.e. the probability that the given consequence occur during the year within a 10 x 10 km grid cell). It is also possible to give the probability as return period (i.e. how many years it is expected to go by between each accident that gives a given environmental consequence). 1 % probability per year is equal to 1 accident per 100 years.

Environmental risk is calculated seasonally according to the following definition of seasons:

- **Spring**: April, May
- **Summer**: June, July, August
- **Autumn**: September, October, November, December
- **Winter**: January, February, March
The input from the ship traffic analysis is given on a monthly level, and then summed up for the seasons defined based on the biology of the resources in the Greenland area.

Spill probability and environmental risk is calculated per season for each 10 x 10 km grid cell. Each grid cell has its unique Id number, and the Id number is used for all grid based information in the analysis. The defined grid for the study area will correspond with all other data information going into the analysis to ensure consistent use of input data and results.

Risk is also summarized for all grid cells within the 15 coastal segments defined.

### 3.1.5 Influence areas from oil spills

Since the frequency of an oil spill is calculated for each single 10 x 10 km grid cell for the different mass categories, it is also necessary to define which area will be affected by that oil spill. Increased oil volumes will basically have a larger potential to be spread and different types of oil will also have different weathering and spread at the sea surface.

Oil drift modelling is not a part of the analysis method, but is performed in the analysis as a basis for estimating radius of a spill for each combination of spill volume and product. The modelling is performed using SINTEFs oil drift model OSCAR /72/. Note that the oil drift modelling in the analysis is only performed to calculate an estimate for maximum and minimum extent of an influence area and hence an ideal radius of the influence area as presented in Table 10. The model computes surface spreading, slick transport, entrainment into the water column, evaporation, emulsification and shoreline interactions to determine oil drift and fate at the surface. The oil drift modelling is run in an area with strong variation in current and wind in order to achieve a circular shape of the influence area. Heavy bunker oil (IFO380) with the highest volume and marine diesel with the lowest volume were used respectively in order to identify a maximum and minimum radius of an influence area. For the other spill volumes and products the radius of the influence areas where distributed in between these extremes. An influence area in this analysis is defined as the area where the probability of oiling is above 50 %, i.e. the area expected to be oiled. Table 10 show the radius used to create influence areas for the different spill categories for the different products. Separate influence areas are used for defining the effect area in the water column, based on 3D simulations of the spread of oil concentrations in the water column.
Table 10 **Overview of calculated influence areas in the water column and on the sea surface for different spill type and volumes.** "-" states that a spill only will have effect in the 10 x 10 km grid cell the spill happens. The influence area is shown as km radius from a particular grid cell.

<table>
<thead>
<tr>
<th>Product</th>
<th>Volume categories (tons)</th>
<th>Influence area water column (km)</th>
<th>Influence area sea surface (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>100-2000</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>Oil products</td>
<td>100-2000</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Chemicals</td>
<td>100-2000</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Marine diesel</td>
<td>&lt;200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Intermediate Fuel Oil (IFO)</td>
<td>&lt;200</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Heavy Fuel Oil (HFO)</td>
<td>&lt;200</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>-</td>
<td>40</td>
</tr>
</tbody>
</table>

Influence areas are produced for each grid cell for each defined radius in the study area. GIS is used to produce these influence areas. The centre point (centroid) in a grid cell is the starting point for measuring radius. Grid cells within a defined radius from that centre point are selected and defined as the influence area for that grid cell for that radius.

The map in Figure 62 visualizes three influence areas for one grid cell.
3.1.6 Ice concentration and spill dispersion

Oil drift in ice covered areas is essentially different compared with oil drift in open water. In this analysis the oil spreading in the ice covered areas is reduced to be within the relevant location grid cell for ice concentration above 70 %.

The data set visualizing monthly ice concentration contained two values, 1 or 0, where 1 indicated an ice concentration above 70 % for that specific month in that specific grid cell /73/. When grouping the data into seasonal values, 1 was given to a grid cell if the grid cell had ice concentration above 70 % in at least one of the months in that season. The seasonal ice concentration data set is used when analysing the environmental risk (Figure 17).
3.1.7 Damage potential

The consequences of a marine oil spill will largely depend on oil specific characteristics like tendency to evaporate, formation of emulsion and ability to disperse in the water. Petroleum distillates generally disperse much faster and to a greater extent than heavy oil: This mean that less oil is concentrated at the surface and can reach shoreline. Only a few petroleum distillates form emulsions in water. In contrast most heavy oils, will relatively quickly take up a lot of water to form "water-in- oil" emulsion, which allows a significant increase in the volume of oil that must be handled in a possible spill response operation.

Oil is made of several different chemical compounds which to varying degrees are biodegradable. Hydrocarbons, the main constituent of oil, are a group of compounds that can vary in size, solubility and toxicity. The lightest hydrocarbons are relatively water soluble and volatile and will fairly quickly become mixed with water or evaporate after a spill. They are also readily taken up by organisms and are generally regarded as the most toxic oil components. Oil with heavier hydrocarbon components are considered most harmful because they are easily taken up by organisms (bioavailable), are relatively toxic and slowly biodegradable (persistent). The heaviest components have low bioavailability and are
very insoluble. These will primarily float on the water surface. Oil will also adhere to particles in the water and sink to the sediment on the seabed. Oil properties change over time in sea water. This is mainly due to the tendency of the lighter components to evaporate or mix with the water, leaving the heavier components behind. The time before an oil spill is completely broken down, will to a large degree depend on oil type. In addition to evaporation and down-mixing in the water, oil can be degraded by sunlight and through biological processes (microbial degradation). Seawater properties are also affecting oil degradation rates. Salinity, temperature, ice, currents, waves and wind will all be factors that will influence the degradation process /74/.

### Table 11 Overview of characteristics for different type of oils given a sea surface spill.

<table>
<thead>
<tr>
<th></th>
<th>Light crude oils and light, refined products (density &lt;870 kg/m³)</th>
<th>Medium heavy crude oils and medium heavy products (density 870 to 920 kg/m³)</th>
<th>Heavy crude oils, heavy products and heavy bunker oil (density &gt;920 kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td>Contains a high part of light components (short hydrocarbon chains)</td>
<td>Contains a high part of medium sized hydrocarbons</td>
<td>Contains few or none short hydrocarbons. High concentration of wax and asphaltenes.</td>
</tr>
<tr>
<td><strong>Solubility</strong></td>
<td>High water solubility; usually contributes &gt;95% of water-soluble fraction</td>
<td>Low water-soluble fraction</td>
<td>Almost no water-soluble fraction</td>
</tr>
<tr>
<td><strong>Volutility</strong></td>
<td>Volatile. Total evaporation in a few hours or few days</td>
<td>Up to 1/3 will evaporate within 24 hours</td>
<td>Low volatility, minimal evaporation (up to 10 %)</td>
</tr>
<tr>
<td><strong>Viscosity</strong></td>
<td>Low viscosity (like water)</td>
<td>Medium viscosity (like syrup)</td>
<td>High viscosity (like tar). Can increase liquidity by heating.</td>
</tr>
<tr>
<td><strong>Dispersion</strong></td>
<td>Fast dispersion on the water surface. Forms large, thin sheets that easily break into smaller sheets. High degree of downmixing into the water column</td>
<td>The spreading decreases as the viscosity and density of the remaining oil increases. Moderate degree of downmixing</td>
<td>Spreads into thick, dark-colored slicks, which can contain large amounts of oil. Will often break up into discrete patches and tarballs when spilled instead of forming slicks. Minimal degree of downmixing</td>
</tr>
<tr>
<td><strong>Toxicity</strong></td>
<td>High acute toxicity because they contain the monoaromatic hydrocarbons (benzene, toluene, xylene) which are soluble and toxic</td>
<td>Moderate acute toxicity because they contain diaromatic hydrocarbons (naphthalenes) which are toxic in spite of their low solubilities</td>
<td>Potential for chronic toxicity, because they contain polynuclear aromatic hydrocarbons (phenanthrene, anthracene, etc.)</td>
</tr>
</tbody>
</table>

An oil spill could potentially harm environmental resources like seabirds, marine mammals, shoreline habitats and fish. The environmental consequence will depend on the amount and type of oil released, in addition to the time of year and location of the spill. This variation is partly due to the large variation in distribution, abundance and vulnerability of environmental resources towards oil pollution.
The size of an oil spill is influencing the size of an affected area and the degree of damage to affected resources. This is reflected in the method by introducing a correlation between spill volume and consequence category (3.1.3). To capture the difference in exposure, toxicity and damage potential for environmental resources associated with either sea surface (seabirds, marine mammals and shoreline) or water column (fish) different consequence categories have been developed (3.1.4).

The link between spill volume and consequence category is based on the following assumptions (/90/, /91/):

- It is anticipated that crude oil and heavy fuel oil (HFO) have the same damage potential and that the environmental consequences rely on the size of the spill only.

- It is anticipated that different kinds of light, refined petroleum products have the same damage potential and that the environmental consequence rely on the size of the spill only.

- Crude oil and HFO have a higher (consequence) potential of affecting sea surface associated resources than refined, lighter petroleum products (distillates). The opposite is true for the water column compartment (fish), where lighter components will to a larger degree become mixed in the water increasing the potential for exposure than heavier components. As both crude oil and HFO are characterized by low bioavailability, damage is induced by oiling and to a lesser degree by uptake. Crude oil is a complex group of compounds that can consist of both light condensates and quite heavy oil types. We have chosen conservative approach by anticipating that spilled crude oil consist of heavy oil, with the highest damage potential on the majority of resource groups.

- Regarding sea surface associated environmental resources (seabirds, marine mammals and shoreline), the consequence category of heavy oil is increased by one category compared to the equal amount of refined petroleum products. For environmental resources in the water column (fish) the opposite is true because heavier oil products and HFO will to a lesser degree mix in the water resulting in one consequence category lower than for lighter oil products and HFO.

The volume categories of spilled oil is divided into 6 different consequence categories (K1 to K6) for either sea surface or water column, as explained above and illustrated in Table 12. The environmental consequence categories are relative and indicate increasing seriousness from K1 to K6. A strict definition is therefore difficult, but the categories can be understood as:

- K1 – low consequence with minor impact on resources/habitats in the area
- K2 – low to moderate consequence
- K3 – moderate consequence
- K4 – high consequence
- K5 – very high consequence
- K6 – extreme consequence with major impact on resources/habitats in the area

It is assumed that the lowest impact category (K1) for seabirds, marine mammals and shoreline will be for distillates in the smallest amount category (< 400 tons). Next volume category (400-1 000 tons of distillate) and products (load) 100-2 000 tons will have second lowest result (category K2) etc. The greatest impact (category K6) is expected by the largest amount category of oil spills of more than 100,000 tons (see Table 13).
For fish it is made a categorization where small volumes are not expected to produce much effect (for low concentrations), and small amount of categories is therefore given lowest consequence category, see Table 14. The greatest potential impact on the water column is assigned the maximum volume of crude oil spills ( > 100,000 tons), but the potential impact is considered less than for sea surface and thereby set the second highest impact category (K5).

### Table 12 Categorisation of consequences for seabirds, marine mammals and coastal habitats (oil on the sea surface) and for fish (oil in the water column) for different discharge categories (product type and volume). The consequences are divided in classes (K1 to K6) where there is increasing environmental impact with increasing volume released. Darker color indicate higher consequence classes.

<table>
<thead>
<tr>
<th>Products</th>
<th>Volume categories (tons)</th>
<th>Consequence category sea surface</th>
<th>Consequence category water column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>100-2000</td>
<td>K3</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>K4</td>
<td>K3</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>K5</td>
<td>K4</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K6</td>
<td>K5</td>
</tr>
<tr>
<td>Oil products</td>
<td>100-2000</td>
<td>K2</td>
<td>K2</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>K3</td>
<td>K3</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>K4</td>
<td>K4</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K5</td>
<td>K5</td>
</tr>
<tr>
<td>Chemicals*</td>
<td>100-2000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>2000-20 000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>20 000-100 000</td>
<td>K2</td>
<td>K2</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K3</td>
<td>K3</td>
</tr>
<tr>
<td>Marine diesel</td>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>K2</td>
<td>K2</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>K3</td>
<td>K3</td>
</tr>
<tr>
<td>Intermediate Fuel Oil (IFO)</td>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>K2</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>K3</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>K4</td>
<td>K2</td>
</tr>
<tr>
<td>Heavy Fuel Oil (HFO)</td>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>K2</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>K3</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>K4</td>
<td>K2</td>
</tr>
</tbody>
</table>

### 3.1.8 Vulnerability for environmental resources

Together with the type and volume of product spilled, the spatial distribution of vulnerable environmental resources throughout the year determines the environmental consequence of a spill in a given area.
The assignment of vulnerability towards oil pollution is based on a series of Oil Spill Sensitivity Atlases /75/-/81/. The Atlases have been prepared to provide oil spill response planners and responders with tools to identify resources at risk, establish protection priorities and identify appropriate response and clean-up strategies for Greenlandic waters.

The sensitivity index value is calculated based on information on natural resource use, biological occurrences and physical environment. Each shoreline and offshore area received a single numeric value (from 1-4), representing the relative sensitivity of that area to a marine oil spill. Sensitivity in areas not covered by the Sensitivity Atlases was evaluated based on resource distribution data that is part of the AMSA IIC report /82/. A numeric value of 1 correspond to “low”, and a numeric value of 4 correspond to “extreme” in the table of environmental consequences below (Table 13). A resource that was not highlighted in the input data (maps of offshore areas) was assigned a value of 1, whereas areas deficient of information about resource groups were assigned a value of 2.

### Table 13 Categorisation of consequences for oil on the sea surface (seabirds, marine mammals and coastal habitats) for different discharge categories (product type and volume) and environmental vulnerability. The consequences are divided in classes (K1 to K6) where there is increasing environmental impact with increasing volume released. Darker colour indicates higher consequence classes.

<table>
<thead>
<tr>
<th>Sea surface</th>
<th>Volume categories (tons)</th>
<th>Environmental Vulnerability and Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Crude oil</td>
<td>100-2000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>2000-20000</td>
<td>K2</td>
</tr>
<tr>
<td></td>
<td>20000-100000</td>
<td>K3</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K4</td>
</tr>
<tr>
<td>Oil products</td>
<td>100-2000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>2000-20000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>20000-100000</td>
<td>K2</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K3</td>
</tr>
<tr>
<td>Chemicals*</td>
<td>100-2000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>2000-20000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>20000-100000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>&gt;100 000</td>
<td>K1</td>
</tr>
<tr>
<td>Marine diesel</td>
<td>&lt;200</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>K1</td>
</tr>
<tr>
<td>Intermediate Fuel Oil (IFO)</td>
<td>&lt;200</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>200-400</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>400-1000</td>
<td>K1</td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td>K2</td>
</tr>
<tr>
<td>Heavy Fuel</td>
<td>&lt;200</td>
<td>K1</td>
</tr>
</tbody>
</table>
Table 14 Categorisation of consequences for oil in the water column (fish) for different discharge categories (product type and volume) and environmental vulnerability. The consequences are divided in classes (K1 to K6) where there is increasing environmental impact with increasing volume released. Darker colour indicates higher consequence classes.

<table>
<thead>
<tr>
<th>Water column</th>
<th>Volume categories (tons)</th>
<th>Environmental Vulnerability and Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Crude oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-2000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>2000-20 000</td>
<td>K1</td>
<td>K2</td>
</tr>
<tr>
<td>20 000-100 000</td>
<td>K2</td>
<td>K3</td>
</tr>
<tr>
<td>&gt;100 000</td>
<td>K3</td>
<td>K4</td>
</tr>
<tr>
<td>Oil products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-2000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>2000-20 000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>20 000-100 000</td>
<td>K2</td>
<td>K3</td>
</tr>
<tr>
<td>&gt;100 000</td>
<td>K3</td>
<td>K4</td>
</tr>
<tr>
<td>Chemicals*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-2000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>2000-20 000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>20 000-100 000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>&gt;100 000</td>
<td>K1</td>
<td>K2</td>
</tr>
<tr>
<td>Marine diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>200-400</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>400-1000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>K1</td>
<td>K2</td>
</tr>
<tr>
<td>Intermediate Fuel Oil (IFO)</td>
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<td></td>
</tr>
<tr>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>200-400</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>400-1000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>Heavy Fuel Oil (HFO)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;200</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>200-400</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>400-1000</td>
<td>K1</td>
<td>K1</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>K1</td>
<td>K1</td>
</tr>
</tbody>
</table>

3.1.9 Limitations in the input data

The present analysis is based on available input data on a format that makes it possible to evaluate the vulnerability for the environmental resources in the different segments annually and seasonally. There are used different sources of data for different areas, and parts of the study area have detailed data on environmental resources, while others lack data or have poor data. To be able to use the input data from
different sources for the whole area, there are made some assumptions and evaluations of the data. Data for environmental resources used in the analysis is described more detailed in chapter 3.2.1.

### 3.2 Environmental Sensitivity

#### 3.2.1 Environmental resource data

Data on biological resources in Greenland waters (seabirds, marine mammals, fish and coastal habitats) and their vulnerability towards oil are derived from offshore areas identified in seven different environmental oil spill sensitivity atlases /75/-/81/ covering most of the area of interest. The data was provided in a GIS-format by the Department of Arctic Environment, Aarhus University, Denmark. This information was supplemented by species distribution data from AMSA IIC-report /82/ in the northern part of the Baffin Bay and on the east coast. An illustration of data coverage in the area included in the assessment is given in Figure 64.
3.2.2 Environmental vulnerability

3.2.2.1 Sensitivity atlases

An environmental sensitivity ranking system is used in the various environmental sensitivity atlases to determine and illustrate the relative sensitivity of shoreline and offshore areas of Greenland to the effects of an oil spill. With basis in these atlases, a species group priority indices (PI) has been used as the vulnerability for a specific resource group in the offshore areas.

The PI consist of an Assigned Value (AV) of the element (species / species group) multiplied by a weighting factor (WF) for the given category. The AV is calculated seasonally by

\[ AV = \frac{(RS \times RA \times TM \times ORI)}{C} \]

where

- \( RS \) = relative sensitivity of the species
- \( RA \) = relative abundance of the species
- \( TM \) = temporal modifier
- \( ORI \) = oil residence index
- \( C \) = constant used to reduce the maximum possible score

The relative sensitivity (RS) for the species relies on available information regarding the vulnerability, recovery potential and the potential for lethal and sub-lethal effects which are summarised in Table 15. The relative sensitivity for the selected species ranges from 7 to 25. The relative abundance and timing of occurrence of the selected species (biological elements) is extracted from available knowledge and encoded for each shoreline and offshore area.

Table 15 The relative sensitivity (RS) and characteristics of the selected species or species groups in relation to oil spills. After /81/.
For each area the highest priority indices (PI) for a various species / species group is extracted from the environmental sensitivity atlases and used for the three main groups: Fish and shellfish, Marin mammals and Seabirds. The highest value (PI value) for each species within the species group has been chosen as representative for the group as this will illustrate the highest consequence potential within the group. This is in line with methodology used in oil spill risk assessment (/90/) that calculates environmental impact and risk on a species by species approach. A limitation of such an approach is that species diversity is not considered and the consequence categories must therefore be understood as the highest consequence for a species within the species group.

The final scaling of low to extreme vulnerability was performed by the following criteria:

- **Low**: $PI < 10$
- **Moderate**: $10 \leq PI < 15$
- **High**: $15 \leq PI < 20$
- **Extreme**: $PI \geq 20$

<table>
<thead>
<tr>
<th>Species/group name</th>
<th>Vulnerability</th>
<th>Mortality potential</th>
<th>Sublethal potential</th>
<th>Recovery period</th>
<th>Relative sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish and Shellfish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scallop</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Long</td>
<td>18</td>
</tr>
<tr>
<td>Snow crab</td>
<td>Very low</td>
<td>Low</td>
<td>Moderate</td>
<td>Short</td>
<td>9</td>
</tr>
<tr>
<td>Deep sea shrimp</td>
<td>Very low</td>
<td>Very low</td>
<td>Low</td>
<td>Short</td>
<td>7</td>
</tr>
<tr>
<td>Greenland halibut</td>
<td>Very low</td>
<td>Very low</td>
<td>Low</td>
<td>Short</td>
<td>7</td>
</tr>
<tr>
<td>Lumpsucker</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Short</td>
<td>15</td>
</tr>
<tr>
<td>Arctic char</td>
<td>Moderate</td>
<td>Low/short</td>
<td>Moderate</td>
<td>Moderate</td>
<td>14</td>
</tr>
<tr>
<td>Capelin</td>
<td>Very high</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>21</td>
</tr>
<tr>
<td><strong>Birds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcids</td>
<td>Very high</td>
<td>Very high</td>
<td>Very high</td>
<td>Very long</td>
<td>25</td>
</tr>
<tr>
<td>Cormorants</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>19</td>
</tr>
<tr>
<td>Gulls</td>
<td>Moderate</td>
<td>High</td>
<td>Very high</td>
<td>Short</td>
<td>17</td>
</tr>
<tr>
<td>Seaducks</td>
<td>Very high</td>
<td>High</td>
<td>Very high</td>
<td>Long</td>
<td>23</td>
</tr>
<tr>
<td>Seaducks breeding</td>
<td>Very high</td>
<td>High</td>
<td>Very high</td>
<td>Long</td>
<td>23</td>
</tr>
<tr>
<td>Tubenoses offshore</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>17</td>
</tr>
<tr>
<td>Tubenoses shorline</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Long</td>
<td>18</td>
</tr>
<tr>
<td><strong>Marine mammals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baleen whales</td>
<td>Low</td>
<td>Very low</td>
<td>Very Low</td>
<td>Moderate</td>
<td>9</td>
</tr>
<tr>
<td>Narwhal</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>No recovery</td>
<td>13</td>
</tr>
<tr>
<td>White whale</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>No recovery</td>
<td>13</td>
</tr>
<tr>
<td>Seals</td>
<td>Low</td>
<td>Very low</td>
<td>Low</td>
<td>Short</td>
<td>9</td>
</tr>
<tr>
<td>Walrus</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>No recovery</td>
<td>18</td>
</tr>
<tr>
<td>Polar Bear</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>19</td>
</tr>
</tbody>
</table>
3.2.2.2 Data from the Arctic Marine Shipping Assessment (AMSA) IIC report

The arctic area is divided into 17 different regions, called Large Marine Ecosystems (LMEs), by The Protection of the Arctic Marine Environment Working Group (PAME). LMEs are regions of ocean space of 200 000 km² or greater, that are defined by ecological criteria such as productivity and trophically linked populations in addition to bathymetry and hydrography. Our vulnerability assessment uses areas of heightened ecological significance within the Greenland Sea and the Baffin Bay LMEs. The identification of these areas was done by the Arctic Marine Shipping Assessment (AMSA) IIc report (2013) /82/. In 11 of the LMEs, areas have been identified based on previous work performed by the Arctic Council Working Groups /83/-/84/, whereas Canada and Greenland/Denmark have identified ecological important areas in separate national processes. A detailed description of the different approaches can be found in /82/.

The AMSA IIC dataset covering Greenland Sea and Baffin Bay gives a comprehensive static representation of the maximum species distribution pattern during any time of the year.

In the analyses of the AMSA IIC data we have applied the definition of sensitivity and vulnerability as described in the AMSA IIC report. Vulnerability is defined as related to sensitivity, but not to be the same. Vulnerability relates to specific pressures or threats. In the absence of the pressures an area can be considered sensitive, but not vulnerable.

The vulnerability of occurring species were assessed used a three-step based approach (Figure 65).

**Figure 65 Outline of methodology for the vulnerability assessment**

**Step 1**

Vulnerability assessment species level

- Individual and species vulnerability/activity/season (1-3)
- Red list status of species (1-5)
- Diversity-index (1-3)

**Step 2**

General sensitivity of the area

- PSSA Criteria (1-3)

**Step 3**

- Oil vulnerability indexing

*Step 1* determines local (area) vulnerability towards oil pollution for each group (mammals, birds and fish) of organisms, using a set of indexes based on the following criteria:

- Species vulnerability index: The species oil vulnerability is based on the assessment performed in the AMSA IIc report /82/. It takes account of both the ecological use of the area for different
purposes (spawning, nursery, migration, wintering, staging, molting, breeding, feeding etc.) and the seasonal variation/distribution of these activities. We construct a numerical scale based on the category developed by AMSA: scientifically based on previous work performed by AMAP /85/. We set their low category equal to 1, medium equal to 2 and high vulnerability equal to 3.

The proportion of the population present in an area is important to determine its ability to recover after a potential loss. The population proportion aspect was taken into account by doubling the individual vulnerability values if more than 90 % of the population was in an area, or if the area was identified as a critical habitat for the species.

- **Red-list index**: Based on the IUCN Redlist /86/, we constructed an index ranging from 1 to 5: Threatened (1); Near threatened (2), Vulnerable (3), Endangered (4), Critically endangered (5). The IUCN Redlist is based on the total global population of the species. There are, however, also local red lists constructed by different countries. We use both the global and the local red list information.

- **Diversity index**: By summing the two indexes above, we constructed an individual species vulnerability score. The species giving the highest vulnerability score was selected to represent the area. But we also wanted to take account of the diversity of species in an area. To do this we made another index, ranging from 1-3, to capture the number of species in the area: 2-6 (1), 7- 11 (2), > 12 (3).

In **Step 2**, the general sensitivity of the area was assessed based on the number of Particularly Sensitive Sea Area (PSSA) criteria a region fulfilled /82/. The PSSA criteria are part of the revised guidelines for the identification and designation of Particularly Sensitive Sea Areas adopted in December 2005 /87/. The areas were ranked according to PSSA criteria.

In **Step 3**, we combine the scores from the vulnerability and the general sensitivity assessments. This gives us the maximum value pr. group of organisms (birds, marine mammals, fish etc.) in an area.

To align the vulnerability scores based on the AMSA data with the scores in the sensitivity atlases three categories corresponding to moderate, high end extreme were applied.

### 3.2.3 Data processing

#### 3.2.3.1 Sensitivity atlases

An example on the use of vulnerability values is given below. Based on Figure 66, the highest priority index (PI) for each species in offshore segment 19 in winter is given by:

- Fish and Shellfish: PI = 12.6 (Scallops)
- Marine Mammals: PI = 5.46 (Narwhal)
- Seabirds: PI = 2.66 (non-alcid pursuit divers)

This corresponds to a low vulnerability value for marine mammals and seabirds (PI less than 10) and a moderate value for Fish and shellfish (PI between 10 and 15).
Vulnerability values were transferred to the 10 x 10 km grid. Seasonal vulnerability values for birds, fish and marine mammals were transferred from the offshore areas to the 10 x 10 km grid. Each grid cell is assigned with values from the offshore area it is located within.

### 3.2.3.2 AMSA data

The same procedure is performed for the identified of Artic marine areas of heightened ecological significance. Vulnerability values for resources are transferred to the 10 x 10 km grid. For grid cells not covered by Offshore Areas or AMSA areas resources are assigned with the vulnerability value 2.

### 3.2.4 Seabirds

The seasonal and spatial variation in the vulnerability of seabirds towards oil pollution is linked with distribution patterns and the species ecological use of the area (i.e. moulting, breeding and staging). A vulnerability ranking, from low to extreme, of seabird areas in Greenland waters is provided in Figure 67 and Figure 68. A short description of the most vulnerable areas and seabird resources, based on information available in sensitivity atlases and AMSA IIC report (/75/-/82/) are provided in the following section.

The shelf area and ice free fjords on the southwest Greenland shelf (segment 7, 8 and 9) is an important wintering area for numerous seabirds (tick billed murre, common and king eiders, long-tailed duck, red breasted merganser, black guillemot, Iceland- and Ivory gull) inferring a high vulnerability during winter in this area. Wintering birds in this area originate from Greenland, Canada, Iceland and Svalbard. During spring and summer the area turn into staging and foraging area for eiders and represent important breeding grounds for tick billed and common murres, razor bills, and Atlantic puffin. The vulnerability is increased from summer to fall because of the moulting of sea ducks (i.e Harlequin) in areas along the outer coast of south-western Greenland as well as the areas importance as migratory route for millions of seabirds on their way into wintering areas in the Labrador Sea or other areas.

The Disko Bay and Store Hellefisk Banke (corresponding to segments 11 and 12) are highly vulnerable areas during all seasons. This area represent critical wintering areas for king eider and ivory gull,
breeding and foraging grounds for auks in spring and summer in addition to moulting grounds for a range of sea ducks from July –September.

The early primary production in the Northeast Water Polynya, located outside the north-eastern corner of Greenland (segment 15) is important for many species as pre-breeding and feeding grounds. Coastlines north and south of the polynya represent important breeding areas for black legged kittywake, Ross`s gull, Sabine`s gull, Arctic tern in addition to the biggest known breeding colony of ivory gull – inferring high vulnerability to these areas in summer.
Figure 67 Vulnerability ranking of seabird resources towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from Environmental Spill Sensitivity Atlases.
Figure 68 Vulnerability ranking of seabird resources towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from AMSA IIC.
3.2.5 Marine Mammals

A vulnerability ranking, from low to extreme, of marine mammals in Greenland waters is provided in Figure 69 and Figure 70. A short description of the most vulnerable areas and marine mammals resources, based on information available in sensitivity atlases and AMSAIIC report (/75/-/82/) are provided in the following section.

The seas surrounding Greenland are rich in marine mammals and represent important areas for feeding, breeding as well as migration routes for a range of species. Common cetaceans are fin whales, sei whales, minke whales and humpback whales. Bowhead whales, killer whales and harbour porpoises are less common. Narwhales and belugas visit coastal areas only in winter. The most important pinniped species include walrus, ringed seals, spotted seals, hooded seals, bearded seals and harp seals. The Greenland polar bear lives and breeds in the north most parts of West and Northeast Greenland but as it is moving with the drift ice it can also be seen elsewhere in Greenland. The Disko Bay, Store Hellefiske Banke and the northwest Greenland Shelf (corresponding to segments 12, 11 and 13) represent the most vulnerable areas for marine mammals in Greenland waters. The Northwest Greenland shelf is an important winter area for polar bears of the Baffin Bay population and the entire area around Store Hellefiske Banke is a critical habitat for walrus that winter in West Greenland. The Disko Bay area is an important wintering area for beluga following the northward retreat of the marginal ice zone. Narwhals reside in the deeper basins of Disko Bay and Store Hellefiskebanke from November to May. They are known to winter in the dense pack ice west of Disko as well as in the coastal areas close to the Disco Bay. The sea ice here also provides an important whelping ground for bearded seals. Bowheads use the area as foraging area in spring. In summer and autumn the Store Hellefiske Banke (segment 12) and the South-western Greenland shelf (segments 10-7) serves as a foraging ground for harbour porpoises and a range of baleen whales. The critically endangered Western Atlantic harbour seal is contributing to the increased vulnerability on the south-western shelf. A high vulnerability for marine mammals in an area off the east cost of Greenland (part of segment 1 and 2) is assigned a high vulnerability due the west ice population of harp and hooded seals are whelping in the area in March-April. The entire drift ice zone (part of segment 1 and 2) is representing an important polar bear habitat.
Figure 69 Vulnerability ranking of marine mammal resources towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from Environmental Spill Sensitivity Atlases.
Figure 70 Vulnerability ranking of marine mammal resources towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from AMSA IIC.
3.2.6 Fish

A vulnerability ranking, from low to extreme, of fish spawning areas in Greenland waters is provided in Figure 71 and Figure 72. The increased vulnerability in areas around Store Hellefiske Bank (segment 11) is inferred by capelin spawning areas.

![Figure 71 Vulnerability ranking of fish spawning sites towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from Environmental Spill Sensitivity Atlases.](image-url)
Figure 72 Vulnerability ranking of fish spawning sites towards oil spill in marine waters around Greenland. Vulnerability is expressed from low to extreme based on values derived from AMSA IIC.
Figure 73 shows vulnerability ranking for seabirds, marine mammals and fish in areas not covered by the sensitivity atlases and not identified as areas of heightened ecological significance in the AMSA IIC report. In areas where no vulnerability ranking for environmental resources is mapped and documented, the vulnerability is set to moderate for the analysis. This is done because the risk picture is divided and there is good input data on spill potential also for the areas lacking mapped and documented information on the environmental resources. It should be noted that the uncertainty of the analysis outcome is therefore higher in these areas than in the areas with more detailed vulnerability data available. This applies to all the resource groups.

**Figure 73** Vulnerability ranking of seabirds, marine mammals and fish spawning sites towards oil spill in marine waters around Greenland, for areas not covered by the sensitivity atlases and AMSA IIC data.
3.2.7 Coastal habitats/Shoreline

A vulnerability ranking, from low to extreme, of coastal habitats in Greenland waters is provided in Figure 74 for the whole coastline, and in Figure 75 zoomed in for the western part of Greenland where there prevails a detailed vulnerability ranking of the coastline. The assessment is based on vulnerability of near shore natural resources like seabird breeding, and fishing areas.

In areas where no vulnerability ranking for the coastline is mapped and documented, the vulnerability is set to moderate for the analysis.

Figure 74 Vulnerability ranking of shoreline habitats Greenland towards oil pollution. Vulnerability is expressed from low to extreme based on values derived from Environmental Spill Sensitivity Atlases.
Figure 75 Vulnerability ranking of shoreline habitats Greenland towards oil pollution. Vulnerability is expressed from low to extreme based on values derived from Environmental Spill Sensitivity Atlases.
3.2.8 Risk Calculator

Data described in the sections above are all input into the risk calculator. As previously mentioned the environmental risk is calculated for each grid cell within the study area. The risk calculations are only performed for grid cells having a probability > 0 for different oil and chemical spills or grid cells belonging to the relevant influence area.

To calculate one grid cell’s environmental risk the first step will be to assign the probability value for that cell to all grid cells within the influence area. The radius to be used for that cell’s influence area is derived from product and volume, see Table 10.

The next step in the calculator is to use the generated environmental vulnerability for each resource for all grid cells within the influence area to calculate the damage category. Table 13 and Table 14 define the relation between the vulnerability and the damage potential category (K1 – K6) for seabirds, marine mammals, shoreline and fish respectively.

The environmental risk is then calculated as a function of product, spill volume, damage potential category for the resources i.e. fish, seabirds, marine mammals and shoreline.

The total environmental risk for one grid cell will also have contribution from adjacent influence areas for all different combinations of volume and products.

For grid cells in ice affected areas (ice concentration > 70%) or defined as land (land coverage = 100%) the risk will only be calculated for the cell itself. This is due to the reduced potential of oil and chemical spread.

3.2.9 Resources in and around Greenland not included in the analysis

When performing an environmental risk analysis covering a large area as Greenland, it is necessary to focus on environmental resources present in most parts of the area to be able to compare segments and areas. The environmental resources forming the basis for the current analyses are seabirds, marine mammals at vulnerable life stages in addition to spawning areas for fish. In the assessment of shoreline, the areas important fishing areas in vicinity to the coast are also included.

There is a lot of information with different levels of detail regarding environmental resources in and around Greenland. The task and aim with the prevailing analysis is to use the result of the analysis to get an overview of the risk level for all of Greenland and to use this as a basis for strategic decisions regarding oil spill contingency. This means that a lot of local and detailed information will not be included in the analysis.
3.3 Environmental Risk Analysis- Results

The results from the environmental risk analysis are given as return period, i.e. number of years between each accident for the different consequence categories shown in 10 x 10 km grid cells in maps, and as probability per year for the different consequence categories, shown graphically and in maps for the 15 predefined coastal segments where the grid cells within each segment are summed up. The results are presented per resource group (seabirds, marine mammals, fish and shoreline) per year.

In chapter 3.4 the annual probability is grouped for the four resource groups for each segment.

The results for each season for the different resource groups are given as return period in 10x10 km grid cells in Appendix D and as summarized probability for the coastal segments in Appendix E.

3.3.1 Seabirds

Environmental risk based on accidental spills from ship traffic for seabirds around Greenland is shown per year as probability in graphs in Figure 76 and in map in Figure 77, and as return period in Figure 78.

Total environmental risk for seabirds per coastal segment is below 4.2 % probability per year, and the risk is highest for segment 8, 10 and 12.

All segments have probability for category 1 consequence for seabirds, and all segments except segment 14 also have a probability for category 2 consequences (up to 1.3 % in segment 13). All segments have a very small probability for a consequence in category 3 (< 0.1 %). Segment 6-9 and 11-12 have a low probability for consequence category 4 (< 0.1 %), and segment 5-8 also have a probability for consequence category 5 (< 0.1 %)

In segment 7 and 8 coastal seabirds have high sensitivity in the winter and spring season due to important wintering areas located in these segments.
Figure 76 Environmental risk for seabirds based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year).
Figure 77 Environmental risk for seabirds based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year). The highest risk in K1 for seabirds is 4.0 %.
Figure 78 Annual environmental risk for seabirds based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
3.3.2 Marine Mammals

Environmental risk based on accidental spills from ship traffic for marine mammals around Greenland is shown per year as probability in graphs in Figure 79 and in map in Figure 80, and as return period in Figure 81.

Total environmental risk for marine mammals per coastal segment is below 4.2 % probability per year, and the risk is highest for segment 8, 10 and 12.

All segments have probability for category 1 consequences (up to 4.1 %) and category 2 consequences (up to 0.15 %) for marine mammals. Segment 3-6, 8-10 and 12-14 also has a very small probability for consequences in category 3 (< 0.1 %), segment 1-2, 6, 13 and 15 for consequences in category 4 (< 0.01 %) and segment 5-6 also for consequence in category 5 (< 0.01 %).

Marine mammals have high sensitivity in the winter and spring season due to important wintering and foraging areas located in the segments on the west coast of Greenland.

![Environmental risk - Marine mammals](image)

*Figure 79 Environmental risk for marine mammals based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year).*
Figure 80 Environmental risk for marine mammals based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year). The highest risk in K1 for marine mammals is 4.1%.
Figure 81 Annual environmental risk for marine mammals based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
3.3.3 Fish

Environmental risk based on accidental spills from ship traffic for fish around Greenland is shown per year as probability in graphs in Figure 82 and in maps in Figure 83, and as return period in Figure 84.

Total environmental risk for fish per coastal segment is below 2.5 % probability per year, and the risk is highest for segment 10, 11 and 12.

All segments have probability for category 1 consequence for fish (up to 2.5 %). The coastal segments 3-13 also have a probability for category 2 consequences (< 0.04 %). Segment 5 and 6 also has a very small probability for consequences in category 3 and category 4 (< 0.02 %).

Fish have high sensitivity in the summer and autumn season due to important spawning areas located in the segments on the west coast of Greenland.

![Environmental risk - Fish](image)

*Figure 82 Environmental risk for fish based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year).*
Figure 83 Environmental risk for fish based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year). The highest risk in K1 for fish is 2.44 %.
Figure 84 Annual environmental risk for fish based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
3.3.4 Shoreline

Environmental risk based on accidental spills from ship traffic for shoreline around Greenland is shown per year as probability in graphs in Figure 85 and in maps in Figure 86, and as return period in Figure 87. Appendix F shows return period in the different consequence categories per year zoomed in on the different coastal segments 1-15.

Total environmental risk for shoreline per coastal segment is below 2 % probability per year, and the risk is highest for segment 8, 10 and 12.

All segments except segment 7 have probability for category 1 consequence for shoreline (up to 0.9 %). Segment 5-6 and 8-12 have probability for category 1 consequence for shoreline (up to 0.8 %). The coastal segments 4 and 6-13 also have a probability for category 2 consequences (1.0 %), segment 6 and 8-14 also has a very small probability for a consequence in category 3 (< 0.06 %), segment 10 has a very small probability for consequence in category 4 and segment 8 in category 5 (both < 0.01 %).

Figure 85 Environmental risk for shoreline based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year).
Figure 86 Environmental risk for shoreline based on ship traffic, shown as probability per year for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk through the year). The highest risk in K1 for shoreline is 0.84%.
Figure 87 Annual environmental risk for shoreline based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
3.4 Risk Summary and Conclusion

Environmental risk based on accidental spills from ship traffic around Greenland grouped with the different resource groups per segment is shown per year as probability in Figure 88.

As the same spill can cause damage to many resource groups, it has been chosen to show the probability for the various resource groups separately (and not added together).

The analysis has covered the Greenland territorial waters and Exclusive Economic Zone divided into 15 predefined segments. Segment 1-14 is based on Danish Maritime Authority’s waters division which is the same as the Danish Meteorological Institute uses. In addition, the northern part has been defined as area 15.

The environmental risk is also presented inside and outside of the 3 nautical mile (nm) limit around Greenland. The 3 nm line will cross grid cells and if a grid cell have ≥50 % of the area inside the border it will be included in the inside area, and the same apply for the outside area.

Figure 89 shows the contribution to the environmental risk inside of 3 nm and Figure 90 shows the contribution outside of 3 nm and out to the economic zone border. The results show a higher risk inside of 3 nm for the segments on the south and western part of Greenland, and also in a higher consequence class than for outside of 3 nm.
Figure 88 Annual environmental risk based on accidental spills from ship traffic around Greenland grouped with the different resource groups per segment shown as probability.
Figure 89 Annual environmental risk based on accidental spills from ship traffic around Greenland inside of 3 nm, grouped with the different resource groups per segment shown as probability.
Figure 90 Annual environmental risk based on accidental spills from ship traffic around Greenland outside of 3 nm, grouped with the different resource groups per segment shown as probability.
The environmental risk analysis is based on a combination of probability for spill and the sensitivity for environmental resources in the area. This means that the risk is not necessarily high even if vulnerable resources are present in the area, because spill probability is low in this area. In the same way there may be high risk in an area with less vulnerable resources because there is higher ship traffic and spill probability in the area.

In the method it is used the highest sensitivity value per resource group to give the best consequence picture for each species within the resource group. The species diversity will not be included, but the consequences will not necessarily be higher if many resources with low vulnerability will be affected.

The analysis shows higher ship traffic, and hence a higher probability for accidents and spill in the south and western part of Greenland. The traffic is mainly connected to the location of cities, industry and populated areas.

The analysis concludes with relatively low probabilities for environmental risk. The highest annual risk is calculated for marine mammals in coastal segment 12 (on the west coast) with about 4.1% probability per year. Most probably the consequence of such a spill will be in the lowest consequence category (K1) with some probability for consequences in category 2. There will be very low probability for consequences in category 3-5, and this will occur in limited areas.

All other segments and environmental resource groups show lower risk. Fish has lower probability for risk than the other resources, mainly because it has to be a large spill of oil to give consequences in the water column compared to on the sea surface and shoreline.

The seasonal results from the analysis show higher probability for spill and hence also higher probability for environmental risk in the summer and autumn season. This is correlated to the extent of ice, which is lower in these seasons. With less ice coverage the traffic increases, and there is more sensitive fauna present.

The analysis gives a total picture of the environmental risk as a result of oil spill from ship traffic in a defined area covering all of Greenland. The results is based on ship traffic and ice conditions for one year, and the input data for environmental resources and vulnerability comes from different sources and have a varying degree of accuracy and quality. Still, the analysis shows that the south and western part and some parts on the east coast of Greenland have the highest probability for risk both seasonally and annually for the resources included in the analysis.
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APPENDIX A
Risk modelling
The model described in this appendix estimates risk related to ship accidents at sea.

Appendix Figure 1 illustrates graphically the structure of the calculations. The following sections will describe each of these building blocks in more detail. Risk related to traffic in ice is modeled separately and described in a separate chapter in this appendix.

**Appendix Figure 1 Overview of the risk calculations (not including ice-related risk)**

Risk is defined as the product of frequency and consequence, as shown in Appendix Equation 1. The calculations are made for each unique combination of accident category, geographic cell, vessel category and vessel size category, and the results are presented in Chapter 06.

\[ R = F_a \times C \]

**Appendix Equation 1**

Where,

- **R**: Risk in terms of yearly average spill in tons
- **F_a**: Frequency of yearly number of accidents
- **C**: Consequence in terms of spill in tons per accident

**FREQUENCY (F_A AND F_S)**

Two sets of results in terms of frequencies are presented. Chapter 2.4.1 gives yearly frequencies of any accident \( (F_a) \), whilst Chapter 2.4.2 gives frequencies of accidents that result in spill \( (F_s) \) regardless of size. These are explained separately in the following. It is important to note that, as illustrated in Appendix Figure 1 and in Appendix Equation 1, frequency input to the risk \( (R) \) is in terms of \( F_a \), not \( F_s \). \( F_s \) is an intermediate result intended to illustrate the rate of occurrence of the subset of accidents that result in spills, discussed in Chapter 2.4.2.
In previous analyses, it has been shown that it may be assumed that the accident probability is proportional to the distance travelled /14/. Based on a general estimated base accident frequency per nautical mile, it is thus possible to estimate the expected number of accidents given a traffic level in terms of sailed distance. Refinements to this method can be done by adjusting for location and traffic density, as shown below.

Appendix Equation 2 gives the accident frequency for any accident occurring \((F_a)\), by multiplication of a base frequency, an adjustment factor and a sailed distance. As shown in Appendix Equation 3, the spill accident frequency \((F_s)\) is obtained by additionally multiplying with the total percentage of accidents that lead to spill (see Appendix Table 6 for definitions on spill volume likelihoods, \(s_k\), and Appendix Table 7 for definitions on the spill volumes, \(a_k\))

\[
F_a = (f_i \times j_i) \times d
\]

**Appendix Equation 2**

\[
F_s = (f_i \times j_i) \times d \times \sum_{k=2}^{4} s_k
\]

**Appendix Equation 3**

Where,

- \(F_a\): Frequency of yearly number of accidents with spill
- \(i\): Accident category
- \(f\): Base frequency in terms of number of accidents per nautical mile sailed, with spill
- \(j\): Adjustment factor based on accident category
- \(d\): Yearly sailed distance in nautical miles

- \(s_k\): Likelihood of spill category 1 to 4 (Appendix Table 6). \(k = 2\) to \(4\) are the spill likelihoods corresponding to above zero spill.

Base frequencies and adjustment factors are described in the following.

**Base frequency \((f_i)\)**

The base frequencies of accidents indicate how often accidents on average can be expected to occur per nautical mile within the four accident categories. The term "base frequency" refers in this case to an accident frequency that is specific for the study area, but not for differences within the study area. The latter is taken care of by the use of adjustment factors, explained later in the appendix.

Accident categories are defined by IHS-Fairplay casualty database /1/:
Grounding:
Includes ships reported hard and fast for an appreciable period of time as well as incidents reported touching the sea bottom. This category includes entanglement on under water wrecks or obstructions.

Collision:
Striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking under water wrecks.

Foundered:
Includes ships which sank as a result of heavy weather, springing of leaks, breaking in two etc.

Fire & Explosion:
Where the fire and/or explosion is the first event reported (except where first event is a hull/machinery failure leading to fire/explosion).
Note: It therefore follows that casualties involving fires and/or explosions after collisions, stranding etc., are categorised under 'Collision', 'Stranding'. Scavenge fires and crankcase explosions are included in this category.

### Appendix Table 1 Base frequencies \( (f_i) \) accidents [per nautical mile]

<table>
<thead>
<tr>
<th></th>
<th>Grounding</th>
<th>Collision</th>
<th>Foundering</th>
<th>Fire &amp; Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Tankers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Product tankers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>5,6E-07</td>
<td>6,3E-08</td>
<td>6,6E-08</td>
<td>6,0E-08</td>
</tr>
<tr>
<td>Container Ship</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Reefers</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Cruise</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Passenger</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Other Activities</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>1,8E-07</td>
<td>2,9E-08</td>
<td>1,2E-07</td>
<td>1,2E-07</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>3,4E-07</td>
<td>5,6E-08</td>
<td>3,1E-08</td>
<td>5,7E-08</td>
</tr>
</tbody>
</table>

The values in Appendix Table 1 are obtained by dividing the number of accidents per year in an area by the total sailed distance per year in the same area. The area in this project has been defined as everything North of 60 degrees North globally. This has been chosen as a compromise between an area with roughly similar conditions to Greenland, and a large enough area so that enough accidents have occurred to represent a reasonable statistical foundation.

The yearly number of accidents is sourced from the IHS-Fairplay/1/ accident database with the following sub selection:

- Serious accidents
- 1990-2012
- North of 60 degrees North (i.e. Marsden grid 217-288)
- Accident categories, Foundering, Contact, Collision, Wrecked/stranded (Grounding)
- All vessels categories excluding unknown
- Demolition C and X

The total sailed distance per year is sourced from AIS data as published by Winther et al. /13/ (this data is for the year 2012 and the area North of 58.95 degrees North globally). It is a simplification that the sailed distances in 2012 is representative for the whole of the period 1990-2012 from which the numbers of accidents is extracted.

With respect to differentiation between vessel categories, separate accident frequencies where created for Fishing vessels, General cargo vessels and the rest combined to one common frequency. This common frequency was created using aggregated data for all vessel categories combined, excluding Fishing vessel. By using aggregated data, some granularity is lost. However, this combination has been done in order to achieve some robustness in the frequencies for the vessel categories for which there is a low number of accidents and low exposure in terms of distance sailed (as seen in Appendix Table 3).

**Appendix Table 2 Sailed distances in 2012 by vessel category**

<table>
<thead>
<tr>
<th>Vessel Category</th>
<th>Sum nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing vessels</td>
<td>18083693</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>14533477</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>2337473</td>
</tr>
<tr>
<td>Passenger</td>
<td>13407127</td>
</tr>
<tr>
<td>Cruise</td>
<td></td>
</tr>
<tr>
<td>Reefers</td>
<td>3703024</td>
</tr>
<tr>
<td>Container Ship</td>
<td>1759719</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td></td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>5245140</td>
</tr>
<tr>
<td>Product tankers</td>
<td></td>
</tr>
<tr>
<td>Crude Oil Tankers</td>
<td>807775</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>479482</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>7405508</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td></td>
</tr>
<tr>
<td>Other Activities</td>
<td>4340713</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>72103132</strong></td>
</tr>
</tbody>
</table>
Appendix Table 3  Number of accidents North of 60 degrees North in the period 1990-2012

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Grounding</th>
<th>Collision</th>
<th>Foundering</th>
<th>Fire &amp; Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing vessels</td>
<td>76</td>
<td>12</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>188</td>
<td>21</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>22</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Passenger</td>
<td>85</td>
<td>6</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Cruise</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Reefers</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Container Ship</td>
<td>12</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>11</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Product tankers</td>
<td>25</td>
<td>13</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Crude Oil Tankers</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other Activities</td>
<td>38</td>
<td>12</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>499</strong></td>
<td><strong>81</strong></td>
<td><strong>86</strong></td>
<td><strong>122</strong></td>
</tr>
</tbody>
</table>

Adjustment factor (\(j_i\))

Of the four base frequencies, Grounding and Collision are adjusted using adjustment factors as detailed in the following.

Adjustment factor Grounding – distance to shore (\(j_{\text{Grounding}}\))

Multiplying the base frequency of grounding with values given in Appendix Table 4 based on distance to shore, ensure that sailing routes are given a proper estimate of risks related to grounding accidents according to their location. [10].

Appendix Table 4 Adjustment factor – distance to shore (\(j_{\text{Grounding}}\))

<table>
<thead>
<tr>
<th>Distance to land category</th>
<th>Adjustment factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast, 0 - 2 nm</td>
<td>10</td>
</tr>
<tr>
<td>Coast, 2 - 10 nm</td>
<td>5</td>
</tr>
<tr>
<td>Coast, 10 - 35 nm</td>
<td>1</td>
</tr>
<tr>
<td>Open sea(^{15})</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^{15}\) Grounding is not relevant for sailing on open sea.
Adjustment factor Collision– distance to shore and traffic density ($J_{\text{Collision}}$)

Multiplying the base frequency of collision with values given in Appendix Table 5 based on a combination of distance to shore and traffic density, ensures that sailing routes are given a proper estimate of risks related to collision accidents according to their location and surrounding traffic [10]. Since the entire study area is considered to fall within the category “Low traffic density” in the global context, the only variable in this project will in practice be the distance to shore.

Appendix Table 5 Collision frequency adjustment factor ($J_{\text{Collision}}$)

<table>
<thead>
<tr>
<th>Distance to land category</th>
<th>High traffic density</th>
<th>Medium traffic density</th>
<th>Low traffic density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast, 0 - 2 nm</td>
<td>15</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>Coast, 2 - 10 nm</td>
<td>7</td>
<td>1.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Coast, 10 - 35 nm</td>
<td>3</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Open sea</td>
<td>0.6</td>
<td>0.15</td>
<td>0.02</td>
</tr>
</tbody>
</table>

CONSEQUENCE (C)

Consequence in this context is the amount of spilled fuel or cargo to the sea, as shown in Appendix Equation 4.

\[ C = S_l \times v_l \]

Appendix Equation 4

Where,

- $C$: Consequence in tons spill per accident
- $i$: Accident category
- $S_l$: Likely share
- $l$: Cargo or fuel
- $v_l$: Volume cargo or fuel

Likely share ($S_l$)

The amount released after an accident is defined down into four release categories, i.e. likely share of available fuel or cargo spilled. The four categories indicate increasing severity, i.e. increasing spill volume. Each category has a probability of occurring given the particular accident in question, as well as a corresponding probable share of cargo or fuel discharged. Probability per release category and its spill volume is described in the next two chapters.

Likely share of available fuel or cargo spilled is given by Appendix Equation 5 below.
Appendix Equation 5

\[ S_i = \sum_{k=1}^{4} s_k \times a_k \]

Likelihood per spill category \((s_k)\)

Appendix Table 6 shows the probability distribution of the four spill categories given one of the four accident categories. The numbers are based on empirical data from DNV GL on probability of spill by accident /15/.

**Appendix Table 6 Likelihood of spill categories 1 to 4 \((s_k)\)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Grounding</th>
<th>Collision</th>
<th>Foundering</th>
<th>Fire &amp; Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>0.74</td>
<td>0.71</td>
<td>0.79</td>
<td>0.12</td>
</tr>
<tr>
<td>Category 2</td>
<td>0.13</td>
<td>0.115</td>
<td>0</td>
<td>0.24</td>
</tr>
<tr>
<td>Category 3</td>
<td>0.03</td>
<td>0.095</td>
<td>0</td>
<td>0.58</td>
</tr>
<tr>
<td>Category 4</td>
<td>0.1</td>
<td>0.08</td>
<td>0.21</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Share spill per spill category \((a_k)\)

Appendix Table 7 shows the share of cargo/fuel spilled corresponding with the four release categories given in Appendix Table 6. The figures are based on empirical data from DNV GL on probability of spill by accident /15/.

**Appendix Table 7 Release quantities for spill categories 1 to 4 \((a_k)\)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Grounding</th>
<th>Collision</th>
<th>Foundering</th>
<th>Fire &amp; Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>[share of cargo/fuel from one tank]</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Category 2</td>
<td>[share of cargo/fuel from one tank]</td>
<td>0.3</td>
<td>1</td>
<td>0.04</td>
</tr>
<tr>
<td>Category 3</td>
<td>[share of cargo/fuel from one tank]</td>
<td>0.6</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>Category 4</td>
<td>[share of the entire available volume of cargo/fuel]</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Values in categories 1-3 represent the share of cargo/fuel spilled from one tank. E.g. a value of 1 is the equivalent of a spill of the entire contents of one tank, and a value of 2 corresponds to the entire contents of the two tanks is spilled.

Values in category 4 represents the share of cargo/fuel spilled from the total available volume of all tanks. The values of category 4 are all equal to 1, which means an accident where all the cargo/fuel on the ship is lost.

**Volume cargo or fuel ($v_1$)**

**Cargo ($v_{Cargo}$)**

Only the ship categories "Crude Oil Tankers", "Product tankers" and "Chemical tankers" are considered to carry cargo in terms of crude oil, petroleum products or chemicals.

The volume of cargo on board tankers, i.e. the number of tons of crude oil, petroleum products or chemicals depending on the type of ship, are set equal to the value of the vessels dead weight tons (Dwt).

Half the sailed distance is assumed with ships fully loaded, i.e. 100% of the load capacity, and the other half is represented by no cargo, i.e. 0% of the load capacity.

The estimated number of tanks on a tanker is dependent on the size of the ship, as shown in Appendix Table 8. For example, the number of dead weight tons for a ship within size category from 1000 to 4999 GT will be divided by 4 as an estimate of the number of tons of cargo per tank.

**Appendix Table 8 Estimated number of cargo tanks [5]**

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Estimated number of cargo tanks</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>12</td>
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</tbody>
</table>

**Fuel ($v_{Fuel}$)**

The analysis calculates the risk of fuel spills from all vessel categories.

Volume of fuel aboard used in the calculations is based on estimates according to vessel and size category /15/.

All ships are considered to have two fuel tanks. This means that the estimate of tons fuel per tank is derived by dividing the total fuel volume on 2. To take into account that all ships will have somewhere between full and empty fuel tanks, vessel are calculated as always having 65% of total fuel capacity aboard. All vessels where the vessel type is unknown, they are assumed to use distillate marine fuels.
### Appendix Table 9 Fuel type onboard ships in each ship type and size category

<table>
<thead>
<tr>
<th></th>
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<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Product tankers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Chemical tankers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
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<tr>
<td>Gas tankers</td>
<td>A*</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Bulk carriers</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
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<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
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<td>Container Ship</td>
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<td>B</td>
<td>C</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
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<tr>
<td>Ro Ro Cargo</td>
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<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C*</td>
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<td>B</td>
<td>C</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
<td>C*</td>
</tr>
<tr>
<td>Cruise</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
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<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
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<td>Other Activities</td>
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<td>A</td>
<td>A</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
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<tr>
<td>Fishing vessels</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
<td>A*</td>
</tr>
</tbody>
</table>

Where,

- A: Distillate marine fuels (<11 cSt)
- B: Residual marine fuels (11-180 cSt)
- C: Residual marine fuels (>180 cSt)

Appendix Table 9 shows the fuel types assigned to vessels within the different vessel and size categories based on studies done in DNV, /4/ and /5/. Fields marked with “*” are combinations of vessel type and size that did not have data in the studies (/4/ and /5/) have been assigned fuel type based on expert judgement.

Appendix Table 10 shows the amount of fuel on board vessels within the different vessel and size categories. As with fuel type, fuel volume ship is a parameter often poorly represented in ship databases. Therefore, this is based on the same methodology as in previous studies for the Norwegian Coastal Administration /5/.
## Appendix Table 10 Fuel volume onboard ships in each ship type and size category [tons]

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<thead>
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<th></th>
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</thead>
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<td>119</td>
<td>206</td>
<td>496</td>
<td>801</td>
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<td>58</td>
<td>106</td>
<td>106</td>
<td>295</td>
<td>624</td>
<td>810</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>22</td>
<td>58</td>
<td>106</td>
<td>106</td>
<td>295</td>
<td>624</td>
<td>810</td>
</tr>
<tr>
<td>Gas tankers</td>
<td>25</td>
<td>56</td>
<td>119</td>
<td>206</td>
<td>816</td>
<td>1453</td>
<td>2010</td>
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<td>Bulk carriers</td>
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<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>General Cargo Ship</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Container Ship</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Ro Ro Cargo</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Reefers</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
</tr>
<tr>
<td>Cruise</td>
<td>65</td>
<td>160</td>
<td>439</td>
<td>612</td>
<td>1566</td>
<td>2576</td>
<td>3934</td>
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<tr>
<td>Passenger</td>
<td>65</td>
<td>160</td>
<td>439</td>
<td>612</td>
<td>1566</td>
<td>2576</td>
<td>3934</td>
</tr>
<tr>
<td>Offshore supply vessels</td>
<td>32</td>
<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
<td>1223</td>
<td>1688</td>
</tr>
<tr>
<td>Other offshore service vessels</td>
<td>32</td>
<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
<td>1223</td>
<td>1688</td>
</tr>
<tr>
<td>Other Activities</td>
<td>32</td>
<td>78</td>
<td>181</td>
<td>274</td>
<td>738</td>
<td>1223</td>
<td>1688</td>
</tr>
<tr>
<td>Fishing vessels</td>
<td>21</td>
<td>58</td>
<td>121</td>
<td>240</td>
<td>516</td>
<td>661</td>
<td>687</td>
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<tr>
<td>Unknown vessel type</td>
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<td>100</td>
<td>200</td>
<td>300</td>
<td>850</td>
<td>1300</td>
<td>1800</td>
</tr>
</tbody>
</table>
ICE RISK ($F_{ICE}$)

Ice-related accidents is not a standard accident category in IHS-Fairplay casualty database. As an estimate of the risks relating to traffic in ice, an accident frequency of ice-related accidents has been developed and is described in the following. The frequency developed ($F_{ICE}$) describes the frequency of accidents involving ice and release of cargo / fuel. The consequence of accidents in terms of quantity or type of discharge is not estimated for ice-related accidents due to lack of statistical basis.

Appendix Figure 2 Overview of the risk calculations for ice-related incidents

In this context sailing in ice is defined as sailing in more than 70% ice concentration. Ice concentration is defined according to the WMO nomenclature; i.e. as the percentage of the sea surface covered by ice. The value 70% is selected based on a qualitative assessment carried out in a workshop with the participation of experts in risk modeling and individuals with experience in sailing in icy waters.

Base frequency of ice-related incidents ($f_{ICE}$)

IHS-Fairplay casualty database /1/ uses Marsden grid (Appendix Figure 3) to indicate the accident location. To estimate the number of shipping accidents related to ice from the accident database, the range is limited from to grids 217 to 288 (i.e., North of 60 degrees North, which is the same area as for the other accident categories) and within the period 1990-2012. Secondly, the search has been constrained to those accidents where ice is mentioned in the accident description.
The total sailed distance that resulted in the number of casualties found in the accident statistics is unknown. As approximation the total distance sailed in more than 70% concentration of ice in the Arctic in 2012 (based on AIS data) has been used as estimate.

The number of ice-related accidents in the period divided by the number of years gives the average annual number of ice-related accidents. Dividing further by the estimate of the average annual distance sailing in ice conditions (i.e. conditions with more than 70% concentration of ice) achieves an accident rate of ice-related accidents per nautical mile sailed.

- Years in the period 1990-2012: 23
- Accidents related to ice within Marsden grid cells 217 to 288, in the period 1990-2012: 32
- Sum Nautical miles in the arctic in 2012 in ice concentration over 70%: 127,703

Resulting base frequency for ice-related accidents: \( f_{\text{ice}} = 1.1 \times 10^{-5} \) [1/nm].

### Likelihood of spill as a result of an ice-related incident (\( s_{\text{ice, oil}} \))

To estimate a probability of spill as a result of an ice-related accident, all accidents registered in IHS-Fairplay related to ice anywhere in the world over the period 1990-2012 were found (IHS-Fairplay, 2012). The proportion of these accidents that resulted in an oil spill was one of 50 (see below). The size of the spill resulting from an ice-related accident has not been estimated.

- Accidents related to ice, on a global basis, in the period 1990-2012: 167
- Accidents related to ice with registered spill, on a global basis, in the period 1990-2012: 3

I.e. 1.8% of the estimated ice-related accidents given by the base frequency results in a spill; \( s_{\text{ice, oil}} = 1.8\% \).
APPENDIX B

Vessel categorisation
### Appendix Table 11 Vessel categorisation

<table>
<thead>
<tr>
<th>ID</th>
<th>Vessel Category</th>
<th>L3 Lloyd Type</th>
<th>L5 Lloyd Type</th>
<th>Main spill product</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Crude Oil Tankers</td>
<td>Oil</td>
<td>Crude/Oil Products Tanker</td>
<td>Crude oil</td>
</tr>
<tr>
<td>20</td>
<td>Crude Oil Tankers</td>
<td>Oil</td>
<td>Shuttle Tanker</td>
<td>Crude oil</td>
</tr>
<tr>
<td>20</td>
<td>Crude Oil Tankers</td>
<td>Oil</td>
<td>Crude Oil Tanker</td>
<td>Crude oil</td>
</tr>
<tr>
<td>21</td>
<td>Product tankers</td>
<td>Oil</td>
<td>Asphalt/Bitumen Tanker</td>
<td>Oil products</td>
</tr>
<tr>
<td>21</td>
<td>Product tankers</td>
<td>Oil</td>
<td>Tanker (unspecified)</td>
<td>Oil products</td>
</tr>
<tr>
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<td>Product tankers</td>
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<td>Oil Tanker, Inland Waterways</td>
<td>Oil products</td>
</tr>
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<td>Product tankers</td>
<td>Oil</td>
<td>Bunkering Tanker</td>
<td>Oil products</td>
</tr>
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<td>Chemical Tanker</td>
<td>Bunkers (3 kinds)</td>
</tr>
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<td>Fruit Juice Tanker</td>
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<td>Molten Sulphur Tanker</td>
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<td>Vegetable Oil Tanker</td>
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<td>Liquefied Gas</td>
<td>LPG Tanker</td>
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<td>CO2 Tanker</td>
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<td>LPG/Chemical Tanker</td>
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<tr>
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<td>Bulk carriers</td>
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<td>Bulk Carrier (with Vehicle Decks)</td>
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<td>Bulk carriers</td>
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<td>Ore/Oil Carrier</td>
<td>Bunkers (3 kinds)</td>
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<td>General Cargo/Tanker</td>
<td>Bunkers (3 kinds)</td>
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<td>General Cargo Ship</td>
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<td>Open Hatch Cargo Ship</td>
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<td>Heavy Load Carrier</td>
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<td>General Cargo Ship</td>
<td>Other Dry Cargo</td>
<td>Heavy Load Carrier, semi submersible</td>
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<td>Dry Cargo/Passenger</td>
<td>General Cargo, Inland Waterways</td>
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<td>General Cargo Ship, Self-discharging</td>
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<td>General Cargo (with Ro-Ro facility)</td>
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</tr>
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<td>Palletised Cargo Ship</td>
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<td>Nuclear Fuel Carrier</td>
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<td>Container Ship</td>
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<td>Vehicles Carrier</td>
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<td>Ro Ro Cargo</td>
<td>Ro-Ro Cargo</td>
<td>Rail Vehicles Carrier</td>
<td>Bunkers (3 kinds)</td>
</tr>
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<td>Ro Ro Cargo</td>
<td>Dry Cargo/Passenger</td>
<td>Ro-Ro Cargo Ship, Inland Waterways</td>
<td>Bunkers (3 kinds)</td>
</tr>
<tr>
<td>27</td>
<td>Ro Ro Cargo</td>
<td>Ro-Ro Cargo</td>
<td>Container/Ro-Ro Cargo Ship</td>
<td>Bunkers (3 kinds)</td>
</tr>
<tr>
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<td>Ro-Ro Cargo Ship</td>
<td>Bunkers (3 kinds)</td>
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<td>Reefers</td>
<td>Refrigerated Cargo</td>
<td>Refrigerated Cargo Ship</td>
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<td>Passenger/Cruise</td>
<td>Bunkers (3 kinds)</td>
</tr>
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<td>Passenger/Landing Craft</td>
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<td>Passenger / General Cargo</td>
<td>General Cargo/Passenger Ship</td>
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APPENDIX C
Additional risk maps
Geographical representation of yearly average number of accidents per 10x10 km grid cell

Figure 91 Accidents within Greenland area 1
Figure 92 Accidents within Greenland areas 2 and 3
Figure 93 Accidents within Greenland areas 4, 5 and 6
Figure 94 Accidents within Greenland areas 7, 8, 9 and 10
Figure 95 Accidents within Greenland areas 11, 12 and 13
Geographical representation of yearly average number of spill accidents per 10x10 km grid cell

Figure 96 Spill accidents within Greenland area 1
Figure 97 Spill accidents within Greenland areas 2 and 3
Figure 98 Spill accidents within Greenland areas 4, 5 and 6
Figure 99 Spill accidents within Greenland areas 7, 8, 9 and 10
Figure 100 *Spill accidents within Greenland areas 11, 12 and 13*
Geographical representation of yearly average spill volume per 10x10 km grid cell [tons]

Figure 101 Spill volumes within Greenland area 1
Figure 102 Spill volumes within Greenland areas 2 and 3
Figure 103 *Spill volumes within Greenland areas 4, 5 and 6*
Figure 104 Spill volumes within Greenland areas 7, 8, 9 and 10
Figure 105 *Spill volumes within Greenland areas 11, 12 and 13*
APPENDIX D
Seasonal environmental risk- return period

Seabirds (Figure 106 to Figure 109)
Marine mammals (Figure 110 to Figure 113)
Fish (Figure 114 to Figure 117)
Shoreline (Figure 118 to Figure 121)
Figure 106 Environmental risk for seabirds in the spring season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 107 Environmental risk for seabirds in the summer season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 108 Environmental risk for seabirds in the autumn season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 109 Environmental risk for seabirds in the winter season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 110 Environmental risk for marine mammals in the spring season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 111 Environmental risk for marine mammals in the summer season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 112 Environmental risk for marine mammals in the autumn season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 113 Environmental risk for marine mammals in the winter season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 114 Environmental risk for fish in the spring season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 115 Environmental risk for fish in the summer season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 116 Environmental risk for fish in the autumn season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 117 Environmental risk for fish in the winter season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 118 Environmental risk for shoreline in the spring season based on ship traffic in the
waters around Greenland. The risk is shown as return period and given in consequence
classes. K1 has the lowest consequence, and K6 has the highest consequence for the
environment.
Figure 119 Environmental risk for shoreline in the summer season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 120 Environmental risk for shoreline in the autumn season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
Figure 121 Environmental risk for shoreline in the winter season based on ship traffic in the waters around Greenland. The risk is shown as return period and given in consequence classes. K1 has the lowest consequence, and K6 has the highest consequence for the environment.
APPENDIX E
Seasonal environmental risk - probability

Seabirds (Figure 122)
Marine mammals (Figure 123)
Fish (Figure 124)
Coastal habitats (Figure 125)
Figure 122 Seasonal environmental risk for seabirds based on ship traffic, shown as probability for each season for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk in each season).
Figure 123 Seasonal environmental risk for marine mammals based on ship traffic, shown as probability for each season for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk in each season).
Figure 124 Seasonal environmental risk for fish based on ship traffic, shown as probability for each season for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk in each season).
Figure 125 Seasonal environmental risk for shoreline based on ship traffic, shown as probability for each season for different consequence categories (K1 to K6) for each coastal segment (1-15) for 2013 (highest risk in each season).
APPENDIX F
Shoreline environmental risk as return period, zoomed in on the coastal segments
To get a more detailed overview of the annual environmental risk as return period for shoreline (shown in Figure 126), Figure 127 to Figure 133 show the risk zoomed in on the coastal segments.

**Figure 126 Annual environmental risk as return period for shoreline for the different consequence categories K1–K6 for Greenland.**
Figure 127 Annual environmental risk as return period for shoreline for the different consequence categories K1–K6 for segment 1.
Figure 128 Annual environmental risk as return period for shoreline for the different consequence categories K1–K6 for segment 2 and 3.
Figure 129 Annual environmental risk as return period for shoreline for the different consequence categories K1-K6 for segment 4, 5 and 6.
Figure 130 Annual environmental risk as return period for shoreline for the different consequence categories K1-K6 for segment 7, 8, 9 and 10.
Figure 131 Annual environmental risk as return period for shoreline for the different consequence categories K1-K6 for segment 11, 12 and 13.
Figure 132 Annual environmental risk as return period for shoreline for the different consequence categories K1-K6 for segment 14 and 15
Figure 133 Annual environmental risk as return period for shoreline for the different consequence categories K1-K6 for segment 15.
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