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Oil spill risk assessment methodology for extreme conditions, including Arctic

D1.10

WP 1: Oil spill detection, monitoring, fate and distribution

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Executive Summary

GRACE WP 1 on *Oil spill detection, monitoring, fate and distribution*, includes a component addressing an oil spill risk assessment methodology forming an important link in the chain of prevention, detection, control, and mitigation of spills. A structured overall spill risk assessment model for oil spills in Arctic and sub-arctic conditions is developed to be used in combination with the SNEBA and its add-ons to identify response capacity needs, priority areas, and localization of resources.

The Arctic spill risk profile is highly related to the type of ship fuel used and quantities carried as cargo. The consumption of HFO in Arctic waters more than doubled from 2012 to 2015 but new regulations amended to MARPOL Annex VI will enter into force 2020 and will likely be followed by new Annex I regulations banning the use of HFO as ship fuel from 2023. This will significantly change the spill risk profile and the conditions for effective spill response. New hybrid fuel oil qualities call for tests and adaptation of existing response resources and spill recovery techniques.

The presented spill risk assessment methodology is based on well-established principles and a large number studies and similar projects have been reviewed and subject for exchange of information. Efficient big data processing of AIS data and integration of data from ship data bases combined with statistics on ship accidents, enable credible predictions of accident probability, associated spill risk and its geographical distribution in Arctic waters. Low traffic intensity, sparse empirical accident data and highly varying ice conditions, however, makes Arctic prediction tools particularly challenging.

The presented spill risk assessment method is applied for two trial sites; one in Disko Bay in west Greenland and one south of Helsinki in the Gulf of Finland. A set of Arctic factors is introduced in the method to take into account risk influence imposed by the presence of sea ice and other characteristic Arctic conditions.

AIS data and empirical accident data were used to derive a monthly accident index for the trial sites and seasonal variation of the index was analysed. The Gulf of Finland demonstrate a correlation between increased accident probability and the presence of ice. The Disko Bay do not demonstrate corresponding correlation.

The accident index derived for the specific trial site in the Helsinki area is essentially the same as corresponding index calculated for the entire Gulf of Finland area. The consequence component of the spill risk is quantified by a calculated spill volume in m^3 for each specific identified accidental event and each identified dimensioning ship category. Associated probability and consequence figures are presented and compared in risk matrices to facilitate identification and prioritization of critical spill risk events.

For the Disko Bay case, accidents (grounding, foundering, or ice damage) with a product/chemical tanker is clearly indicated as a high risk event in terms of spill risk. For the Gulf of Finland area, accidents with a crude oil carrier indicates the highest risk in the matrix.

Expected increase of future sea traffic in remote and sensitive Arctic waters calls for enhanced preparedness and tools for prioritization of response methods, identification of risk hot spots, response capacity needs, and adequate localization for resources.

Emerging spill risks follow with expansion of Arctic shipping and the risk profile will change dramatically by a stepwise transition from the use of HFO to distillate and hybrid fuels with lower sulphur content. New fuel types also require a revisit of existing response technique, its efficiency and potential needs for adaptation for new and future fuel types.

The combined output from technical and environmental prediction methods developed within GRACE and its different work packages, will facilitate future planning processes for sustainable utilization and protection of Arctic resources, specifically by providing effective tools for planning of oil spill response preparedness and for the design and selection of adequate resources.

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1 Introduction

Current report constitutes deliverable D1.10, which is one of the deliverables from work package 1 in the GRACE-project, and outlines an oil spill risk assessment methodology.

1.1 GRACE

The project focuses on developing, comparing and evaluating the effectiveness and environmental effects of different oil spill response methods in a cold climate. In addition to this, a system for the real-time observation of underwater oil spills and a strategic tool for choosing oil spill response methods are developed.

The results of the project will be made available for use to international organizations that plan and carry out cross-border oil spill response cooperation in Arctic sea areas. The full name of the project is: ”Integrated oil spill response actions and environmental effects – GRACE".

Within work package 5, a tool for Strategic Net Environmental Benefit Analysis (SNEBA) is developed. Work package 5 also includes development of ads-ons to the SNEBA which shall

1.1.1 Work package 1

Within *Work Package 1 Oil spill detection, monitoring, fate and distribution*, methods to identify and predict where and when oil spills may occur are developed. An oil spill risk assessment is an important link in the chain of prevention, detection, control, and mitigation of spills. The methodology is developed to contribute to the design of an appropriate response by taking the both probability and consequences into account.

1.2 Background

A spill risk assessment is determined to be an important tool in order to design an adequate integrated oil spill response for a specific region or area. The spill risk assessment can provide answer to the questions:

- Where?
- How often?
- What type of oil?
- and how large oil spills may be excepted?

Spill risk assessments have been carried out for some arctic regions and with various levels of detail but there is still no circumpolar spill risk assessment. For areas not yet covered by any spill risk assessment or for areas where the circumstances in terms of e.g. traffic intensity, ice coverage, have changed drastically since previous assessment, a methodology is needed to provide the answers which can ensure the design aof an adequate oil spill response capacity.

1.2.1 Relation to other deliverables in GRACE

Deliverable D5.6 *Spill risk assessment methodology* describes the background data on spill risk modelling and the design of the designated spill risk assessment model for application in GRACE. The methodology which is outlined in D5.6 is further developed in D1.10 and will be applied for the two trial sites. The D5.6 report presents a literature review of existing tools and ongoing projects related to oil spill risk assessment and arctic applications. A number of selected components from other presented models and combined state-of-the-art analysis technique for streaming high resolution AIS information are further investigated in D1.10.

1.3 Objectives

A structured overall spill risk assessment model for oil spills in Arctic and sub-arctic conditions is developed. The developed model shall be used in combination with the SNEBA and its add-ons to identify response capacity needs, priority areas, and localization of resources.

The model is applicable for limited areas where ice or arctic conditions may be present during part of a year and enables identification of worst credible spill scenarios which are dimensioning the need of preparedness and prevention resources in the analysed area.

1.4 Scope of work

Deliverable D1.10 includes further development of the oil spill risk assessment methodology outlined in deliverable D5.6. The methodology covers calculations and estimations of probability for an accident in a certain area and estimations of consequences in terms of oil spill volumes.

The work also includes application of the methodology on two trial sites, the area west of Disko Bay in Greenland and the area south of, and around, Helsinki in Gulf of Finland.

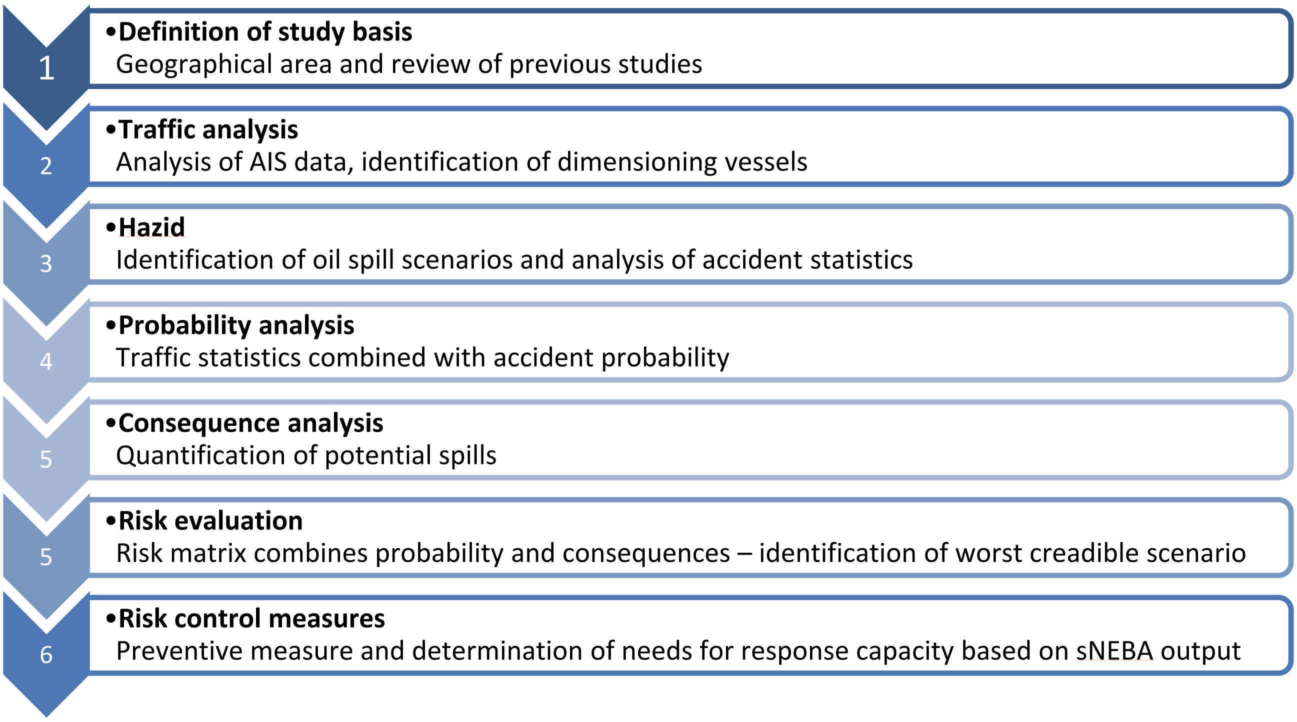
Present and future regulation regarding carriage and use of HFO in Arctic is mapped. The report also includes mapping of the present use of HFO in Arctic and mapping of future oil qualities to be carried as cargo and used as ship fuel in Arctic waters, as this may influence the risk profile over time.

1.4.1 Limitations

The model is developed to be used in combination with the SNEBA and its add-ons, which have been developed within WP 5. Environmental sensitivity and environmental consequences caused by a potential oil spill are not assessed in D1.10 as the methodology is limited to estimate the consequence in terms of volume of spilled oil. The trial application sites are selected to correspond to the SNEBA process in WP 5.

1.5 Methodology

The methodology is based on Formal Safety Assessment (FSA) methodology which is IMO´s proactive process to be used as a tool in the rulemaking process. The FSA preferably addresses a specific category of ships or navigational area but may also be applied to specific maritime safety or pollution prevention issue to identify cost effective risk reduction options. Figure 1.1 shows the FSA structure applied for the current oil spill risk assessment.



1
- **Definition of study basis**
  Geographical area and review of previous studies

2
- **Traffic analysis**
  Analysis of AIS data, identification of dimensioning vessels

3
- **Hazid**
  Identification of oil spill scenarios and analysis of accident statistics

4
- **Probability analysis**
  Traffic statistics combined with accident probability

5
- **Consequence analysis**
  Quantification of potential spills

5
- **Risk evaluation**
  Risk matrix combines probability and consequences – identification of worst creadible scenario

6
- **Risk control measures**
  Preventive measure and determination of needs for response capacity based on sNEBA output

Figure 1.1 Structure for the oil spill methodology based on the FSA approach.

2 Literature review and related projects

2.1 OpenRisk

SYKE, Finnish Environment Institute, together with Marin, WMU (World Maritime University), and HELCOM were partners in the project; OpenRisk – Methods for Maritime Risk Assessment on Accidental Spills, co-financed by the EU – Civil Protection Financial Instrument. HELCLOM was lead partner for the project that was conducted during 2017 – 2018. The project was also supported by the BONN Agreement (North Sea), the Copenhagen Agreement (Nordic seas), REMPEC (Mediterranean), as well as the Norwegian Coastal Administration. Four inter-regional workshops on Risk Assessment Tools for Pollution Preparedness and Response were arranged within the project and two documents with project output have been presented by HELCOM:

- OpenRisk Guideline for Regional Risk Management to Improve European Pollution Preparedness and Response at Sea. October 2018 (OpenRisk, 2018) and
- Baltic Sea case study – A Practical Demonstration on the Use of the OpenRisk Guideline. Baltic Sea Environment Proceedings No. 165, February 2019 (OpenRisk, 2019).

SSPA has been observer of the project and participated in the fourth and final workshop hosted by WMU in Malmö, Sweden on 30 October 2018.

Figure 2.1. WMU´s President Doumbia-Henry with the OpenRisk Workshop participants in Malmö 30 October 2018.

The OpenRisk project and the Guideline presented (OpenRisk, 2018), is referred and briefly described in GRACE deliverable D5.6 (D5.6, 2018). The guideline document review 20 different tools and methodologies applicable for screening, intermittent, and for strategic spill risk assessment and PPR (Pollution Preparedness and Response) risk management.

In the Case study report (OpenRisk, 2019), six of the listed tools are applied and combined for the three sequential steps of; Risk Identification, Risk analysis, Risk evaluation of a risk management process characterised as an intermittent spill risk assessment.

Two test areas, reproduced in Figure 2.2, are selected for the case studies and the following tools are applied:

- Maritime Event Risk Classification Method (ERC-M) (No.7, (OpenRisk, 2018)), for the risk identification step
- Functional Resonance Analysis Method (FRAM) (No.13, (OpenRisk, 2018)), for the risk identification step
- Accidental Damage and Spill Assessment Model for Collision and Grounding (ADSAM), (No.8, (OpenRisk, 2018)), for the risk analysis step

- Strength of Evidence Assessment Schemes (No.17, (OpenRisk, 2018)), for the risk analysis step
- Risk Matrices and Probability Consequence Diagrams (No.18, (OpenRisk, 2018)), for the risk evaluation step
- As Low As Reasonably Practicable Principle (No.19, (OpenRisk, 2018)), for the risk evaluation step

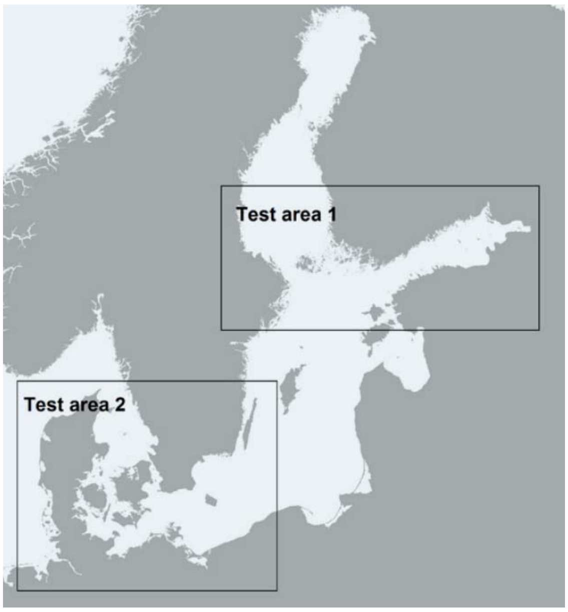


Figure 2.2. Geographical areas used for the OpenRisk case study (OpenRisk, 2019).

For the risk identification step, VTS incident reports and HELCOM accident statistics from the period 2014-2016 are analysed to identify representative spatial and temporal risk distribution figures, see Figure 2.3 and Figure 2.4 .

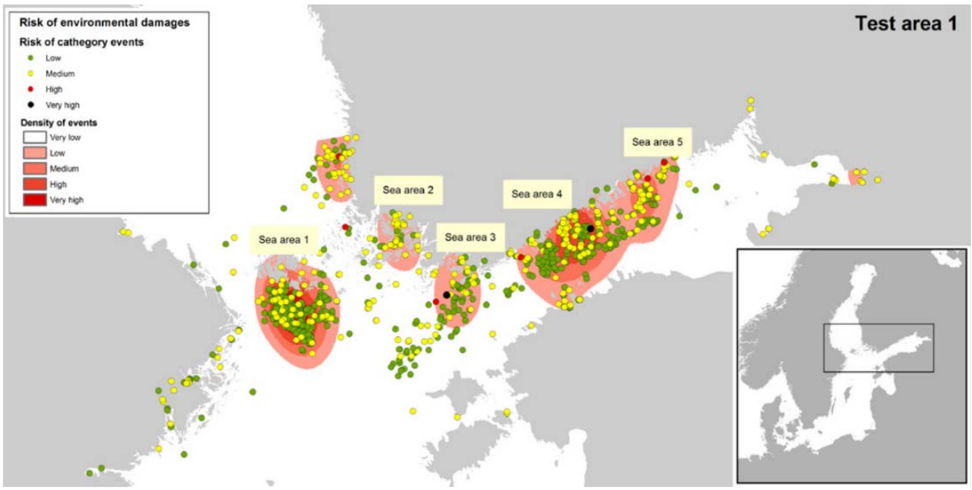


Figure 2.3. Kernel density GIS feature applied to incident statistics (with a total of 982 incidents registered from 2014-2016) for identification of accidental hotspot areas,
(OpenRisk, 2019)..

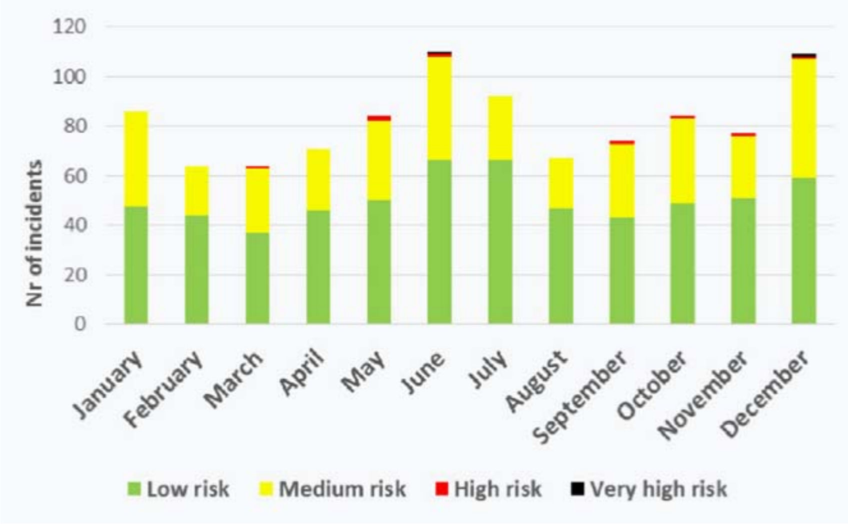


Figure 2.4. Temporal distribution of recorded incidents 2014-2016 in test area 1.

The applied ERC-M does not consider aspects related to sea ice or winter conditions but the variation of the temporal incident distribution by month for test area 1 may include seasonal variations of operational navigation conditions influenced by the presence of ice in the test area. The winter months December and January show somewhat higher incident frequencies than average and so does June. Available incident records do not specifically categorize incident descriptions with respect to ice or winter conditions, and the first step for further analysis of potential correlation should be to normalize the temporal incident distribution to the actual ship traffic frequency per month.

For the subsequent risk analysis step of the OpenRisk case study, the incident statistics is further used to define ten credible product tanker and crude carrier accident scenarios with grounding and collision accidents. ADSAM-G and ADSAM-C are then applied to derive representative spill quantities and characteristics for each of the scenarios. Two different advection and trajectory tools are then applied to provide representative descriptions of spill drift, spreading and weathering effects for the occurrence of the scenarios at various time of the year (months). The advection and trajectory models predict different fate and behaviour of the spills depending on what month they occur. The presence of ice during the winter months and potential confinement of spill in pack ice areas may also be considered by such scenario modelling.

SYKE´s partnership in OpenRisk links the project with GRACE and the support from the Norwegian Coastal Administration also links the OpenRisk project with the EPPR initiative and project addressing Arctic spill risk assessment tools.

2.2 EEPR Arctic risk assessment tool and guideline

EPPR (Emergency Prevention, Preparedness and Response), one of the working groups within Arctic Concil, have initiated the project Guideline and tool for Arctic Marine Risk Assessment. The project leads by Norwegian Coastal Administration and DNV GL are contracted to facilitate the work, assisted by UiT The Arctic University. The aim of the project is to create a common approach for conducting qualitative and quantitative Arctic Marine Risk Assessments, enabling comparable assessments. The guideline shall also provide a better foundation and decision support for establishing optimized risk management strategies. A toolbox including the best practice document(s) and an overview of available tools, data sources, incl. their accessibility, quality, completeness/coverage, contact persons, etc. will be developed within the project.

The project started in 2017 and is planned to be finalised by end of 2019. The work during 2018 included identification and assessment of Δ (Delta) arctic risk factors (arctic factors hereafter) and a screening of existing methods and data. A number of workshops and webinars for stakeholders were organized where contact and cooperation between the GRACE project and the EPPR project was established.

The screening of existing methods and data identified 25 different methods for risk assessment, excluding generic methods such as HAZID, HAZOP, FMECA, QRA, HRA, Monte Carlo, etc. Of these are 18 classified as quantitative area-wide methods and 8 of these methods contained some elements of arctic accidents or arctic risk shaping factors (≈ 30%).

The considered arctic factors are based on the sources of hazards defined in the International Code for Ships Operating in Polar Waters (Polar Code). In 2019, guidelines and a toolbox will be developed. The proposed Arctic factors are further described in Chapter 5.2.

2.3 AISyRisk

One of the most interesting models for application in Arctic spill risk assessment, reviewed in the OpenRisk project is the AISyRisk presently under development within DNV-GL in cooperation with the Norwegian Coastal Administration. The model uses high-resolution streaming AIS data in combination with empirical model data on accident and oil spill probabilities together with detailed data on specific ship from established ship data bases, to generate a live GIS map of ship accident risk distribution in Norwegian waters. The calculations in real time require availability of large computer resources but may easily be expanded to cover other sea areas vulnerable to impacts from shipping activities, e.g. The Baltic Sea or all EU waters. Aggregated results and services from the completed model tool will be published and publicly available on a web portal administered by the Norwegian Coastal Administration.

3 Regulation and future oil qualities in Arctic

3.1 Regulations regarding carriage and use of HFO as bunker fuel quality in Arctic waters

Statistics on marine oil spills demonstrate that frequency wise spills of bunker fuel oil are much more frequent than crude or oil products carried as cargo in tankers. In Arctic waters the frequency of crude carriers and oil product tankers are lower than for other cargo vessels and in the Baltic Sea the tanker traffic represents about 25% of the total ship traffic. Design requirements further implies cargo tanks to be located inside double hull thereby more protected from damage and leakage due to low energy grounding or collision incidents.

For other ship types, bunker tanks with fuel oil for engines and propulsion, may be located directly inside the outer bottom or side plating of the hull. IMO adopted in March 2006 an amendment to MARPOL Annex I to include a new regulation 12A on oil fuel tank protection. The regulation applies to all ships delivered 2010 or later with a total bunker capacity of 600 m^3 or more, international regulations require fuel oil tanks to be located 0.76 m – 2.0 m (depending on ship size) inside the hull plating (MARPOL, 2006). A maximum capacity limit of 2 500 m^3 per oil fuel tank is included in the regulation. The fuel tank regulation does not address Heavy Fuel Oil HFO versus other lighter fuel oil qualities. This means that also in a near future it may be anticipated that fuel oil spills from grounding, collision or bunkering accidents, will represent the main portion of marine oil spills, but also that the quality and properties of the bunker fuel oil will be a crucial factor for the efficiency of response actions for mitigation of environmental impact and resilience of spill consequences.

From a global environmental perspective, the sulphur content of fuel oil and its impact to human health, contribution to acid rain and ocean acidification caused by particles and sulphur oxide (SOx) in ships’ exhaust emission, has been the main focus for stricter regulations. From 1 January 2015 the limit for sulphur content of ships fuel is 0.10% (mass%) in IMO established SOx Emission Control Areas (ECAs) as per MARPOL Annex VI Regulation 14. The established ECAs for SOx are: the Baltic Sea area, the North sea area, the North American area (covering designated coastal areas off the United States and Canada), and the United States Caribbean area (around Puerto Rico and the United States Virgin Islands). The current global limit for sulphur content of ship´s fuel is 3.50% as per MARPOL Annex VI Regulation 14. From 1 January 2020 the new global sulphur limit will be 0.50% (IMO, 2017a) in sea areas outside ECA, see Figure 3.1.

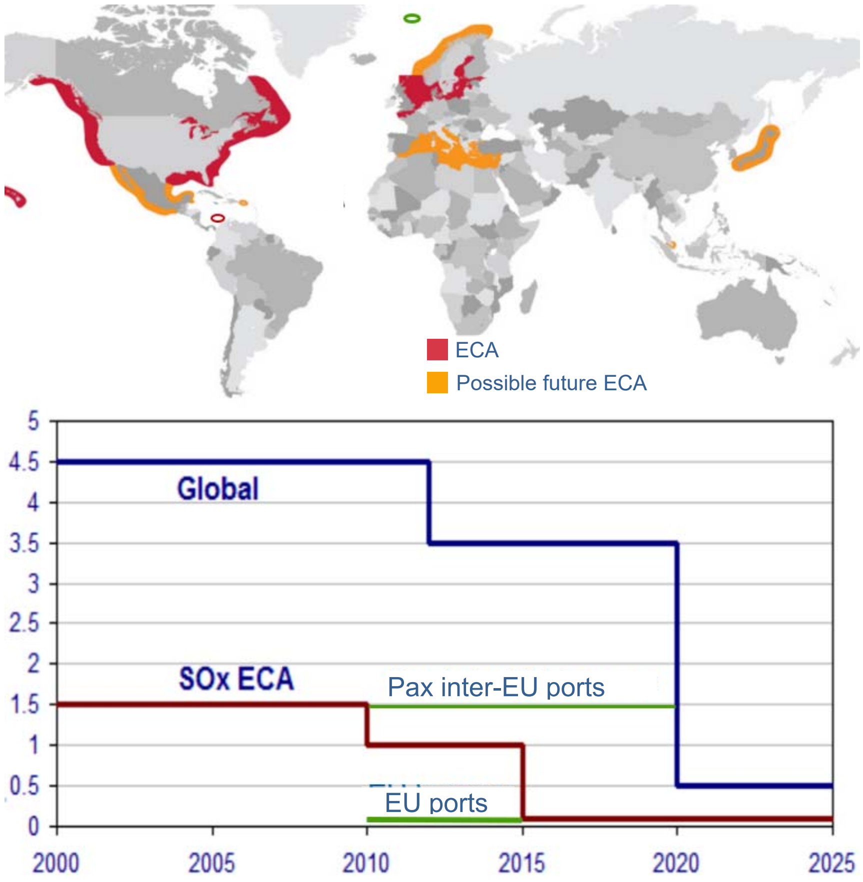


Figure 3.1. Present and possible future Emission Control Areas ECA and the time schedule for stepwise stricter regulations on maximum sulphur content marine fuel.

Even though the amount of heavy fuel oil is anticipated to be reduced due to the new global sulphur limit, it is still expected to be sold and used as ship fuel since ships can be authorised by the flag State to use alternative technologies for exhaust gas cleaning systems, i.e. scrubbers, to meet the SO_x emission requirements of MARPOL Annex VI (IMO, 2017b). The number of orders for scrubber installations is increasing significantly and more than 3 000 vessels are expected to have scrubbers by 2020. Predictions indicate that the consumption of high-sulphur HFO will be in the order of 140 000 tonnes per day compared with about 460 000 tonnes per day estimated for 2017 (Goldman_Sachs, 2018).

As shown in Figure Figure 3.1, the entire Baltic Sea is part of an ECA whilst the Arctic Ocean is not. The Svalbard islands, encircled by a green line in the figure, have, however, introduced national regulations for parts of the territorial waters. For these protected areas (designated national parks and nature reserves) the Governor of Svalbard has issued a ban on carriage and use of HFO other than DMA-grade fuels (marine gas oil) according to the ISO 8217 Fuel Standard (The Governor of Svalbard, 2017). The regulation was introduced in 2007 mainly justified by known difficulties to recover and clean-up potential HFO spills. The clean-up difficulties have been indicatively quantified in monetary terms in report from CE Delft in 2018, (CE_Delft, 2018). Referred examples from the US indicate a reduced response cost of 30 000 USD/tonne of spilled oil for MGO compared to HFO, (Etkin, 2000).

Corresponding reasoning was also the background for the international ban of use and carriage of heavy fuel oil in the Antarctic area as per regulation 43 of IMO MARPOL Annex I since 1 August 2011. Regulation 43 prohibits both the carriage in bulk as cargo and the carriage and use as fuel, of: crude oils having a density at 15°C, higher than 900 kg/m^3; oils, other than crude oils, having a density, at 15°C, higher than 900 kg/m^3 or a kinematic viscosity, at 50°C, higher than 180 mm^2/s; or bitumen, tar and their emulsions (IMO, 2017c).

The well-known difficulties of recovery and clean-up of potential HFO spills is obviously also relevant for the Arctic area. In addition reports from IPPC and from Arctic Council (EGBCM, 2017) show that the Arctic area is specifically sensitive for emission of black carbon (BC) from combustion of HFO and its contribution to melting of glaciers and reduction of sea ice coverage. Recent research results indicate that the melting rate of Greenlandic glaciers is faster than previously documented. The current melting rate is estimated to be six times higher than it was in 1980 and the cumulated melting of Greenlandic glaciers since 1972 has contributed to a global sea level rise of 13,7 mm (PNAS, 2019).

A similar ban on HFO in the Arctic was considered by IMO in 2013 during the preparations of the Polar Code but no consensus was reached but the Polar Code, which entered into force in 2017 In total ships traveling throughout the Arctic carried more than 830,000 tons of HFO on board in 2015, more than twice the figure of 2012.with mandatory amendments to SOLAS and MARPOL, includes a formulation that “ships are encouraged to apply regulation 43 of MARPOL Annex I” when operating in Arctic waters, i.e. not to use or carry heavy fuel oil in the Arctic (IMO, 2017c). According to the Polar Code (Chapter 1.1.1), any discharge into the sea of oil or oily mixtures from any ship shall be prohibited in Arctic waters (IMO, 2017d).

Deliberations on an Arctic HFO ban have been on the agenda of IMO´s MEPC meetings in 2018 and elaborated by PPR Sub-Committee expected to present a proposal to the MEPC 74 in May 2019 meeting. A final proposal is expected to be adopted by 2021 and may then enter into force from 2023 (CCA, 2019).

The definition of HFO in the Antarctic ban as per regulation 43 MARPOL Annex I, has been subject for discussions as new types of low sulphur Annex VI compliant fuels (0.5% sulphur) may have properties close to the limiting definitions. A number of member states have presented submissions to the MEPC in favour of an Arctic HFO ban and the government of Greenland has also expressed its support, particularly with a view on the potential pollution risk imposed by increasing cruise ship traffic using HFO (MAREX, 2018). Russia and Canada have,however, not yet committed to the ban. Some ship operators, e.g. Norwegian Hurtigruten and French Ponant cruise operator has announced they have voluntarily stopped used HFO fuel in the Arctic area. (Humpert, 2019)

A somewhat incongruous position is represented by Denmark’s implementation of MARPOL Annex VI where the national regulations for the prevention of air pollution from ships exclude Greenland by noting “The regulations shall not apply to ships registered in Greenland”, (DMA, 2016).

3.2 Present use of HFO fuel in Arctic waters

The consumption of HFO in the Arctic is growing and in total ships traveling throughout the Arctic carried more than 830 000 tons of HFO on board in 2015, more than twice the figure of 2012. The International Council on Clean Transportation (ICCT) has investigated the use of HFO as ship fuel in the Arctic area and its reports have frequently been referred by organisations and nations advocating an Arctic ban of HFO. The top five flag states in Arctic shipping was estimated to consume 298 200 tonnes of marine fuel within the IMO Arctic in 2015 and 63% of this HFO, (ICCT, Prevalence of heavy fuel oil and black carbon in Arctic shipping, 2015 to 2025. International Council on Clean Transportation, May 2017., 2017).

By far most of the ship movements recorded in the Arctic area is conducted by fishing vessels. Another study conducted by ICCT was specifically addressing the HFO use of fishing the fishing vessels. The results shows that a total of 755 fishing vessels consumed 144 000 tonnes of fuel and were collectively carrying 176 000 tonnes of fuel on board. 38% of the carried fuel quantity was HFO, (ICCT, 2018).

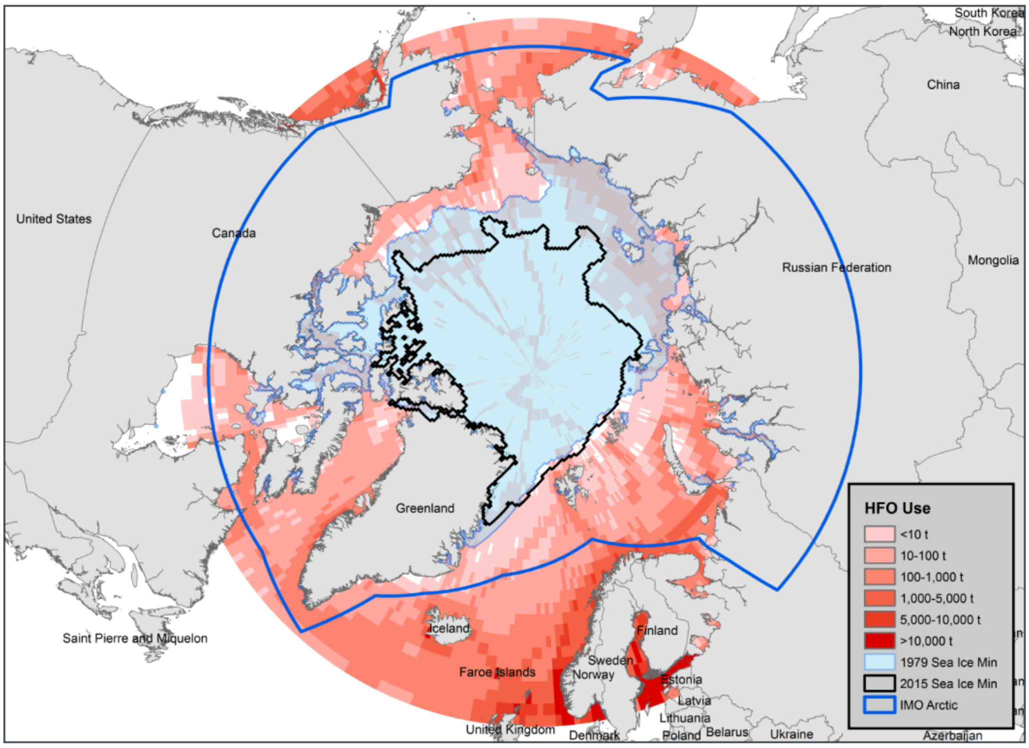


Figure 3.2 HFO use (tonnes) in the Arctic, 2015, with minimum sea ice extents, (ICCT, 2017)

3.3 Future oil qualities to be carried as cargo and used as ship fuel in Arctic waters

The introduction of the global IMO regulations on maximum 0.5% sulphur in fuel oil from 2020 and the potential introduction of an Artic HFO ban from 2023 will change the risk pattern imposed by ship accidents with oil spills from bunker or cargo tanks dramatically.

The ECA sulphur restrictions were introduced to reduce of harmful effects from SOx emissions from the shipping sector and it was generally anticipated that HFO would be replaced primarily by MGO (Marine Gas Oil) and similar distillate oil products in the designated ECAs. The development of and use of alternative fuels as LNG and methanol as well installation of scrubbers were also triggered by the ECA regulations and predicted negative consequences caused by increased fuel costs proved to be overestimated as the introduction coincided with a period of low oil price.

The positive consequences of reduced SOx emissions from the shipping sector is significant and in line with previously introduced fuel sulphur restriction introduced for other transport sectors, see Figure 3.3.

Figure 3.3. Reduction of SOx emissions form the transport sector in the Baltic countries, Russia excluded. [Source: HELCOM, 2018]

The positive health consequences of the introduction of the global 0.5% requirements were illustrated by calculations presented by a submission from Finland to the MEPC 70 in 2016, showing that more than 570,000 premature deaths would be avoided between 2020-2025 thanks to the introduction of the stricter sulphur cap, (MEPC, 2016)

In the North Sea and Baltic Sea SECA (Sulphur Emission Control Area) the consumption of MGO increased significantly from 2015 but during the succeeding years various types of hybrid oils have gained an increasing market share primarily by a somewhat lower price, see

Table 3.1.

Table 3.1. Indicative price difference example of various bunker fuel oil qualities in USD/tonnes in November 2018, deliveries in the Gothenburg-Skagen area.

IFO 380 Intermediate Fuel Oil	***ULSFO 0.1% sulphur Ultra Low Sulphur Fuel Oil***	***MGO Marine Gas Oil***
442 USD/tonne	643 USD/tonne	650 USD/tonne

Hybrid oil are essentially mixtures of various distillates and residual oil components and a wide variety of denotations, grades and commercial brand names exists, see Table 3.2. The specification requirements for ship fuel oil composition and properties are given by the standard ISO 8217:2017standard.

Table 3.2. Frequently used denotations and grades for ship fuel oil qualities. [Source: The International Bunker Industry Association, IBIA]

Examples of denotations frequently used for marine fuel oil qualities
RM: residual marine (needs to be heated)
DM: distillate marine (do not need to be heated)
FO: fuel oil
ULSFO RM: maximum 0.10% sulphur RM product
ULSFO DM: maximum 0.10% sulphur DM product
VLSFO RM: RM products that are above 0.10% but meeting a 0.50% sulphur limit
VLSFO DM: DM products that are above 0.10% but meeting a 0.50% sulphur limit
Distillate grade names DMA (clear and bright MGO), DMB and DMC (marine diesel oil grades, not required to be clear and bright) and the usual heavy fuel oil grades, e.g. RMG 380.
ULSGO/LSGO may be provided as marine fuel but are primarily used in land vehicles. ULSGO vehicle diesel environmental class 1, typically has sulphur content of 10-15 ppm (0.001% to 0.0015%).

From 2020 the demand for HFO is expected to decrease and be replaced by new types VLFSO grade hybrid fuel oils. There will still be a small market for HFO successively increasing due to an increasing number of scrubber installations but a possible Arctic HFO ban, including carriage of HFO, from 2023 may make the scrubber option less attractive. The LNG option will continue to grow but is not predicted to break the dominance of fuel oil for the next 25 years. Current trends indicate that the total quantities of marine fuel will increase due to increased shipping and trading activities and different predictions on the pace of increased fuel consumption and its distribution in different fuel types have been presented and Figure 3.4 shows a schematic graph on possible future global distribution of different marine fuel type demands.

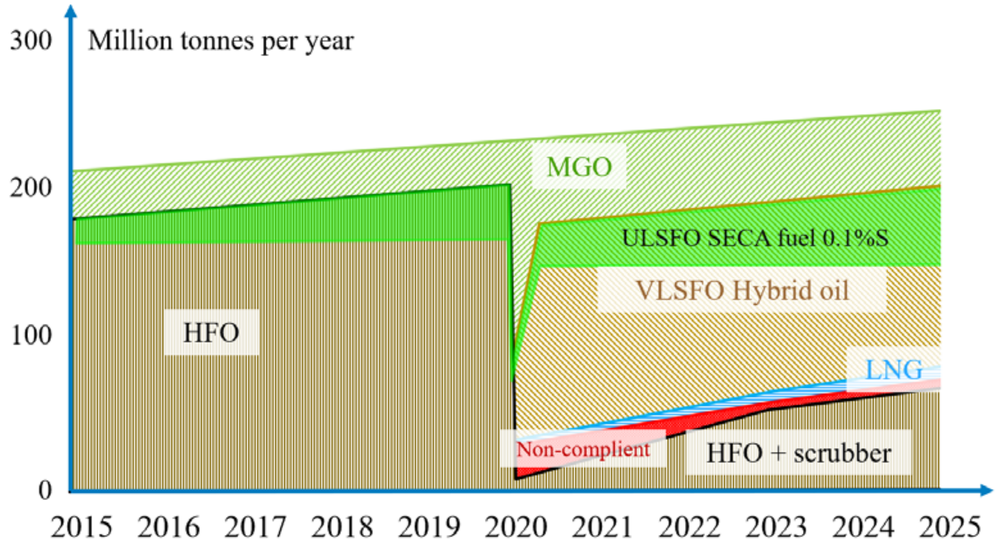


Figure 3.4. Predicted future global demand for marine fuel and its possible distribution into different qualities.

Ship operators and engine manufacturers have reported some issues related to the transition from HFO to hybrid fuels related to varying properties, mixability, higher viscosity and pour point compared with MGO.

With respect to oil spill and potential risk changes imposed by new sulphur regulations and associated introduction of new hybrid fuel types, important experiences have been gained from recent accidents with spills of hybrid fuel oils. For example the Swedish Coast Guard found that their main mechanical spill recovery equipment failed to be effective in a ship accident with leakage of hybrid fuel oil from a grounded car carrier on the Swedish east coast in 2018, see Figure 3.5. The Coastal Administration of Norway, has also experienced similar difficulties of mechanical recovery of spilled hybrid oil.

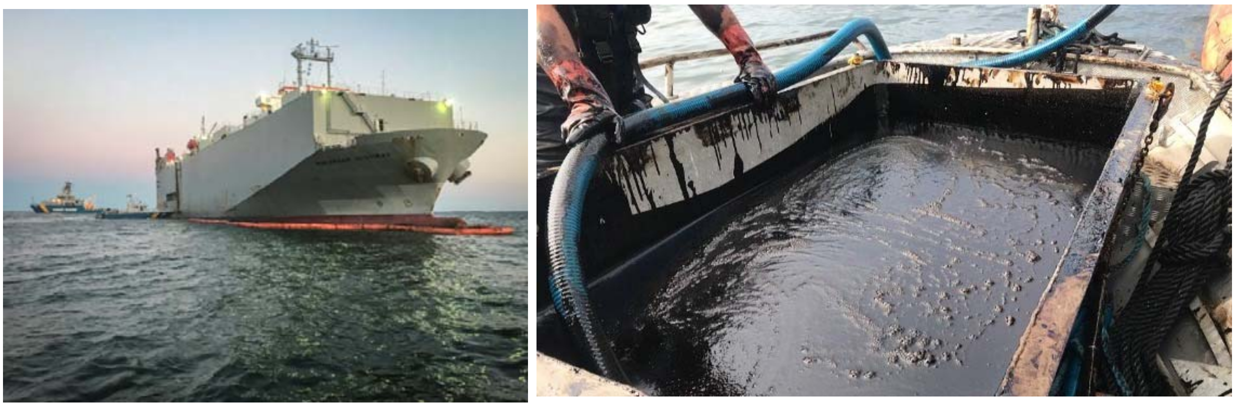


Figure 3.5. The 139 m long (6890 dwt) car carrier Makassar Highway grounded at the coast of Valdermarsvik, Sweden on 23 July 2018. [Photos: Swedish Coast Guard].

The spilled hybrid oil from the grounded Makassar Highway was not possible to collect by the Coast Guard´s standard rotating brush skimmers and the spill separated into non adhesive chunks surround by sheen of light fractions. The Coastal Administration of Norway has conducted tests with different skimmers in four different types of SECA compliant marine fuel oils and found that brush skimmers as well as conventional dis skimmers were not effective in the tested hybrid oil, (Kystverket, 2017). The weathering properties and toxicity of marine fuel oils including SECA compliant hybrid oil have also been tested and compared, (SINTEF, 2017).

The referred experience calls for more research efforts and investigations on how to overcome the detected deterioration of the existing spill recovery capacity for common future marine fuel oil qualities. It is possible that envisaged VLSFO hybrid fuels compliant to the global 0.5% requirements to be introduced 2020, will not show similar difficulties as the SECA hybrid fuels. However, with a view on the magnitude of the potentially affected skimmers and recovery resources world-wide, it is considered urgent also to investigate the coming VLSFO hybrid fuels and potential emerging recovery problems.

4 Traffic analysis

Vessel traffic considers the major influencing factor for the risk of an oil spill. The analysis of the traffic for a specific area therefore forms the basis for quantification of probability of a spill. The traffic analysis includes quantification of vessel movements for different types and sizes of vessels as well as analysis of seasonal variations of the traffic pattern and its influence of ice presence.

The analysis is based on AIS-data for the specific areas. For the arctic areas the AIS coverage is generally less dense compared to regions where so called Terrestrial AIS from coastal AIS receivers are provided. In the arctic areas, as well as for other ocean areas AIS data is provided through satellites services. While the terrestrial receivers provides real-time updates of vessel position, the satellite AIS data updates less often. The interval for updates in such areas varies from a few minutes up to several hours ('Satellite AIS - Global AIS Coverage | AIS Marine Traffic', n.d.). On average for vessels with AIS transponder sailing at the oceans the update frequency of position is one per hour. The accuracy of analysis in remote areas e.g. Disko Bay is therefore lower. Since the traffic in those areas is generally much less extensive and since the analysed area is relatively large, the poorer accuracy is of minor importance and the traffic characteristics can be assessed with sufficient accuracy.

4.1 Trial site – Disko Bay, Greenland

The terrestrial network for AIS do not cover the Disko Bay and the current waters between Greenland and Canada. For the analysis, satellite AIS-data from 2016 provided by The Norwegian Coastal Administration have been used. Also the web-based application *Havebase Arcitc* developed by The Norwegian Coastal is used for the retrieving and monitor data.

Fishing vessel dominates the traffic in the region dominating traffic. Figure 4.1 shows AIS tracks of fishing vessels around Greenland in 2017. Figure 4.2 shows tracks from other types of vessels in 2017.

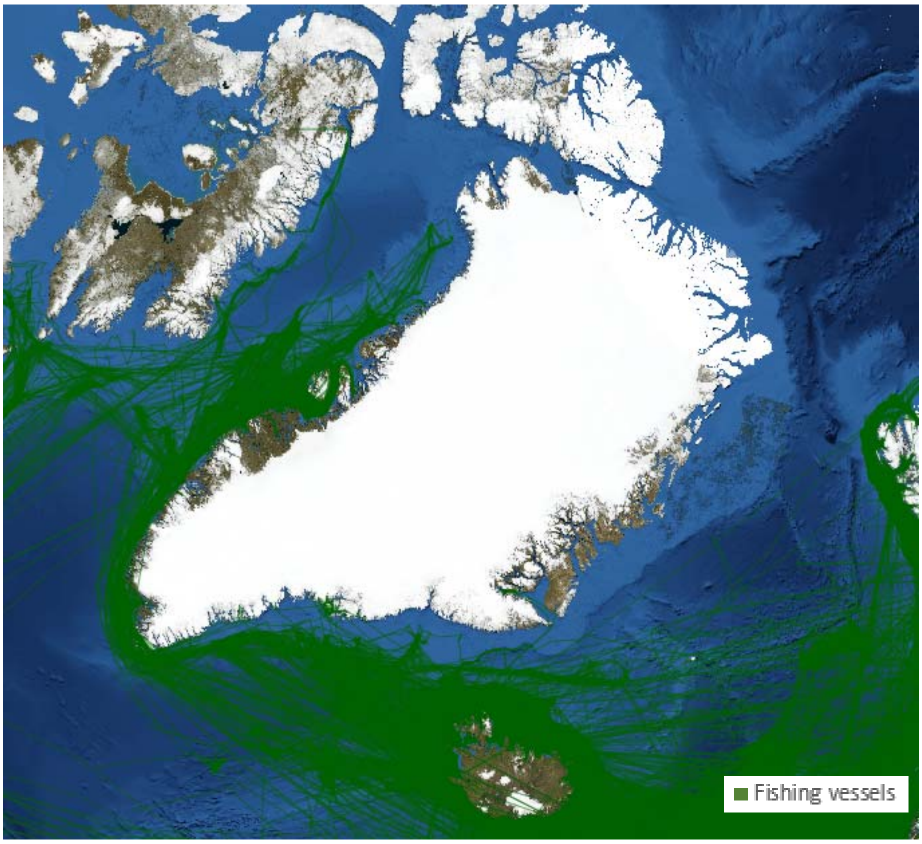


Figure 4.1 AIS tracks of fishing vessels from 2017 around Greenland.

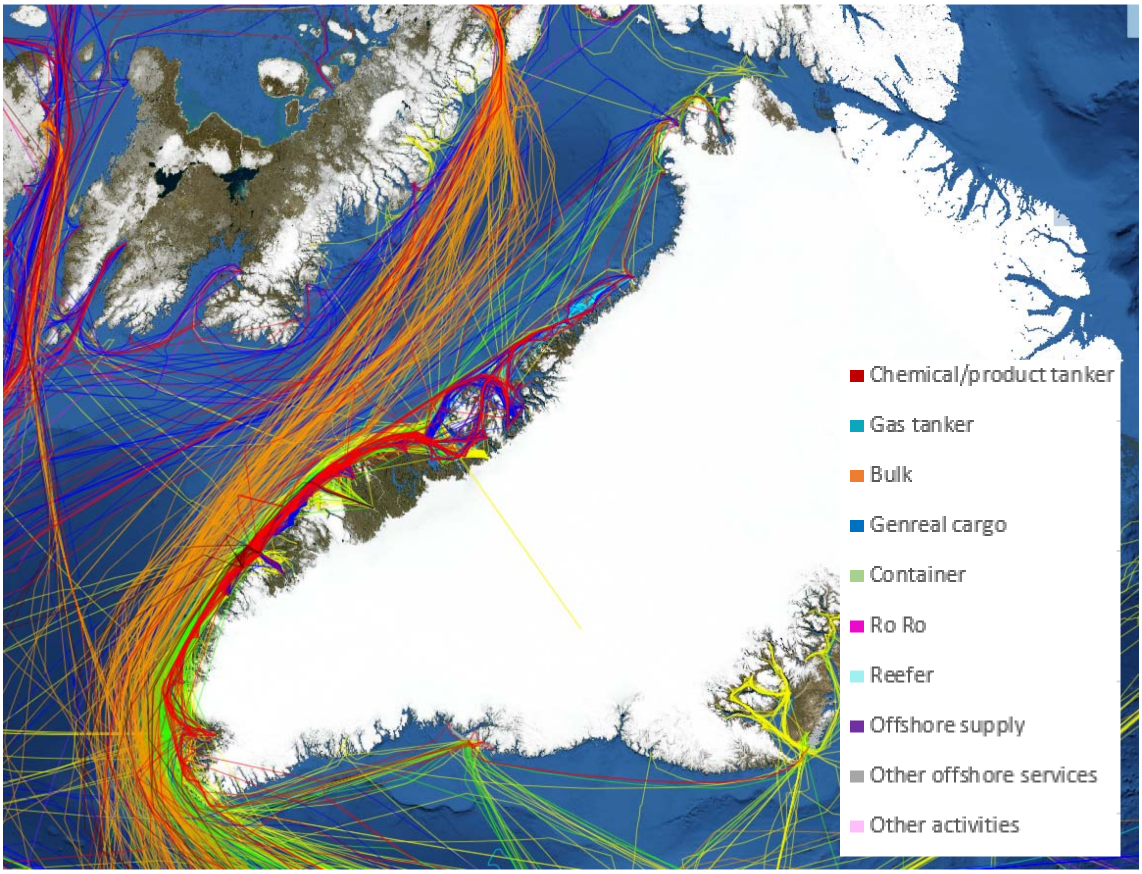


Figure 4.2 AIS tracks of vessel traffic excluding fishing vessels around Greenland in 2017.

In order to quantify the traffic around Disko Bay, the number of passages across two lines; *Davies strait north of Illulisat* and *Davies strait Nuuk and Illulisat,* see Figure 4.3, have been analysed.

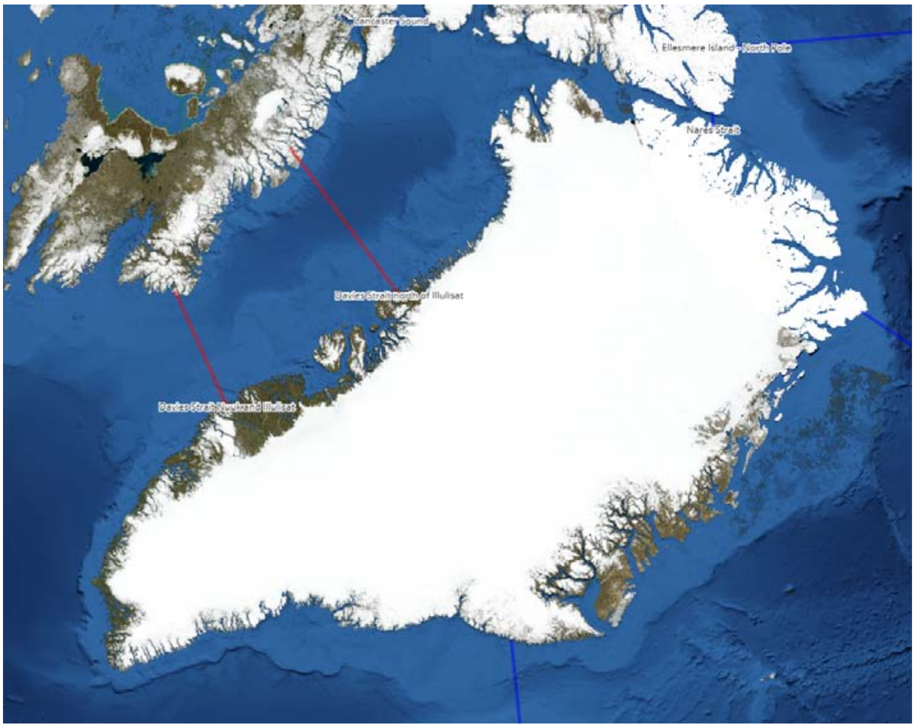


Figure 4.3 Passage lines between Canada and western Greenland used for traffic analysis of Disko Bay.

Figure 4.4 and Figure 4.5 show the yearly number of passages across the southern and northern passage line respectively for the period 2012 to 2017.

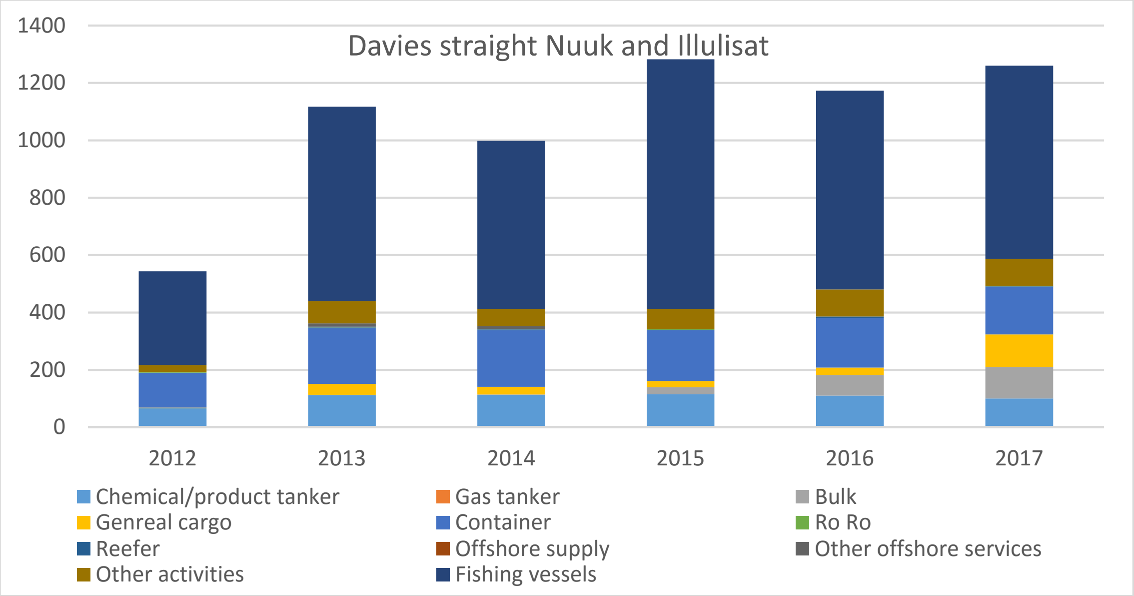


Figure 4.4 Number of passages at the southern passage line per year for the period 2012-2017.

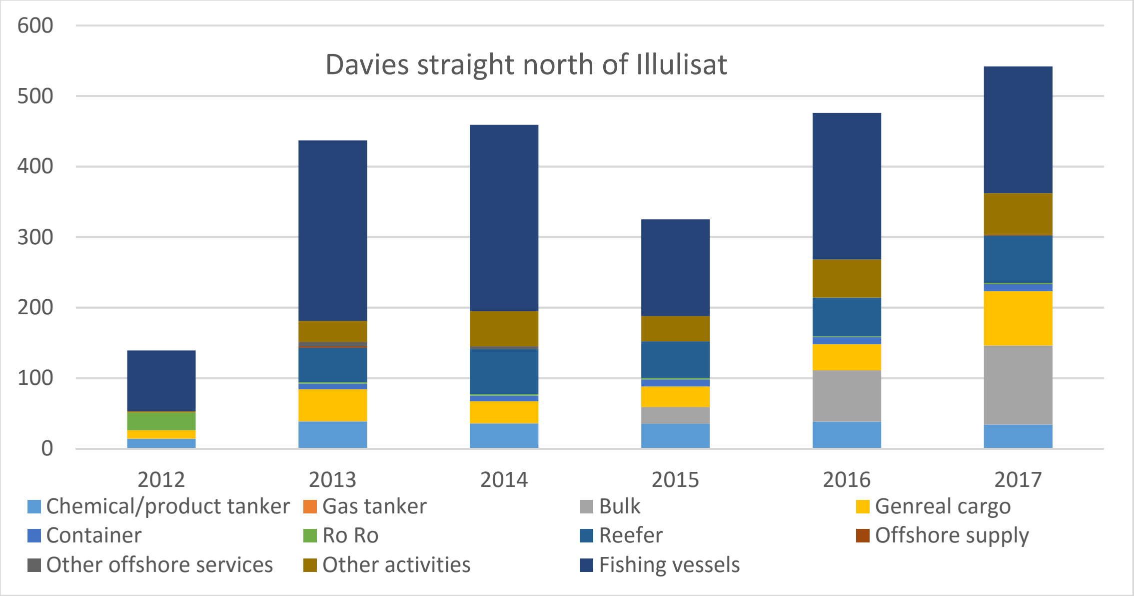


Figure 4.5 Number of passages at the northern passage line per year for the period 2012-2017

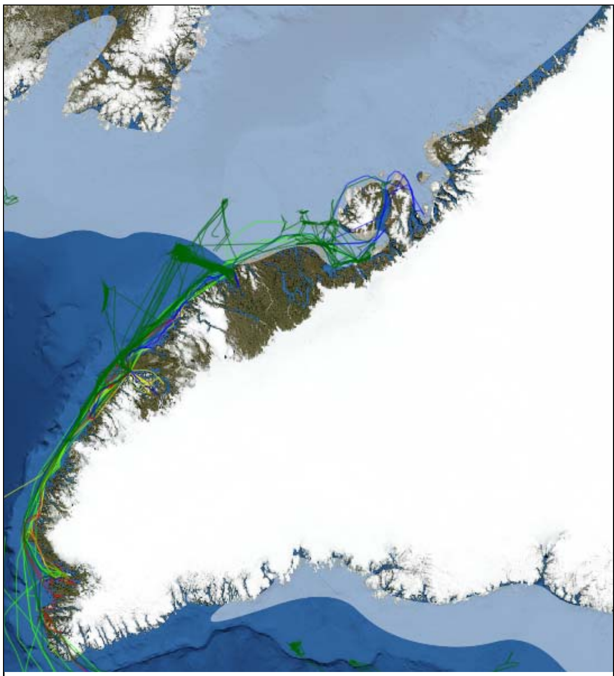
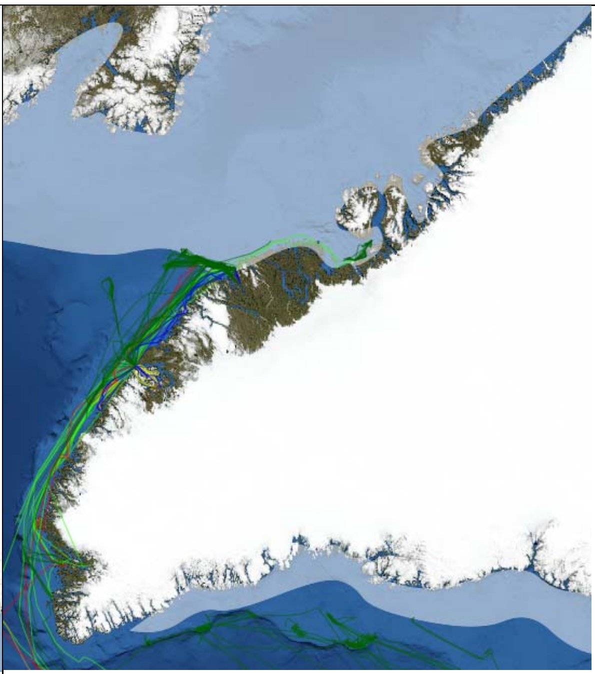
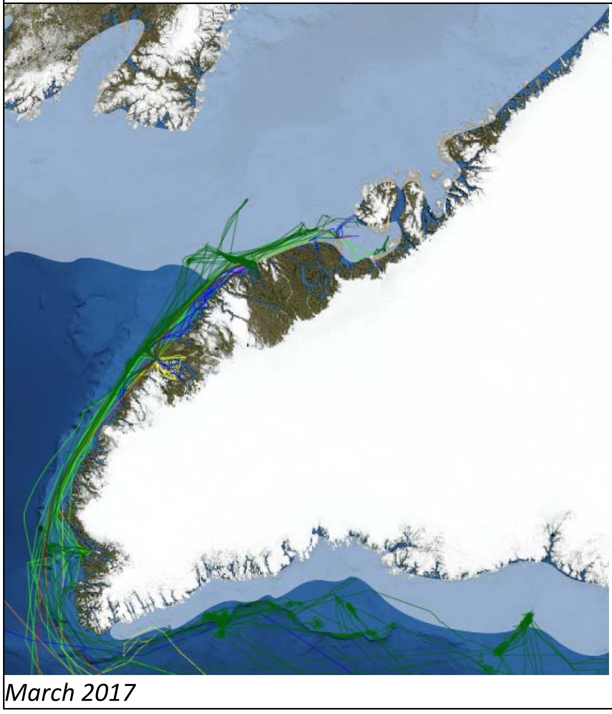
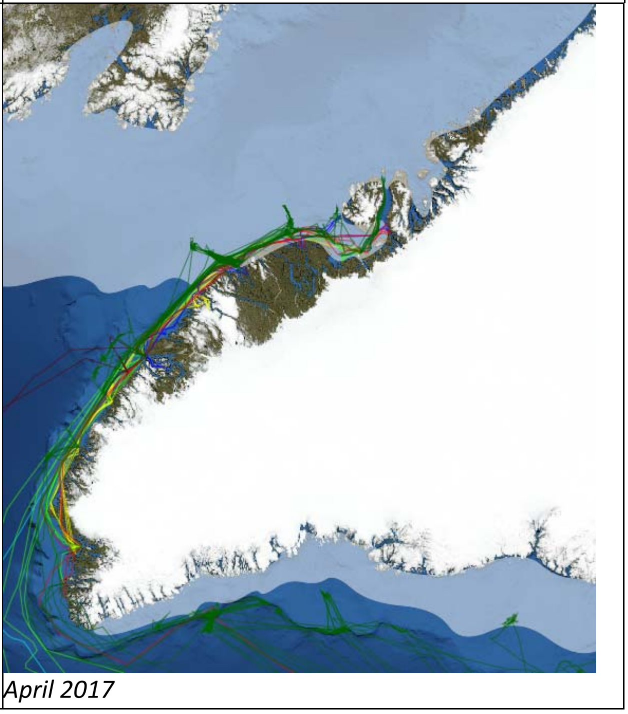
In 2017, the total number of vessel passages across the southern line was 1 260, of which fishing vessels accounts for about 50% of the passages. The traffic across the northern line is more limited with 542 passages in total during 2017.

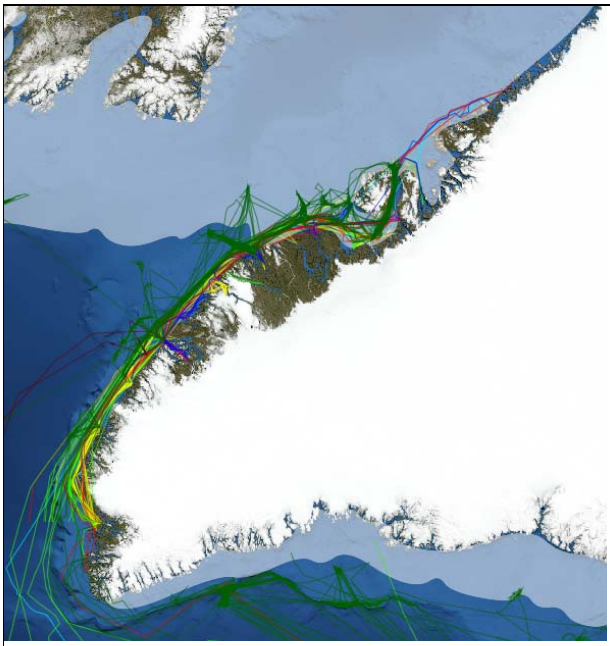
4.1.1 Seasonal variations

The traffic pattern is highly dependent on the ice coverage. Table 4.1 shows AIS tracks and ice coverage per month during in 2017. During January to May, ice was percent in the area around Disko Bay and hence restricted the traffic. Fishing activities along the coast are the only registered AIS tracks.

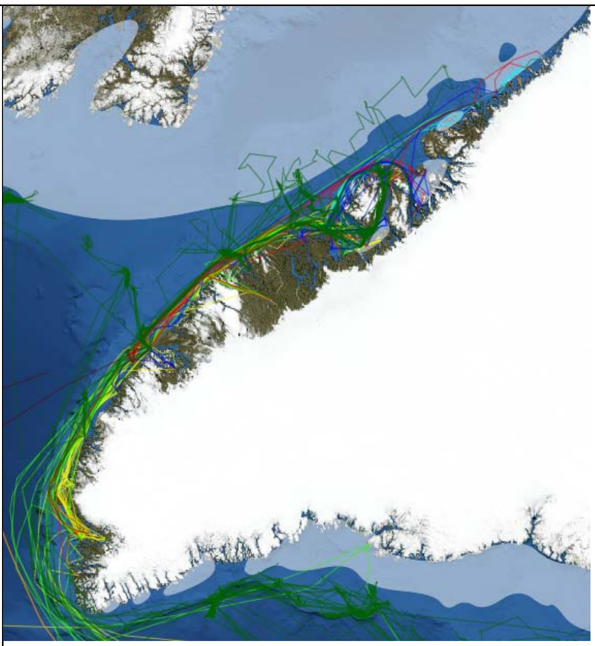
During the period July to October, bulk carriers pass Disko Bay on their voyages to and from Milne Inlet port on the Baffin Island where iron ore from the The Mary river iron mine is shipped (Indigenous and Northern Affairs Canada, 2017). In 2017, 4.1 million tonnes of iron ore were shipped from Milne Inlet port on 50 different shipments.

Table 4.1 Traffic pattern and ice coverage per month in 2017.

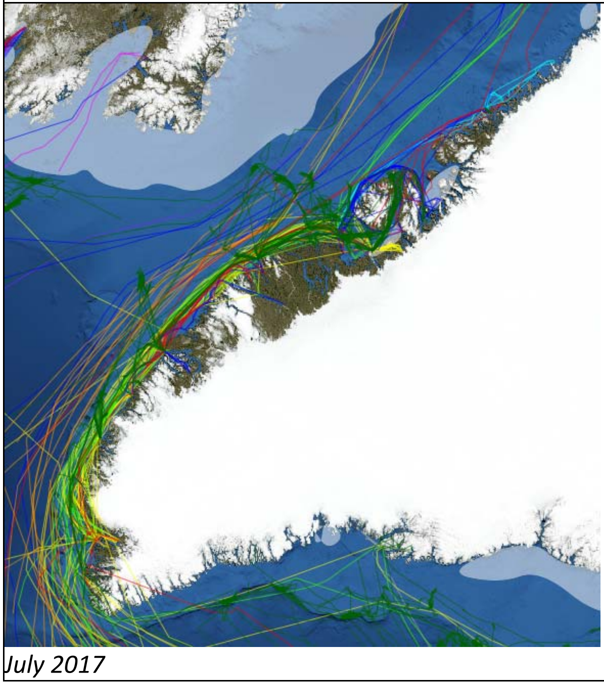
 *January 2017*	 *February 2017*
 *March 2017*	 *April 2017*



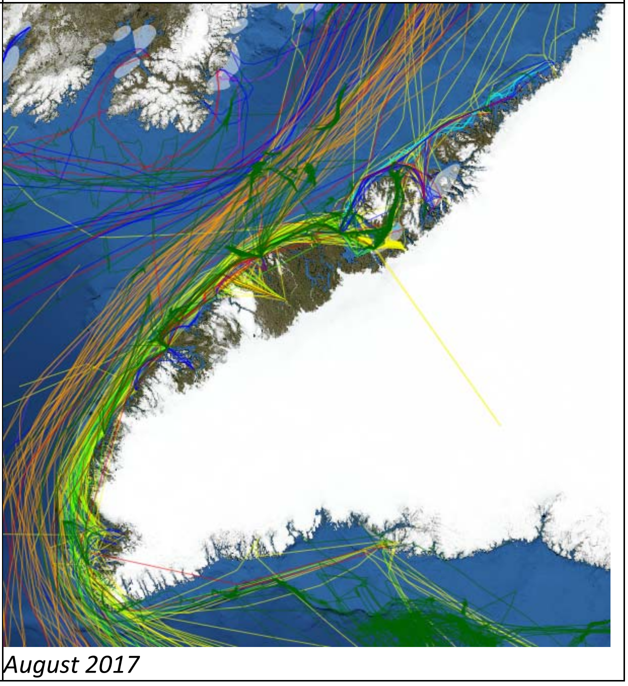
May 2017



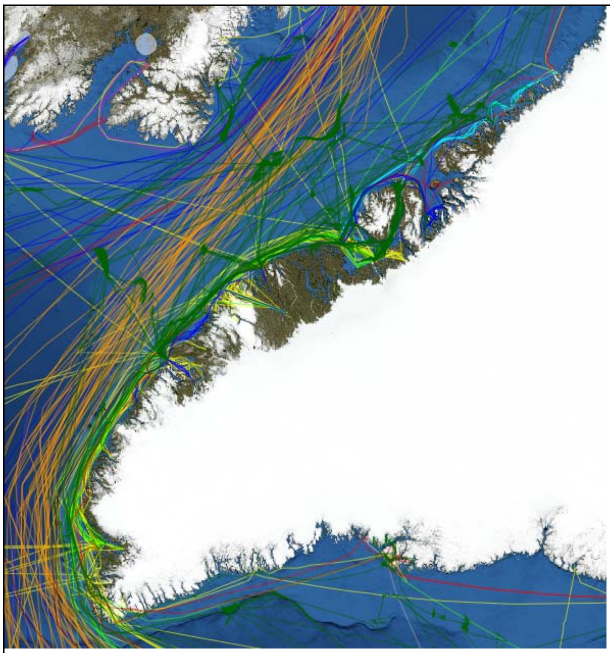
June 2017



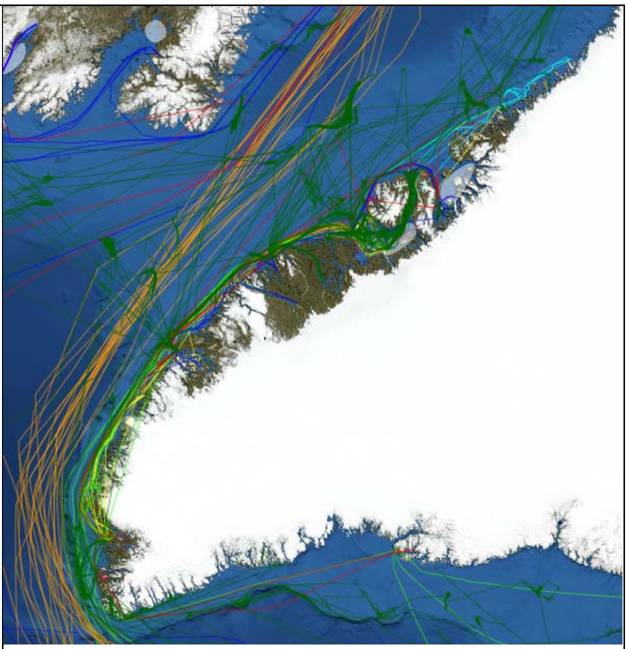
July 2017



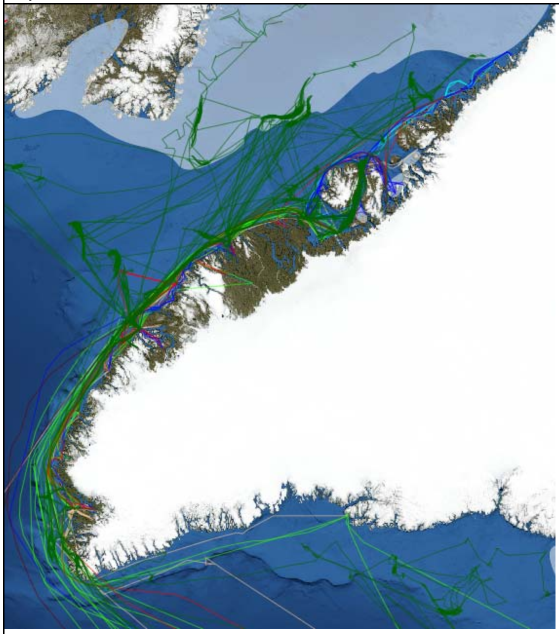
August 2017



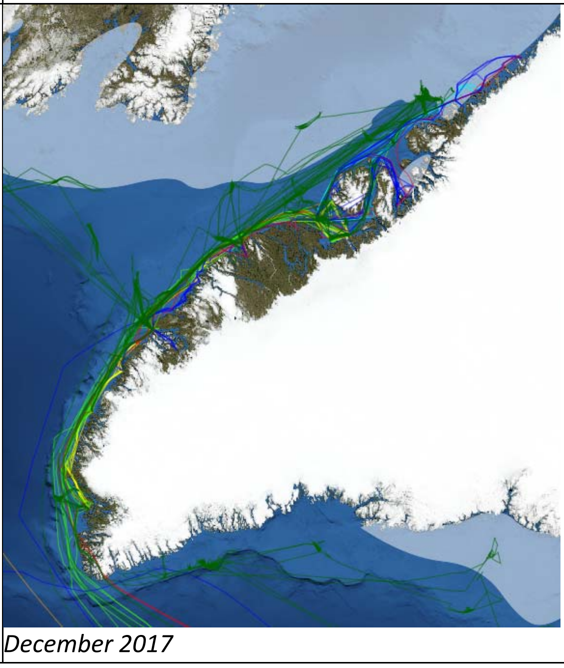
September 2017



October 2017



November 2017



December 2017

Figure 4.6 and Figure 4.7 shows the number of passages per month across the southern and northern line respectively in 2017. From January to April, no passages were registered across the northern line. At the southern line, fishing activity takes place all year round with decrease during summer. At the north line, the fishing activity is intensified from September to December.

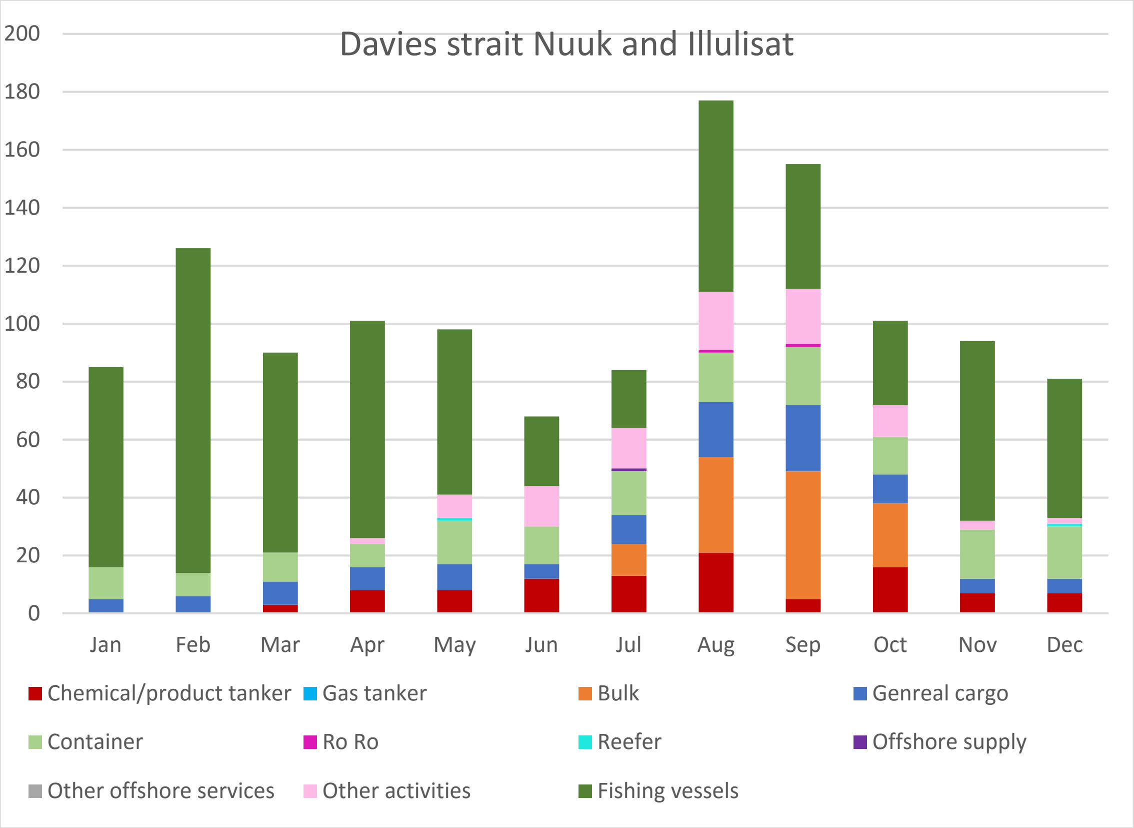


Figure 4.6 Number of passages per month and for different ship types across the line south of Disko Bay

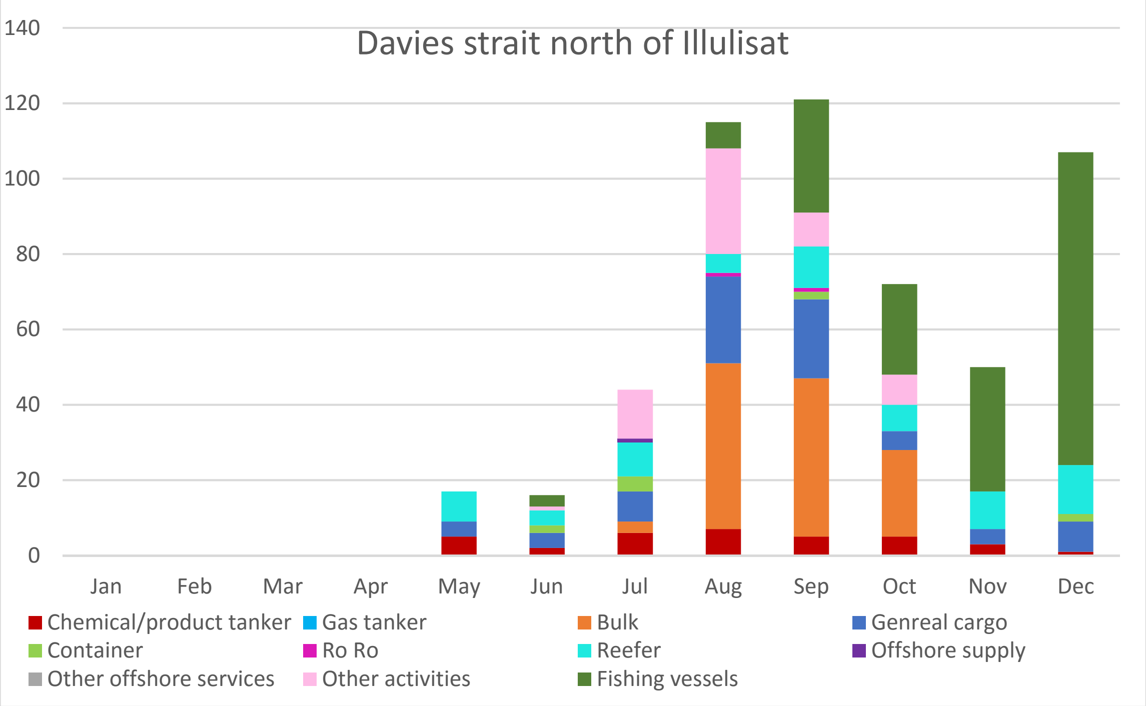
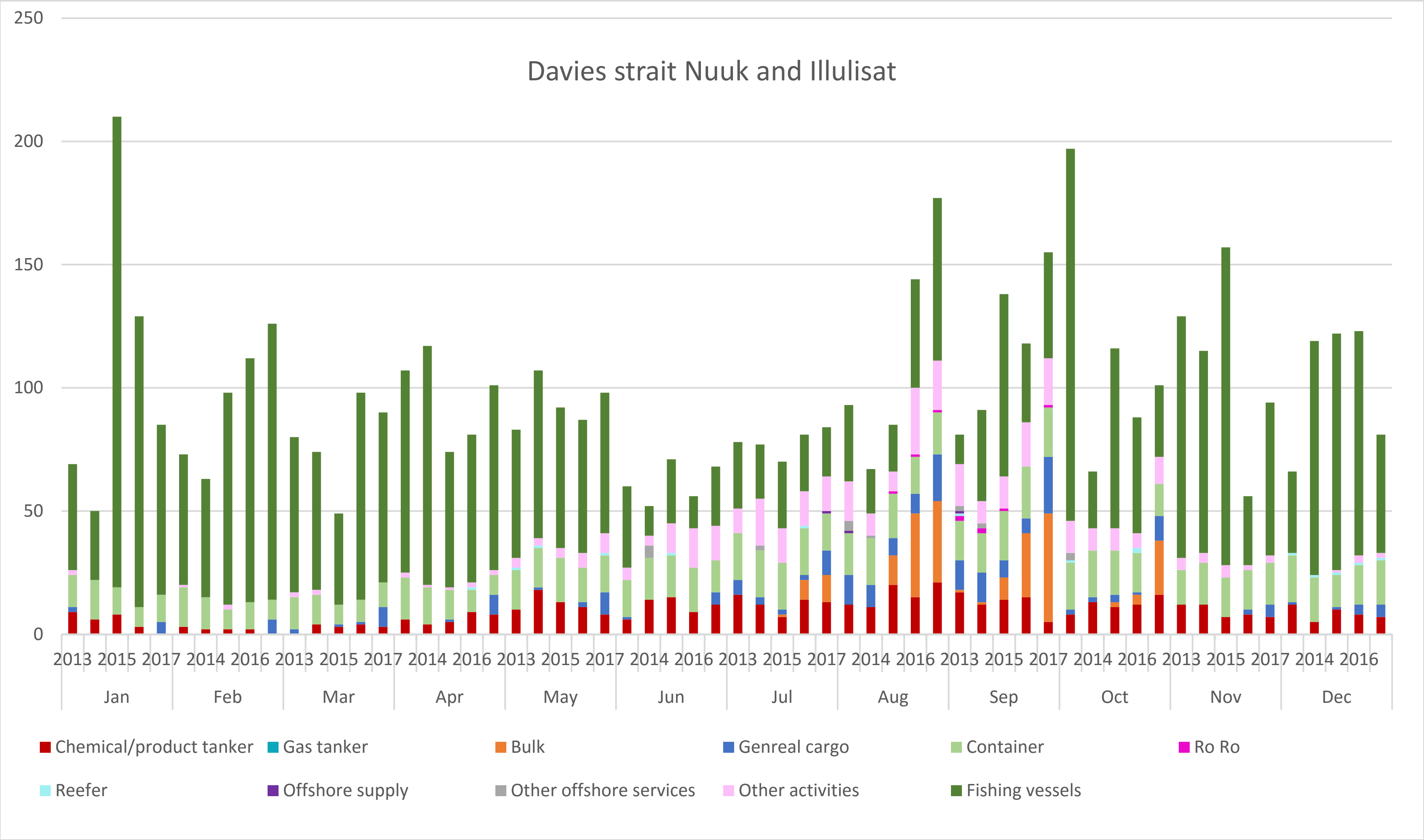


Figure 4.7 Number of passages per month and for different ship types across the line north of Disko Bay


Davies strait Nuuk and Illulisat
250
200
150
100
50
0
2013 2015 2017 2014 2016 2013 2015 2017 2014 2016 2013 2015 2017 2014 2016 2013 2015 2017 2014 2016 2013 2015 2017 2014 2016 2013 2015 2017 2014 2016
Jan
Feb
Mar
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May
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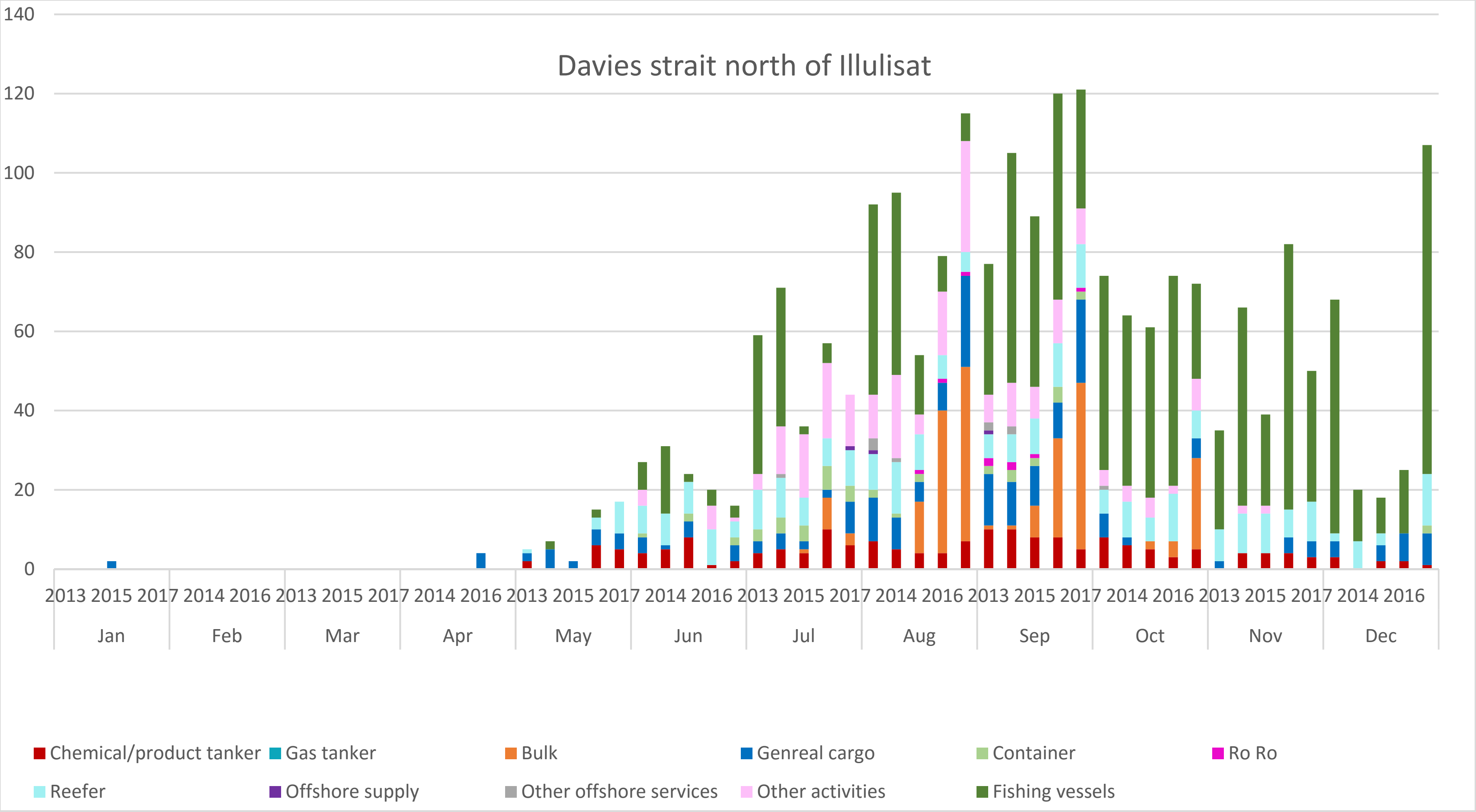
Chemical/product tanker
Gas tanker
Bulk
Genreal cargo
Container
Ro Ro
Reefer
Offshore supply
Other offshore services
Other activities
Fishing vessels


Davies strait north of Illulisat
140
120
100
80
60
40
20
0
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Chemical/product tanker
Gas tanker
Bulk
Genreal cargo
Container
Ro Ro
Reefer
Offshore supply
Other offshore services
Other activities
Fishing vessels

To identify vessels and voyages conducted in presents of ice, AIS data and ice statistics from DMI are analysed. Figure 4.8 shows AIS-tracks of voyages conducted in ice from the period November 2016 until July 2017. The vessel which sailed the largest distance in ice during the analysed is the 45 m long general cargo vessel Ivalo Arctica, which is operated by Royal Arctic Line. Ivalo Arctica sailed 9 800 km in ice in the area covered by Figure 4.8. Ivalo Arctica is operated by Royal Arctic Line, which has an exclusive concession issued by the Government of Greenland for the transportation of all sea cargo to and from Greenland and between the Greenlandic towns and settlements (Royal Arctic Line , 2019). Royal Arctic Line also operate the reefer vessel Pajuttaat which was the 5th most operated vessel in ice.

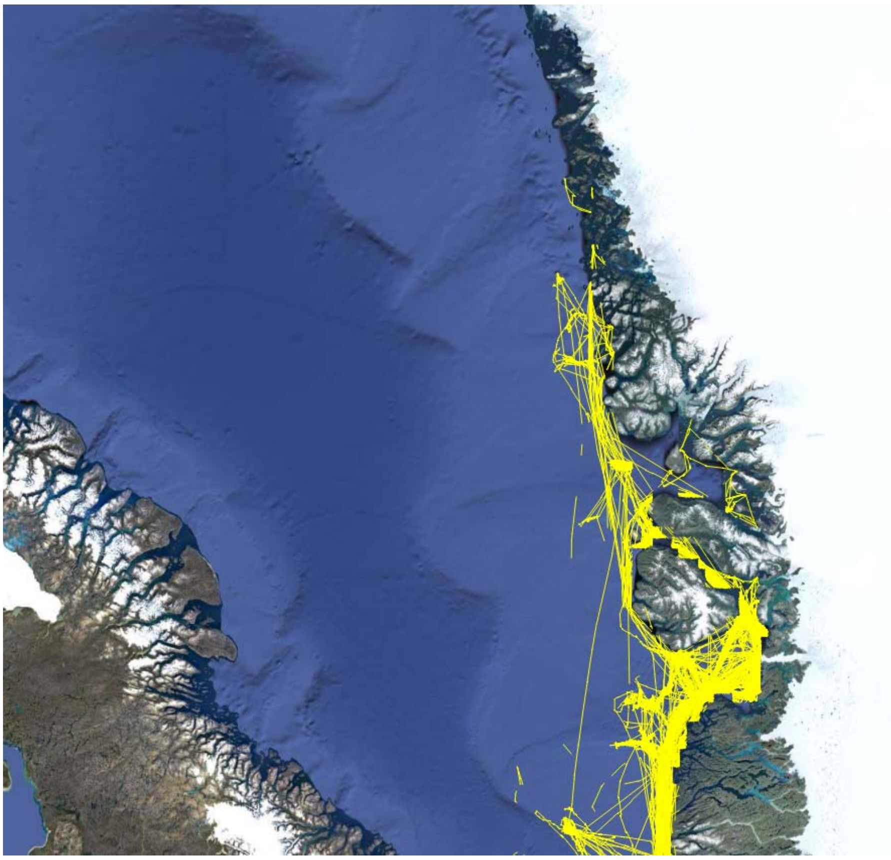


Figure 4.8 AIS-tracks from vessels sailing in ice west of Greenland during the ice period 2016-2017. (2016-12-01 – 2017-06-07.

Other vessels operating frequently in ice in the area around Disko Bay are trawlers and fishing vessels, see Table 4.2.

4.1.2 Identification of dimensioning vessels

Identification of dimensioning vessel is based on traffic statistics across the passage lines. The vessels are selected to be representative for the fleet in the area, therefore the most frequent vessels of different ship types are selected, as well as the largest vessels. The selected vessels are used in the risk evaluation to identify the worst credible spill scenario. Table 4.2 shows the selected dimensioning vessels. As the selected vessels are assume to represent the total fleet in the area, a percentage distribution of the total fleet to each vessel is estimated based on traffic statistics.

Table 4.2 Selected dimensioning vessels representing the fleet in waters outside of Disko Bay. Vessel dimensions and tank capacities are retrieved from IHS Sea web

Name	Type	Length overall [m]	Fuel Capacity [m^3]	Tank capacity (Liquid) [m^3]	Comment	Percentage of total fleet
NS Yakutia	Bulk carrier	225	DF: 260 RF: 2 310	-	Largest vessel, only during summer time to Milne Inlet port	5%
Ugale	Chemical/ product tanker	195	DF: 194 RF: 1 590	56190	Largest tanker	5%
Orasila	Oil/Chemical tanker	89	DF: 306	1 862	Most frequent tanker, 5th most frequent in ice	5%
Acadienne Gale Ii	Trawler	71	DF: 648		Most frequent vessel	60%
Ivalo Arctica	General cargo	45	DF: 130		Most frequent vessel in ice, Ice strengthen, Icebreaking, RAL	10%
Irena Arctica	Container	109	888		Most frequent Container vessel	15%

4.2 Trial site – Helsinki, Gulf of Finland

The sea traffic intensity in Gulf of Finland is considerably higher compared to traffic around Disko Bay. Figure 4.9 shows the traffic pattern in Gulf of Finland based on AIS-data from November 2017 to October 2018.

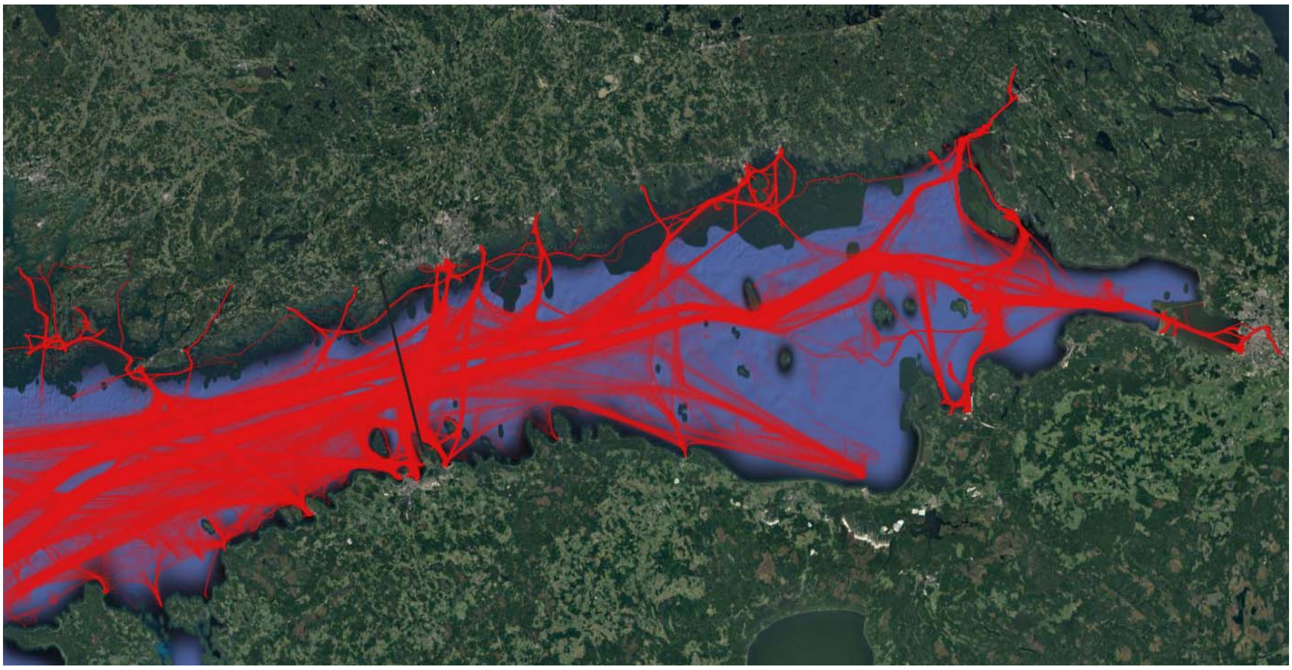


Figure 4.9 Traffic pattern in Gulf of Finland based on AIS-data from one year (November 2017 - October 2018). Passage line marked in black.

The number of passages across the black line in Figure 4.9 have been analysed. During the period November 2017 to October 2018 the total number of vessel passages across the black line in Figure 4.9 was 34 000. With regard to intense ferry traffic between Helsinki and Tallinn as well as between Stockholm and Helsinki the most frequent vessel type is Ro-Pax with 9 000 passages yearly, see Figure 4.10.

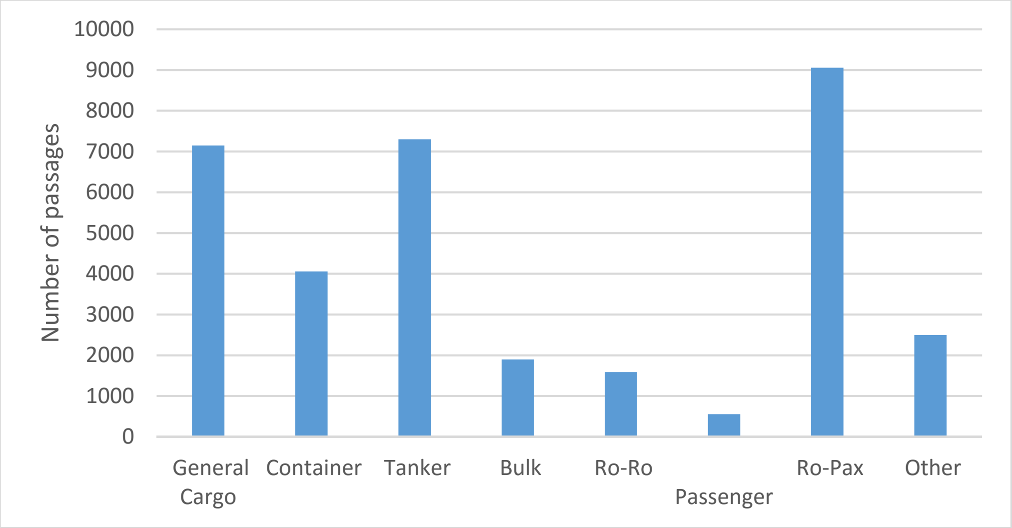


Figure 4.10 Number of passages of different vessel types during November 2017-October 2018.

Figure 4.11 shows AIS tracks of passenger and Ro-Pax traffic in Gulf of Finland in one year. In addition to the traffic in the western part consisting of traffic between Estonia, Finland and Sweden, the traffic also includes traffic to St Petersburg in the eastern part of the Gulf.

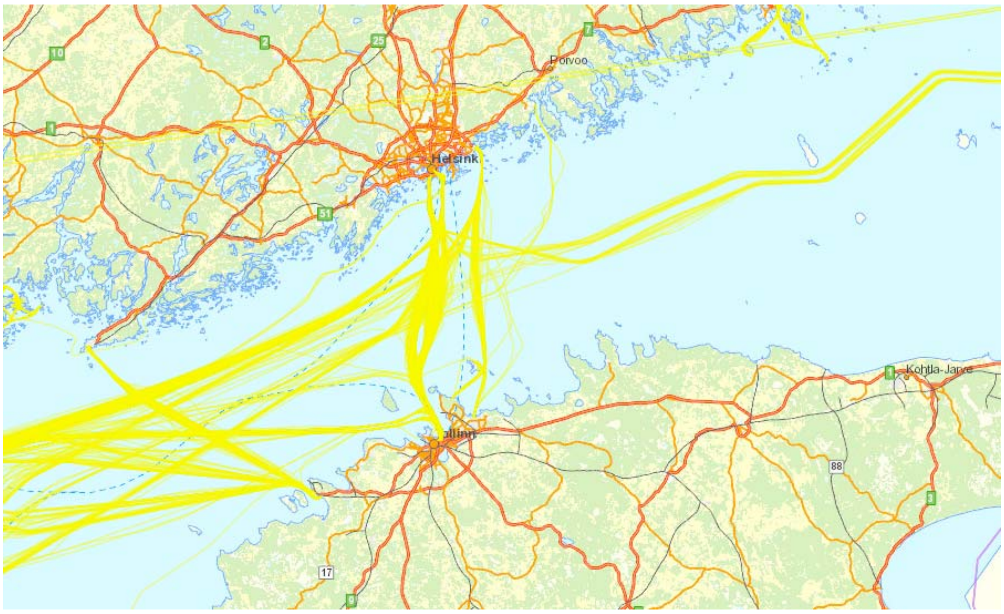


Figure 4.11 Passenger and Ro-Pax traffic in Gulf of Finland during one year (Havbase, 2019).

The number of tanker passages in Gulf of Finland is large, 7 300 passages yearly. The tanker traffic consists of crude oil tankers that are loaded in the Russian oil ports, primarily Ust Luga in the south east part and Primorsk in the north east part of the gulf. In addition, there is also tanker traffic to Porvo in Finland as well as to Tallinn, Muuga and Paldiski in Estonia, see Figure 4.12.

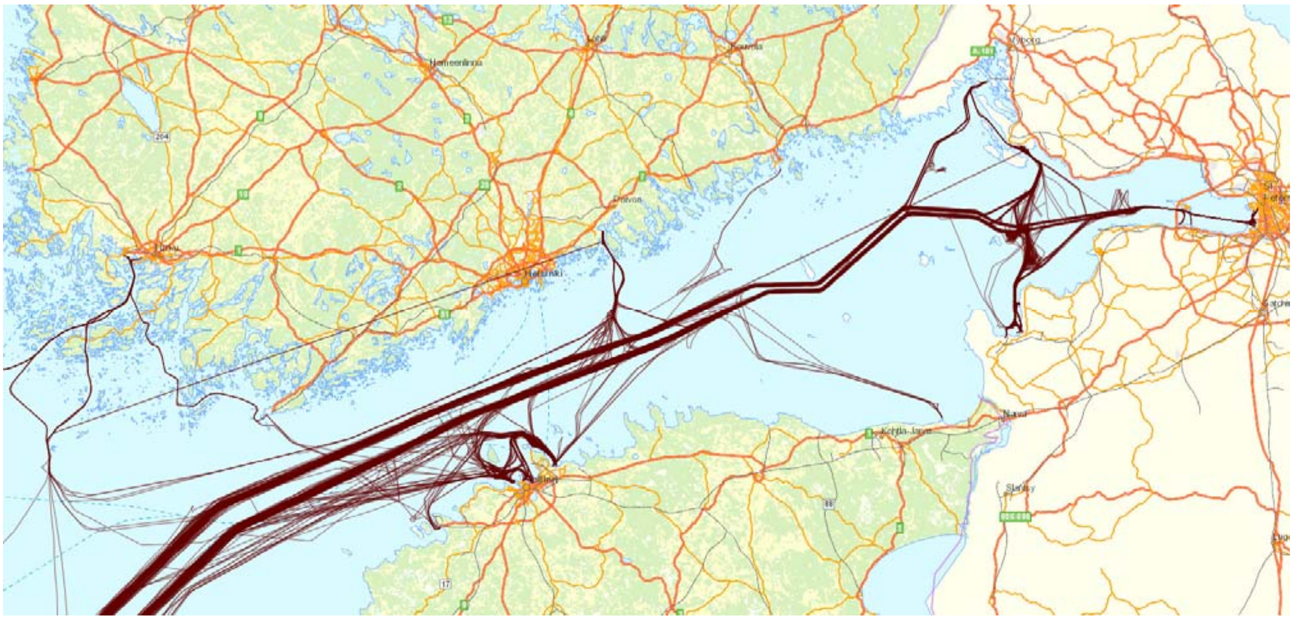


Figure 4.12 Tanker traffic in Gulf of Finland during one year (Havbase, 2019).

The largest vessels trafficking the Gulf of Finland are tankers with a length of 275 to 285 m and about 150 000 dwt.

4.2.1 Seasonal variations

Figure 4.13 shows the number of passages across the passage line per month. The most extensive traffic occurred during November followed by December and January, before a drop in traffic in February. The monthly fluctuations mainly depend on variations in general cargo vessels as well as minor variations in number of bulk carriers, other vessels and passenger vessels, which only operates during the summer months, May to October.

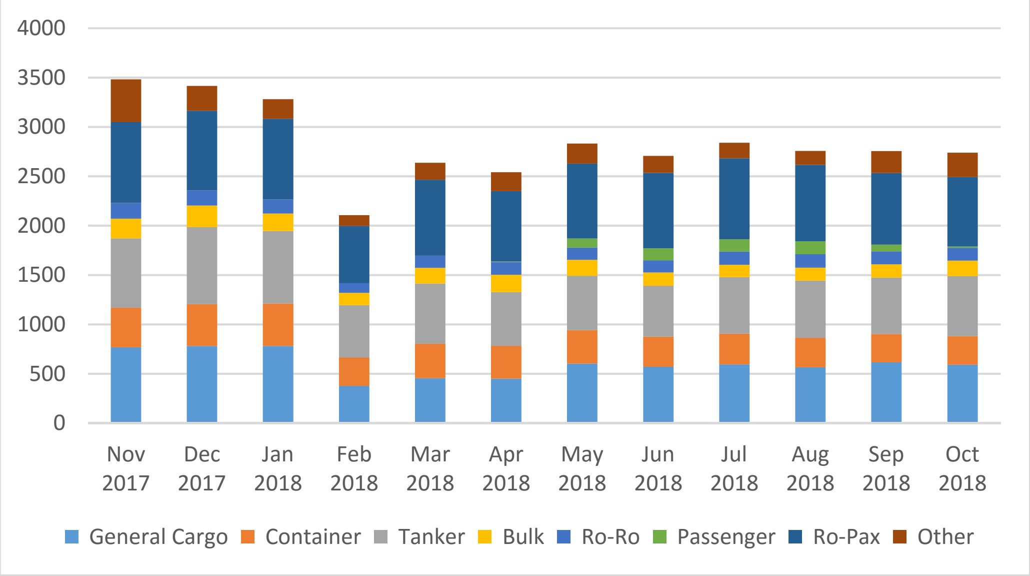


Figure 4.13 Monthly number of passages across passage line in Gulf of Finland.

The maximum ice extent in the Gulf of Finland during the analysed period was registered 2018-03-05. Figure 4.14 shows the ice chart of the maximum ice extent in 2018 which is regarded as an normal ice winter (SMHI, 2019).

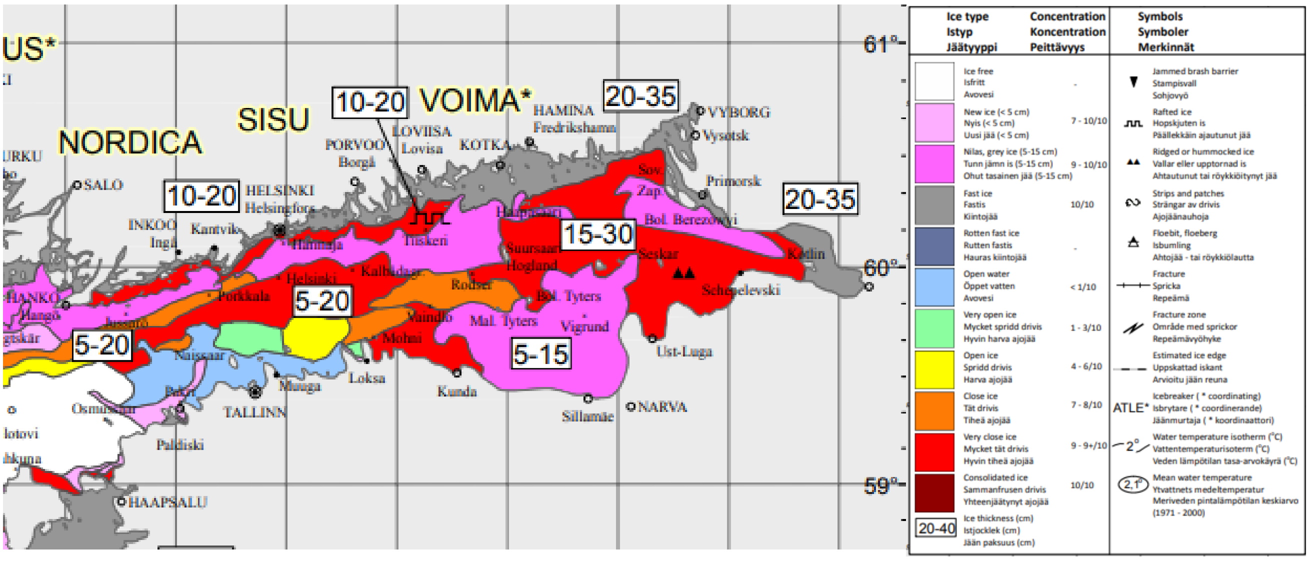


Figure 4.14 Ice chart of maximum sea ice extent during 2018, recorded 2018-03-05 (SMHI, 2019).

The ice conditions are usually harsher in the inner part of the Gulf compared to western and central part. As per 2018-03 0-05, more ice is packed along the northern shore while the south-western part around Tallinn is ice-free.

AIS data from March 2018 is compared to AIS data from September in order to identify potential differences in traffic pattern and navigational behaviours between ice covered waters and ice free waters. Figure 4.15 shows the traffic pattern in March (yellow) and September (red) respectively.

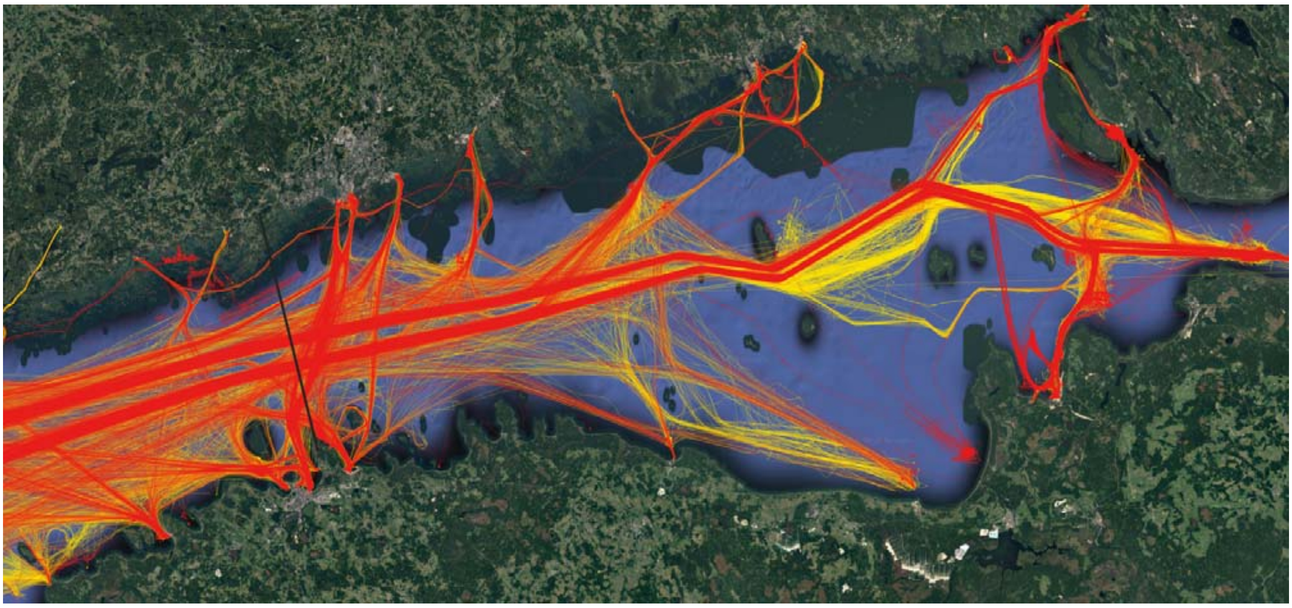


Figure 4.15 AIS data from March 2018 (yellow) and September 2018 (red).

No significant difference of traffic pattern in the area south of Helsinki can be identified, whereas in the eastern part the traffic clearly divagates from the normal routes and the TSS. The deviation can be explained by the presence of ice and that the vessels sail in the broken channel, which may be moving as the ice is moving.

The average speed for vessels passing the passage line east of Helsinki in March 2018 was higher than the average speed in September, 15.37 knots compared to 14.22 knots. The presence of ice may. The lateral distribution of vessel passages along the passage line does not clearly distinguish between March and September, which may indicate that the ice conditions in March did not restrict the navigation.

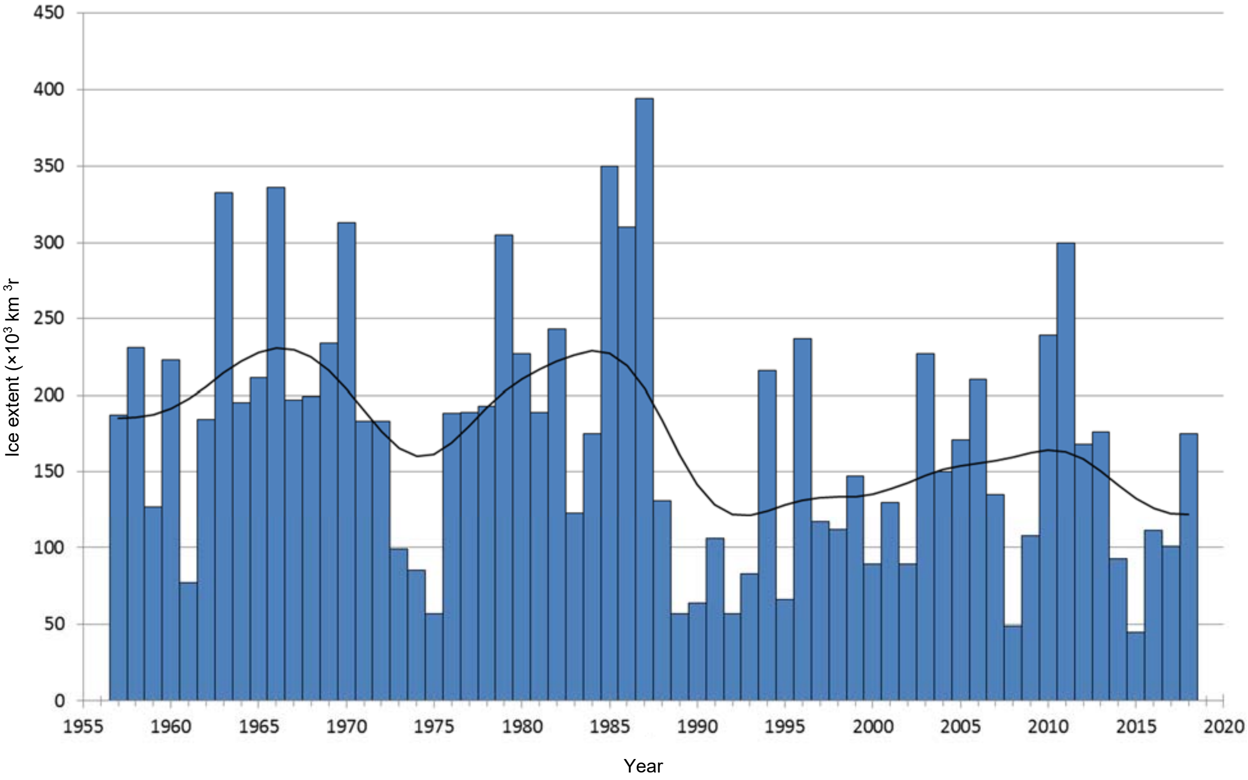


Figure 4.16 Maximum ice extent in the Baltic Sea, including Gulf of Finland, during the winters 1957 to 2018 (SMHI, 2019).

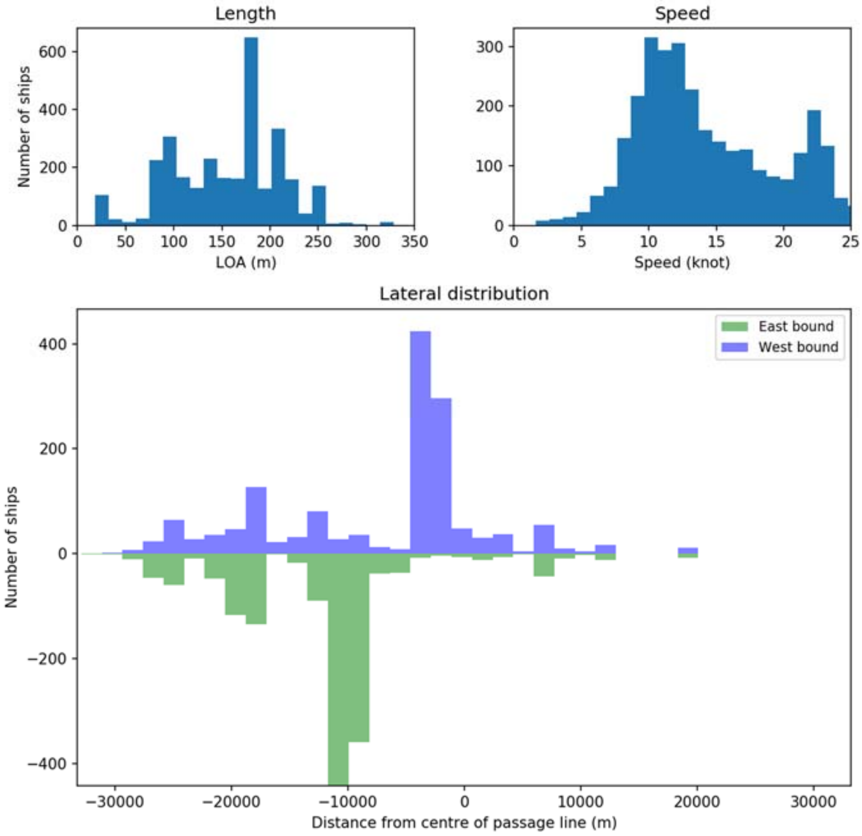


Figure 4.17 Passages across line 1 in September 2018.

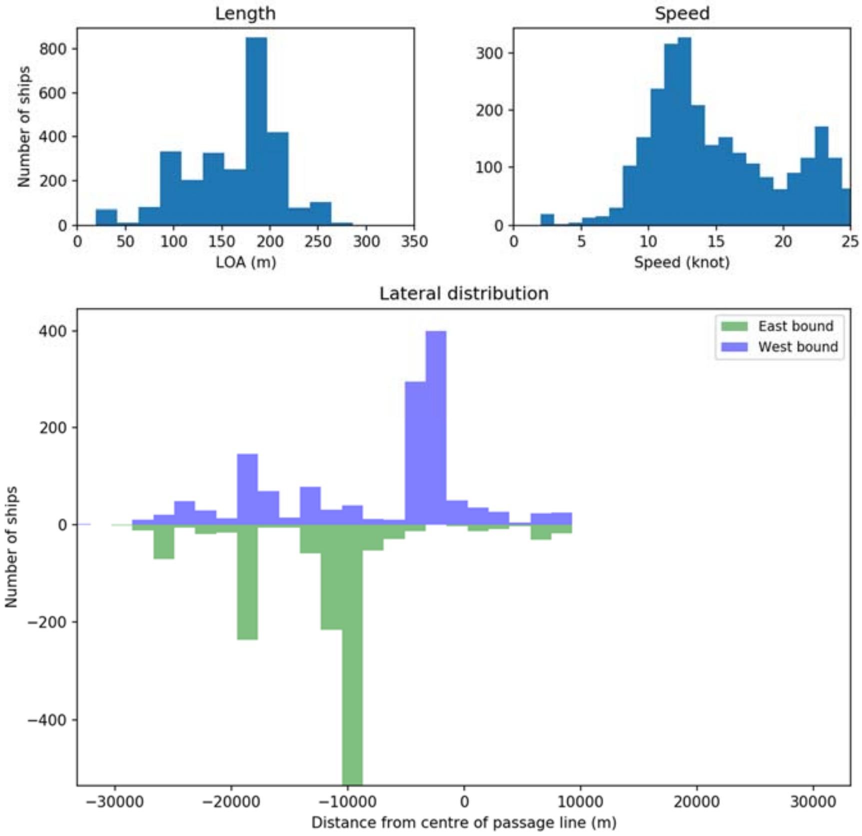


Figure 4.18 Passages across line 1 in March 2018.

4.2.2 Identification of dimensioning vessels

As for Disko Bay, based on AIS statistics a number of different vessels of different types are selected to be representative for vessels operating in the area. Table 4.3 shows the selected dimensioning vessels for the Helsinki area and the percentage distribution of the total fleet.

Table 4.3 Selected dimensioning vessels representing the fleet in waters outside of Helsinki. Vessel dimensions and tank capacities are retrieved from IHS Sea web.

Name	**Type**	**Length overall [m]**	**Fuel Capacity [m^3]**	**Tank capacity (Liquid) [m^3]**	**FS Ice Class**	**Comment**	**Percentage of total fleet**
Megastar	Ro-Pax	212	LNG: 1189		IA	Most frequent vessel, LNG fuelled	1%
Finlandia	Ro-Pax	175	RF: 1400		IA	2nd most frequent vessel, scrubber	32%
Viimsi	Product tanker	77		2538		Most frequent tanker vessel, Bunker vessel Tallinn	23%
Mastera	Crude Oil tanker	252	DF: 309 RF: 2832	116561	IA Super	Most frequent crude oil tanker and largest tanker	4%
Jeanette	General cargo	111	DF: 46 RF: 350		IA	Most frequent general cargo vessel	28%
Solong	Container	141	DF: 105 RF: 933		IA	Most frequent container	12%

5 Hazard Identification

The hazards considered are scenarios that may imply release of oil or other bunker fuel from ship into the sea.

5.1 Spill scenarios

Relevant spill scenarios may be grouped according to Figure 5.1. Vessel traffic, and scenarios related to ship cargo and ship bunker, are consider the major influencing factors for the risk of an oil spill. Figure 5.1, however, includes oil spill from offshore activities as well. Such activities are thus generally regulated on governmental and national levels which implies that they are subject to strict control, monitoring and extensive risk assessment processes.

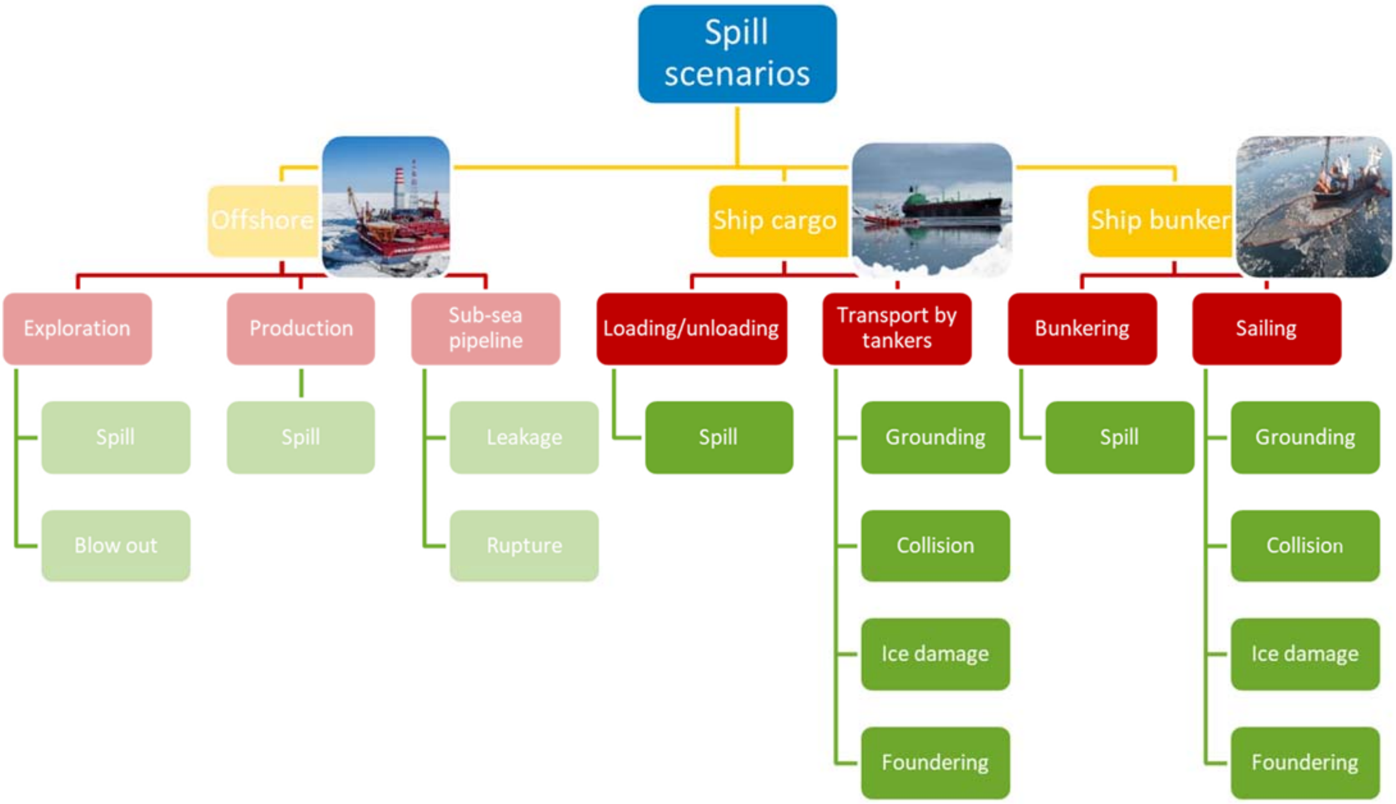


Figure 5.1 Grouping of relevant spill scenarios.

The scenarios during loading/unloading and during bunkering are related to technical or human failure in handling of oil or bunker. The probability for such scenarios may though be influenced by weather conditions and presence of ice etc. The other eight spill scenarios are accidents or hazards related to navigation and ship traffic at sea and port approaches.

5.1.1 Grounding

The crude oil tanker Exxon Valdez ran aground at Prince William Sound, Alaska, March 24, 1989, and caused an oil spill of 37,000 tonnes. With regard to the remote location of the spill and hence the lack of infrastructure as well as response capacity, the Exxon Valdez oil spill is considered to be one of the worst oil spill accidents in terms of response costs and environmental consequences.

One of the best-known cases of oil spills in ice also occurred due to a grounding accident when the Islandic container ship Godafoss ran aground in the Norwegian Hvaler-Fredrikstad archipelago. The accident caused a spill of 110 to 120 tonnes of IFO 380 bunker fuel in ice-infested waters.

Bunker tanks are often located in bottom tanks along the centreline and in case of grounding accidents, leakage from bunker tanks located directly inside the bottom plating frequently occurs. Vessels constructed 2010 or later with a total bunker capacity of 600 tonnes or more must not have their bunker fuel tanks directly inside the bottom or side hull plating and are thereby less prone to cause oil spills in case of low energy grounding accidents. In case of bottom plating penetration and tank leakage, normally only a fraction of the oil content will be discharged whilst the main fraction of the oil will remain in the tank due to hydrostatic balance with the sea water which normally has higher density than the oil.

5.1.2 Collision

Collision primarily refer to ship-ship collision, but may sometimes also incorporate ship collision with structures such as bridges, quays, platforms or icebergs (frequently referred as allisions or contact accidents). For low energy collision events, bunker tanks located along the hull side plating of the struck ship may lead to leakage or loss of tank content. High energy collision accidents may penetrate double hull structures of bunker tanks as well as cargo tanks. Tank penetration close to the waterline level will normally cause total discharge of the tank content into the sea. Tankers are normally designed with a number of separate cargo tanks, each with capacities from 5 000– 20 000 tonnes. Collision accidents when tankers are struck often result in damage of one or two cargo tanks with immediate discharge of large oil quantities.

5.1.3 Ice damage

Ice specific accidents include long term ice pressure damage as well as impact contacts with hard multi-year ice features. Hull plating may be exposed to large forces, buckling and possibly cracking resulting in minor leakages. Hull appendices like rudder and propellers may also experience ice damage and lub oil leakage from shaft sealings may occur.

5.1.4 Foundering

Foundering may follow as a result of collision, grounding, or fire accidents but may also be caused by adverse weather and hull structural failure or flooding of cargo holds and enclosed deck areas. Severe ice pressure may also cause foundering accidents. Foundered ships sinking at large water depth, often suffer sever structural damage and tank leakage frequently occurs wrecks on the sea bed.

5.2 Arctic factors

The Polar Code (The International Code for Ships Operating in Polar Waters, MEPC 68/21/Add.1 Annex 10) identifies 10 different hazards specifically related to polar waters and Arctic conditions which may lead to elevated levels of risk due to increased probability of occurrence, more severe consequences, or both (IMO, 2019):

1. Ice, as it may affect hull structure, stability characteristics, machinery systems, navigation, the outdoor working environment, maintenance and emergency preparedness tasks and malfunction of safety equipment and systems;
2. Experiencing topside icing, with potential reduction of stability and equipment functionality;
3. Low temperature, as it affects the working environment and human performance, maintenance and emergency preparedness tasks, material properties and equipment efficiency, survival time and performance of safety equipment and systems;
4. Extended periods of darkness or daylight as it may affect navigation and human performance;
5. High latitude, as it affects navigation systems, communication systems and the quality of ice imagery information;
6. Remoteness and possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compounded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the potential to affect incident response;

7. Potential lack of ship crew experience in polar operations, with potential for human error;
8. Potential lack of suitable emergency response equipment, with the potential for limiting the effectiveness of mitigation measures;
9. Rapidly changing and severe weather conditions, with the potential for escalation of incidents; and
10. The environment with respect to sensitivity to harmful substances and other environmental impacts and its need for longer restoration.

The presence of number 1 to 9 above may affect the probability of a spill scenario compared to operation in other waters. Dependent on geographical location concerned and time of the year, the influence of each factor will vary.

The effect of the identified Arctic risk influencing factors are difficult to quantify for general application in risk assessment but are further discussed from a qualitative case by case perspective in the trial site applications in chapter 5.4.1 and 5.5.1.

5.3 Accident statistics

Figure 5.2 shows accidents reported in the sea-web database. Within the arctic region based on IMO's definition there are 152 reported accidents between 1996 and 2018 (yellow dots). Of these are six accidents reported to have caused oil spill.

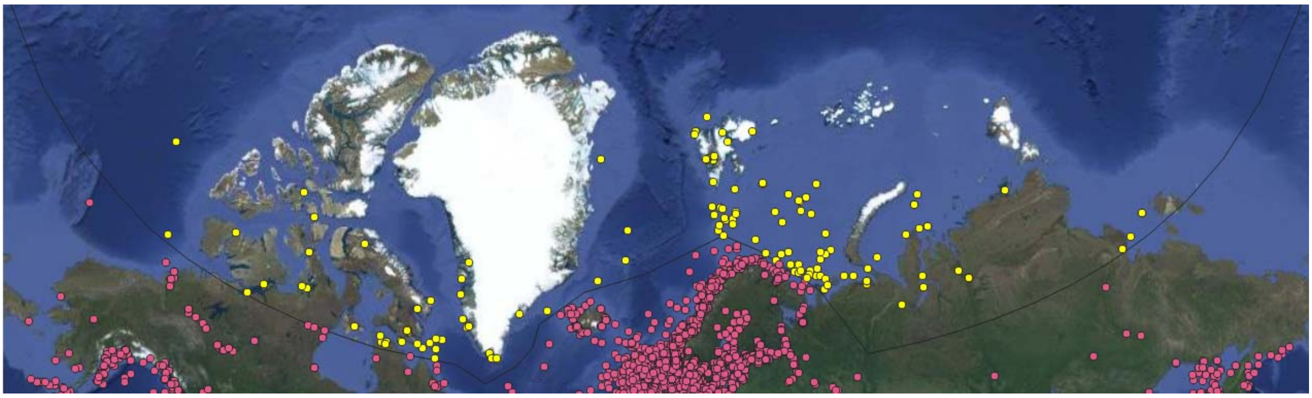


Figure 5.2 Accidents in Arctic waters (yellow dots) reported in sea-web database.

The most frequent casualty type based on reported data is Hull and/or machinery damage, see Table 5.1. Of the incidents reported as hull and/or machinery damage only one have been reported to cause a pollution; an oil spill of two litres. Wrecked/stranded includes grounding incidents.

Table 5.1 Number of incidents reported incidents in Arctic based on casualty type.

Casualty type	**Number of incidents**
Hull and/or machinery damage	73
Wrecked/stranded	32
Collision	19
Contact	15
Fire/Explosion	7
Foundered	6

Most incidents are reported in August and September, see Figure 5.3, which also reflects the period with most traffic in the Arctic region.

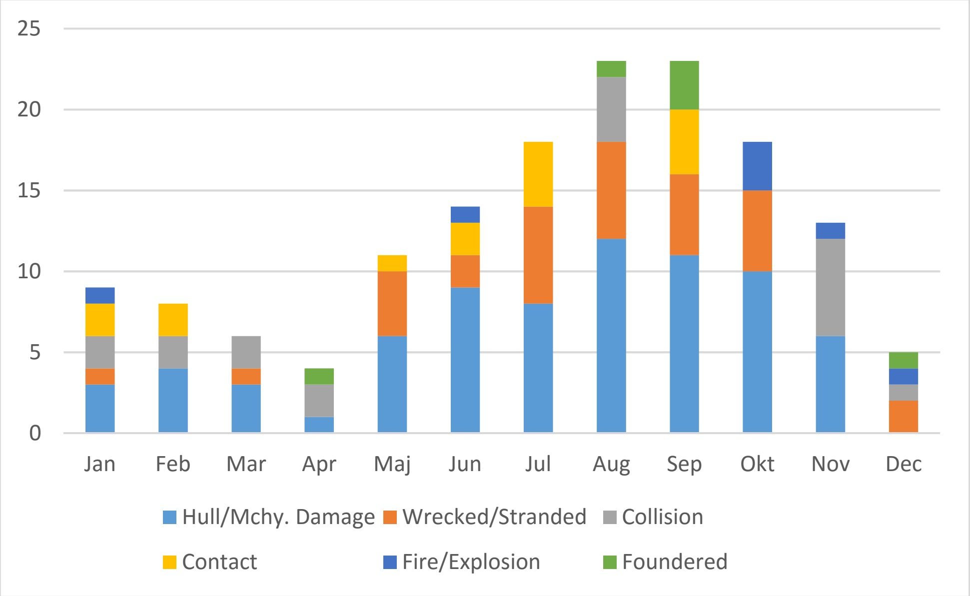


Figure 5.3 Number of accidents per month and per casualty type reported in Arctic during 1996 to 2017

Bulk carriers are the most frequent vessel type involved in accident in Arctic, see Figure 5.4.

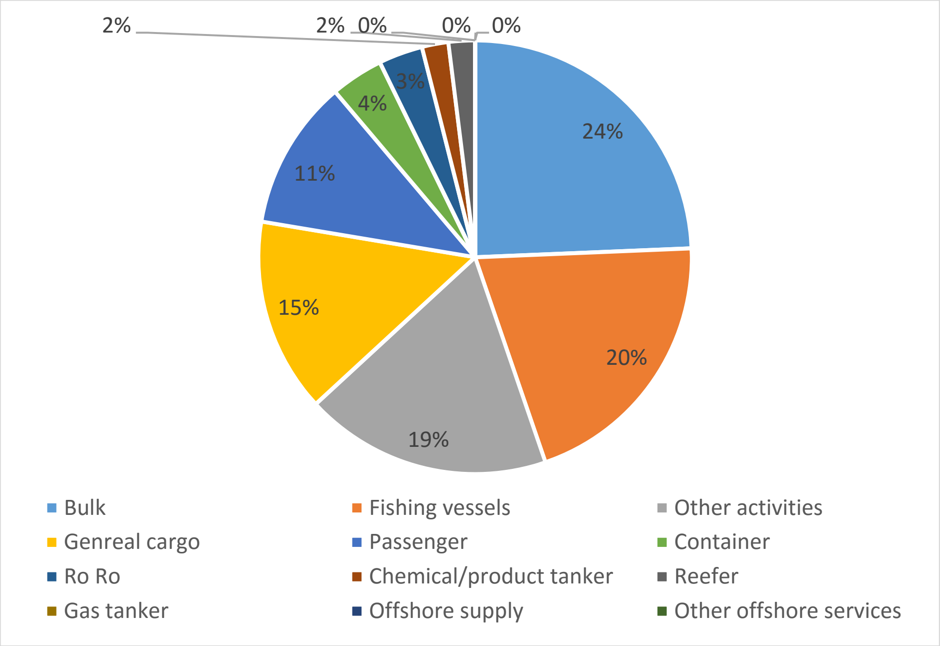


Figure 5.4 Percentage of accident by vessel type.

5.4 Trial site – Disko Bay

The traffic during winter is very sparse due to the harsh arctic conditions and the absence of icebreaking assistance. With regard to the few number of vessels operating in the area, the probability of ship-ship collisions is very low. Thick level ice also limits the probability of groundings as it restricts the navigational lanes. Ice damage as well as foundering are hazards to be considered for the area during a major part of the year. There is no bunker vessel operating frequently in the area and potential spill from bunkering operations are therefore limited to harbours. There are no larger oil ports in the area and no crude oil tankers operate in the area around Disko Bay. Product tankers are supplying the harbours along the west coast of Greenland with oil products and fuel. However, loading/unloading of oil products are limited to unloading in the harbours in the area.

Relevant spill scenarios for Disko bay includes:

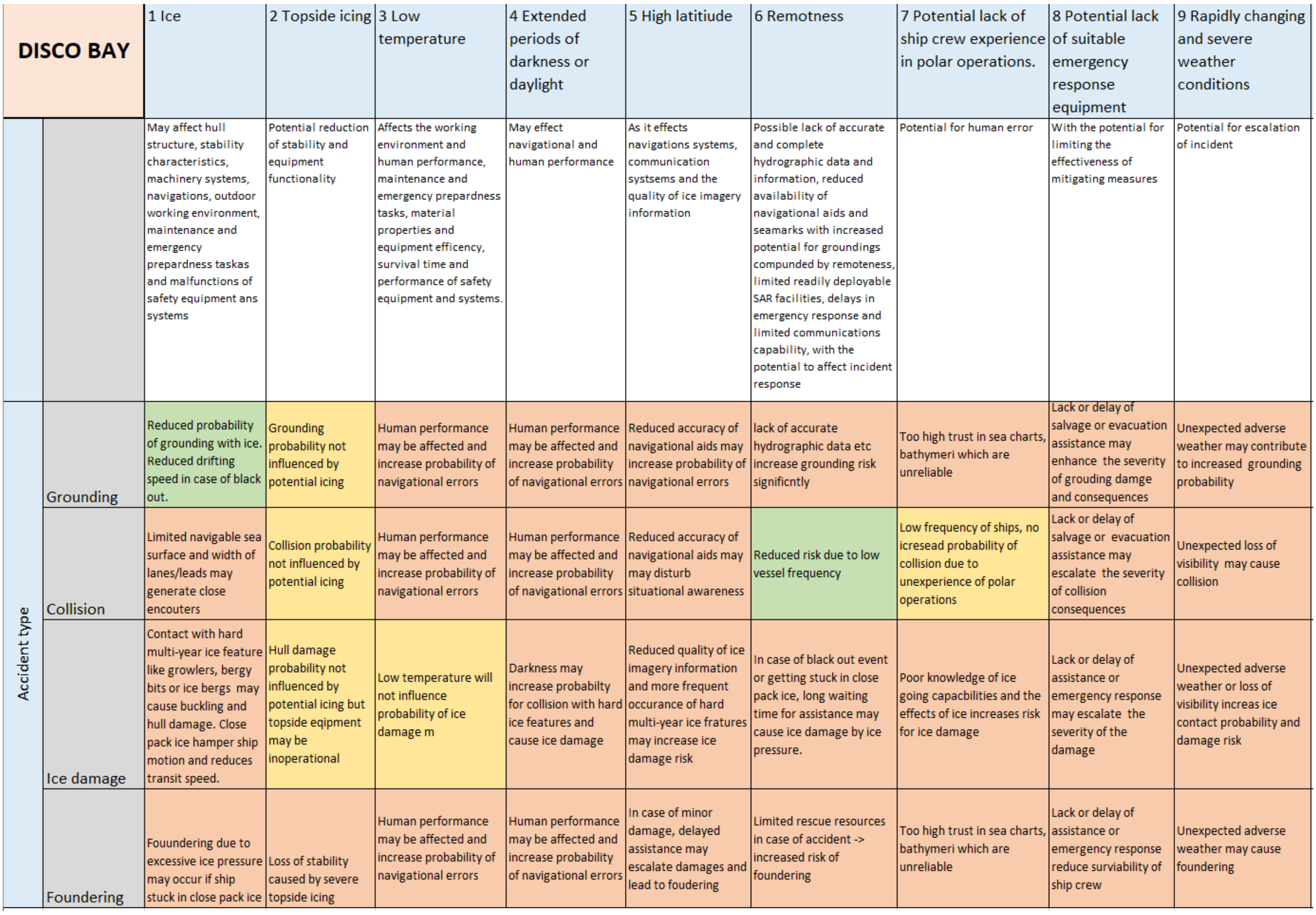
- Spill of oil products transported as cargo by product tankers caused by grounding, ice damage or foundering
- Spill of bunker fuel from ship traffic caused by grounding, ice damage or foundering

Smaller spills of bunker fuel or oil products may also occur in the harbours during bunkering or unloading activities.

5.4.1 Identification of relevant arctic factor

The applicability of arctic factors for the conditions in Disko Bay have been evaluated, see Table 5.2. The potential impact of each factor for respectively accident type; grounding, collision, ice damage and foundering, are estimated qualitatively on a comparable level.

Table 5.2. Comparative qualitative assessment of identified Arctic factors of relevance for the Disko Bay trial site. The table cells with green background indicate that risks are reduced by the presence of ice. Yellow colour indicates indifferent risks with regard to the identified Arctic factors. The light red cells indicate aspects where identified Arctic factors contribute to increased risks.



DISCO BAY		1 Ice	2 Topside icing	3 Low temperature	4 Extended periods of darkness or daylight	5 High latitiude	6 Remotness	7 Potential lack of ship crew experience in polar operations.	8 Potential lack of suitable emergency response equipment	9 Rapidly changing and severe weather conditions
		May affect hull structure, stability characteristics, machinery systems, navigations, outdoor working environment, maintenance and emergency prepardness taskas and malfunctions of safety equipment ans systems	Potential reduction of stability and equipment functionality	Affects the working environment and human performance, maintenance and emergency prepardness tasks, material properties and equipment efficency, survival time and performance of safety equipment and systems.	May effect navigational and human performance	As it effects navigations systems, communication systsems and the quality of ice imagery information	Possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compunded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the potential to affect incident response	Potential for human error	With the potential for limiting the effectiveness of mitigating measures	Potential for escalation of incident
Accident type	Grounding	Reduced probability of grounding with ice. Reduced drifting speed in case of black out.	Grounding probability not influenced by potential icing	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	Reduced accuracy of navigational aids may increase probability of navigational errors	lack of accurate hydrographic data etc increase grounding risk significntly	Too high trust in sea charts, bathymeri which are unreliable	Lack or delay of salvage or evacuation assistance may enhance the severity of grouding damge and consequences	Unexpected adverse weather may contribute to increased grounding probability
	Collision	Limited navigable sea surface and width of lanes/leads may generate close encouters	Collision probability not influenced by potential icing	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	Reduced accuracy of navigational aids may may disturb situational awareness	Reduced risk due to low vessel frequency	Low frequency of ships, no icresead probability of collision due to unexperience of polar operations	Lack or delay of salvage or evacuation assistance may escalate the severity of collision consequences	Unexpected loss of visibility may cause collision
	Ice damage	Contact with hard multi-year ice feature like growlers, bergy bits or ice bergs may cause buckling and hull damage. Close pack ice hamper ship motion and reduces transit speed.	Hull damage probability not influenced by potential icing but topside eqipment may be inoperational	Low temperature will not influence probability of ice damage m	Darkness may increase probabilty for collision with hard ice features and cause ice damage	Reduced quality of ice imagery information and more frequent occurance of hard multi-year ice fratures may increase ice damage risk	In case of black out event or getting stuck in close pack ice, long waiting time for assistance may cause ice damage by ice pressure.	Poor knowledge of ice going capacbilities and the effects of ice increases risk for ice damage	Lack or delay of assistance or emergency response may escalate the severity of the damage	Unexpected adverse weather or loss of visibility increas ice contact probability and damage risk
	Foundering	Fouundering due to excessive ice pressure may occur if ship stuck in close pack ice	Loss of stability caused by severe topside icing	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	In case of minor damage, delayed assistance may escalate damages and lead to foudering	Limited rescue resources in case of accident -> increased risk of foundering	Too high trust in sea charts, bathymeri which are unreliable	Lack or delay of assistance or emergency response reduce surviability of ship crew	Unexpected adverse weather may cause foundering

5.4.2 Accident statistics Disko Bay

Figure 5.5 shows reported accident around the south western part of Greenland. There are three incident along the coast in the vicinity of Disko Bay (numbered 1-3 in figure) and one incident reported south west of Disko Bay at the Canadian coast (number 4).

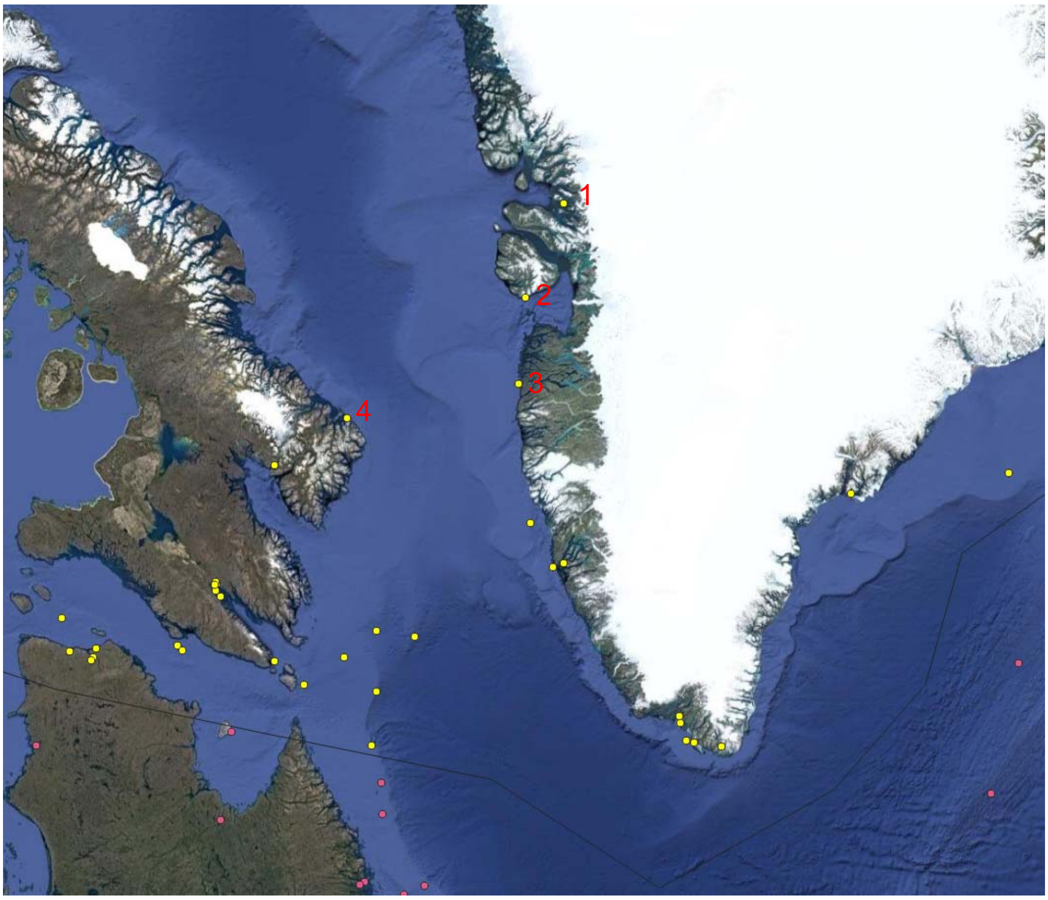


Figure 5.5 Reported accident in the area around Disko Bay, Greenland.

Description of the incidents are listed in Table 5.3. None of the accidents has been reported to have caused any oil spill. All accidents are registered during periods when the area can be expected to be ice free (June to October).

Table 5.3 Description of accidents reported in the area around Disko Bay.

	Casualty type	Date	Ship name	Pollution	Description
1	Wrecked/ Stranded	2017-09-02	Pajuttaat	No	General Cargo ship stranded in the Uummannaq fjord. No pollution or injuries reported. Refloated 7 hours later by own means and arrived at Aasiaat, greenland for cargo discharge and diving inspection. Sustained significant damage to hull. Subsequently arrived at Nuuk, Greenland on 18/09/17 for repairs.
2	Wrecked/ Stranded	2007-06-27	Disko II	No	Tug/Stand-By Safety Vessel stranded off Qeqertarsuaq island in calm weather. Subsequently refloated, repaired and returned to service. 52 passengers and 2 tour guides were evacuated to shore by ship’s lifeboats and other small local vessels as a precaution. All 18 crew members remained on board. Refloated on 29/06/07. Divers inspection effected. Sustained cracks in bulbous bow and dents to bottom of hull. Proceeded to shipyard at Nuuk for temporary repairs.

	Casualty type	Date	Ship name	Pollution	Description
3	Fire/Explosion	2011-10-06	Aleqa	No	Cement Carrier caught fire west of Kangeq, Greenland and requested assistance. Crew abandoned vessel to lifeboats. Extent of damage unknown.
4	Hull/machinery damage	2014-08-20	Qamutik	No	Research vessel. Sustained electrical transformer failure in Derban hanour off Derban island, Canada. Subsequently repaired and continued on voyage. Transformer isolated and repairs effected.

5.5 Trial site – Helsinki, Gulf of Finland

The traffic in Gulf of Finland is intense compared to Disko Bay. The large number of vessel operating in the area implies that the risk of collision is considerable. The traffic includes crude oil tankers as well as product- and chemical tankers which implies that large oil spills scenarios related to ship cargo are relevant. The largest oil terminals are located in the inner part of the Gulf. Large quantities of oil products area also loaded/unloaded at the refinery in Porvo. Loading/unloading of smaller quantities are also conducted in Helsingfors as well as in other smaller ports in area. There are also several bunker vessels operating in the area implying that spills during ship-to-ship bunkering off the coast may occur, and bunkering spills are not limited to the harbour areas.

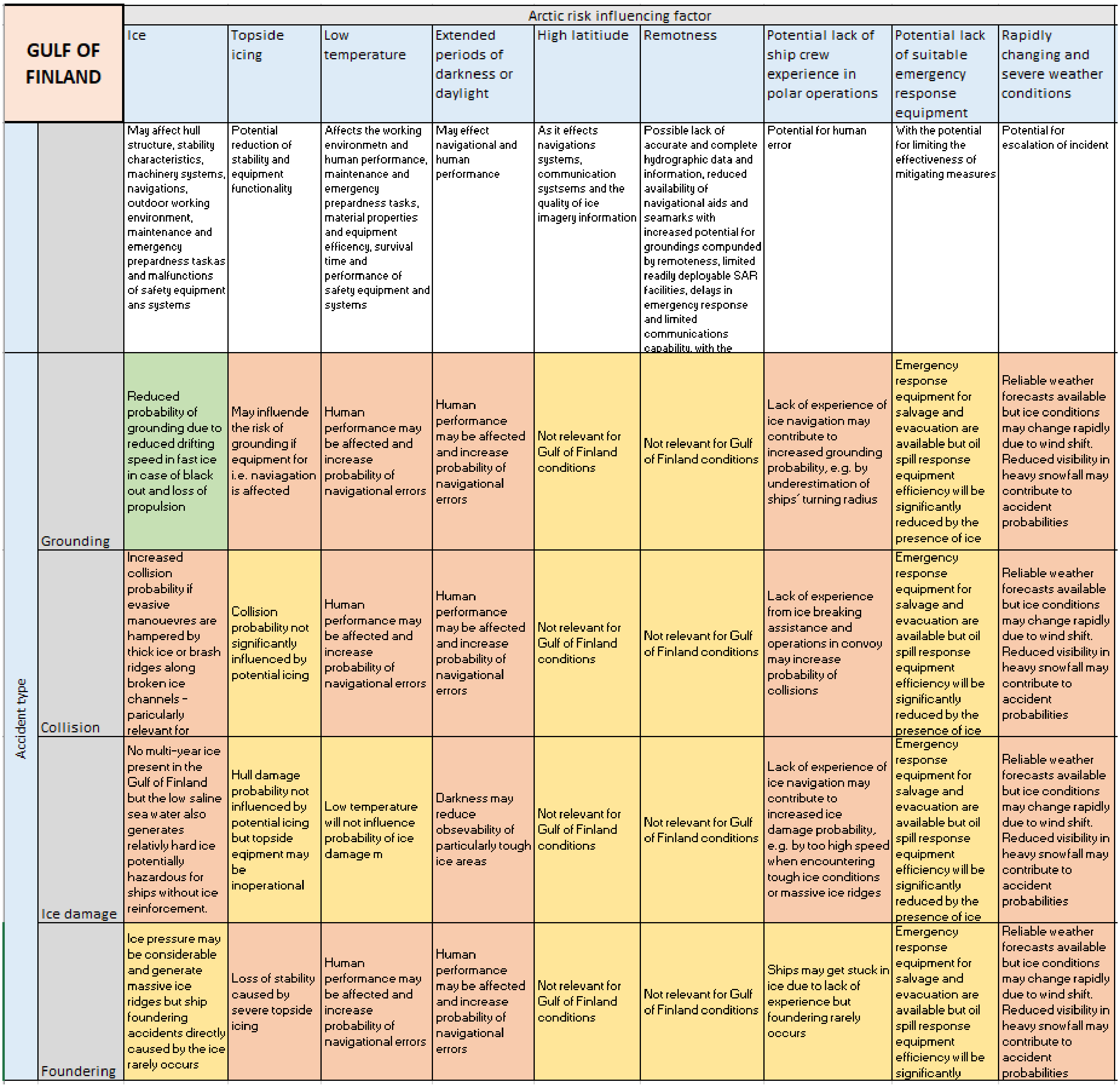
Relevant spill scenarios for Disko bay includes:

- Spills of chip cargo (bunker fuel) related to bunkering
- Spills of ship cargo due to grounding or collision. Even ice damage or foundering may occur and cause an oil spill but the hazardous is smaller than in arctic regions with more severe ice conditions.
- Spills of bunker fuel due to grounding or collision as well as due to ice damage or foundering.

5.5.1 Identification of relevant Arctic factors

Table 5.4 shows the evaluation of applicability of Arctic factors for the area south of Helsinki.

Table 5.4 Comparative qualitative assessment of identified Arctic factors of relevance for the Disko Bay trial site. The table cells with green background indicate that risks are reduced by the presence of ice. Yellow colour indicates indifferent risks with regard to the identified Arctic factors. The light red cells indicate aspects where identified Arctic factors contribute to increased risks



GULF OF FINLAND		Arctic risk influencing factor								
		Ice	Topside icing	Low temperature	Extended periods of darkness or daylight	High latitiude	Remotness	Potential lack of ship crew experience in polar operations	Potential lack of suitable emergency response equipment	Rapidly changing and severe weather conditions
		May affect hull structure, stability characteristics, machinery systems, navigations, outdoor working environment, maintenance and emergency prepardness taskas and malfunctions of safety equipment ans systems	Potential reduction of stability and equipment functionality	Affects the working environmetn and human performance, maintenance and emergency prepardness tasks, material properties and equipment efficency, survival time and performance of safety equipment and systems	May effect navigational and human performance	As it effects navigations systems, communication systsems and the quality of ice imagery information	Possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compunded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the	Potential for human error	With the potential for limiting the effectiveness of mitigating measures	Potential for escalation of incident
Accident type	Grounding	Reduced probability of grounding due to reduced drifting speed in fast ice in case of black out and loss of propulsion	May influende the risk of grounding if equipment for i.e. naviagation is affected	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	Not relevant for Gulf of Finland conditions	Not relevant for Gulf of Finland conditions	Lack of experience of ice navigation may contribute to increased grounding probability, e.g. by underestimation of ships´ turning radius	Emergency response equipment for salvage and evacuation are available but oil spill response equipment efficiency will be significantly reduced by the presence of ice	Reliable weather forecasts available but ice conditions may change rapidly due to wind shift. Reduced visibility in heavy snowfall may contribute to accident probabilities
	Collision	Increased collision probability if evasive manouevres are hampered by thick ice or brash ridges along broken ice channels - paricularly relevant for	Collision probability not significantly influenced by potential icing	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	Not relevant for Gulf of Finland conditions	Not relevant for Gulf of Finland conditions	Lack of experience from ice breaking assistance and operations in convoy may increase probability of collisions	Emergency response equipment for salvage and evacuation are available but oil spill response equipment efficiency will be significantly reduced by the presence of ice	Reliable weather forecasts available but ice conditions may change rapidly due to wind shift. Reduced visibility in heavy snowfall may contribute to accident probabilities
	Ice damage	No multi-year ice present in the Gulf of Finland but the low saline sea water also generates relativly hard ice potentially hazardous for ships without ice reinforcement.	Hull damage probability not influenced by potential icing but topside eqipment may be inoperational	Low temperature will not influence probability of ice damage m	Darkness may reduce obsevability of particularly tough ice areas	Not relevant for Gulf of Finland conditions	Not relevant for Gulf of Finland conditions	Lack of experience of ice navigation may contribute to increased ice damage probability, e.g. by too high speed when encountering tough ice conditions or massive ice ridges	Emergency response equipment for salvage and evacuation are available but oil spill response equipment efficiency will be significantly reduced by the presence of ice	Reliable weather forecasts available but ice conditions may change rapidly due to wind shift. Reduced visibility in heavy snowfall may contribute to accident probabilities
	Foundering	Ice pressure may be considerable and generate massive ice ridges but ship foundering accidents directly caused by the ice rarely occurs	Loss of stability caused by severe topside icing	Human performance may be affected and increase probability of navigational errors	Human performance may be affected and increase probability of navigational errors	Not relevant for Gulf of Finland conditions	Not relevant for Gulf of Finland conditions	Ships may get stuck in ice due to lack of experience but foundering rarely occurs	Emergency response equipment for salvage and evacuation are available but oil spill response equipment efficiency will be significantly	Reliable weather forecasts available but ice conditions may change rapidly due to wind shift. Reduced visibility in heavy snowfall may contribute to accident probabilities

5.5.2 Accident statistics Gulf of Finland

Figure 5.6 shows the reported accidents in Gulf of Finland between 1996 and 2017 (pink dots). The number of accidents reported within the area marked with green line is 266. Most accidents are reported in the eastern part.

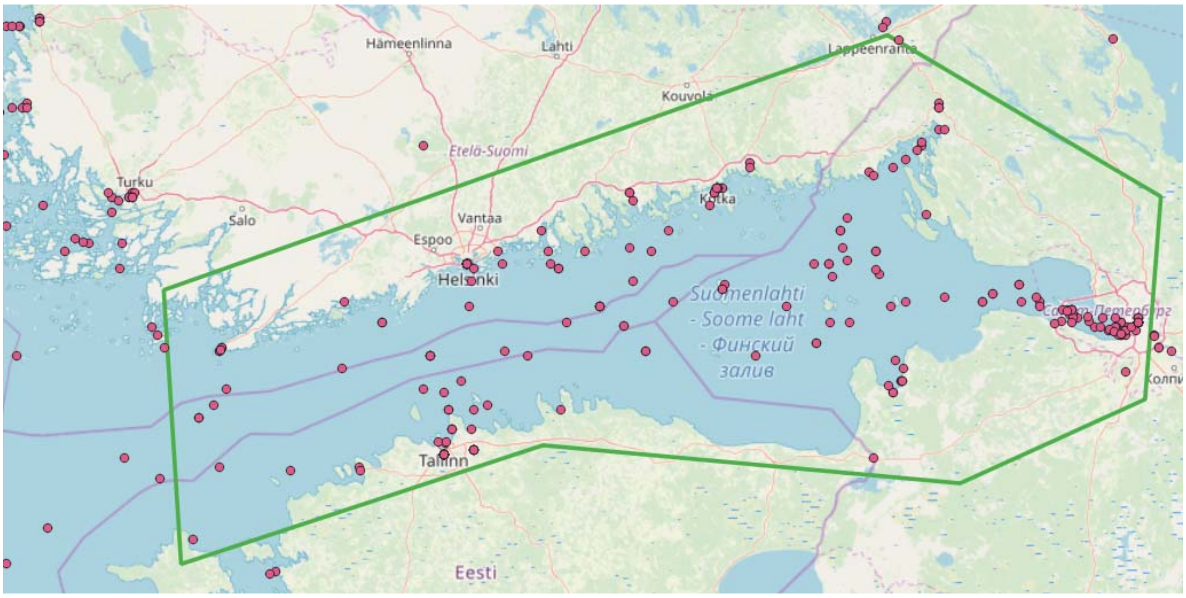


Figure 5.6 Reported accidents in Gulf of Finland.

The most frequent casualty type of the reported accidents is collision, see Table 5.5. Figure 5.7 shows that most accidents have occured in March when the number of collsions is high.

Table 5.5 Number of accidents reported in Gulf of Finland based on casualty type.

Casualty type	Number of incidents
Collision	88
Wrecked/stranded	81
Hull and/or machinery damage	35
Fire/Explosion	32
Contact	25
Foundered	5

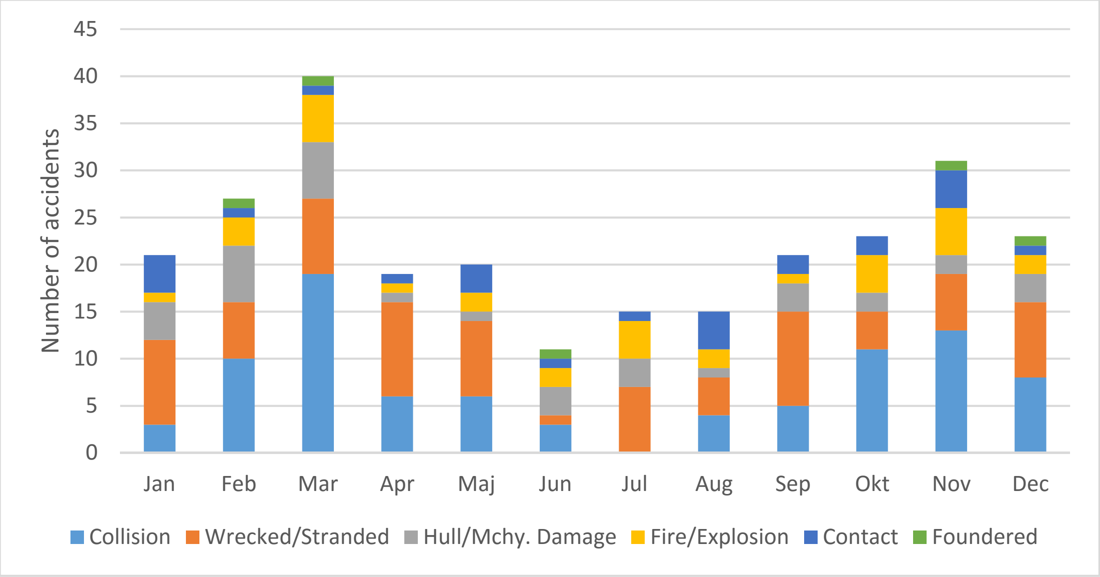


Figure 5.7 Number of accidents per month and per casualty type reported in Gulf of Finland during 1996 to 2017.

Other analyses of accidents in Finnish sea areas also shows that collision is the most frequent accident type during winter navigation (Valdez Banda, Goerlandt, Montewka, & Kujala, 2015). Even though icebreaker assistance implies increased risk for collision, the total accident risk is reduced compared to ship independent navigation. Of the reported 28 accidents in Gulf of Finland during the analysed period (winters 2002-2003 and 2009-2012), 24 occurred under ship independent navigation and only 4 accidents with icebreaker assistance.

About 80 accidents are reported in area the between Helsinki and Tallinn, see Figure 5.8.

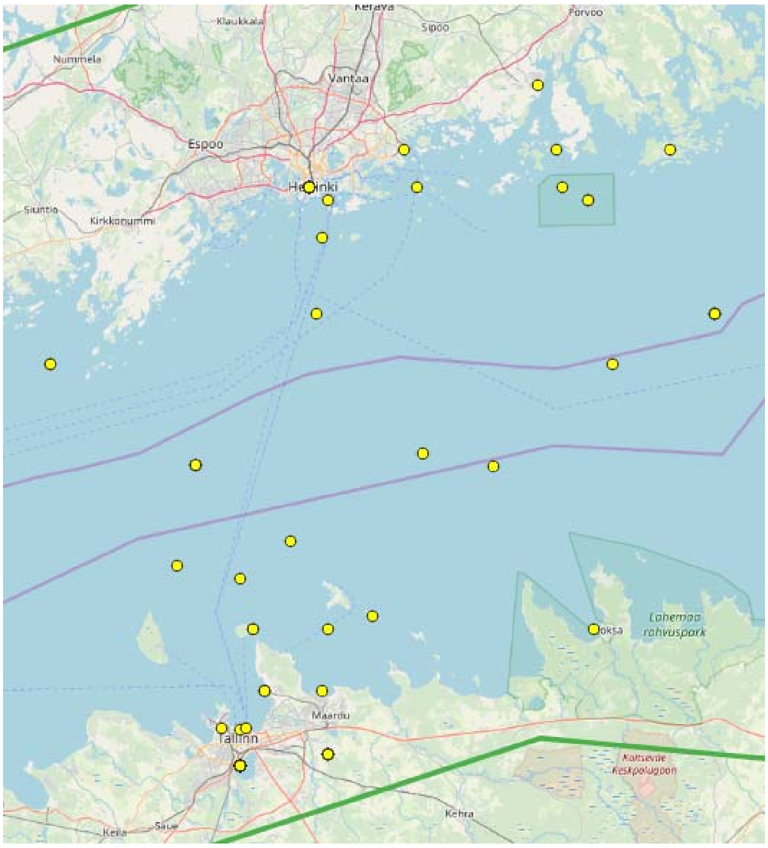


Figure 5.8 Accidents reported in thea area between Helsinki and Tallinn.

Figure 5.9 shows the distribution by month and the casualty of the 80 reported accidents. Most accident are registered in March, where the frequency of collisions as well as accidents caused by wrecked/stranded, hull/machinery damage and fire/explosion is high compared to the other months.

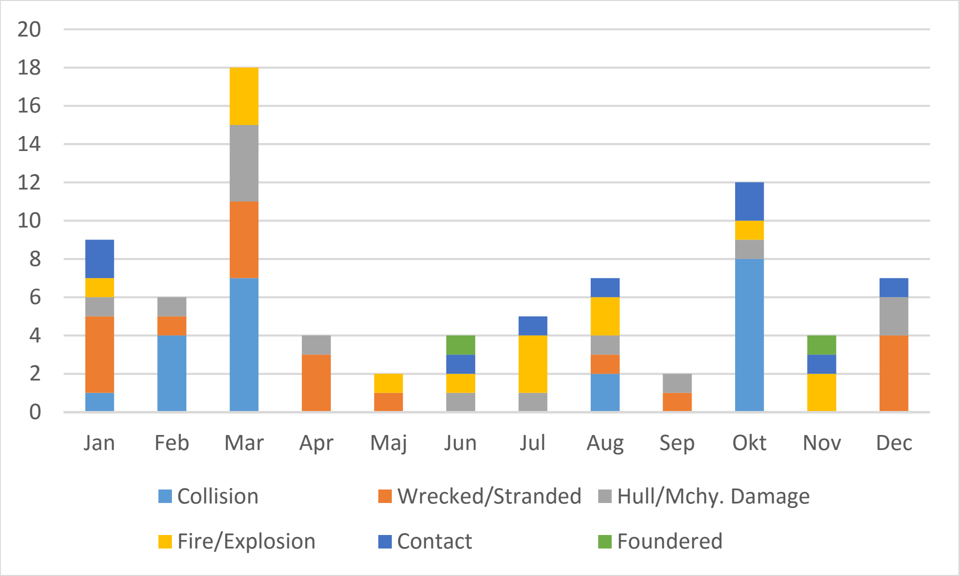


Figure 5.9 Number of accidents by month and casualty type reported in area between Helsinki and Tallinn during 1996 to 2017.

6 Probability analysis

There are tools available for estimations of probability and risk levels based on accident- and traffic statics. None of the tools are developed for winter navigation, navigation in ice, or for Arctic conditions. Dependent on the area, its specific traffic and conditions, different tools may be applicable.

6.1 Quantitative analysis of ship accident frequency

By combining ship traffic statistics, i.e. AIS-data, and historical statistics of ship accidents, an accident index figure may be estimated for a certain area.

In Table 6.1, a monthly accident index for Arctic is calculated. The calculated accident index is based on accumulated sailed distances in Arctic per month during 2016 (derived from AIS-registrations) and accidents statistics for Arctic between 1996 and 2017 (22 years) (see section 5.3).

Table 6.1 Monthly accident index (accident/nm) for Arctic based on sailed distance in Arctic region during 2016 and accident statistics from 1996-2017.

	Sailed distance Arctic 2016 (nm)	**Accidents in Arctic 1996-2017**	**Average number of accidents in Arctic**	**Accident index (accident/nm)**
January	1 949 525	9	0,4	2,1E-07
February	2 015 409	8	0,4	1,8E-07
March	2 073 272	6	0,3	1,3E-07
April	2 268 508	4	0,2	8,0E-08
May	2 291 053	11	0,5	2,2E-07
June	2 465 289	14	0,6	2,6E-07
July	2 785 406	18	0,8	2,9E-07
August	3 174 724	23	1,0	3,3E-07
September	3 236 995	23	1,0	3,2E-07
October	2 813 602	18	0,8	2,9E-07
November	2 319 160	13	0,6	2,5E-07
December	1 763 459	5	0,2	1,3E-07
Yearly	*29 156 402*	*152*	*6,9*	*2,4E-07*

The highest accident index is obtained in August; $3{,}3 \cdot 10^{-7}$ accidents/sailed nautical mile. August, together with September, are the months with most traffic and the months with least ice. This does not support the presence of any Arctic factors supposed to contribute to higher accident index during the winter months and ice season.

Table 6.2 shows corresponding accident index for Gulf of Finland. The highest index is obtained in March; $4{,}0 \cdot 10^{-6}$ accidents/sailed nautical mile. Also February obtains a relatively high index; $2{,}8 \cdot 10^{-6}$. These results, however, indicate a correlation between the presence of sea ice and accident index as registered peak values correspond well to the normal period of most severe ice conditions in Gulf of Finland.

Table 6.2 Monthly accident index (accident/nm) for Gulf of Finland (GoF) based on sailed distance in GoF between November 2017 and October 2018, and accident statistics from 1996-2017.

	Sailed distance GoF Nov 2017 - Oct 2018 (nm)	Accidents in GoF 1996-2017	Average number of accidents	Accident index (accidents/nm)
January	516 184	21	0,95	1,8E-06
February	439 355	27	1,23	2,8E-06
Mars	458 616	40	1,82	4,0E-06
April	472 162	19	0,86	1,8E-06
May	530 696	20	0,91	1,7E-06
June	529 050	11	0,50	9,5E-07
July	547 609	15	0,68	1,2E-06
August	552 986	15	0,68	1,2E-06
September	519 425	21	0,95	1,8E-06
October	475 859	23	1,05	2,2E-06
November	555 371	31	1,41	2,5E-06
December	570 781	23	1,05	1,8E-06
Yearly	*6 168 094*	*266*	*12,09*	*2,0E-06*

The overall accident index for Arctic is lower than the index calculated for the Gulf of Finland. Hence, the result does not directly reflect the applicability of Arctic factors as those are expected to be larger and more significant in Arctic compared to Gulf of Finland. There may be several explanations to the differences in accident index, for example:

- Larger analysis area for the Arctic case means more open sea transit distances and fewer port calls and port entrance manoeuvres
- Differences in operating fleet. Vessels suitable for operation in ice. Ice classed tonnage
- Less dense traffic reduces probability for collision significantly in ice free waters

6.1.1 Tools for quantification of accident frequency

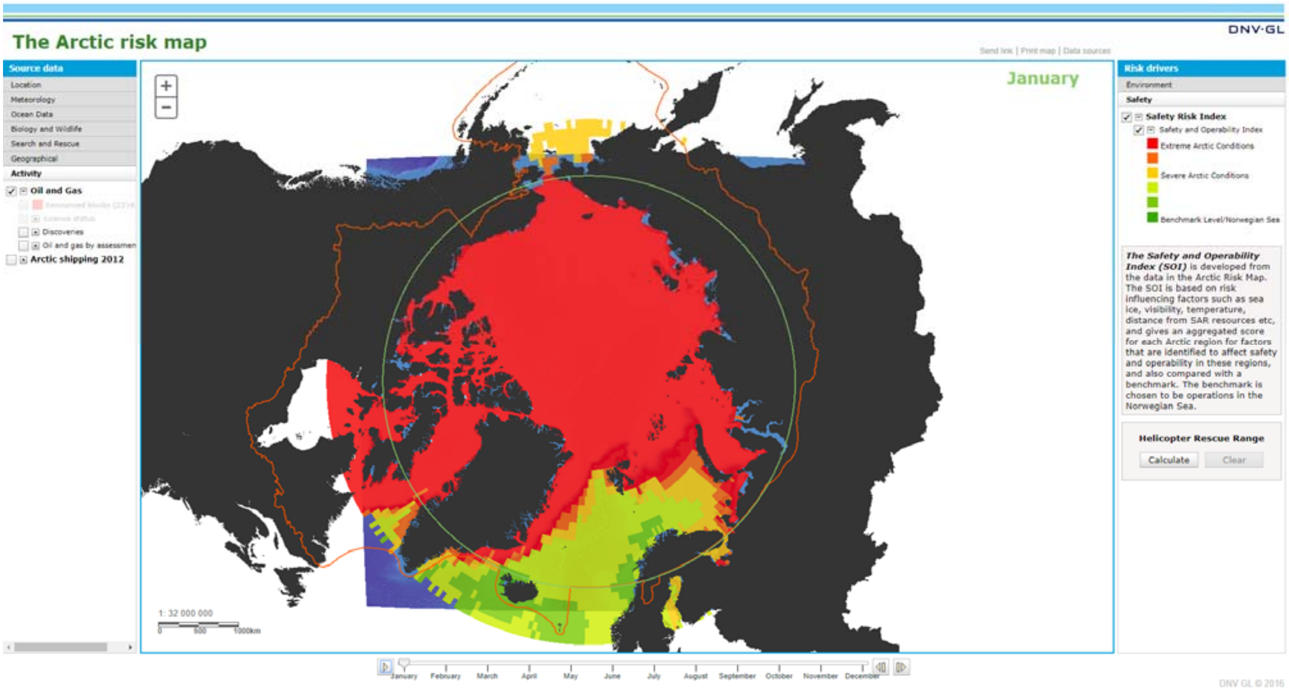
The software IWRAP (IALA Waterway Risk Assessment Programme) is a geometric probability model for estimation of expected grounding and collision frequency based on specified traffic. The tool requires relatively dense traffic in order to define relevant traffic lanes to be divided into so called legs for calculation purposes.

For Norwegian waters, the AISyRisk tool may be used to estimate the probability of ship accidents. The calculation model can be applied for other sea areas as well but does not account specifically for arctic conditions and navigation in ice.

6.2 Qualitative analysis of Arctic factors influence

The Arctic risk map, developed by DNV GL, defines a *Safety and Operability Index (SOI*) which is based on factors that are identified to affect safety and operability in Arctic. The factors include sea ice, visibility, temperature, distance from SAR resources etc, and gives an aggregated score for each Arctic region. The aggregated score is compared to a benchmark which is chosen to be operations in Norwegian waters (DNV GL, 2016).

The Arctic risk map tool is available online and provides information of changes in the environmental conditions for different regions, see Figure 6.1.



The Safety and Operability Index (SOI) is developed from the data in the Arctic Risk Map. The SOI is based on risk influencing factors such as sea ice, visibility, temperature, distance from SAR resources etc, and gives an aggregated score for each Arctic region for factors that are identified to affect safety and operability in these regions, and also compared with a benchmark. The benchmark is chosen to be operations in the Norwegian Sea.

Figure 6.1 The online tool The Arctic risk map showing Safety and Risk Index for Arctic in January (DNV GL, 2016).

The tool may be utilized to estimate the influence of Arctic factors during different parts of year when a risk assessment for an Arctic region is carried out.

6.3 Trial site – Disko Bay

Due to the sparse traffic and the absence of any clear pattern, tools like IWRAP are not applicable for Disko Bay. The accident index for Arctic defined in Table 6.1 shows that the accident probability is relatively low with the highest index in August. The index for months with more severe Arctic and environmental conditions, e.g. December to April is lower.

A corresponding accident index, for the area around Disko Bay have been calculated based on accidents registered in the area and on sailed distance within the area marked with green line in Figure 6.2.

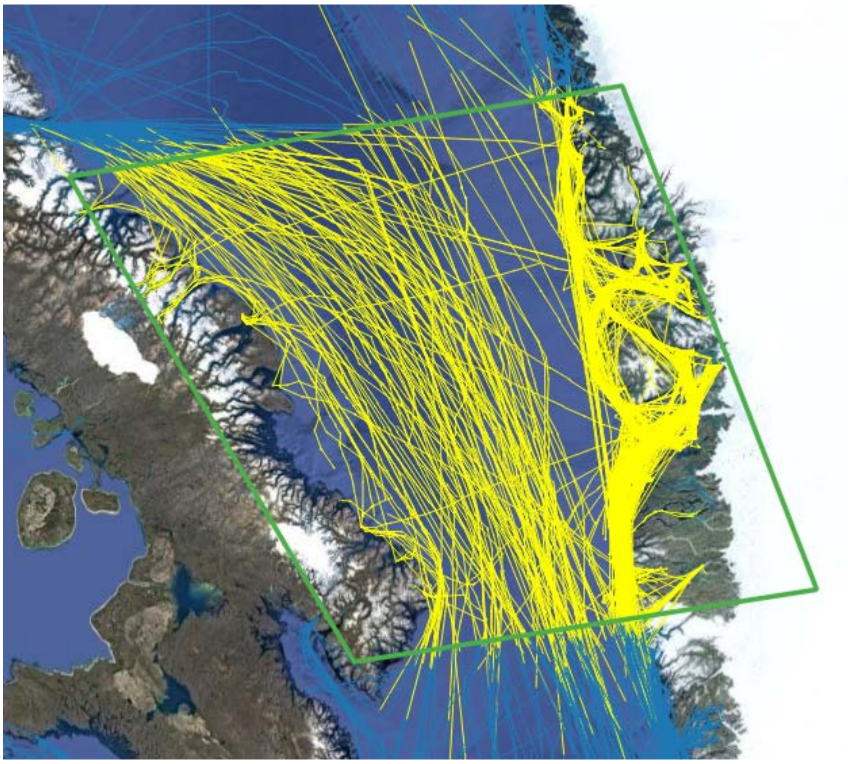


Figure 6.2 Area outside of Disko Bay (green line) for which accident index have been calculated.

Table 6.3 shows the calculated accident index. The calculated index is higher compared to the index calculated for the whole Arctic region; $2{,}5 \cdot 10^{-6}$ on a yearly basis for Disko Bay compared to $2{,}4 \cdot 10^{-7}$ for the Arctic region. Thus, the probability for an accident in this region is higher compared to other Arctic regions. The total number of registered accidents is, however, too low for statistical analyses and recorded seasonal variation only indicates that accidents are more likely to occur during the summer months with more frequent traffic.

Table 6.3 Accident index for the Disko Bay area based on sailed distance in the area and accident reported in the area.

	Sailed distance in Disko Bay area 2016 (nm)	**Accidents in Disko Bay area 1996-2017**	**Average number of accidents in Disko Bay area**	**Accident index (accident/nm)**
January	424		0,000	0
February	485		0,000	0
Mars	793		0,000	0
April	2690		0,000	0
May	3994		0,000	0
June	5903	1	0,045	7,70E-06
July	9952		0,000	0
August	20224	1	0,045	2,25E-06
September	13234	1	0,045	3,43E-06
October	5876	1	0,045	7,74E-06
November	4927		0,000	0
December	4655		0,000	0
Yearly	73157	4	0,182	2,49E-06

Fishing vessels represent the most frequent vessel type in the area. These are operating all year round. Bulk carriers tend to be more likely to be involved in accidents than other vessel types. In the area around Disko Bay, bulk carriers are only operating from July to October.

6.4 Trial site – Helsinki, Gulf of Finland

Accident index, for the area around, and south of, Helsinki, see Figure 6.3, have been calculated. The results are presented in

Table 6.4.

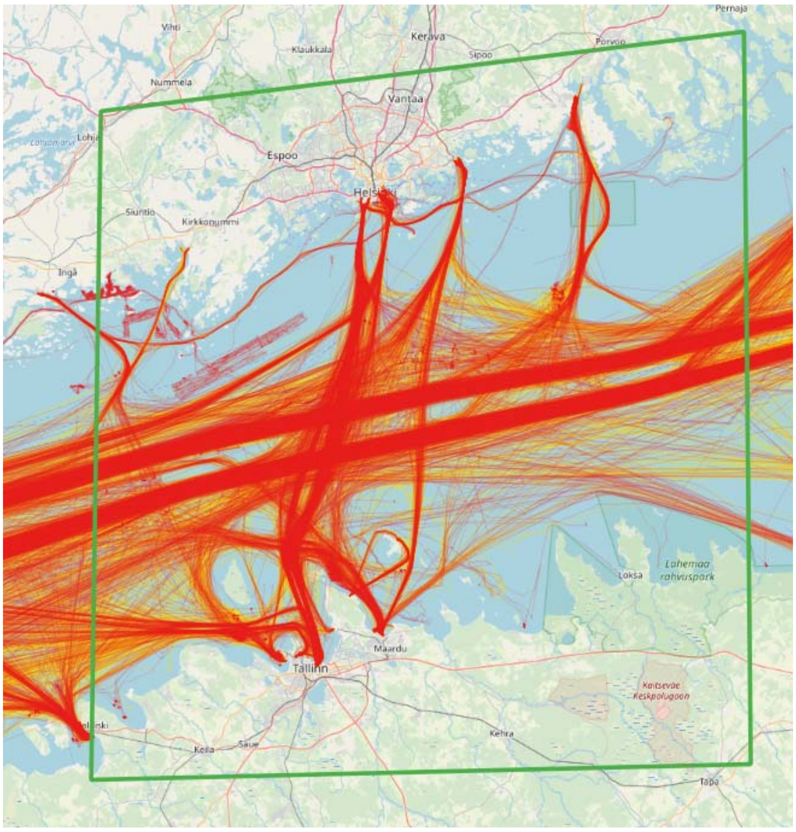


Figure 6.3 Area around Helsinki (green line) for which accident index is calculated.

Table 6.4 Accident index for the area around Helsinki based on sailed distance in the area and accident reported in the area.

	Sailed distance in Helsinki area Nov 2017 –Oct 2018 (nm)	Number of accidents in Helsinki area 1996-2017	Average number of accidents	Monthly accident index Helsinki (accidents/nm)
January	193 800	9	0,4	2,1E-06
February	199 068	6	0,3	1,4E-06
Mars	183 922	18	0,8	4,4E-06
April	129 958	4	0,2	1,4E-06
May	163 322	2	0,1	5,6E-07
June	160 203	4	0,2	1,1E-06
July	184 560	5	0,2	1,2E-06
August	184 302	7	0,3	1,7E-06
September	191 387	2	0,1	4,8E-07
October	189 392	12	0,5	2,9E-06
November	175 480	4	0,2	1,0E-06
December	171 884	7	0,3	1,9E-06
Yearly	2 127 278	80	3,6	1,7E-06

Accident index for the area south of Helsinki is lower compared to index for the Gulf of Finland, a yearly index of $1{,}7 \cdot 10^{-6}$ for the Helsinki area compared .to $2{,}0 \cdot 10^{-6}$ for Gulf of Finland.

The monthly variation in accident index is similar with the highest index in March, see Figure 6.4.

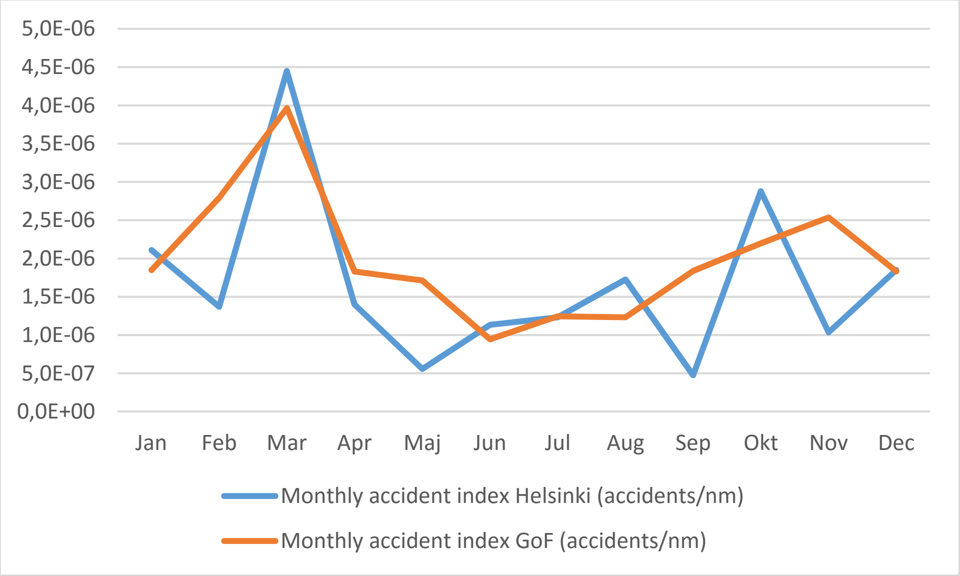


Figure 6.4 Monthly variation of accident index calculated for Gulf of Finland and for the Helsinki area.

6.4.1 IWRAP

IWRAP have been used to identify potential differences in groundings and collision frequency between different seasons and how the presence of ice may affect the frequency. Figure 6.5 shows the results from the calculation when the traffic pattern and traffic intensity for September were used. Figure 6.6 shows corresponding results when using the traffic for March 2018.

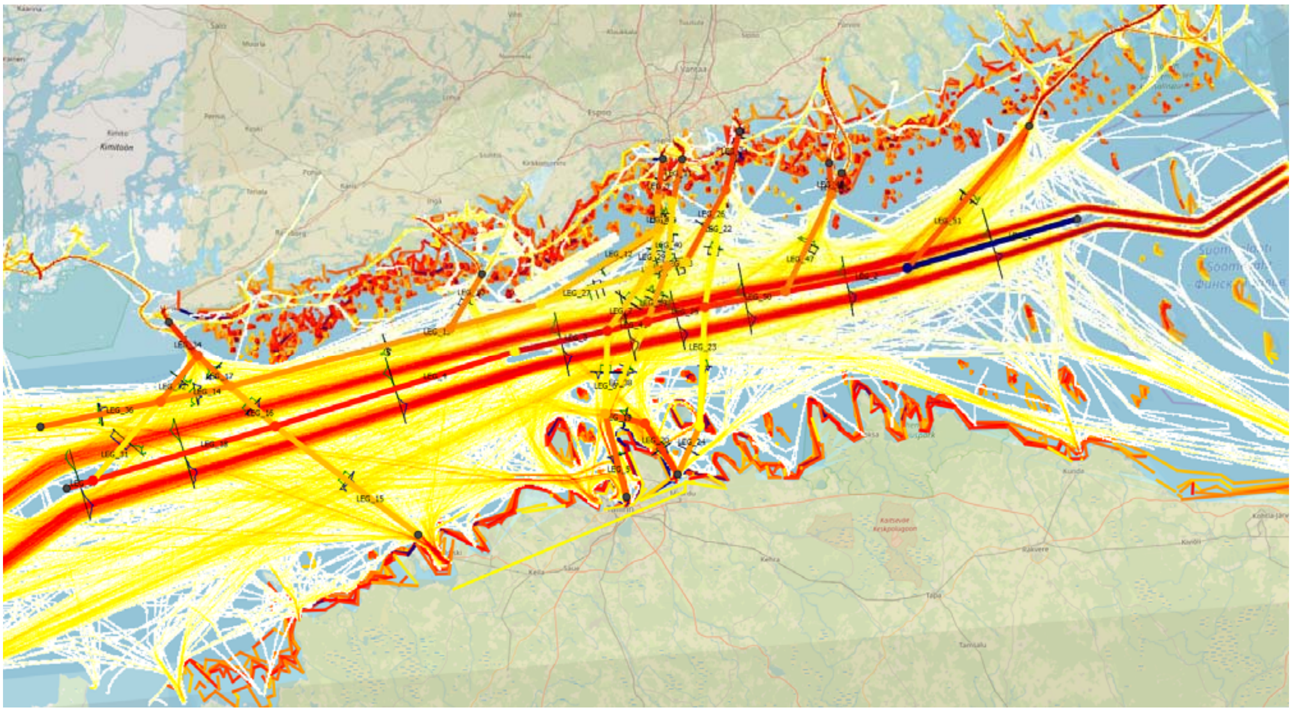


Figure 6.5 Density plot of the traffic and IWRAP calculations for Gulf of Finland based on traffic in September 2018.

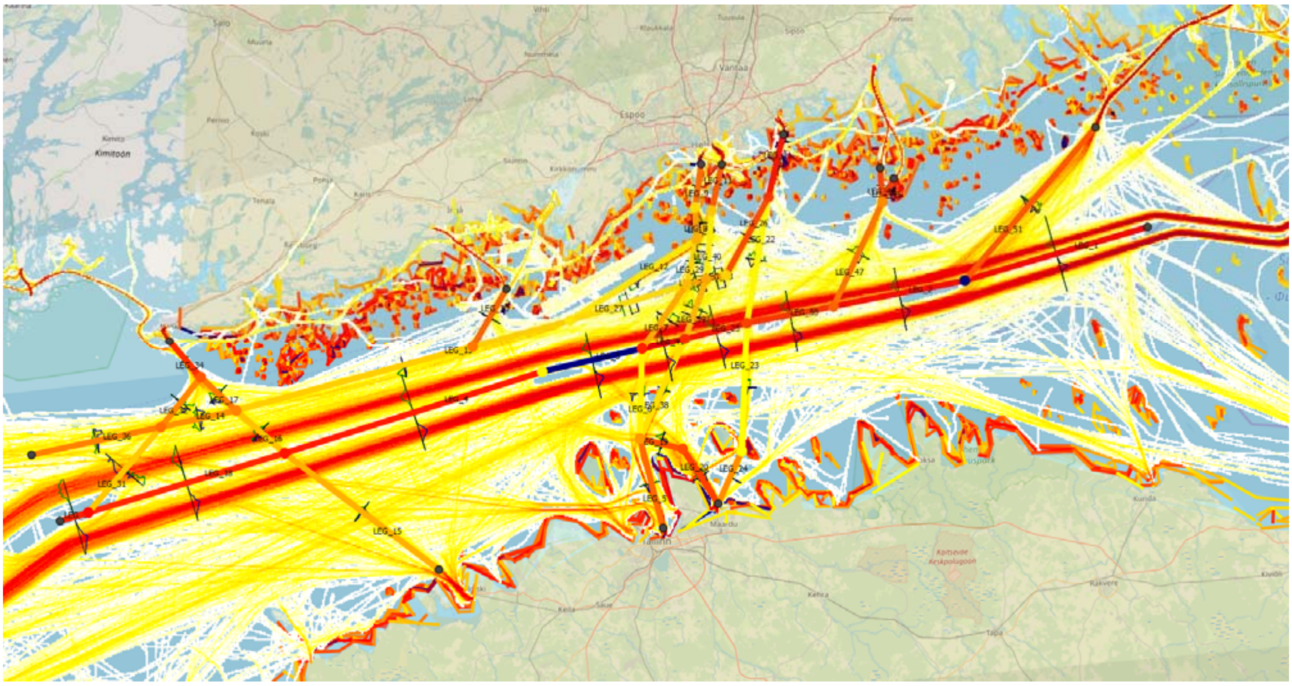


Figure 6.6 Density plot of the traffic and IWRAP calculations for Gulf of Finland based on traffic in March 2018

Table 6.5 compares the calculated accident frequencies for September and March. Based on the results in the table, the probability for grounding is almost the same for September and March, whereas the probability for a collision is higher in September than in March. The increase of expected overtaking collision risk may possibly be attributed to a tendency of reduced lateral distribution along the one-directional traffic lanes during winter navigation in narrow ice leads and broken channels.

Table 6.5 Comparison of calculated groundings and collisions frequency in Gulf of Finland for September and March respectively.

	September	March	Unit
Powered Grounding	2,903	2,6 (-11%)	Years between incidents
Drifting Grounding	6,519	7,8 (20%)	Years between incidents
Total Groundings	2,008	1,9 (-3%)	Years between incidents
Overtaking	48,12	69,8 (45%)	Years between incidents
Head On	601,9	472,0 (-22%)	Years between incidents
Crossing	592,8	718,7 (21%)	Years between incidents
Merging	1 426	1 452 (2%)	Years between incidents
Bend	5 096	5 698 (12%)	Years between incidents
Total Collisions	39,96	53,5 (34%)	Years between incidents

7 Consequence analysis

Accidents can be categorized into four different spill categories. Most accidents, 97%, do not cause any spill and only about 1% cause spill of the vessel's total available volume of cargo or bunker fuel. Based on figures for Norwegian waters (DNV GL, 2014), probabilities for each category have been estimated. Collisions are separated from other accidents as the spill volumes, as well as the probability distribution among spill category 2-4, is significant different compared to other accident types. Table 7.1 shows probability distribution and spill amounts for the spill category 1-4.

Table 7.1 Probability for different spill categories.

Spill category	Probability distribution	Spill amount as part of volume of 1 tank	COLLISION Probability distribution	COLLISION Spill amount as part of volume of 1 tank
1. No spill	97%	0	97%	0
2. Spill from 1 bunker/cargo tank – small fraction	0,75%	0,3	1,2%	1
3. Spill from 1 bunker/cargo tank – large fraction	0,75%	0,6	1,0%	2
4. Spill of the ship's total volume of cargo/bunker	1,5%	1 × number of tanks	0,8%	1 × number of tanks

Calculations of spill volumes for tankers are based on the cargo capacity volume. For other vessels, the calculations are based on bunker tank capacity which is assumed to have a filling level of 65%.

7.1 Trial site – Disko Bay

Table 7.2 shows calculated spill volumes for each spill category for the dimensioning vessels in Disko Bay area. The largest consequences, in terms of spilled volume, occur in a scenario with an accident where the total cargo volume of Ugale is released as a spill; 56 190 m^3 of oil.

Table 7.2 Potential spills from the dimensioning vessels in Disko Bay in case of accident. For category 2 and 3, figures within brackets represents the spill volume in case of collision.

Name	**Type**	**Length overall (m)**	**Fuel Capacity (m^3)**	**Tank capacity - Liquid (m^3)**	**Comment**	**Bunker volume (m^3)**	**Number of bunker/cargo tanks**	**Volume/tank (m^3)**	**Spill Cat.1 (m^3)**	**Spill Cat.2 (m^3)**	**Spill Cat.3 (m^3)**	**Spill Cat.4 (m^3)**
NS Yakutia	Bulk carrier	225	DF: 260 RF: 2 310	-	Largest vessel, only during summer time to Milne Inlet port	1671	2	835	0	251 (835)	501 (1671)	1671
Ugale	Chemical/ product tanker	195	DF: 194 RF: 1 590	56190	Largest tanker		6	9365	0	2810 (9365)	5619 (18730)	56190
Orasila	Oil/Chemical tanker	89	DF: 306	1 862	Most frequent tanker, 5th most frequent in ice		4	466	0	140 (466)	279 (931)	1862
Acadienne Gale Ii	Trawler	71	DF: 648		Most frequent vessel	421	2	211	0	63 (211)	126 (421)	421
Ivalo Arctica	General cargo	45	DF: 130		Most frequent vessel in ice, Ice strengthen, Icebreaking, RAL	85	2	42	0	13 (42)	25 (85)	85
Irena Arctica	Container	109	888		Most frequent Container vessel	577	2	289	0	87 (289)	173 (577)	577

7.2 Trial site – Gulf of Finland

Table 7.3 shows calculated spill volumes for each spill category for the dimension vessels in the area around Helsinki. Several large crude oil tankers operate in the area. An accident where one of these releases the total cargo volume implies a spill of 121 653 m^3 crude oil. The most frequent vessel in the area, the Ro-Pax ferry Megastar, uses LNG (Liquified Natural Gas) as fuel. An accident involving this vessel is not expected to cause any significant oil spill. A spill of LNG will rapidly evaporate and rise in the air.

Table 7.3 Potential spills from the dimensioning vessels in the Helsinki area in case of accident. For category 2 and 3, figures within brackets represents the spill volume in case of collision.

Name	Type	Length overall [m]	Fuel Capacity [m^3]	Tank capacity (Liquid) [m^3]	FS Ice Class	Comment	Bunker volume (65% of capacity)	Number of bunker/cargo tanks	Volume/ tank	Spill Cat.1 (m^3)	Spill Cat.2 (m^3)	Spill Cat.3 (m^3)	Spill Cat.4 (m^3)
Megastar	Ro-Pax	212	LNG: 1189		IA	Most frequent vessel, LNG fuelled	0	2	0	0	0	0	0
Finlandia	Ro-Pax	175	RF: 1400		IA	2nd most frequent vessel, scrubber	910	2	455	0	137 (455)	273 (910)	910
Viimsi	Product tanker	77		2538		Most frequent tanker vessel, Bunker vessel Tallinn		4	635	0	190 (635)	381 (1269)	2538
Mastera	Crude Oil tanker	252	DF: 309 RF: 2832	116561	IA Super	Most frequent crude oil tanker and largest tanker		8	14570	0	4371 (14570)	8742 (29140)	116561
Jeanette	General cargo	111	DF: 46 RF: 350		IA	Most frequent general cargo vessel	257	2	129	0	39 (129)	77 (257)	257
Solong	Container	141	DF: 105 RF: 933		IA	Most frequent container	675	2	337	0	101 (337)	202 (675)	675

8 Risk evaluation

The risk is defined as the product of the probability and the consequence. For the two trial sites, consequence and probability are calculated for eight different scenarios for each dimensioning vessel; one scenario for each spill category in case of collision and one scenario for each spill category in case of any other accident, see Table 7.1.

The probability for scenario *i* from vessel *x*, $P_{i,x}$, is calculated according to:

$$P_{x,i} = P \cdot a_x \ \cdot \ b_i \cdot c$$

or

$$P_{x,i} = P \cdot a_x \ \cdot \ b_i \cdot d$$

Where

$P =$ Accident probability for the area (accidents/year)
$a_x =$ Percentage of total fleet represented by vessel *x*
$b_i =$ Probability distribution of scenario *i* according to Table 7.1
$c =$ Proportion of the total amount of accidents in the area which is a collision
$d =$ Proportion of the total amount of accidents in the area which is not a collision

For each vessel *x* a spill risk index, SRI_x, is calculated according to:

$$SRI_x = \sum_{i=1}^{8} P_{x,i,} \cdot Q_{x,i}$$

Where

$Q_{x,i} =$ Spill volume for vessel *x* in case of spill scenario *i* (m^3/year) calculated based on Table 7.1

The total spill risk index for the analysed area, SRI, can thereby be calculated according to:

$$SRI = \sum SRI_x$$

The spill risk index represents an annual average spill volume based on probability. The index can be used to compare different areas or regions. The vessel specific SRI_x tells how much each vessel type x contributes to the spill risk in the area.

In order to graphically illustrate the character of the identified risks, presentation in a risk matrix is an established way for clarification. Figure 8.1 shows a schematic 5 x 5 risk matrix with a vertical probability axis and a horizontal axis for severity of consequences. With the risk index RI defined by the sum of the probability and consequence figures 1-5, the diagonals of the matrix will represent equal risk levels, and the lowest risk index figures are found in the lower left corner. If probabilities and consequences may be determined in quantitative terms, various risk acceptance criteria may also be introduced in the matrix by diagonal risk level limits. The yellow area between the tolerable green level and the unacceptable red level, is often referred as the ALARP (As Low As Reasonably Practical), and hazards and potential accident events found in this area should be priority subjects for risk control measures.

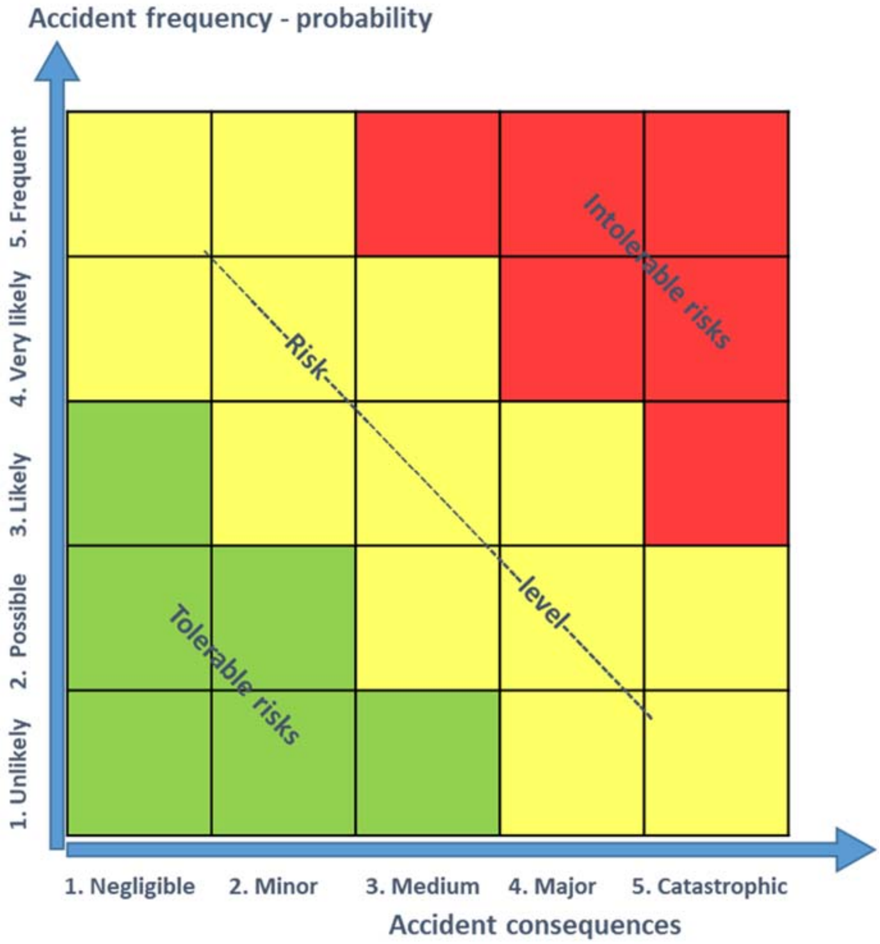


Figure 8.1 Schematic risk matrix.

For evaluation of the oil spill risk, a similar matrix is applied where the probability and consequence for each scenario are paired in the matrix to illustrate the risk levels and to identify the worst credible scenario. Results of the risk evaluation for the two trial sites are presented in the sections below.

8.1 Trial site – Disko Bay

For Disko Bay, the accident probability, P, is $1{,}8 \cdot 10^{-1}$. The number of registered accident in the current area (4 registered accidents) is too low to identify the proportion of collisions of the total number of accidents, c. Instead, statistics from the whole Arctic region is used to define c and d for Disko Bay.

$$c = \frac{19\ collision}{152\ accidents} = 12{,}5\%$$

$$d = 100\% - 12{,}5\% = 87{,}5\%$$

The calculated probabilities and spill risk indices for Disko Bay are shown in Table 8.1. The total spill risk index for Disko Bay is 9,68 m^3/year.

Table 8.1 Calculated spill quantities, probabilities and spill risk indices for vessel types representing the fleet in Disko Bay.

Name	**NS Yakutia**	**Ugale**	**Orasila**	**Acadienne Gale Ii**	**Ivalo Arctica**	**Irena Arctica**	***SUM***
Type	Bulk carrier	Chemical/ product tanker	Oil/ Chemical tanker	Trawler	General cargo	Container	
% of total traffic	5%	5%	5%	60%	10%	15%	*100%*
Spill Cat. 1 (m^3)	0	0	0	0	0	0	
Spill Cat. 2 (m^3)	251	2810	140	63	13	87	
Spill Cat. 3 (m^3)	501	5619	279	126	25	173	
Spill Cat. 4 (m^3)	1671	56190	1862	421	85	577	
COLLISION Spill Cat. 1 (m^3)	0	0	0	0	0	0	
COLLISION Spill Cat. 2 (m^3)	835	9365	466	211	42	289	
COLLISION Spill Cat. 3 (m^3)	1671	18730	931	421	85	577	
COLLISION Spill Cat. 4 (m^3)	1671	56190	1862	421	85	577	
Accident Prob. (acc./year)	9,09E-03	9,09E-03	9,09E-03	1,09E-01	1,82E-02	2,73E-02	*1,82E-01*
Probability Cat. 1 (97%)	7,72E-03	7,72E-03	7,72E-03	9,26E-02	1,54E-02	2,31E-02	
Probability Cat. 2 (0,75%)	6,10E-05	6,10E-05	6,10E-05	7,32E-04	1,22E-04	1,83E-04	
Probability Cat. 3 (0,75%)	6,10E-05	6,10E-05	6,10E-05	7,32E-04	1,22E-04	1,83E-04	
Probability Cat. 4 (1,50%)	1,17E-04	1,17E-04	1,17E-04	1,40E-03	2,33E-04	3,50E-04	
COLLISION Prob. Cat. 1 (97%)	1,10E-03	1,10E-03	1,10E-03	1,32E-02	2,20E-03	3,31E-03	
COLLISION Prob. Cat. 2 (1,2%)	1,36E-05	1,36E-05	1,36E-05	1,64E-04	2,73E-05	4,09E-05	
COLLISION Prob. Cat. 3 (1,00%)	1,14E-05	1,14E-05	1,14E-05	1,36E-04	2,27E-05	3,41E-05	
COLLISION Prob. Cat. 4 (0,8%)	9,09E-06	9,09E-06	9,09E-06	1,09E-04	1,82E-05	2,73E-05	
Spill risk index (m3/year)	0,24	6,47	0,23	0,74	0,02	0,25	*9,68*

Figure 8.2 shows the risk matrix for Disko Bay with 36 dots representing six different spill scenarios (category 1 not included as the spill volume is zero) for the six dimensioning vessels.

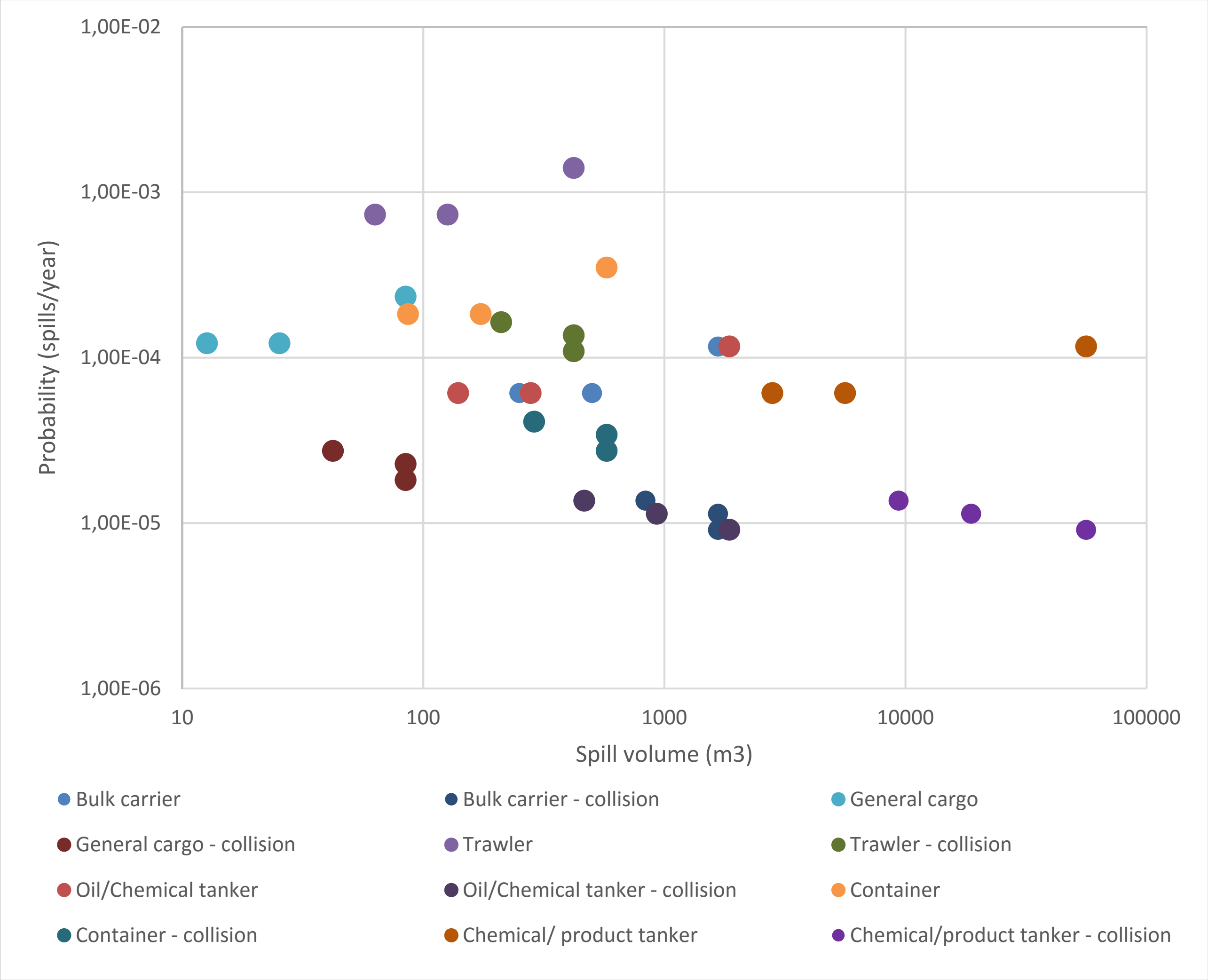


Figure 8.2 Risk matrix for Disko Bay.

The Chemical/product tanker generates the largest spill and the scenarios with a spill of category 4 are found to the far right. The spill not caused by a collision has a higher probability and thereby imposes a higher risk. An accident with a trawler is the only scenario with a higher probability than $1 \cdot 10^{-3}$, e.g. can be expected to occur more than once per 1000 years.

8.2 Trial site – Gulf of Finland

For area around Helsinki, the accident probability, P, is $3{,}6$. Of the 80 registered accidents in the area, 22 were collisions.

$$c = \frac{22\ collision}{80\ accidents} = 28\%$$

$$d = 100\% - 28\% = 72\%$$

The calculated probabilities and spill risk indices for Helsinki are shown in Table 8.2. The total spill risk index for Helsinki area is 309 m^3/year.

Table 8.2 Calculated spill quantities, probabilities and spill risk indices for vessel types representing the fleet in Helsinki area.

Name	**Megastar**	**Finlandia**	**Viimsi**	**Mastera**	**Jeanette**	**Solong**	***Sum***
Type	Ro-Pax	Ro-Pax	Product tanker	Crude Oil tanker	General cargo	Container	
% of total traffic	1%	32%	23%	4%	28%	12%	*100%*
Spill Cat. 1 (m^3)	0	0	0	0	0	0	
Spill Cat. 2 (m^3)	0	137	190	4371	39	101	
Spill Cat. 3 (m^3)	0	273	381	8742	77	202	
Spill Cat. 4 (m^3)	0	910	2538	116561	257	675	
COLLISION Spill Cat. 1 (m^3)	0	0	0	0	0	0	
COLLISION Spill Cat. 2 (m^3)	0	455	635	14570	129	337	
COLLISION Spill Cat. 3 (m^3)	0	910	1269	29140	257	675	
COLLISION Spill Cat. 4 (m^3)	0	910	2538	116561	257	675	
Accident Prob. (acc./year)	0,04	1,15	0,81	0,14	1,02	0,43	*3,6*
Probability Cat. 1 (97%)	2,53E-02	8,06E-01	5,71E-01	1,01E-01	7,16E-01	3,04E-01	
Probability Cat. 2 (0,75%)	2,00E-04	6,37E-03	4,52E-03	8,00E-04	5,66E-03	2,40E-03	
Probability Cat. 3 (0,75%)	2,00E-04	6,37E-03	4,52E-03	8,00E-04	5,66E-03	2,40E-03	
Probability Cat. 4 (1,50%)	3,83E-04	1,22E-02	8,64E-03	1,53E-03	1,08E-02	4,59E-03	
COLLISION Prob. Cat. 1 (97%)	9,60E-03	3,06E-01	2,17E-01	3,84E-02	2,72E-01	1,15E-01	
COLLISION Prob. Cat. 2 (1,2%)	1,19E-04	3,78E-03	2,68E-03	4,75E-04	3,36E-03	1,43E-03	
COLLISION Prob. Cat. 3 (1,00%)	9,90E-05	3,15E-03	2,23E-03	3,96E-04	2,80E-03	1,19E-03	
COLLISION Prob. Cat. 4 (0,8%)	7,92E-05	2,52E-03	1,79E-03	3,17E-04	2,24E-03	9,50E-04	
Spill risk index (m3/year)	0	21	34	244	5	6	*309*

Figure 8.3 shows the risk matrix for the Helsinki area with 30 dots representing six different spill scenarios (category 1 not included as the spill volume is zero) for the five dimensioning vessels.

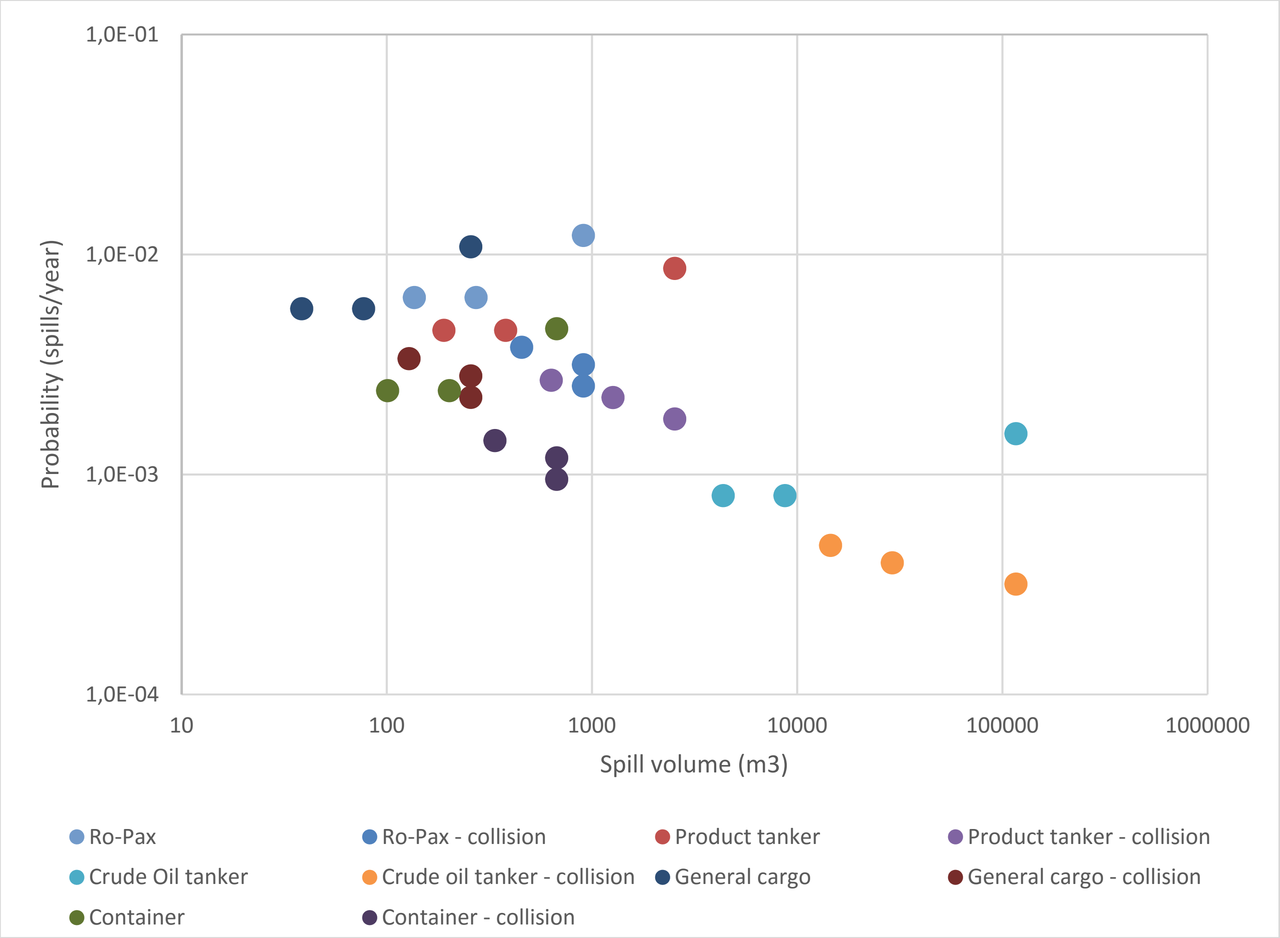


Figure 8.3 Risk matrix for Helsinki area.

The scenarios involving a crude oil tanker will cause significant larger spill than any other vessel type. Most of the scenarios are placed within the same box corresponding to a probability between $1 \cdot 10^{-3}$ and $1 \cdot 10^{-2}$ and with a spill volume between 100 and 1 000 m^3.

9 Results

9.1 The spill risk assessment methodology

The developed and presented spill risk assessment methodology is based on well established principles for maritime safety assessment methods and tools, e.g. the FSA-methodology elaborated by IMO and applied in several studies in the rule making process. During the course of the GRACE project, a number of other projects related to maritime risk assessment and oil spills were also initiated and recently, by initiative from Arctic Council and its EPPR, a project specifically addressing Arctic spill risks was also commenced.

The GRACE team involved in WP 1 and 5 concerning the Arctic spill risk assessment, has regularly exchanged information with the other projects and some of the presented components are similar to methods applied in other established methods or methods under development.

The AIS requirements and continuous registration of ship position data in combination with modern technique for big data processing have enabled availability of detailed on-line ship traffic data from remote areas. By integration of data from various general ship data bases and empirical statistics on ship accidents, causes, conditions, and consequences in terms of oil spill, credible prediction tools are developed for dynamic accident probability and spill risk and its geographical distribution in specific sea areas e.g. in Arctic waters. Low traffic intensity, sparse empirical accident data and highly varying ice conditions, however, makes Arctic prediction tools particularly challenging.

The presented spill risk assessment method combined with the developed SNEBA scheme and associated add-ons, provides a useful tool for assessment of spill probabilities and credible quantities, and the examples from different trial sites illustrate its applicability for comparative risk considerations.

9.2 Application of methodology and comparison of the two different trial sites

For the trial site in the Gulf of Finland, intense ship traffic generates detailed traffic data and available empirical accident statistics is also much more detailed than for Arctic areas. Traditional accident prediction models based on geometric grounding and collision candidates and comfort zones may be applied but the causation probability factors need to be adjusted by Arctic correction factors to take into account specific risks related to the presence of ice and characteristic Arctic conditions.

A number of different Arctic factors, based on conditions specified in the Polar Code, are identified and compared for the different trial sites. Most of the identified Arctic factors tend to increase accident and spill risks, but some characteristic factors rather reduce the accident risks encountered by ships operating in ice conditions.

Based on a monthly accident index per travelled ship nm, derived from AIS data and empirical accident statistics, the seasonal variation of accident probability is analysed. For the trial site in the Gulf of Finland, monthly accident index indicates a correlation between increasing presence of ice during the winter season and increased accident index, whilst for the Arctic Disko Bay case, the accident index tends to be higher in summer with less harsh ice conditions.

The accident index derived for the specific trial site in the Helsinki area is essentially the same as corresponding index calculated for the entire Gulf of Finland area. For the entire Arctic area, the accident index is an order of magnitude lower that in the Gulf of Finland. For the specific trial site in Disko Bay, however, the calculated index indicates a value somewhat higher than for the Helsinki trial site.

The accident probability, in this methodology represented quantitatively by an accident index, represents one of two components of the spill risk. The other component reflects the severity of the accident consequences. The prime unit for quantification of spills´ severity is normally the quantity of spilled oil, e.g. specified in volume m^3 or mass tonnes. In practice the severity of spill consequences is dependent on a wide range of additional factors, including the composition of the oil, the fate and behaviour of the spilled oil, the actual on site conditions for recovery, and of course the sensitivity and vulnerability of the affected environment. The relation between environmental vulnerability and response efforts is specifically addressed by the SNEBA methodology developed within WP 5 of the GRACE project.

In this spill risk assessment methodology, spill consequences are quantified by a calculated spill volume in m^3 for each specific identified accidental event. For each accident type, an empirical probability distribution is attributed to each of four levels/cases of damage rate including partial or complete damage of fuel oil tanks and/or cargo tanks. The analysed ship traffic is proportionally represented by five or six categories of representative dimensioning ships, each with a typical set of bunker fuel tank and cargo tank capacities. By multiplying the probabilities for each accident event with corresponding spill volume, an expected representative annual cumulated spill quantity, a spill risk index, was calculated for each trial site. As the cumulated spill risk index primarily reflects the size and traffic intensities of the analysed trial sites, it differs significantly between the two trial sites - a factor 30 higher in the Helsinki area, but direct comparison is not considered relevant for comparative risk considerations.

More useful comparison of risks and identification of critical accident scenarios are represented by graphical representation in risk matrices of associated pairs of probability figures and characteristic oil spill volume for each of the identified accidental events for the fleet of analysed dimensioning ship traffic.

For the Disko Bay case, accidents (grounding, foundering, or ice damage) with a product/chemical tanker is clearly indicated as a high risk event in terms of spill risk. Tanker collision and trawler accident also represent relatively high spill risks; for the trawler because of high probability and for the tanker because of severe consequences in terms of spill volume. The trawler accident is indicated with an expected reoccurrence period of about one thousand years.

For the Gulf of Finland area, accidents (grounding, foundering, or ice damage) with a crude oil carrier indicates the highest risk in the matrix. Its expected reoccurrence period is indicated to be slightly less than one thousand years.

It should be noted that the empirical accident frequencies applied in the trial applications, are based on historical accident statistics and tanker accidents with oil spills occurs significantly less frequently today than 25 years ago.

9.3 Changes in future Arctic oil spill risk profile

The quest to find new challenging destinations for cruise operators, will continue contribute to increasing cruise ship traffic in Arctic waters and the long term reduction of the Arctic ice coverage will eventually open up for regular year round commercial ship traffic through the Northern Sea Route (NSR). Increasing Arctic ship traffic will also carry increasing ship accident risks in remote and ice infested areas and hence, the probability of oil spills from ship grounding and collision will also increase. The overall risk profile and potential consequences of spill accidents will be mitigated by successive introduction of regulative provisions for transition from HFO to low-sulphur fuel qualities generally also considered less difficult to recover and clean-up in case of spill. Most likely the use of HFO as ship fuel will be phased out in Arctic waters within five years.

Today, 2019, the Arctic area is not designated for application of SECA provisions, and HFO with sulphur content up to 3.5% is allowed as ship fuel (in practice todays HFO quality is 2.7%). This type of fuel is frequently used for Arctic shipping today e.g. within the fishing vessel fleet. Operators active with offshore explorations within the Greenlandic Exclusive Economic Zone (EEZ) are however required to use fuel quality with maximum 1.5% sulphur by their concession conditions. The study´s trial site in the Gulf of Finland is part of North Sea and Baltic SECA and since 2017 only MGO or ULSFO hybrid fuel qualities are used except for ship with scrubbers.

From 2020 new stricter provisions will enter into force by MARPOL Annex VI with a global cap of maximum 0.5% sulphur. It is anticipated that new types of hybrid fuels or mixtures of residual and distillate fuel oil will be introduced and become the dominating type of ship fuel. The properties and conditions for recovery and clean-up of this type of fuel in case of spillage in cold sea water or ice infested areas, is unknown and not fully predictable today, but it is known that ECA compliant hybrid fuel qualities with 0.1% sulphur have proved to be difficult to handle with existing recovery equipment. For the Disco Bay trial site, located inside the Greenlandic EEZ, Greenlandic flagged vessels may, however, continue to operate with HFO since Greenland is exempted from Annex VI. Non-Greenlandic vessels may also operate on HFO within Greenlandic EEZ but it would be difficult to do so because of their flag state´s Annex VI provision will not allow them to carry HFO with sulphur content above 0.5% in their fuel tanks, after March 2020. If Greenland´s exemption from Annex VI remains 2020, this will imply a competitive advantage for Greenlandic fisheries, (Incentive, 2018).

In 2023, if an Arctic HFO ban will be introduced by amendments to MARPOL Annex I, it will prevent all ships, irrespective of flag, from using HFO in Arctic waters, including Greenland EEZ. If the ban include carriage of HFO in bunker tanks, ships equipped with scrubbers will not be able to operate the scrubber system.

Expected increase of future sea traffic in remote and sensitive Arctic waters calls for enhanced preparedness and tools for prioritization of response methods, identification of risk hot spots, response capacity needs, and adequate localization for resources.

Emerging spill risks follow with expansion of Arctic shipping and the risk profile will change dramatically by a stepwise transition from the use of HFO to distillate and hybrid fuels with lower sulphur content. New fuel types also require a revisit of existing response technique, its efficiency and potential needs for adaptation for new and future fuel types.

The combined output from technical and environmental prediction methods developed within GRACE and its different work packages, will facilitate future planning processes for sustainable utilization and protection of Arctic resources, specifically by providing effective tools for planning of oil spill response preparedness and for the design and selection of adequate resources.

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