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A PRELIMINARY RISK ANALYSIS OF WINTER NAVIGATION IN THE BALTIC SEA

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FOREWORD

In its report no 57, the Winter Navigation Research Board presents the study to assess the risk involved with winter navigation in the Baltic Sea. The study was carried out by Mr. Risto Jalonen, professor Kaj Riska and Mr. Samuli Hänninen from the Technical University of Helsinki. This information can be used in the development of rules and recommendations for the safety of winter navigation in the Baltic Sea area.

The Winter Navigation Research Board warmly thanks Mr. Risto Jalonen, Mr. Samuli Hänninen and professor Kaj Riska for this report, and the Ministry of Transport and Communications for financing the work.

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Markku Mylly

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PREFACE

The purpose of this risk analysis is to assess the risk involved with winter navigation on the Baltic Sea. The basis for this work was laid in the second meeting of HELCOM's Ice Expert Working Group in Helsinki, 17-18 June, 2003. This risk analysis is carried out in the period of autumn 2003 – winter 2004 by the Helsinki University of Technology as commissioned by the Finnish Ministry of Transport and Communications and the Finnish Maritime Administration.

CONTENTS

BASIC TERMINOLOGY

The following glossary is collected from several sources, including (DNV 2002, Hammer 1972, IMO 2002, Kaplan 1997, Storey 1996, Suokas and Rouhiainen, 1993, TSB 2002, Webster 1996).

Accident:	An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.
Accident scenario:	A sequence of events starting from the initiating event to one of the final stages of the accident.
Collision:	An impact between two or more vessels. The object of the impact may be underway, anchored or moored. An impact on the aft end of a ship, which stopped due to difficult ice conditions is included in this definition.
Consequence:	The outcome of an accident.
Contact:	An impact with an external object, which is not another ship or barge (i.e. collision), or sea bottom (i.e. grounding).
Damage:	Damage is the kind of injury or the effect of injury that directly impairs value, appearance, usefulness, soundness etc. of an object, which can be e.g. an artifact.
Danger:	Danger expresses the relative exposure to a hazard. It is the general word for liability to all kinds of injury or evil consequences, either near at hand and certain, or remote and doubtful. A hazard may be present, but the danger may be low, if sufficient precautions are taken.
Failure:	Termination of the ability of an item to perform its required function. Transition to a downgraded state.
Fault:	A state in which an entity is unable to perform its function. Generally, but not always the consequence of a failure.
Foundering:	To fill a vessel from above the waterline and sink.
Frequency:	Frequency is a measure of likelihood. It may be expressed as the number of occurrences (e.g. accidents) per unit of time (e.g. per one year). Expected frequency is the value of frequency that we assume to be realized in the future.
Generic model:	A set of functions (and structures) common to all ships or areas under consideration.
Generic ship:	A ship representing all the ships under consideration.
Grounding:	To touch bottom and remain stranded or continue the movement after contact(s).
Hazard:	A condition with the potential to threaten human life, health, property or the environment.
Hull ice damage:	Damage of the ship hull sustained as a consequence of contact with ice.
Ice damage:	Damage sustained as a consequence of contact with ice.

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Icing:	Ice accumulation on the structures, deck equipment, outfitting and deck cargo of a vessel.
Impact:	The striking of one thing against another, forceful contact.
Incident:	An incident (or near miss) is an unintended event or sequence of events that does not result in loss, but, under different circumstances, has the potential to do so.
Initiating event:	The first event in a sequence of events leading to a hazardous situation or accident.
Injury:	Wrongful action or treatment, harm, damage.
Likelihood:	An alternative expression for probability.
Potential:	A possibility, a latent ability that may or may not be developed.
Probability:	A measure of likelihood, which is sufficiently small. It is a number, which is between 0 and 1. A probability is sometimes defined also as the expectancy that an event, or a set of events will occur a certain number of times in a specific number of trials.
Propeller damage:	Damage to a vessel's propeller, propeller portion or propeller adjoining parts affecting a vessel's seaworthiness or rendering the vessel unfit for its purpose.
Reliability:	Ability of a system or one part of it to perform its intended function without failure for a specified period of time under stated conditions.
Risk:	The combination of the frequency (or probability) and the severity of the consequence of an accident. Uncertainty is an inherent feature of risk.
Risk analysis:	Assessment of the relationship between frequency (or probability) and consequences of an accident or an unwanted event.
Rudder damage:	Damage to a vessel's rudder or rudder adjoining parts affecting a vessel's seaworthiness or rendering the vessel unfit for its purpose.
Safety:	"Freedom from hazards". As it is practically impossible to eliminate all hazards completely, safety is defined as a matter of relative protection from exposure to hazards. Safety can be defined as a property of a system that it will not endanger human life or the environment. Safety is the opposite to danger.
Sinking:	To become submerged from water intake below the waterline and to settle to the bottom.
Structural damage:	Hull damage, such as cracks and fractures, sustained by a vessel affecting its seaworthiness or rendering the vessel unfit for its purpose.
Threaten:	To be a source of danger to someone.

ABBREVIATIONS AND SYMBOLS

AHTS	Anchor Handling Tug Supply (Ship)
ANR	Arctic News Record
BWL	Ballast waterline
DAMA	Database for Marine Accidents (used by the FMA)
E	East
EUCC	European Union for Coastal Conservation
FIMR	Finnish Institute of Marine Research
FMA	Finnish Maritime Administration
FMI	Finnish Meteorogical Institute
FSA	Formal Safety Assessment
GoF	Gulf of Finland
HELCOM	Helsinki Commission
HS	Helsingin Sanomat (a Finnish daily newspaper)
HUT	Helsinki University of Technology
IB	Icebreaker
IMO	International Maritime Organization
IMR	Institute of Marine Research
LSA	Life-saving appliance(s)
LWL	Load waterline
MKL	Merenkulkulaitos (Finnish Maritime Administration)
N	North
NE	North-East
NW	North-West
S	South
SE	South-East
SMA	Swedish Maritime Administration
SMHI	Swedish Meteorological and Hydrological Institute
SST	Svensk Sjöfarts Tidning (a Swedish maritime journal)
SW	South-West
USD	United States Dollar ($)
VTS	Vessel Traffic Service
VTT	Technical Research Centre of Finland (in Finnish: Valtion Teknillinen Tutkimuskeskus)
W	West
nm	nautical mile (1 nm = 1852 meters)

1   INTRODUCTION

The development of powerful icebreakers and ice-strengthened cargo vessels has made winter navigation possible in the northern parts of the Baltic Sea as well as in some other seasonally, or even permanently, ice-covered sea areas. Thus the ice barriers, which previously closed these coasts and sea areas from shipping, have been mostly overcome.

At a glance, the consequences of the current hazards of winter navigation seem to be limited to minor structural damage. No ice related ship disasters with large-scale consequences measurable in human or environmental losses have taken place in the Baltic Sea during the last decades. However, it should not be forgotten that some of the worst accidents in the history of shipping are closely related to ice. Titanic hit an iceberg in 1912 with the loss of life over 1500 persons. Exxon Valdez grounded in 1989 when trying to avoid ice on its route with the result of more than 40 000 tons of spilled oil. This kind of huge disasters have to be avoided in the Baltic Sea by careful risk management. On the other hand, the ability to counteract small but frequently occurring accidents, oil spills for instance, is important, too.

In the Finnish-Swedish winter navigation system the risk of ice damage is traditionally controlled by the combined use of a) traffic regulation, which is mainly based on the extent of ice cover and the severity of the ice conditions, and b) ice class regulation and c) the icebreaker assistance based on the available fleet of state owned and operated icebreakers. Parallel, but to some extent different systems are in use in the other parts of the Baltic Sea.

The amount and patterns of traffic in the Baltic Sea have been in a process of a rapid and remarkable change after 1990. The ship traffic in the Gulf of Finland has grown considerably during the last decade, and it is still growing, which is a result of growing economical activity in the area. According to the recent statistics from the FMA (FMA 2004), there are now nearly 4-5 times more passengers crossing between Finland and Estonia than about 10 years ago. New ports or port terminals have recently been opened or are under construction in Russia, in the eastern parts of the Gulf of Finland. The growth of the frequency of all ship movements, not only the oil tanker traffic, is an inevitable fact. The increase in traffic increase the risks in winter navigation, too.

With the traditional traffic patterns, ship types and sizes, the applied winter navigation systems have worked rather well, although the occurrence of some limited ice damages each winter have not been totally eradicated. Therefore, the impression of a high safety level of winter navigation has grown strong during the past long period of mild and normal winters. However, this impression, which may be based too strongly on the favourable accident statistics, may not take into account the combined effects of the continuous or occasional changes in the numerous parameters of the whole system. All the accident mechanisms are not too well known and the complexity of the large and both functionally and geographically distributed system of the winter navigation is difficult to grasp.

New operators in shipping in the Baltic Sea may well be aware of the hazards of winter navigation. However, exceptions certainly exist. Even some of the most experienced operators as well as the whole shipping society may not be sufficiently prepared for some of the hazards and possible risks that e.g. a rarely occurring winter storm may introduce.

Analysis of the marine accident statistics have shown that disasters with the most severe consequences may have a major contribution to the total outcome of the risk, which can be measured e.g. in the numbers of lives lost. The problem with low frequency or low probability events is, that as they are rare, it is usually difficult and time consuming to gather empirical knowledge concerning them. Another problem with them comes from the fact that the parameters affecting these low probability events may not remain constant during the time period of observation. However, the shipping world is full of stories based on some experience and, in the case of safety or risk related studies, the lessons learned from incident information should not be left unused. However, a clear distinction should be made between truthful statistics, official accident reports, incident reports and, on the other hand, the most doubtful sailor's stories. Therefore, some limited reviews of old incident and accident data from years 1961-1990 and accident statistics were performed as well as a study of ice related damages of ships in the Baltic Sea in the winter 2002-2003 (Hänninen 2004).

Risk analysis shall not be limited to those accidents or incidents that already have occurred. It is also important to assess the risk of occurrences that may happen, but have not yet happened. Therefore, the results of a previously held expert meeting about winter navigation for the hazard identification purpose, see (Juva 2002, VTT 2002) are also utilized in this work.

The topic of this risk analysis is the winter navigation in the whole Baltic Sea. However, the viewpoint has been focused mainly on the Gulf of Finland. This is so, because of the concentration of traffic in this area. However, most of the issues that have been studied and considered here, the analysis itself and its results, are applicable on the other areas of the Baltic Sea area. The objective of this study is to identify hazards in winter navigation and assess the risks involved. Options to manage these risks are presented and discussed.

In this risk analysis a set of accident scenarios and the basis for a complete risk model for winter navigation are presented. Risk analysis is often based on a multi-phased and iterative analysis. This study includes the following stages of work:

- a description of the system,
- identification and description of hazards,
- assessment of the risks,
- description and assessment of risk control options and, finally,
- conclusions and recommendations based on the previous phases of the work.

Risk analysis should be an iterative process. In the case of tight time limits, that are often set for it, the depth of the analysis and/or the number of iterations may be limited, too.

Theoretical models can be used to several purposes, such as to present ideas and structures or to investigate and create understanding and new knowledge about some interesting phenomena. In the case of accident modelling both conceptual and mathematical models can be useful. The former ones may serve as a platforms for clarifying and understanding the problem. Risk models are much similar to accident models, but in the case of risk all relevant initiating events should be included. Conceptual models are important for the purpose of risk communication, too. Analysis of conceptual risk model can be used for supplementing the development of more complicated mathematical risk models.

The time and resources allocated for this risk analysis imply that the development of a scientific basis for analysing e.g. the hull ice damage from the point of view of total risk and safety is not the purpose of this work. In many cases theoretical tools that could be used for such a purpose[1] do not exist yet. Existing methods, which are capable to handle part of this task, could be developed further within time limits set to meet the target. Therefore, considering the wide scope of hazards in winter navigation this risk analysis should be seen as an interim work before performing a full Formal Safety Assessment for winter navigation in the Baltic Sea.
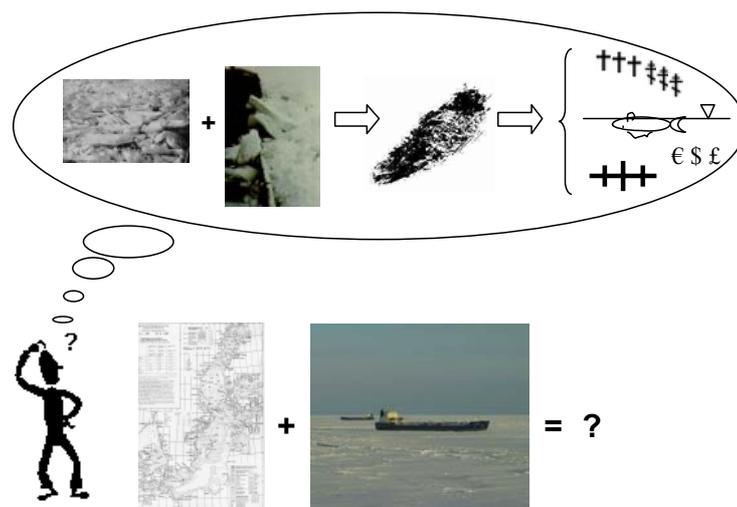
Figure 1   The purpose of this risk analysis is to identify hazards of winter navigation and assess the risk that is involved.

However, the risk model, that is developed in this study for analysing the risk by using some of the present tools, is still a step forward. It enables the performance of a concise risk analysis of winter navigation and, at least to a certain extent, it can be used for evaluating some of the risk control options available, too. A risk model should be like a toolbox, which allows the replacement of some of the older tools, when new tools are available.

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[1] An example of such a theoretical tool could be a theoretical calculation method for analysing the ice conditions under which the inner hull of a double hull oil tanker would be breached by a compressing ice field.

2   METHOD

2.1   OBJECTIVE

The objective of this study is to identify hazards and risks connected with winter navigation, to assess the risks connected to these hazards and to identify and analyse various risk control measures and options and their influence on the risk.

2.2   APPROACH

This study follows broadly the analysis of safety of winter navigation in the Gulf of Finland presented in (Juva 2002, VTT 2002)[2], some results of which are utilized here, too. However, as a contrast to the former study, where the approach was qualitative, new quantitative risk models for winter navigation are developed in this study. This study is addressing the hazards, risks and safety influences of some selected risk control options in winter navigation from the regulatory and the ship operations point of view.

The risk is analysed as a function of ice conditions, if relevant, by using the results of a limited damage statistics acquired from (Hänninen 2004). The efficiency of various risk control options, e.g. the ice class of the ship, the required ice class, i.e. the traffic restrictions and the icebreaker assistance, are analysed by using a quantitative approach, where applicable. In the lack of time or dedicated tools available, e.g. for the two latter tasks, the assessment is based on subjective experience.

The guidelines for the Formal Safety Assessment, FSA, presented in (IMO 2002), are broadly followed. When compared to the principles of FSA, the flow of this study is almost similar to these principles. However, a cost-benefit analysis is not included in this study. Thus, all phases of a full FSA process are not included here. However, this study can be seen as a step towards a risk based safety management, which is also the aim of the FSA.

2.3   SCOPE

This risk analysis is composed of system description, hazard identification, risk assessment and description of some risk control options with an analysis of their effects. The system description includes a short presentation of the environment and the environmental conditions in the Baltic Sea. The scope is concentrated especially to the Gulf of Finland. Geographical conditions, the temperature and wind conditions in winter months as well as the ice conditions and their relationship are described. The Finnish-Swedish winter navigation system, the icebreaker fleets of Finland, Sweden, Estonia and Russia (in the Baltic Sea) and the present status of the maritime traffic in this sea area are also shortly described. The scope of this risk analysis is presented in Figure 2.

Hazards of winter navigation are identified and structurized according to the following main categories: 1) hull ice damage, 2) rudder damage, 3) propeller damage, 4) icing, 5) grounding, 6) collision and some other. The nature of the typical accident categories is

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[2] The safety analysis study in reference (Juva 2002) is one part of a more comprehensive study that is compiled in reference (VTT 2002).

described and some representative accident cases for each category are presented. Risk assessment and a short evaluation of the efficiency of the risk control options are the final phases of this work. A short review of the results of (Juva 2002, VTT 2002) is included in this study.

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│                   SYSTEM DESCRIPTION                      │
│   ENVIRONMENTAL CONDITIONS & WINTER NAVIGATION SYSTEM     │
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│   DESCRIPTION OF TYPICAL ACCIDENTS IN WINTER NAVIGATION & │
│                   HAZARD IDENTIFICATION                   │
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│                     RISK ASSESMENT                        │
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│          DESCRIPTION OF RISK CONTROL OPTIONS              │
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│          SUMMARY, CONCLUSIONS & RECOMMENDATIONS           │
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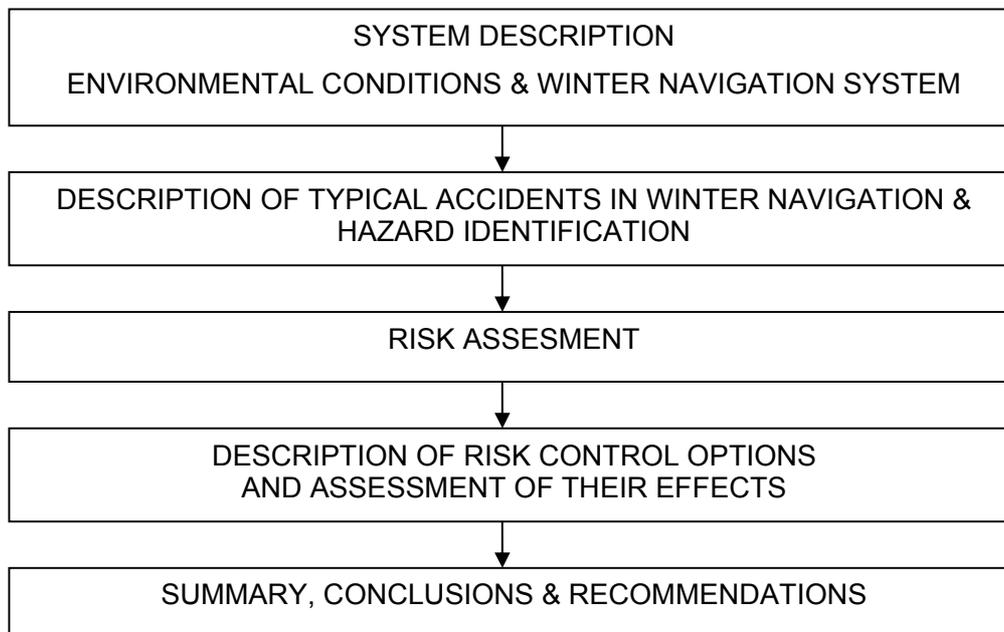
Figure 2   The scope of this risk analysis

The winter period is here defined as the time when there is first-year ice, which is usually the annual period of December-April. This study is limited to commercial shipping, transport of bulk, goods and passengers. The whole infratructure of shipping is considered to some extent, too. Therefore, no ships and ship types operating in ice-covered waters in winter are a priori excluded. The scope is limited to operations on the open sea, however. Thus, operations in harbours and occupational safety are not included in this study.

The study examines also the risk as a function of some parameters, e.g. the ice conditions. The risk is understood here as a risk composition including the risk to people onboard a ship (the ship crew as well as passengers if relevant), the environmental risk and the risk to property. Material damage, which is most often connected to the first phase of the consequences of an accident belong naturally to the last group (damage to property).

Hazards and risks of winter navigation originate from the environmental factors such as the presence of ice (and snow) and the low temperature. However, it is typical to a technological system that, in addition to the environmental factors, the technical and human/organisational factors as well as factors or rather the interaction between factors in two or three of these areas as depicted in Figure 3 are important contributors to the risk.

In winter navigation, many safety hazards are located in these borderlands. Thus, risk contributing factors belonging to these areas are included in the scope of this study.

- temperature
- ice thickness
- ice strength
- ridges
- wind
- visibility
- etc.

Environmental factors

Technical factors

- ship size
- ship type & cargo
- ship design
- ice class
  -- strength
  -- max. power
- etc.

Human factors & organisational factors

- restrictions to navigation
- icebreaker assistance
- route planning
- speed (if reduced voluntarily)
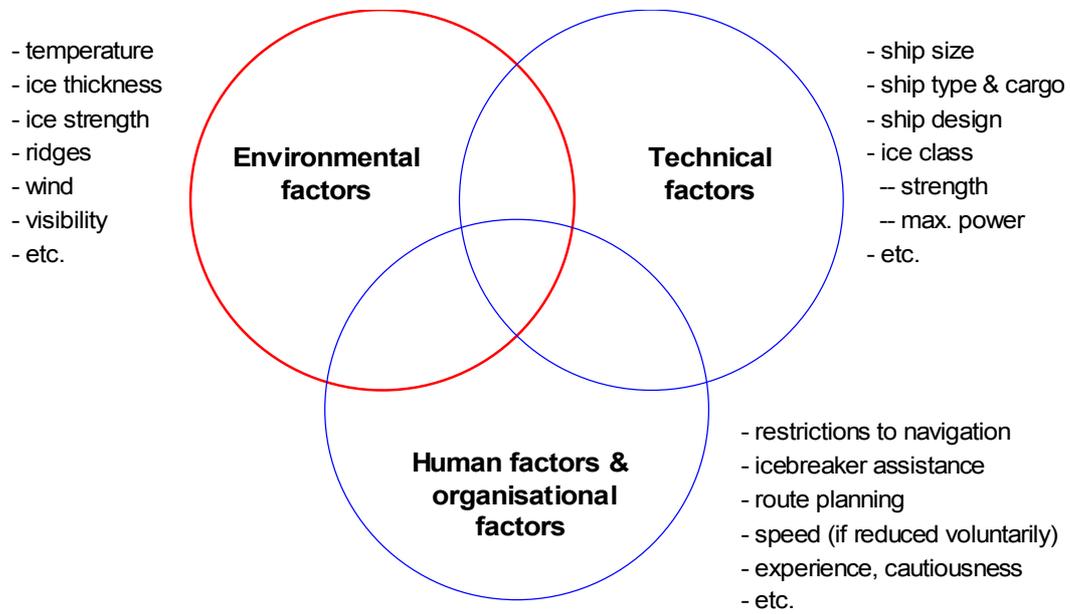- experience, cautiousness
- etc.

Figure 3   The areas of hazards and risk contributing factors in winter navigation

3   ENVIRONMENTAL CONDITIONS IN THE BALTIC SEA

This description of the analysed system comprises a short review of the geographical characteristics and conditions of the Baltic Sea and a general introduction to the ice conditions in the area of the Gulf of Finland. The maritime traffic in the northern parts of the Baltic Sea and a description of the Finnish-Swedish winter navigation system are presented in the next chapter, chapter 4.

Figure 4   The Baltic Sea with its sub-basins and sub-areas[3]

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[3] Note! Skagerrak does not belong to the Baltic Sea.

3.1 GEOGRAPHICAL CONDITIONS OF THE BALTIC SEA AREA

The Baltic Sea is located in the north-eastern part of Europe, between latitudes 54°N - 66°N and longitudes 10°E - 30°E. The Baltic Sea is connected to the North Sea at the border between Skagerrak and Kattegat at the latitude of the Skaw (57°44'N). Several countries have their coastlines at the Baltic Sea: Denmark and Sweden, Germany, Poland, Lithuania, Latvia, Estonia, Russia and Finland, see Figure 4.

According to (Grönvall & Korhonen 1983) the total area of the Baltic Sea area, including Kattegat, is about 422 000 km^2. The sea area without Kattegat is about 365 000 km^2. The Baltic Sea is not very deep, the mean depth of the sea being 60 m. The Baltic Sea area comprises the following sub-areas or basins: Kattegat, Belt Sea, Baltic Proper, Gulf of Riga, Gulf of Finland, Archipelago Sea, Bothnian Sea and the Bothnian Bay. Some of the sub-areas are shallow, like the Gulf of Finland, with a mean water depth of 38 m, the Finnish Archipelago (23 m) and the two straits at the Great Belt and the Sound, with even more limited water depths. When compared to the mean depth of all oceans, which is about 4000 m, the mean depth and the amount of water in the Baltic Sea is rather limited, see Figure 5. Thus, it can be considered more sensitive to environmental disturbances than many other sea areas. The shallow depth of water constitutes a grounding risk for navigation and the sensitivity of the area accentuates the risk for environment.

The length of the coastline of the Baltic Sea has been estimated to be roughly 7 000 km (Furman et al 1998). An other estimate taking more closely into account the effects of islands, skerries etc. is much higher, about 69 000 km, distributed to the coastal states according to Table 1 (EUCC 2002). The large variation of the coastline length is caused by the local geographical conditions. The effect of the inclusion of the numerous islands in the Finnish archipelago in the figures of Table 1 may overemphasize the length of the Finnish coast, when compared to the Swedish coast.

Table 1   Length of the Baltic coastline (EUCC 2002)

Coastal State	Denmark	Germany	Poland	Lithuania	Latvia	Estonia[4]	Russia	Finland[5]	Sweden[6]
Length (km)	7 300	2 000	843	91	496	3 794	839	46 064	7 600
Percentage	10.6 %	2.9 %	1.2 %	0.1 %	0.7 %	5.5 %	1.2 %	66.7 %	11.0 %

At least five different types of coasts are typical for the Baltic Sea area. Large parts of it are *open and flat*, especially on the southern and eastern sides of it, but *archipelago*s with rocky shores and skerries are also very common on the Finnish and Swedish coasts. Shore *cliff*s can be found on the coasts of Estonia and the islands Gotland and Bornholm. *Lagoons and Bodden-coast*s are located in the south. Fjords can be found on the Swedish coast at the Bothnian Sea. The distribution of these coast types in the the Baltic Sea as presented in (The Baltic Sea University 2004) is reproduced in Figure 6.

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[4] 1,242 km of the coastline length is on the mainland and 2,552 km is divided among the islands
[5] including all islands and archipelagos
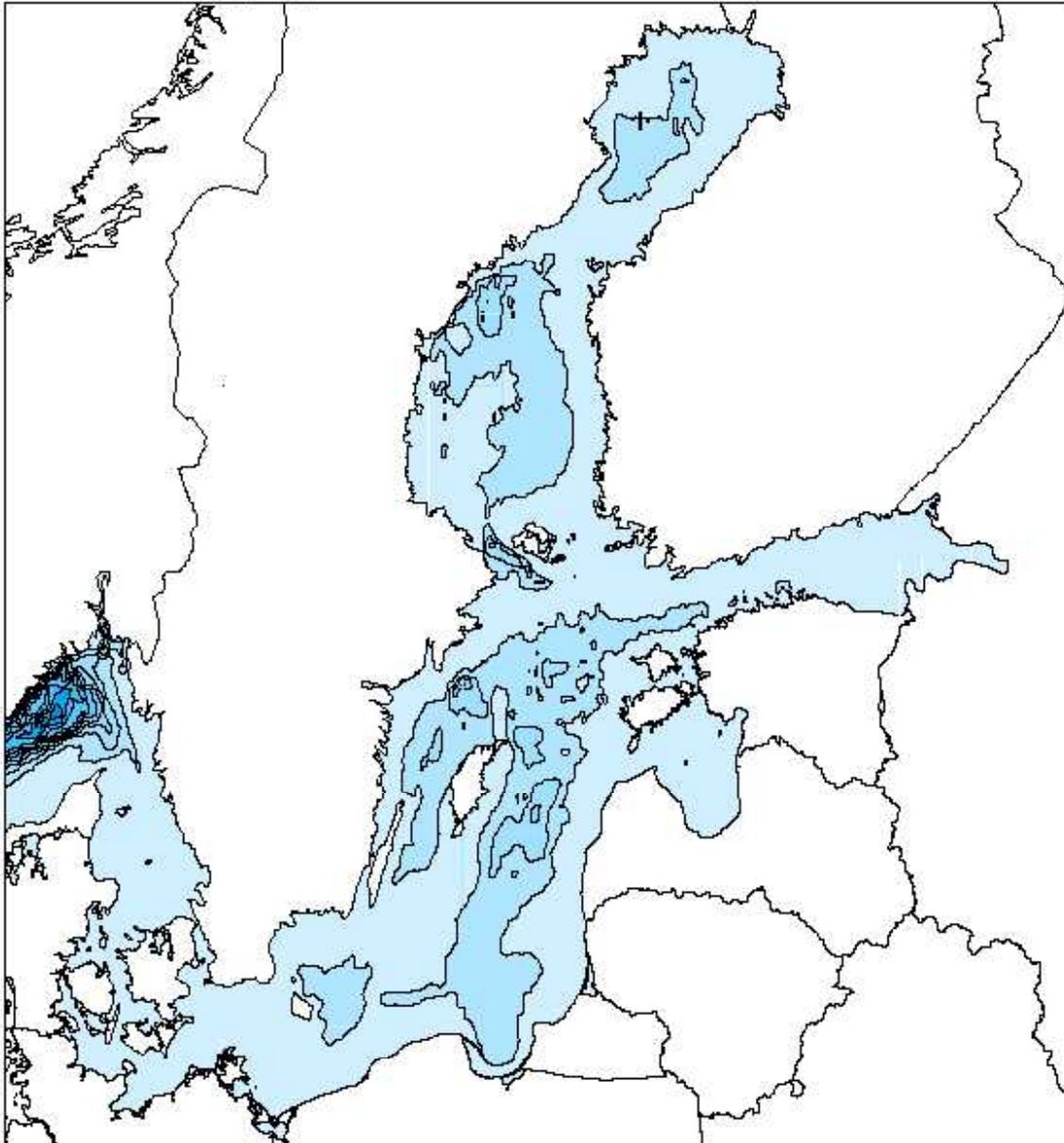[6] including all mainland bays and the coasts of the large islands

Figure 5   The bathymetric map of the Baltic Sea[7]

In the case of an oil spill and pollution the consequences on different coast types may be
technically different and the requirements for equipment needed for oil removal and
cleaning operations may differ consequently.

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[7] This map is produced with the courtesy of Mr. Christian Andersson from the Baltic Sea University.
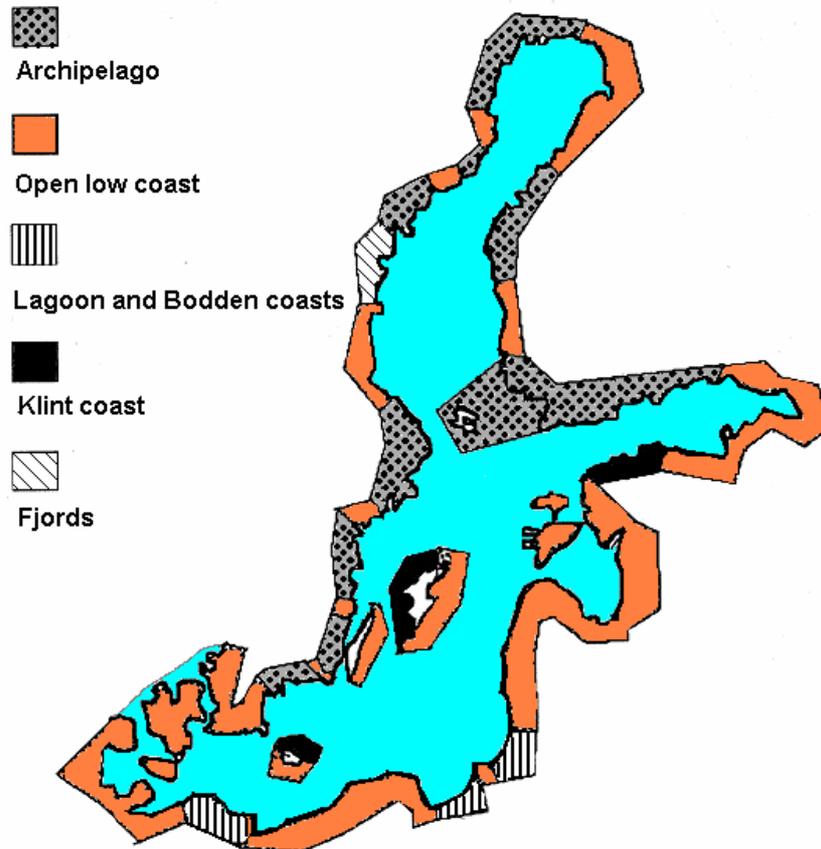
Figure 6   Main types of the different coasts in the Baltic Sea area, reproduced from the map published by The Baltic Sea University (2004)

Due to the limited dimensions of the narrow and shallow Danish Straits, the Baltic Sea has a very slow rate of water exchange with the oceans. It takes some decades, 25-35 years for all the water in the Baltic Sea to be replenished by water from the North Sea and beyond (Walday et al 2002). The Baltic Sea is the worlds second largest ecosystem of brackish water (if the Kattegat area is not included the Black Sea is the largest). The mean value of the water salinity in the Baltic Sea is just below 10 ‰, but at the latitude of Helsinki it is about 5 ‰ and at the height of Hailuoto, in the Bothnian Bay, about 2 ‰.

The tidal variation in the Baltic Sea is very small, varying between 8-18 cm (Walday et al 2002), and along the Finnish coast it is just a few centimeters (FIMR 2002). However, variations due to air pressure, wind and currents may be much larger. The highest and lowest water level e.g. in Helsinki have been: +1.36 m (in 27.1.1990) and –0.92 m (in 22.3.1916) (FIMR 2002). In the eastern parts of the Gulf of Finland and in the northernmost parts of the Bay of Bothnia the sea level variations are usually much larger.

In the northern areas of the Baltic Sea the sea currents are not usually extremely strong. In the Gulf of Finland the main directions are inwards, to the east, on the southern side of

the gulf, and outwards, to the west-south-west, on the northern side of the gulf. Currents across the gulf are also possible.

3.2 TEMPERATURE CONDITIONS

The temperature conditions in the Baltic Sea are essential information regarding winter navigation. At sea areas the wind speed and direction as well as the temperature are most important information for navigation. This paragraph, which is mainly based on the information published by the Meteorological Institute of Finland, see (FMI 2004a) gives a short review on the topic.

In some of the most severe winters, when the whole (or almost whole) Baltic Sea has been covered with ice, the mean air temperature has been below zero already in November. Depending on the temperature of the consecutive winter months, the ice conditions may develop to mild, average or severe. Some of the most severe winters in the time period 1951-2003 are: 1955-56, 1962-63, 1965-66, 1984-85 and 1986-87. Monthly mean temperatures for these winters, as well as for winter 2002-03 are presented in Figure 7 with the minimum and maximum mean temperatures for the same months. The range between minimum and maximum monthly mean temperatures is divided in three zones according to the 33 %- and 67 %-percentiles.
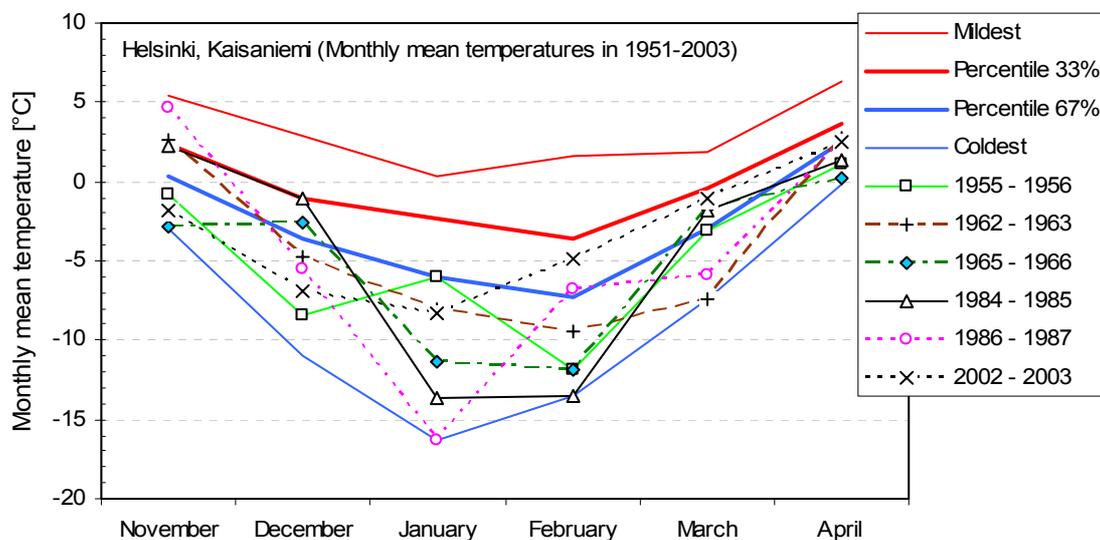

Figure 7   Monthly mean temperatures (November-April) in winters 1951-52 – 2002-2003 in Helsinki (Kaisaniemi). Source of data: (FMI 2004a).

It can be easily noticed from Figure 7, that in details the hard winters are not much alike each other. In some winters the mean temperatures may decrease abruptly to very low value and then rise back to more normal values, whereas in some other winters the temperature may stay rather, but not extremely cold for a much longer period. It can also be seen, that all cold winters may include some milder or more normal months. The

extreme winter with consecutive monthly frost records has not yet been seen. In the latitude of Helsinki, sea ice thickness 0.8 meters might be exceeded, if temperature conditions like that would occur (without any influence of snow cover).

An extremely cold period may last for several weeks. In time period 1961-2001, there has been four very cold periods lasting at least two weeks with daily temperatures below –15°C in Helsinki (-Vantaa Airport). The longest period was 21 days, in January 1968. However, there is usually a lot of variation in the air temperature in general, see e.g. Figure 8. Main components of the temperature variation are the seasonal variation, the variation due to movement of low pressure areas, which control the winds, and the diurnal variation, which is strongest when the dampening effect of clouds is absent.
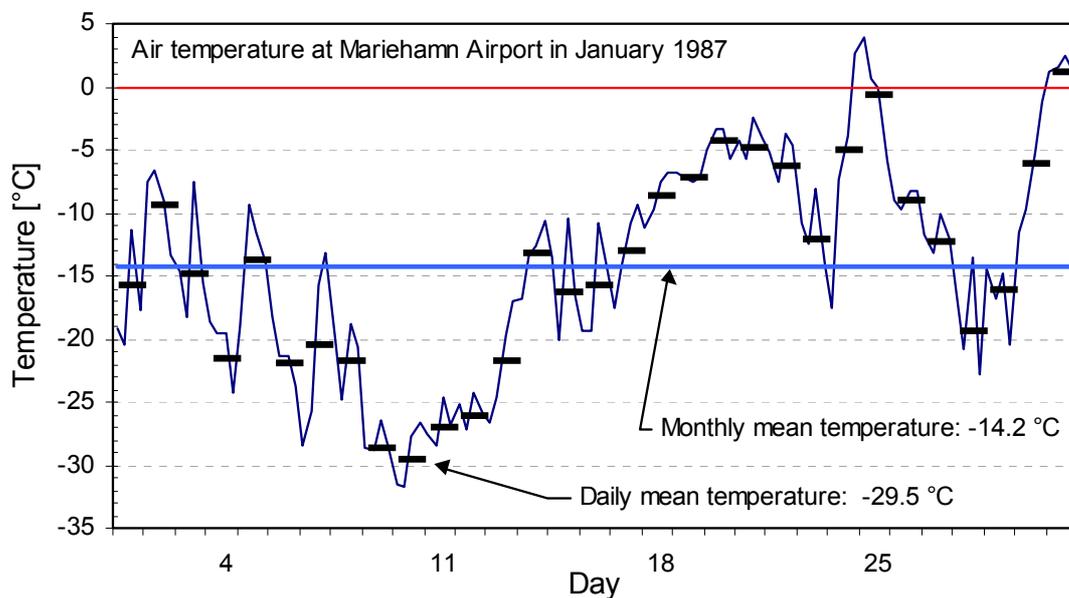

Figure 8   Air temperature measured at 6 hour intervals at Mariehamn airport in January 1987 shows clearly the temperature variations during an extremely cold month. Source data is from: (FMI 1987)

The air temperature has a significant effect on the sea surface water temperature and ice formation. If the well known formula of Zubov (Zubov 1938):

$$h_i^2 \quad + \quad 50h_i \quad = \quad 8R \tag{1},$$

where h_i is the ice thickness and R is the cumulative sum of freezing degree days (FDD) based on 0°C, i.e. integral of temperature time history below freezing point in C° × Day, is applied to the daily air temperature data of Figure 6, we can get a rough estimate on maximum growth in ice thickness from 0 cm to almost 40 cm during this extremely cold month in Mariehamn.

The correlation between the maximum extent of ice cover on the Baltic Sea in winters 1952 – 2003 and the cold sum is obvious, see Figure 9, even if the latter is based on the monthly mean air temperatures[8] (November-March) in Helsinki (Kaisaniemi), see (FMI 2004a).
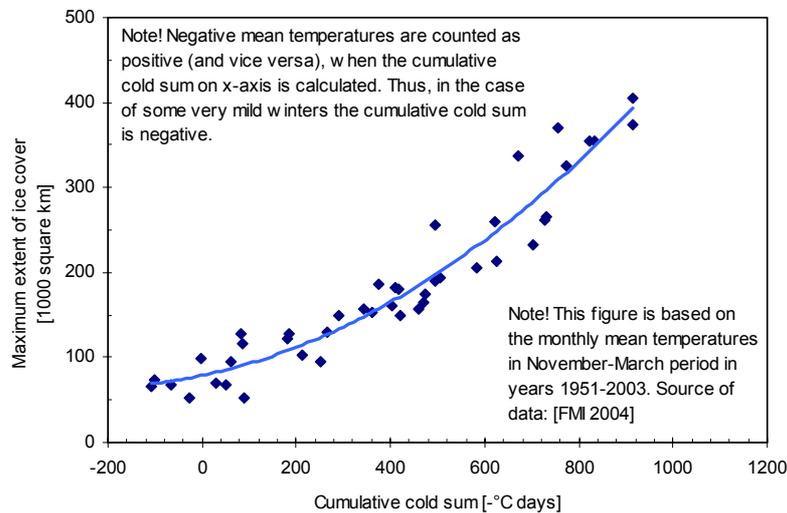

Figure 9   Relationship between cumulative cold sum of monthly mean temperatures (November-April), in Helsinki (Kaisaniemi) and the maximum extent of ice cover (1000 km^2) on the Baltic Sea in winters 1952 – 2003.

Information regarding air and sea temperature is needed also to assess the likelihood of problems caused by icing. The rate of icing depends on some other parameters, too, like wind speed.

3.3   WIND CONDITIONS

The wind conditions of the sea area are important for a risk analysis related to navigation as ice motion is driven by winds. Distributions of wind speed and wind direction are needed e.g. to assess the likelihood of problems caused by drifting ice and compressive ice, although, for this purpose, some other information is also needed. This paragraph is based mainly on the information published by the Finnish Institute of Marine Research and the Meteorological Institute of Finland, giving just a short general review on the topic with some examples.

Open drift ice moves as a consequence of wind and current, but this phenomenon can be observed with close ice and pack ice, too. Based on observations in the Gulf of Bothnia, where movements of pack ice were recorded, it was found that the ice drift follows the wind closely with response times shorter than one hour (Leppäranta 1981). A rough approximation of open ice drift speed to be about 2.5 % of wind speed, being made in the

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[8] Cold sums are normally calculated using the daily temperatures, here, however, the cold sum is based on monthly mean temperatures.

same reference, seems to be reasonable, see Figure 10. However, some natural variation in this relationship should always be taken into account. In compact ice the velocity is lower and does not follow well a simple linear rule. In extreme cases the ice may be stationary even with strong wind conditions (Leppäranta 2004).
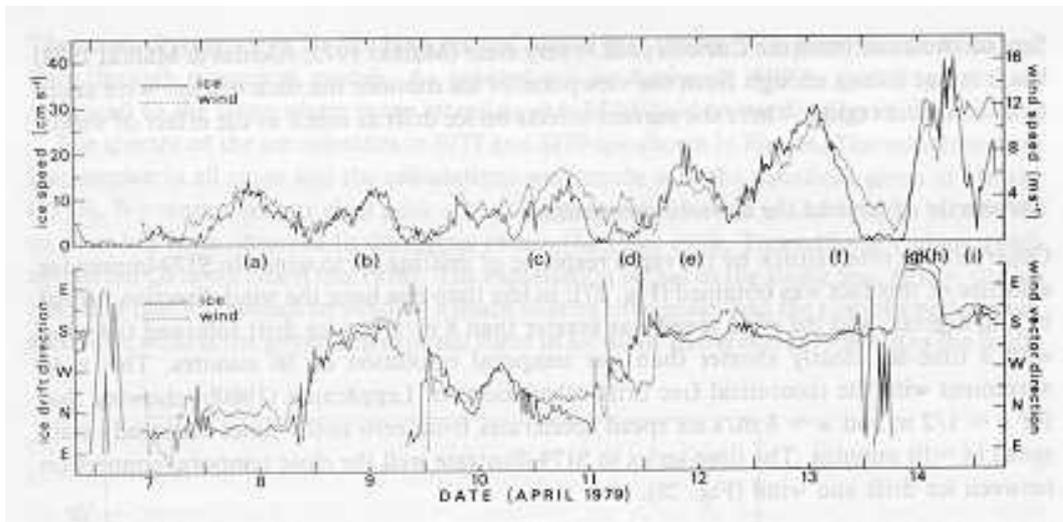

Figure 10   Recorded time series of ice and wind speed and direction in the Gulf of Bothnia (Leppäranta 1981)[9]. Note that the scale for ice drift speed is 0.025 times the scale for wind speed.

The wind conditions can be characterized by the wind speed and the wind direction. Average wind speed for different wind directions and the frequency of wind blowing from each direction on two sea weather stations on the Finnish coast at the Gulf of Finland[10] are given in Figure 11 to depict the general wind patterns. This information is based on data from (Drebs et al 2002) and (FMI 2002/03) and it is presented here separately for all winter months (November-April) in winter 2002/2003 and in winter periods 1971-2000.

At sea weather stations, the wind may blow freely from all directions. However, in the Gulf of Finland the wind direction south-west is the most frequent, as can be noticed from Figure 11. The average wind speed is generally a bit lower in the eastern part of the Gulf of Finland. In winter 2002/2003 the average mean wind speed of winter months was lower than on average, but the frequency of northern (N), north-western (NW) and north-eastern (NE) winds was higher than on average.

Average wind speed and wind direction do also affect the development of the ice cover on the northern Baltic Sea. However, the number of storm-days may be a more interesting parameter in the case of a risk analysis. The mean and maximum number of

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[9] This figure is reproduced here by the permission of the Finnish Institute of Marine Research
[10] These are: Russarö (Lat 59°46'N, Long 22°57'E) and Rankki (Lat 60°22'N, Long 26°58'E)

monthly storm-days[11] in all Finnish sea stations in time period 1990-2003 are presented in Figure 12. From this figure it can be easily noticed that the number of storm-days is biggest in January, November and December. Considering the risk of icing and compressive ice it should be remembered, however, that wind speed is not the only important parameter.

a)

b)

c)

d)
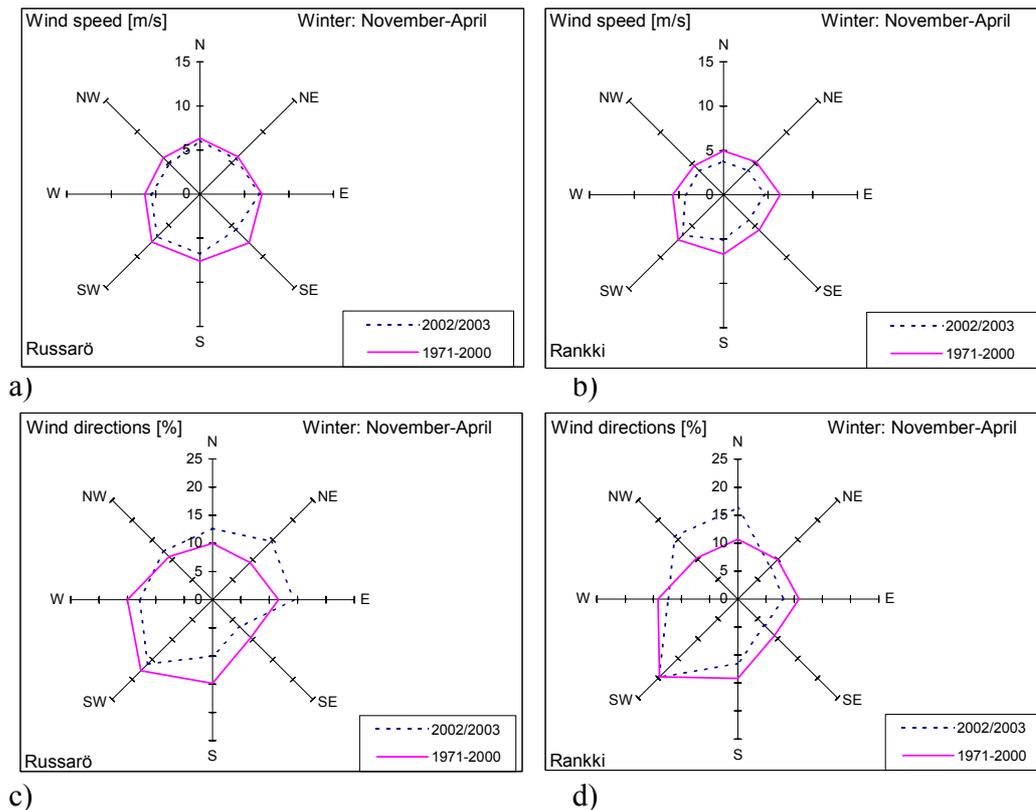
Figure 11   Average wind speed values for different wind directions a) and b), frequencies for different wind directions at Russarö and Rankki sea weather stations in period November-April in winter 2002/2003 (dotted line) and in winters 1971-2000 (solid line) c) and d) . Source of data: (Drebs et al 2002) and (FMI 2002/03).

The average frequency of storm days is highest in January, being about 13 %, but then decreases gradually towards the spring and summer. The highest 10-minute average wind speed measured at the Finnish sea weather stations since 1959 have been (FMI 2003):

1) 25.2.1971 at Mustasaari, Valassaaret (Lat 63°26 N, Long 21°04 E), 31 m/s north
2) 15.12.1975 at Korsnäs, Moikipää (62°53 N, 21°06 E), 31 m/s, west, and Valassaaret 31 m/s, west
3) 23.12.1975 at Korsnäs, Moikipää 31 m/s, north-west
4) 23.1.1995 at Hanko, Tulliniemi (60° N, 23° E), 31 m/s

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[11]   A storm-day is defined here to be such a day, that the 10 minute average wind speed at least at one sea weather station (in Finland) has been at least 21 m/s.

The highest values of 10-minute average wind speed, measured at the Utö sea weather station on monthly basis since 1959 are presented in Table 2:

Table 2   Monthly records of wind speed (10 minute average wind speed) at Utö sea weather station (59°47 N, 21°23 E) in winter (FMI 2003)

Month	Direction	Wind speed (m/s)	Date
November	North - North-West	28	1.11.2001
December	South	26	18.12.1966
January	South - West	27	19.1.1960
February	North	23	20.2.1962
March	South	22	26.3.1997
April	North	24	5.4.2003
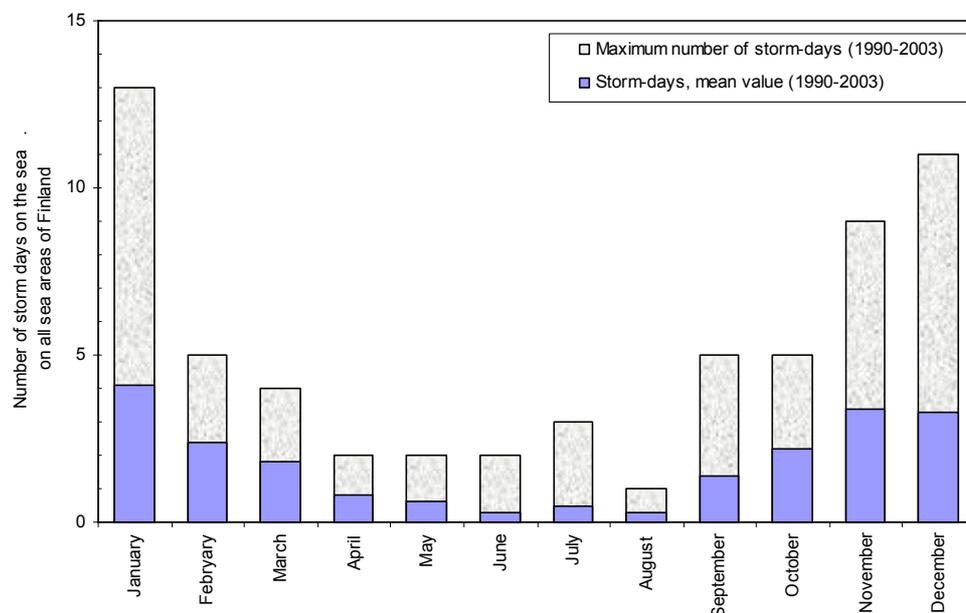
Figure 12   The monthly mean and maximum numbers of storm-days ($v_{10\,min} \geq 21$ m/s) in years 1990-2003 in Finnish sea weather stations (FMI 2004b)[12].

The duration of winter storms, caused by large scale low pressure areas, is usually several hours. The wind speed increases gradually, when the distance to the center of the low pressure area is decreasing. The duration of the storm is longest when the low pressure area is moving at slow speed. Wind direction changes, when the center of the low pressure area has passed the site. A typical storm starts with a wind direction first from south or south-west (S or SW). Then the wind turns to north (N), being at that phase

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[12]   Note! The number of storm-days in a single sea area (or weather station) is lower than the number of storm-days in this figure, which presents the general condition considering all sea areas on the coasts of Finland (FMI 2003).

usually the strongest and gustiest one. The highest wind gust speed measured at any sea weather station in Finland has been 39 m/s (in Korsnäs, Moikipää) (FMI 2003).

Most important factors affecting the movement of drifting ice are the surface stresses of wind and water on ice and the internal friction. Gravitational force due to the sea surface tilt, sea currents and Coriolis force are other factors having influence on the movement of ice masses. The major sink of kinetic energy is the friction in shearing between ice floes (Leppäranta 1981). The air temperature and the wind direction, in general, which have influence on the former parameter are important, because they have significant roles in controlling the ice growth together with some other factors. Modern models of sea ice dynamics and thermodynamics are presented e.g. in (Cheng et al 1999).

3.4   ICE CONDITIONS

Due to the location in the northern latitudes, sea ice can be found in the Baltic Sea areas in a normal winter. The ice conditions in the northern parts of the Baltic Sea, in the Gulf of Finland as well as in the Bay of Bothnia are mostly affected by two factors: the cumulative sum of freezing days and the direction of prevailing winds. The count of freezing days (i.e., the cumulative average temperature of the winter) controls the ice growth and the amount of ice. The prevailing winds control the drifting and ridging of the ice field. The annual variation of the maximum extent of the ice covered area in the Baltic Sea has been great, see Figure 13. Most often the ice cover has extended to cover about 20 – 40 % of the Baltic Sea, see Figure 14.
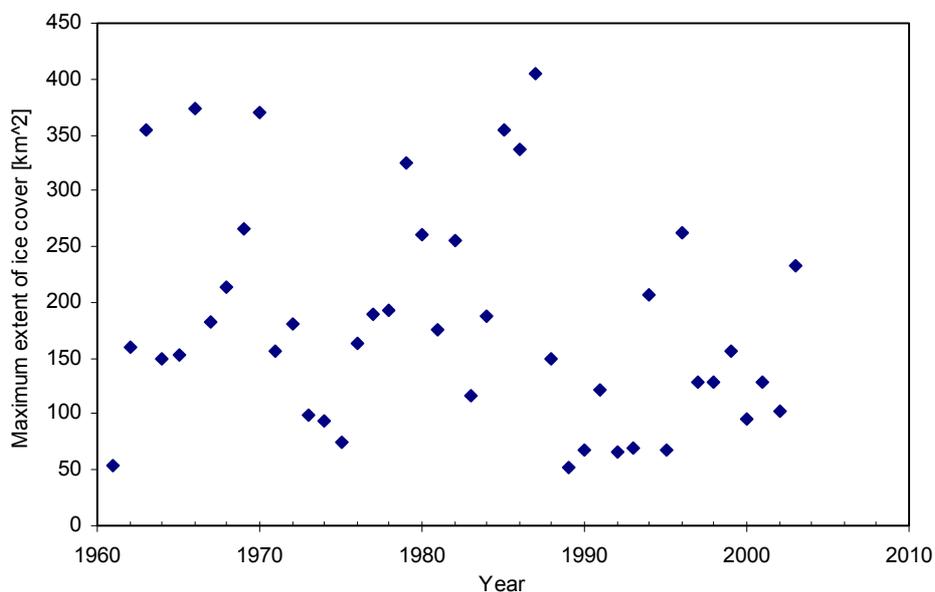

Figure 13   The maximum extent of ice cover in the Baltic Sea in years 1961-2003. The data in this figure is based on the information given in (Seinä & Peltola 1991) and (FMA Y 1992-2003)
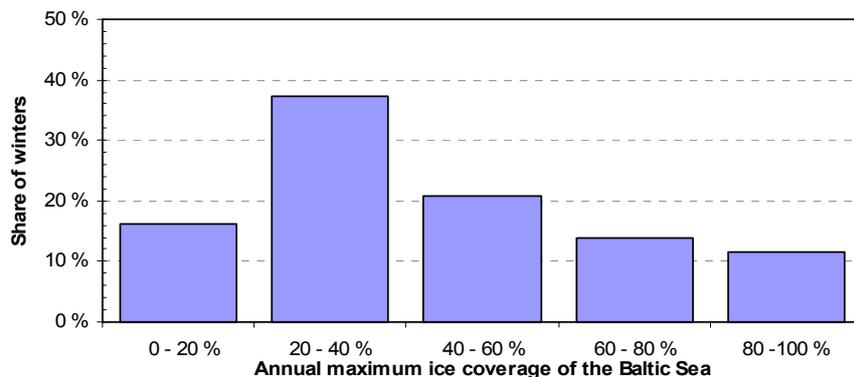
Figure 14   The annual maximum ice coverage of the Baltic Sea in years 1961-2003
             presented as a histogram.

The following description of the seasonal changes in the ice conditions in the Baltic Sea,
which is focused on the conditions in the Gulf of Finland, is based on the references
(Leppäranta et al 1988) and (VTT 2002).

Formation of the ice cover

In the region of the Gulf of Finland the temperature contours lie generally in the north-
south direction during the winter season. When moving from west to east the temperature
gets colder and therefore the formation of the ice cover starts from the easternmost parts
of the gulf. Generally the Gulf of Finland (GoF) starts to freeze only slightly after the
Bay of Bothnia. In the GoF the border between the open water area and the ice cover
moves towards west as the winter proceeds.

On average the Gulf of Finland starts to freeze in the beginning of December. The earliest
freeze up days recorded are in the mid-November. After the ice cover formation has
started at the coastline, the bays and the archipelago will freeze quite quickly. At the open
sea area the formation of the ice cover proceeds according to the temperature curves.
Thus, the ice edge is in the north-south direction and moves towards west.

In the spring the breaking up of the ice proceeds in the opposite order. On an average
winter the whole Gulf of Finland is free of ice in the beginning of May. This gives an
average ice season length of 120 days in the Gulf of Finland, outside St. Petersburg, and
about 30-60 days at the entrance of the gulf. The length of the ice season between these
two locations can be estimated from Figure 15.

The thickness of level ice is controlled by the cumulative sum of freezing days. There-
fore, it resembles much the pattern of the length of the ice season. The maximum values
of level ice thickness can usually be measured at the eastern parts of the Gulf of Finland.
There, about 50 cm is a typical value for ice thickness on an average winter. However, in
a hard winter the maximum value of level ice thickness can be as high as 70 cm. The

distribution of the maximum value of level ice thickness on an average winter is presented in Figure 16.

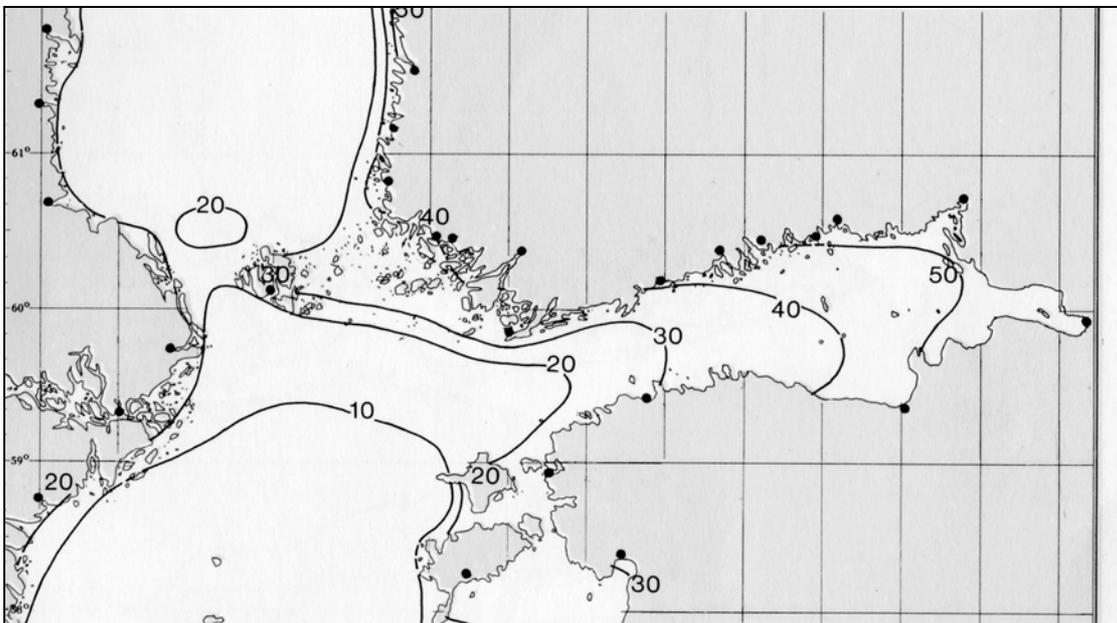Figure 15   Average length of the ice season of winter in days. (Leppäranta et al. 1988)[13].

Figure 16   Maximum level ice thickness (cm) on an average winter (Leppäranta et al. 1988)[14].

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[13] Reproduced here by the kind permission of the Finnish Institute of Marine Research

Dynamics of the ice cover

In the Gulf of Finland fast ice is found only at the shores. In the open sea area of the gulf a drift ice zone is created. Winds break and drive the ice constantly causing compression in the ice field and ridging. Large open water areas may also occur in the drift ice zone. Ice coverage of drift ice is an important quantity. It tells us how large portion of a particular sea area is covered with ice. If the ice coverage is, say 7/10, or less, it is possible to navigate in open water, thus avoiding the ice floes (Leppäranta et al. 1988).

Drifting and ridging of the ice is characteristic to the Gulf of Finland. These two phenomena have important effects on the winter navigation. Westerly winds prevail in the area, and they often push the ice towards east causing heavy ridging in the eastern parts of the gulf. The probability of encountering big ridges gets bigger when moving eastwards and the distance between ridges gets smaller, too. During a hard winter, when the ice cover freezes immobile, the active zone, where the ridging occurs, moves towards west.

In the Gulf of Finland the ice ridges have normally sail heights varying between 0.3 – 1.0 m and keel depths of about 4 to 7 times the sail height. The ridges are difficult to penetrate by ships, especially due to the consolidated layer of the ridges, which is normally thicker than the surrounding field of level ice. The ice ridges form the biggest obstacle for winter navigation.
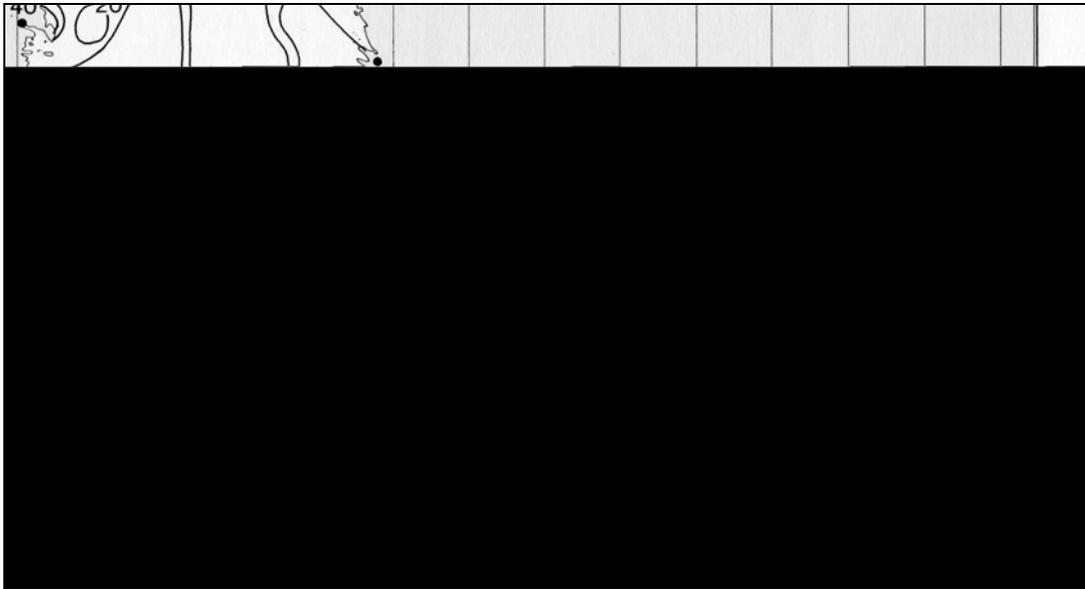

Figure 17   The biggest addition to the level ice thickness caused by ridging (Leppäranta et al. 1988)[15].

The level ice thickness in a particular open sea area does not describe the characteristics of a ridged ice field well. However, for ridged ice fields it is possible to calculate a so-called *equivalent ice thickness*[16]. This parameter is the thickness that is obtained, when the amount of ice in the ridges would be evenly distributed on the whole area. This addition to the level ice thickness is about 10 cm on an average winter in some parts of the Gulf of Finland, but on a hard winter it may be as high as 70 cm as presented in Figure 17.

The ridge density (ridges per nautical mile) is another important measure describing the ridged ice field. The closer the ridges are to each other the more difficult the ice field will be to navigate. Due to it's strong effect on the navigation, the ridge density is usually described in the ice charts with the number of ridge symbols. This highly important information is based on the reports from the vessels navigating in the area.

Ridging is not the only matter causing direct problems to winter navigation. If ice ridges are passive obstacles to the winter navigation, compaction and compression in an ice field due to wind drag can be active hazards to it. Vessels navigating in a compressive ice field may get stuck in a compressive ice field, and they may also get ice damages to the hull in it. Even if the ship is following an icebreaker, proceeding in a closing channel, high compressive loads may occur on the vessel's midship.

The disappearance of the ice cover

The disappearance of the ice cover is controlled mainly by the solar radiation, which gets more intensive during the spring. The ice itself is not very effective in absorbing the solar radiation, only 20-60 % of it is usually absorbed. However, when the sun warms up the open sea and the land areas surrounding the ice covered areas of it, the convection of energy from the warmed sea water and air to the ice starts. Then, the snow on the ice and the ice cover itself start to melt more efficiently. Water on the ice absorbs solar radiation more efficiently than ice, so when once started, the melting of ice can continue at a higher rate. Therefore, ice will disappear more quickly than it grew, see Figure 18.
Ice floes will break from the ice edge starting to drift with winds and currents. Due to the strong influence of solar radiation, the date of breaking up of the ice and it's degradation is more strictly bounded to the datum than the datum of the ice formation (Leppäranta et al 1988).

Each sub-area in the Baltic Sea has its own characteristic time and duration of the largest extent of ice cover. The duration of ice cover is short in the southern parts of the Baltic Sea. In the Gulf of Finland the ice cover forms and melts earlier than in the Bothnian Sea. In the Bothnian Bay the duration of the ice cover is longest, but the rate of ice melting is the highest (SMHI&FIMR 1982). Ice drifting from the Gulf of Finland to the northern part of the Baltic Proper extends slightly the duration of ice winter in the latter. The Bothnian Sea and the Gulf of Finland usually get rid of ice in April, but in the Bothnian Bay the ice usually stays till May (Leppäranta et al 1988).

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[16] A similar approach may be used to take into account the effects of a snow layer on the level ice.
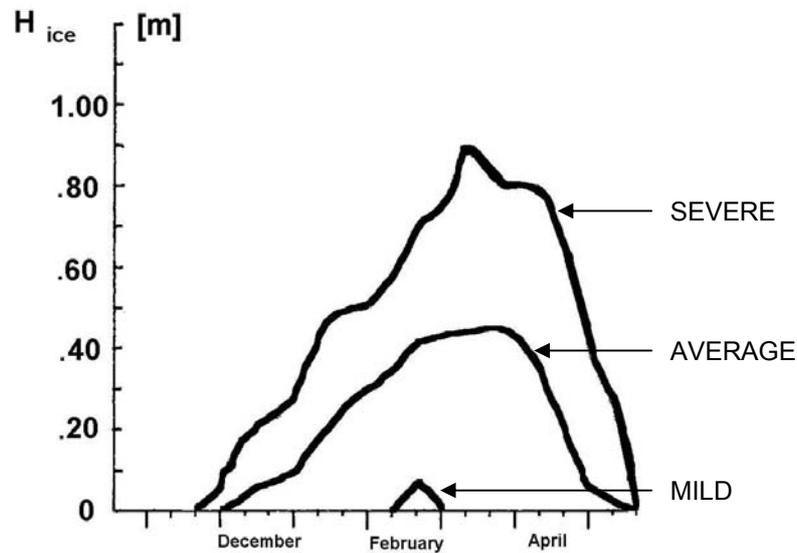
Figure 18   Development of the ice thickness in Kotka during a most severe, average and
extremely mild winter, reproduced from (Leppäranta et al, 1988)

When sea ice gets warmer, its brine volume will increase. This main phenomenon will
make the ice weaker, although there are several other effects too. In general, thick ice
may loose its strength quicker than its thickness. Therefore, at a certain time of the
spring, the ice thickness will loose its validity as the best characteristic parameter for ice,
when navigation through it is considered.

Ice covered navigation channels to ports

The fairways to many Finnish harbours are typically leading through shallow and rocky
waters. Therefore, these fixed fairways stay often as the only possible ways for use in
wintertime. The ice cover in the fairways is constantly broken by ships, and refrozen.
Thus the amount of ice and the ice thickness in these broken channels grow rapidly.
Older channels, that have been frequently navigated, will soon get a thick brash ice layer
in the middle and thick side ridges. The latter may sometimes grow several meters thick.
The brash ice layer in the middle of an old channel can become up to one meter thick.
Older channels of this kind are difficult and heavy to navigate. Because of the side ridges,
which may get consolidated to a certain extent, passing of other vessels in the channel
becomes very difficult.

In the open sea areas the channels broken by icebreakers or other strong ships do not
usually last for navigation for any longer period. The reasons for this are the effects of the
winds and currents. In wide and open sea areas drifting ice deforms, closes and moves the
channels rather rapidly.

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Different problems of mild and severe winters

Due to the geographical and climatological characteristics in the area of the Gulf of Finland, there are no so-called easy winters. On a hard winter there exists a great amount of ice and the ice cover is extending to a large area, see Figure 19c). The distances for ships to be travelled in ice become long and the likelihood of encountering massive ridges becomes bigger. On a hard winter the majority of harbours and their surrounding areas in the northern Baltic Sea are covered with ice. On milder winters not necessarily all harbours become icebound, and especially the central areas in the sea basins (e.g. in the Bothnian Sea, the Gulf of Finland and the Baltic Proper) may stay open.

a)   b)   c)
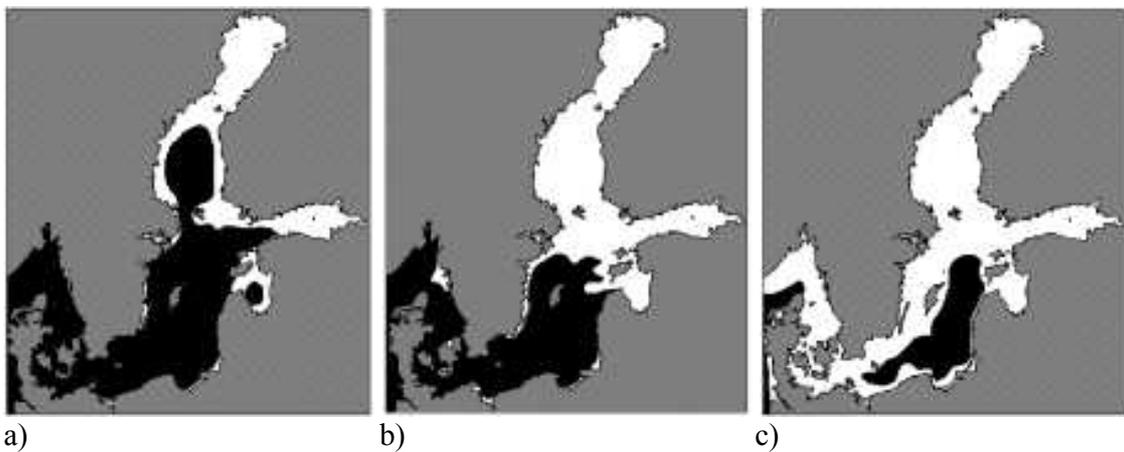
Figure 19   The maximum extent of ice cover a) on a typical mild winter (1990-1991, 122 000 km^2), b) on a typical average winter (1993-1994, 206 000 km^2) and c) on a typical hard winter (1985-1986, 337 000 km^2)[17].

The Finnish harbours are all surrounded by ice even on rather mild winters, but the distances travelled in ice are fairly short as the ice edge is at the skerries and outer islands. The situation in the eastern parts of the Gulf of Finland is somewhat different. On milder winters the total amount of ice in the GoF is smaller than on hard winters, but the winds push that ice towards east. Thus, it packs drift ice and ridges against the far end of the gulf. Therefore, in every winter the fairways to the eastern harbours in the Gulf of Finland are covered with ice and the vessels have to sail through heavily ridged ice fields.

There are several forms of sea ice. Level ice and fast ice can usually be found in coastal areas. It is attached to the shore or between the shoals. Brash ice can be found in the channels and port areas, where the ship traffic and it's effects are obvious. However, in the more open sea areas, where there is no shelter or support from islands or skerries, the forms of ice are more manifold. Here the forms of ice is affected by the dynamic forces of winds and currents. Thus, in addition to level ice, there will be deformed ice, rafted

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[17] Source of these figures, which are reproduced here with the kind permission of mr. J.Vainio and the Finnish Maritime Research Institute, and which are presented on the following website in 13.1.2004, is: http://www2.fimr.fi/fi/itamerikanta/bsds/897.html

ice, ice cover with different degrees of concentration, from open ice to very close ice and consolidated ice. Although the forces of the nature may arrange natural channels for the navigation, leads in the ice cover, it can also build severe obstacles for shipping such as hummocks and ridges, see Figure 20. Different forms of first-year ice that can be found in the Baltic Sea, such as those mentioned above, are listed e.g. in the Sea Ice Nomenclature (FMA 2002b).

Figure 20   A typical view in the ice covered sea in the northern Baltic Sea. Some ice ridges are visible ahead of the ship's bow. The old channel ahead of the ship has been compressed narrow by the environmental forces. (photo: T.Leiviskä)

4   WINTER NAVIGATION SYSTEM IN THE NORTHERN BALTIC SEA

4.1   TRAFFIC PATTERNS AND DISTANCE TRAVELED IN ICE

The winter traffic in the northern Baltic Sea has been increasing during the 90's. This growth has been described recently in (VTT 2002). Based on the information given in this reference the total number of ship movements in year 2000 to the ports of the Gulf of Finland was about 37 488, excluding the ferry traffic. This means a monthly average of 3 124, if divided evenly per each month. About 7.5 % of this traffic remains between the ports of the Gulf of Finland. However, the ferry traffic across the Baltic Sea, e.g. between Estonia, Finland and Sweden has also a great impact on the general traffic numbers. The passenger-car-ferry traffic from Helsinki alone included 6 276 departures e.g. in year 2001, which makes 523 departures/month on average.

Traffic frequency in the ports of Finland is not constant through the year, see Figure 21. There are changes during the year, especially in passenger traffic. Based on the Finnish statistics the total number of passengers, arrived and departed, in January 2003 (FMA 2004a) was about 66 % of the corresponding average monthly number for the whole year, 15,6 million (FMA 2004d). Corresponding ratio (period/average level) for period January-March 2003 is 76 %, for period January-April 2003 it is 80 %.
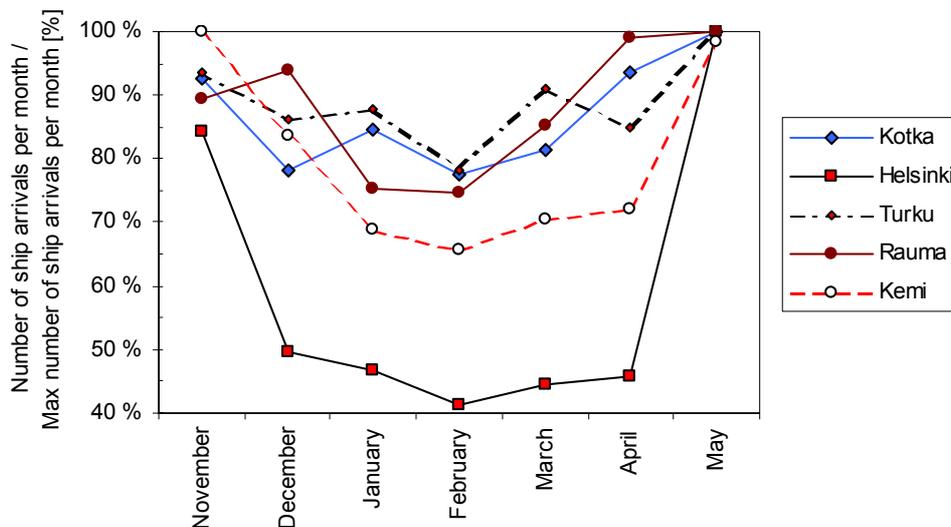
Figure 21   The relative variation[18] in the number of ship arrivals in some Finnish ports during the winter 2002-2003 based on the monthly shipping statistics published the FMA (2004a).[19]

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[18]   In this figure the number of ship arrivals per month is compared to the maximum number of ship arrivals per month considering the whole November-May-period.

[19]   Note! The large drop in the ship arrivals in Helsinki for the period December-April is mainly due to the interruption of the traffic of the high speed passenger vessels in the route between Helsinki and Tallinn.

The nature of the seasonal variation in the number of ship arrivals in Finnish ports has similarities with the seasonal variation of passenger traffic to a certain extent. The share of all ship arrivals in the period January-March 2003 was 72 %, and in the period January-April 74 %, of the average monthly number of arrivals based on the numbers for the whole year 2003. Thus, there is a clear difference between winter months and the rest of the year. Such a difference should be taken into account in risk assessment.

In order to assess the quantity of winter traffic in the Finnish waters and to characterize the effects of the winter the number of ship arrivals in Finnish ports were counted from the monthly statistics of Finnish Maritime Administration (FMA 2003a). The number of ships that arrived in Finnish ports in January-April 2003 was 9 280. The average voyage length in ice, considering the traffic (and traffic frequency) to nine major ports along the coast of Finland and calculated from the ice edge to port and back, was roughly estimated to be about 125 nm in the same time period, see Figure 22. The number of ship arrivals and departures in the time period of traffic restrictions (due to ice conditions) was 16 891 in the winter 2002-2003.

The mean ice thickness encountered along the routes of this traffic was estimated [20] to be about 0.30 m. Thus, a coarse estimate on the amount of ice encountered by an average ship visiting a Finnish harbour in the period January-April 2003 is about 38 m*nm/visit (meters times nautical miles per visit).
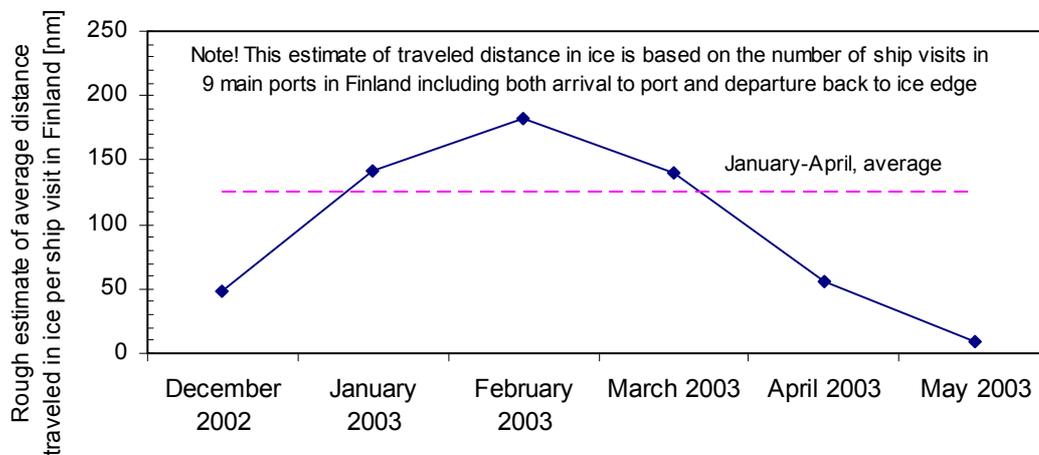
Figure 22   Estimated monthly average of mean length of voyage in ice when visiting a Finnish port during winter 2003 (ice edge – port – ice edge)

According to the statistics of the Russian Port of St. Petersburg (Kudryavtsev, 2003) the number of ship calls in that port in size range 15 000 – 50 000 tons was 218 in January-

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[20] This estimate was based on the information published in the ice charts of the Finnish Institute of Marine Research and a simplified assumption on all ships being in centralized traffic concerning 9 main ports along the Finnish coast (Kotka, Helsinki, Hanko, Turku, Maarianhamina, Rauma, Vaasa, Raahe and Kemi). All traffic was assumed to be between these ports and some distant ports in the south. Distance from the ice edge to these ports was measured from the ice charts and used than in the calculation of the average distance traveled in ice.

April, 2003. This traffic formed a share of about 10 % of the general ship traffic in that period. Thus, it can be estimated that the total traffic for this time period was about 2180. The Port of Primorsk was visited by about 58 times, with an average number of 14-15 ships/ month and a turnover of a bit more than 81 000 tons/ship. The number of ship visits in the ports of Vyborg, Vysotsk and Ust-Luga was 382 for the whole winter period. Based on the monthly traffic numbers of the Port of St. Petersburg it is here estimated that the number of ship visits in Vyborg, Vysotsk and Ust-Luga in January-April 2003 was 287. When summed up this makes altogether about 2525 ship visits in the Russian ports in the eastern part of the Gulf of Finland.

In winter 2002/2003 the average distance from ice edge to St. Petersburg, see Figure 23, has been significantly longer than the average distance in ice to the Finnish ports. The average distance travelled in ice, when visiting St. Petersburg in January-April period in 2003 was estimated to be roughly about 440 nautical miles[21].
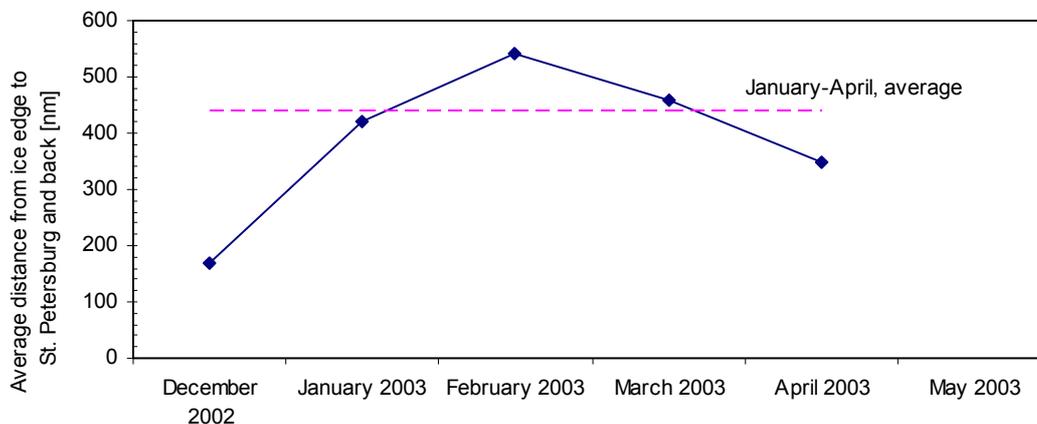
Figure 23   The monthly average distance from ice edge to St. Petersburg (and back) in winter 2002/2003. This figure is based on (Kudryavtsev, 2003) and some assumptions concerning the distribution of traffic. Note the difference in the vertical scale in this figure and the vertical scale that is used in Figure 22.

According to the statistics of port of Tallinn (PoT 2004a) the number of ship calls in the Estonian ports Muuga, Tallinn and Paldiski was 10 805 in year 2003. The number of passenger ship visits in Tallinn was 7 549 and the number of cargo ship calls 3256 (PoT 2004a, PoT 2004b). Based on the monthly traffic statistics the number of passengers visiting Tallinn by ship in the period January-April is about 78 % of the average annual 4-month level, which can be calculated by dividing the yearly number of passengers by 3.

The amount of total cargo turnover in the Port of Tallinn decreased from 37,9 million tons in 2002 to 37,6 million tons in 2003 (PoT 2004a). However, it seems that the average yearly growth of about 17 % stopped in 2003 with a 1,5 % decrease from the total cargo turnover of the previous year. However, the winter 2002-2003 with the whole Gulf of Finland covered with ice did not make an exceptionally large drop in the monthly

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[21] When converted to kilometers, 440 nautical miles is about 820 kilometers.

cargo turnover in the Port of Tallinn. The distance from Tallin to ice edge is usually shorter than the distance from Helsinki to the ice edge due to the prevailing SW winds.

In this risk assessment the total number of ship visits in Finnish, Russian and Estonian ports in the period from the beginning of December 2002 to the end of April 2003 is assumed to be about 19 000. Approximately 63 % of this number is assumed to be the share of the traffic to all Finnish ports, 17 % is assumed to be the share of the traffic to the Russian ports (at the eastern end of the Gulf of Finland) and 20 % is assumed to be the share of the traffic to Estonian ports.

Table 3   The assumed distribution of ship port visits in the northern Baltic Sea in winter 2002-2003. The total number of port visits is rounded to 19 000.

	Number of port visits in January-April	
Finland	11 845	63.3 %
Russia	3 114	16.6 %
Estonia	3 747	20.0 %
Total	18 706	100.0 %

4.2   THE PRINCIPLES OF THE WINTER NAVIGATION SYSTEM

The Finnish-Swedish winter navigation system includes three main supports: ice class rules, traffic restrictions and icebreaker assistance, see Figure 25. These factors are tightly connected. Ice class rules determine the required hull and propulsion machinery strength and propulsion power. The traffic restrictions limit the number of vessels eligible for icebreaker assistance based on their ice class and deadweight. The traffic restrictions allow only those ships that are more capable to operate in ice to enter the area. This is needed to ensure that the number of icebreakers is adequate to guarantee assistance to all vessels, which fulfil the ice class rules and traffic restrictions. On the other hand, the rules and restrictions are based on the assumption of icebreaker assistance whenever it is needed. Ice service, which informs about the development of ice conditions, is also an important element of the winter navigation system.

Figure 24   Icebreaker assistance in the Gulf of Bothnia: IB Urho is towing a tanker (photo: R. Jalonen)
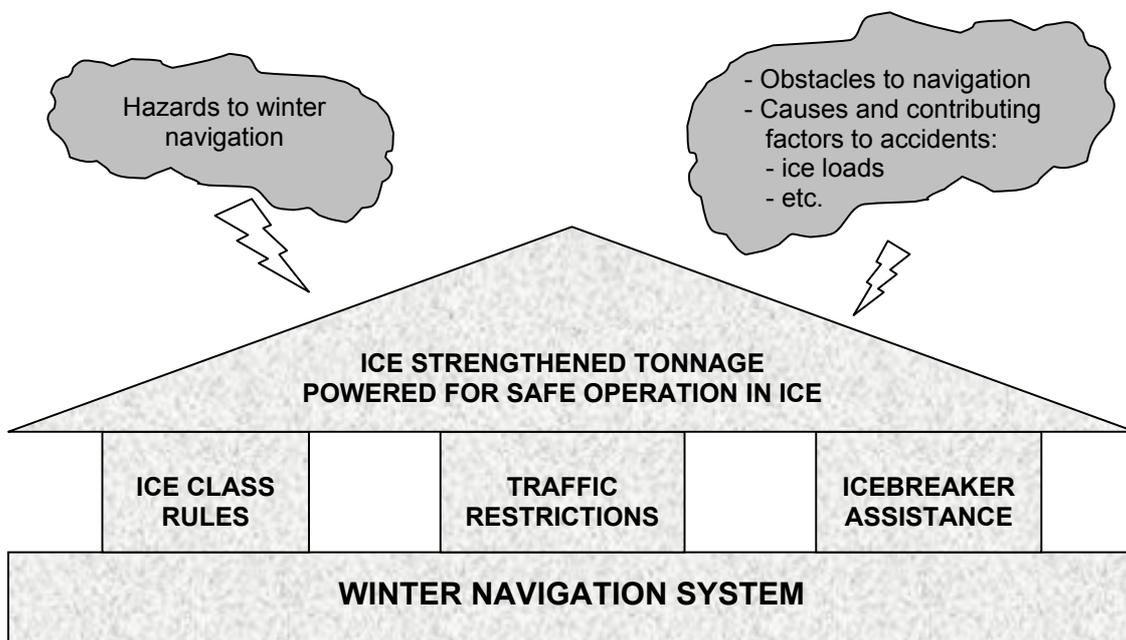
Figure 25   Basic elements of the present winter navigation system

4.3   FINNISH-SWEDISH ICE CLASS RULES

The Finnish-Swedish winter navigation system has evolved during a long time to its present form. The first ice class rules were established in year 1932. After a long interval these rules have been updated in years 1960, 1965, 1971, 1985 and 2002 (Salonen 2003). Common ice class rules were introduced in Finland and Sweden in 1971. A large number of hull ice damages in the Baltic Sea (Johansson 1967) was one of the reasons to develop the ice strengthening at that time.

The present rules (FMA 2002a) are based on the assumption that all vessels bound to and from Finnish ports are given icebreaker assistance. These ice class rules are set to guarantee that the vessel has adequate strength of hull, propulsion machinery and rudder as well as sufficient propulsion power in normal operation conditions. These conditions are met when the ship is proceeding with own propulsion behind an icebreaker in a ridged ice field or when it is proceeding independently in opened fairways leading to ports. Vessels designed for completely independent operation at the Baltic Sea require more hull strength and propulsion power and their capability lies above the Finnish-Swedish ice classes.

The ice class IA Super is designed for year-round operation in the Baltic, in all Baltic ice conditions (with the assumption of the icebreaker assistance). The traffic restrictions never apply to this class. Class IA has been found to be adequate in the Gulf of Finland.

In most severe ice conditions smaller IA-vessels must be restricted from icebreaker assistance. Classes IB and IC are designed for early winter or late spring traffic. They are excluded from icebreaker assistance during most winters. Class II is basically an open water vessel and used only for occasional operation in light ice conditions.

The current Finnish-Swedish ice strengthening rules (FMA 2002a) are based on a long experience of winter navigation. In these rules the ice strengthening is based on the load height and the design ice pressure, the values of which depend on the ice class, the displacement and the machinery power of the ship. The design ice pressure is highest at the bow and lowest at the afterbody of the ship. A comparison of design ice pressures to be applied for the plate thickness dimensioning of a generic, 150 m long ship in the cases of various ice class categories of the Finnish-Swedish ice class rules is given as an illustrative example in Figure 26. In addition to the plate thickness several other structural elements of hull are included in the requirements. In order to design efficient structures for ice class vessels a well balanced strengthening of plates, frames, stringers and webs is needed. In addition to the ice pressure, realistic contact areas and ice loads need to be taken into account.
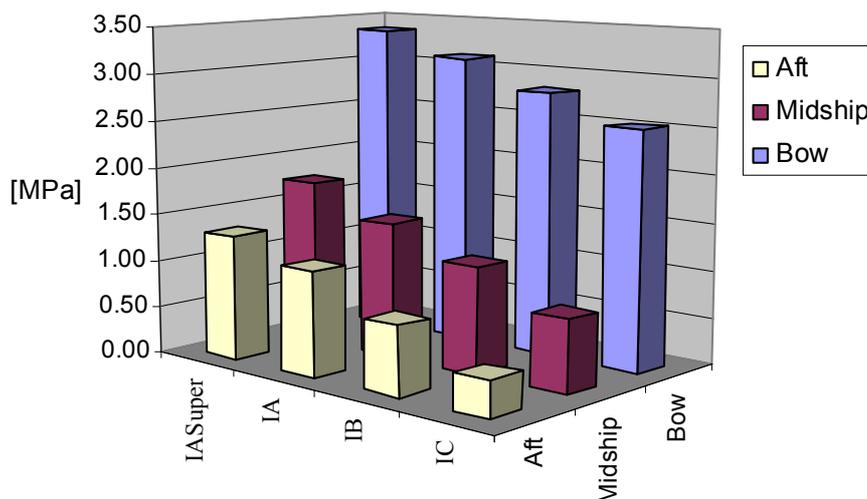
Figure 26   An example of design ice pressure (p) in different ice classes to be applied when calculating ship plate thickness in various areas of ice belt (Ship data: L = 150 m, B = 25 m, T = 9 m, Displacement = 23 625 t). Note! Plate thickness is not the only component to be ice strengthened.

It should be noted that the design ice pressures are just calculated pressure levels, the magnitude of which can be exeeded even during normal operation in ordinary ice conditions. Maximum level of local ice contact pressures of the order 10 MPa have been recorded in first-year level ice (Riska et al 1983).

The hull strength requirement in these rules is determined based on the assumption of the icebreaker assistance. Especially the strength of the vessels at the midship region is not

adequate to withstand high compressive ice loads. Therefore, it is assumed that the icebreaker cuts the vessel loose immediately, when this kind of situation occurs.

A thorough knowledge and understanding of the ship-ice contact phenomena, including the behaviour of the ship structures under ice loads are essential prerequisites when the ice class rules, used for design of ice strengthened ships, are under development. Realistic evaluation of the ice conditions to be encountered by the ship and the ice loads are important, when the hull structures for any ship operating in ice conditions are designed.

The required engine power output, see (FMA 2002a), is determined so that the vessels can operate independently in the fairways leading to ports. These design ice conditions are decided to be a channel with 1 meter thick brash ice layer and 10 cm thick consolidated layer for class IA Super. For classes IA, IB and IC there is no consolidated layer and the brash ice thicknesses are 1 m, 80 cm and 60 cm, respectively. An example of differencies in power requirements for various ice class categories, given in (FMA 2002a), is presented in Figure 27.
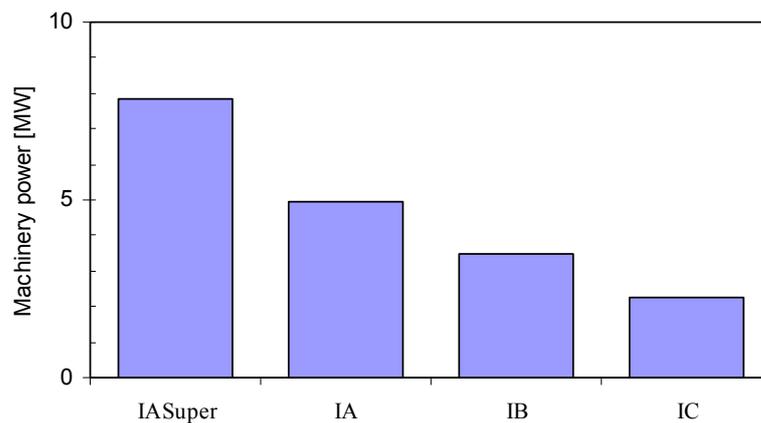
Figure 27   A comparison of ship machinery power requirements in different ice classes to be applied on an example ship (data: L = 150 m, B = 25 m, T = 9 m, displacement = 23 625 t)

4.4   OTHER ICE CLASS RULES

Many vessels do not originally have a Finnish-Swedish ice class. Therefore, in practice, the ice classification is assigned to a vessel by one of the commercially operated ship classification societies. The classification societies all have their own ice class rules and they determine the ice classification according to those rules. The Finnish Maritime Administration compares the different ice class rules with the Finnish-Swedish rules and assigns the vessels the Finnish-Swedish ice classification according to the equivalencies of the different rule sets.

Table 4   Approximate correspondence between different Ice Classes of the Finnish-Swedish Ice Class Rules (Baltic Ice Classes) and the Ice Classes of other Classification Societes (FMA 2003).

Classification Society	Ice Class				
Finnish-Swedish Ice Class Rules	IA Super	IA	IB	IC	Category II
Russian Maritime Register of Shipping (Rules 1995)	UL	L1	L2	L3	L4
Russian Maritime Register of Shipping (Rules 1999)	LU5	LU4	LU3	LU2	LU1
American Bureau of Shipping	IAA	IA	IB	IC	D0
Bureau Veritas	IA SUPER	IA	IB	IC	ID
CASPPR, 1972	A	B	C	D	E
China Classification Society	Ice Class B1*	Ice Class B1	Ice Class B2	Ice Class B3	Ice Class B
Det Norske Veritas	ICE-1A*	ICE-1A	ICE-1B	ICE-1C	ICE-C
Germanischer Lloyd	E4	E3	E2	E1	E
Korean Register of Shipping	ISS	IS1	IS2	IS3	IS4
Lloyd's Register of Shipping	1AS	1A	1B	1C	1D
Nippon Kaiji Kyokai	IA Super	IA	IB	IC	ID
Registro Italiano Navale	IAS	IA	IB	IC	ID

Many classification societies have adopted the Finnish-Swedish rules directly, but some have employed a totally different approach. In Russia quite different ice class rules from the Finnish-Swedish rules have been applied. However, a list of equivalencies of the different ice classes has been recently issued (see Table 4). Investigating and listing of the equalities between these two rule sets has been a matter of high priority.

4.5   TRAFFIC RESTRICTIONS

Due to the limited number of operating icebreakers, it is not possible to offer individual assistance for all vessels in busy sea areas. Therefore, the number of vessels in the ice covered sea area must be reduced based on the ice conditions and the number of the icebreakers in the area. Also, the vessels with inadequate hull strength compared to the

prevailing ice conditions must be excluded from the area. By announcing traffic restrictions the safety and continuity of the traffic can be assured so that possible waiting times for the icebreaker assistance do not become too long.

The traffic restrictions state the minimum ice class and the minimum deadweight of vessels, which are given icebreaker assistance. The restrictions evolve as the winter proceeds and ice conditions become more severe. In springtime the restrictions are then stepwise removed. Thus, the length of the period of restricted traffic depends on the length and severity of the winter. The average length of the period with traffic restrictions in Finnish ports is presented in Figure 28.
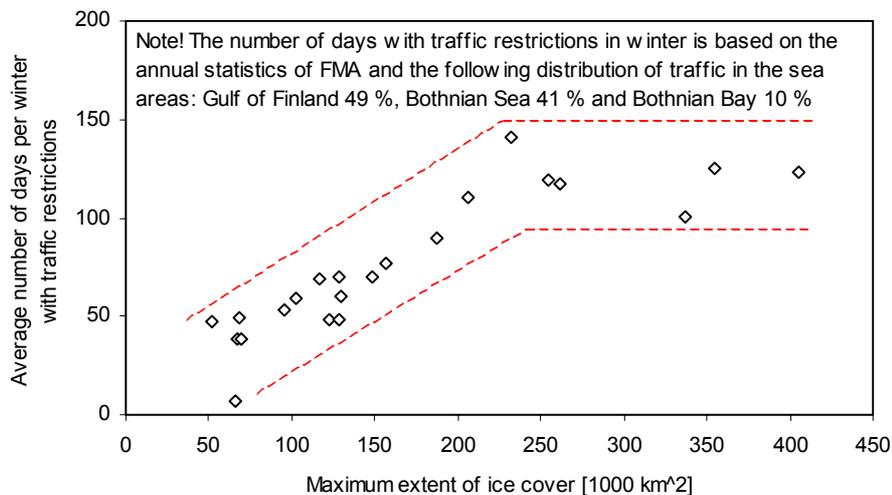
Figure 28   The length of the period of traffic restrictions in Finland plotted as a function of the maximum extent of ice cover in the Baltic Sea in winters 1982-2003.

During the most severe winters in Finland this period has been roughly about 100-150 days long, on average. The longest period of restricted traffic in winter 2002-2003 was in Tornio, Kemi and Oulu, where the restrictions for navigation (for ships in any ice class: I and II with tonnage of 1000 dwt or below) were first announced to be started 19.11.2002 and removed 23.5.2003. Thus, in the northern ports in the Bay of Bothnia this period lasted more than 180 days. The length of the periods presented in Figure 28 is always below 145 days due to the weighting with the number of ship arrivals in the ports of the selected sea areas. The ship traffic in Finland is concentrated in the ports in the southern part of the country. Therefore, the average number of the port visits per day (during the period of restricted traffic) is not influenced much by the ice conditions in the Bay of Bothnia, where the period is longest, as can be deduced from the figures in Table 5. An example of traffic restrictions for ships navigating in the Gulf of Finland is given in Figure 29.

Table 5   Traffic data concerning Finnish ports in winters 1982-2003 in the period of traffic restrictions due to ice conditions acording to the statistics of FMA (2004e) and (Federley 2004).

Winter	Average length (and max length) of the period of traffic restrictions* [days]		Number of ship arrivals & departures during the period of traffic restrictions	Number of port visits (arrivals & departures)/2	Visits per day (average)[22]
1982	119	(166)	8 235	4 118	35
1983	68	(119)	4 109	2 055	30
1984	91	(174)	6 503	3 252	36
1985	125	(163	7 996	3 998	32
1986	101	(157)	6 833	3 417	34
1987	123	(152)	8 360	4 180	34
1988	71	(153)	4 598	2 299	33
1989	47	(167)	3 226	1 613	34
1990	38	(157)	2 484	1 242	33
1991	48	(157)	4 359	2 180	46
1992	6	(48)	1 319	660	105
1993	38	(183)	3 036	1 518	40
1994	110	(162)	10 209	5 105	46
1995	49	(149)	3 616	1 808	37
1996	119	(179)	13 921	6 961	59
1997	70	(164)	5 015	2 508	36
1998	60	(169)	9 669	4 835	81
1999	76	(183)	10 270	5 135	67
2000	53	(167)	5 487	2 744	51
2001	48	(135)	7 745	3 873	81
2002	59	(177)	9 822	4 911	83
2003	142	(185)	16 891	8 446	60
					Median
1984-1987	110	(162)	29 692	14 846	34
1982-2003	76	(158)	153 703	76 852	39

* Note! The average length of this period is calculated as a weighted average. Traffic and traffic restrictions in the ports on three sea areas, Bay of Bothnia, Bothnian Sea and Gulf of Finland are taken into account. The maximum length of the period of restricted traffic (in parenthesis) is always regarding to the Bothnian Bay.

As can be seen from Table 5 there are large variations in the number of ship visits in Finnish ports during various winter periods. One of the main reasons for this variation is the length of the period for traffic restrictions, which is not the same for all winters, see Figure 28. The highest number of ship visits in Finnish ports was about 8 446 in winter 2003. This value was higher than during any other winter period in Table 14. The number of ships arriving to Finnish ports (and leaving them) during the time of traffic restrictions in winter 2003, which can be considered as a normal or severe winter, was about 76 % higher than the median value during the years 1984-1987. The lowest number of port visits in Finnish ports was about 660 in winter 1992, which was a very mild winter. A very short period of traffic restrictions may produce a peak in the average number of port visits per day. This phenomen is strong in the case of winter 1992.

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[22]   The visits/day in Table 14 are indicative only due to the simplified calcution procedure, which does not take into account the ice conditions and traffic restrictions in all ports separately.

In Finland the restrictions are set by the Traffic Manager of the Finnish Maritime Administration. The Traffic Manager decides on the restrictions based on the information obtained from the Ice Service, the satellite images, the Weather Service and the icebreakers in the area. The restrictions are announced generally five days before they come into force in order to give the shipowners and shippers enough time to react to the change.
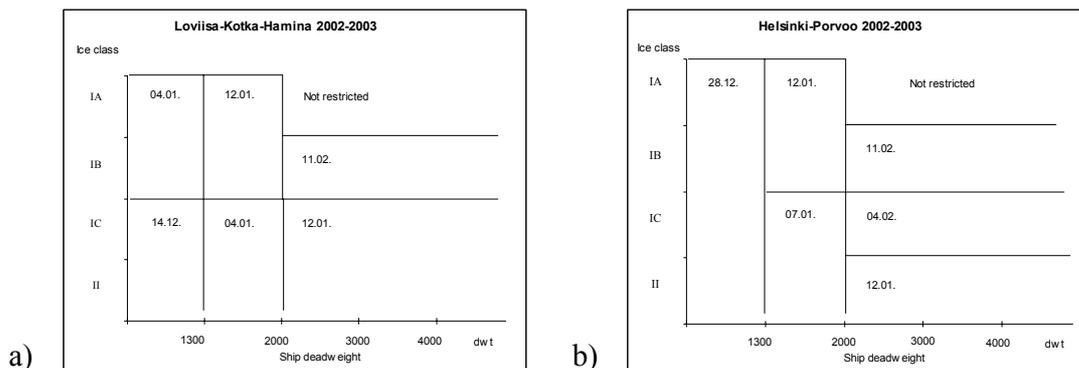
Figure 29   Traffic restrictions declared to Finnish ports, a) Loviisa, Kotka and Hamina, and b) Helsinki and Porvoo, in the Gulf of Finland in the early months of winter 2002–2003. Note! Traffic restrictions to Hanko and Koverhar, Inkoo and Kantvik, and the rest of the winter are not included here.

The most severe traffic restrictions to Finnish ports in the Gulf of Finland have normally been ice class IA and 2000 dwt as shown in Figure 29. These apply to ports east from Porkkalanniemi. To western ports the most severe restrictions have been IA and IB and 2000 dwt or IC and II and 3000 dwt. On many winters the restrictions have been less severe or not applied at all (in the GoF). Lately in Finland there has been a general tendency towards more severe restrictions. (FMA 1999). However, on some occasions, exemptions to the restrictions, considering all relevant matters, have been issued.

In the Baltic Sea Sweden has similar traffic restrictions as Finland. Russia has also applied similar type of traffic restrictions as Finland. The latter are issued based on the Russian ice class rules and determine the minimum hull strength, deadweight and engine power. The difference between Finnish and Russian restrictions is that in Russia the ports control their own icebreaker assistance and traffic restrictions. In Russia there is not a centrally controlled system as in Finland and therefore the ports may have a different approach to restrictions and assistance operations. The port authority of St. Petersburg controls the operations in the eastern Gulf of Finland including the ports of Primorsk and Vysotsk. It is known that the restrictions are not applied in all cases, and the Harbour Masters have the possibility to allow assistance also to vessels which are below the restrictions.

In Finland this possibility for allowing exemptions from the ice class restrictions is limited to the FMA. This kind of exemptions have been used e.g. in last winter. However, the details of the current practice with exemptions from the ice class restrictions are not

investigated in this study. A long time ago, in the 1960's, when there were not enough ice strengthened oil tankers available, exemptions given for tankers without ice strengthening, importing oil to Finland , were heavily critisized (HS 1966). The situation in that very cold winter was exceptional with the country's oil reserves almost empty. However, the importance of the assurance of proper operating conditions for ice strengthened tonnage was understood both by the authorities and the industry. The need for securing the oil import at any risk was considerably reduced, when new ships with stronger and safer hull structure and engine power, that is suitable for winter navigation, were acquired. The policy of using traffic restrictions as a tool for controlling the quality of ships in winter navigation has several effects, see e.g. Figure 30. However, the principal effects are: the safety of the winter navigation and the ensuring of the uninterrupted flow of traffic.

Note ! This figure is based on the statistical data by FMA concerning ship arrivals in the Finnish ports during the period of traffic restrictions and the length of this period in winters 1982-2003

Y-axis: Ship arrivals / day. X-axis: Average number of days of traffic restrictions per winter.

Data labels: 1992, 2001, 1999, 1996, 2003, 1990, 1994, 1982, 1987, 1985
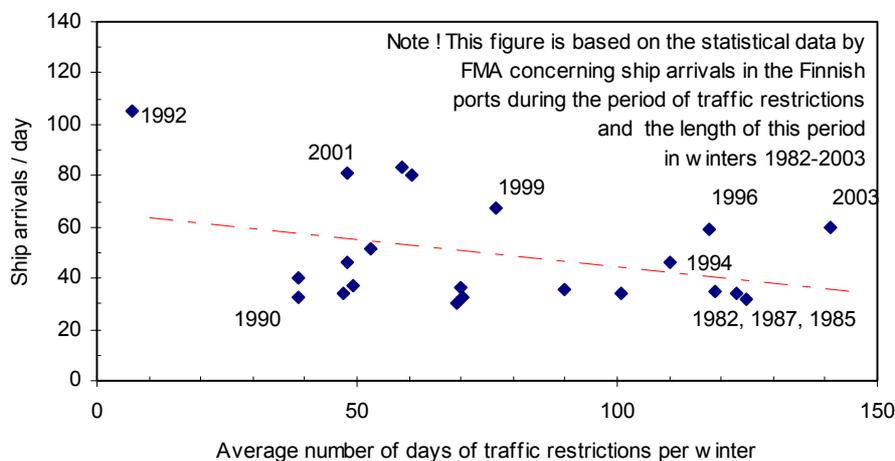
Figure 30   The average number of ship arrivals per day[23] in Finnish ports during the period of traffic restrictions in winters 1982-2003. A slight trend to a less frequent traffic during a longer period of traffic restrictions is observed.

Ice conditions, ice edge in the Gulf of Finland and traffic restrictions

An example of the relationship between the ice conditions and the traffic restrictions is given below. The following data of the traffic restrictions and descriptions of the winter conditions in the Gulf of Finland have been taken from the references (Seinä et al 2001) and (Kalliosaari 2003).

The winter proceeds so that the ice edge expands from the eastern part of the Gulf of Finland towards west during the winter months. Thus the traffic restrictions also develop so that the most stringent restrictions are placed on the easternmost ports on the Finnish side. The traffic separation schemes are located outside the clustered Finnish ports and thus it would be natural to relate the icebreaking zone, traffic restrictions and traffic

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[23]   Note! The average number of days of traffic restrictions per winter is calculated so that it takes into account the number of ship arrivals in three sea areas: Gulf of Finland (49 %), Archipelago Sea & Bothnian Sea (41 %) and Bothnian Bay (10 %).

separation schemes in some way. As discussed later, one alternative to treat the traffic separation schemes is that when the winter proceeds, the separation schemes are replaced with icebreaking zones which include traffic restrictions and icebreaker escort. In order to gain insight how the winter and traffic restrictions usually proceed, winters 1996-97 to 2002-03 have been analysed here. The average location of the ice edge over the winter period is presented in Figure 31 and the traffic restrictions issued by the FMA are presented in Figure 29, both apply for the last winter (2002-2003). The corresponding figures for winters 1997 – 2002 are presented in appendix 1.
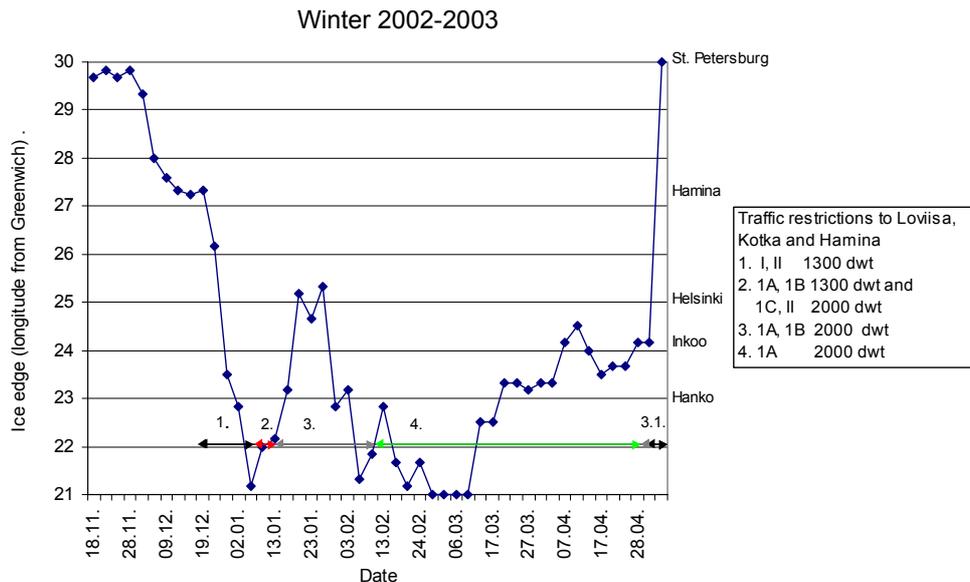
Figure 31   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 2002–2003.

The average longitude of the ice edge has been estimated from the ice charts published by the Finnish Ice Service (Finnish Institute of Marine Research). These ice charts are produced daily and published officially two times a week (Vainio 2003). The ice edge does not actually lie directly in the north-south direction, it bends more to the northwest-southeast direction. The longer the winter proceeds and the ice edge moves towards west, the more the ice edge also bends to the northwest-southeast direction. When the ice edge is still far in east, in the beginning of the winter, the ice edge lies quite well in the north-south direction.

The longitudes of the main harbours in the Gulf of Finland are: St. Petersburg 30°15', Hamina 27°12', Kotka 26°56', Loviisa 26°15', Porvoo 25°35', Helsinki 24°57', Kantvik 24°21', Inkoo 24°00', Koverhar 23°13' and Hanko 22°58'.

Winters 1997 - 2002

The average location of the ice edge over the winter periods 1997 – 2002 are presented in Appendix 1. Traffic restrictions issued by the FMA for the Gulf of Finland are also presented in Appendix 1.

Winter 2002–2003

In winter 2002-2003 the ice formation on the Gulf of Finland started in November, about three weeks earlier than on the average. Cold weather prevailed in the first half of December and ice freezing was fast. However, milder and windier weather on the second half of the month moved the ice eastwards to the mouth of the Bay of Vyborg and east of the Seskar island. Towards the end of the year the weather became colder again and in the end of the year the Gulf of Finland was totally ice-covered. The edge of the ice cover was then about at the longitude of Jussarö.

Cold weather continued in the beginning of January, so new ice was formed even in the northern Baltic Proper. The edge of ice extended from the western side of Ventspils to the west of Bogskär and to the Åland Sea. The ice thickness grew in the Gulf of Finland. After the cold period a milder and windier one started. Therefore, ice was packed to the ice edge and in ridges in the GoF. In February ice was formed on all sea areas again and the edge of ice was at Ventspils-Bogskär-Söderarm. Cold weather continued and in the end of the month the ice edge was at the line Liepaja-west of Ventspils-north of Gotska Sandön-Häradskär-Öland.

The maximum extent of ice cover was 232 000 km^2. This area was reached on the 5th of March. Then, milder weather with south-westernly winds started again and the ice drifted against the Finnish coast. West of Porkkala a lead was formed, but east of it thick ridged ice made navigation more difficult. The rest of March was mild, so the thin new ice in the northern Baltic Proper started to recede and break up. The April was cool, which prolonged the melting, and the varying winds made the ice drifting from coast to coast. The ice break up occurred near the beginning of May in the western parts of GoF, and about two weeks later in the eastern parts of it.

The maximum ice thickness was about 50 - 65 cm in the western parts of the Gulf of Finland and 65 - 80 cm in it's eastern parts. In the central sea area of the GoF the ice thickness was 40 – 75 cm. The ice season in the GoF was more than one month longer than on an average.

Most of the winters analysed here were mild and thus no very general conclusions can be drawn. The ice class IC was required for the ports of Loviisa to Hamina in every year and in 1999 the requirement was ice class IB. In 2003 the requirement was raised to ice class IA. In general, the decisions about the traffic restrictions followed the ice edge, but with some delay. This is natural because, before a restriction comes into force, there must be time to inform all the potential ships bound to the Baltic Sea. The analysis showed, however, that it is feasible to plan the interaction between the traffic separation schemes and the icebreaking zones so that one always changes to the other. This requires, however, willingness of all the port states to deploy icebreakers when the icebreaker zone comes into force.

In the Gulf of Finland the port authority of St. Petersburg issued restrictions that were set on ship traffic, from 22.12.2002 for ships in ice class LU1 or below, and from 13.01.2003 for ships in ice class LU2 with power 3500 hp and below (Kudryavtsev 2003).

4.6   ICEBREAKER ASSISTANCE

Icebreaker assistance includes the following issues:
- advice given to the merchant ships regarding ice conditions etc.
- assistance by opening channels in the ice for merchant vessel visiting winter harbours
- cutting loose merchant ships that are beset in ice
- keeping the ice channels in a condition more easy to navigate, in severe winters this
  may include forming and leading ship convoys through the ice barriers
- towage of merchant ships, see Figures 24 and 32, through the most severe ice barriers
- various other tasks, such as some rescue and emergency service tasks

In the northern Baltic Sea vessels bound to and from Finland or Sweden operate at the same area. Finland and Sweden have an agreement for icebreaker co-operation, which has been very useful in practice. In the Gulf of Finland vessels bound to and from the three countries, Finland, Estonia and Russia, operate at the same area. Finland has an agreement for icebreaker co-operation with both Russia and Estonia, but in practice the co-operation has been quite limited. All countries operate their icebreakers practically independently according to their own rules and regulations.

Figure 32   Icebreaker Urho is towing a merchant vessel (photo: M.Lensu)

Finland

The size of the Finnish icebreaker fleet is, as judged based on the short waiting times for assistance, at the moment adequate for the traffic flow to Finnish harbours. The fleet consists of nine icebreakers, see Table 6. This icebreaker fleet size has been found to be sufficient in the recent mild or at most average winters to guarantee all vessels assistance without unreasonable waiting times, i.e. waiting times longer than four hours. This is the goal that has been set for the Finnish icebreaker fleet (LVM 2004).The total amount of icebreaker assistance work has varied a lot, depending mainly but not solely on the extent of the ice cover, see Figure 33.

Table 6   The Finnish fleet of icebreakers [24]

| Icebreaker	Built	Displacement (ton)	Speed[25] (kn)	Power (MW)	L_{OA} (m)	B_{WL} (m)	T (m)	Bollard pull (ton)
Voima	1954/79	5 209	16	10,2	83,5	19,4	7,0	96
Apu	1970	4 890	18	8,8	86,5	21,3	7,3	108
Urho	1975	7 925	19	16,2	106,6	23,8	8,3	190
Sisu	1976	7 925	19	16,2	106,6	23,8	8,3	190
Otso	1986	9 130	18,5	15,0	99,0	24,2	8,0	165
Kontio	1987	9 130	18,5	15,0	99,0	24,2	8,0	165
Fennica	1993	9 700	16,5	15,0	116,0	25,2	7,0	234
Nordica	1994	9 700	16,5	15,0	116,0	25,2	7,0	234
Botnica	1998	7 300	15	10,0	96,7	23,1	7,2	117
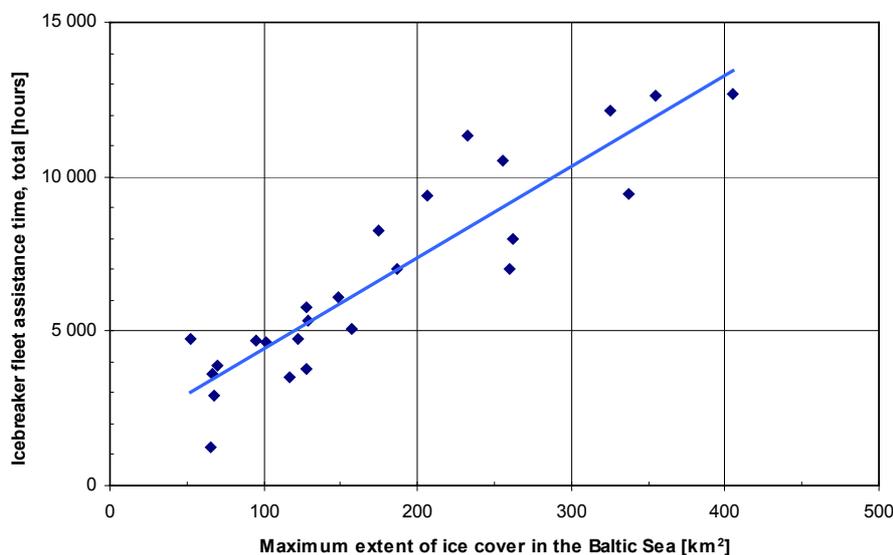
Figure 33   Total time used for cargo ship assistance by the Finnish icebreaker fleet in winters 1979-2003. Data source: (FMA 1971-2002)

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[24] Data sources: see appendix 2.
[25] Speed is maximum speed in open water conditions
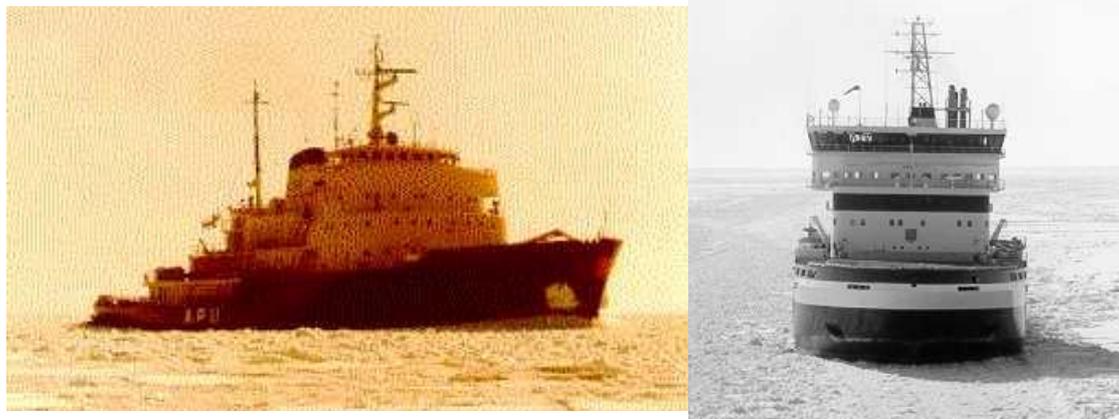
a)   b)

Figure 34   Finnish icebreakers: a) IB Apu and b) the multipurpose icebreaker Fennica
(photos: R. Jalonen)

The icebreaker operations are controlled by the Traffic Manager operating in the Finnish
Maritime Administration. He decides on the traffic restrictions and orders the icebreakers
to their operating areas according to ice conditions and traffic flows. The Traffic Division
of the Finnish Maritime Administration does not control the assistance operations on the
operational level, but it sets the boundaries and provides the icebreakers information to
support their activities. This information includes ice and weather information, satellite
pictures, traffic information, etc. An important activity is to maintain and update the
IBNet- and IBPlott-systems. In the IBPlott-system the icebreakers can see a satellite
image on top of an electronic chart and also the positions and courses of the icebreakers
and commercial vessels in the area.

On the operational level the icebreakers control the traffic in the operating area. They
make the decisions on the assistance operations and routes independently within the
boundaries set by the Traffic Manager. If there is more than one icebreaker in the area,
the oldest of the captains works as a coordinator who makes the decisions and gives the
orders. On the operational level the co-operation with Swedish icebreakers is strong in
the Bay and Gulf of Bothnia. The Finnish and Swedish icebreakers operate there
practically as one fleet. The Finnish-Swedish co-operation model and the information
flows in the IBNet-system are presented in Figure 35.

In normal situations the icebreakers are in direct contact with the vessels in the area and
give them information on ice conditions and the easiest routes through ice covered
waters. To support the navigation they also give the vessels waypoints, which they should
follow. Also, the icebreakers open channels for the vessels and in severe ice conditions
tow them into harbours.
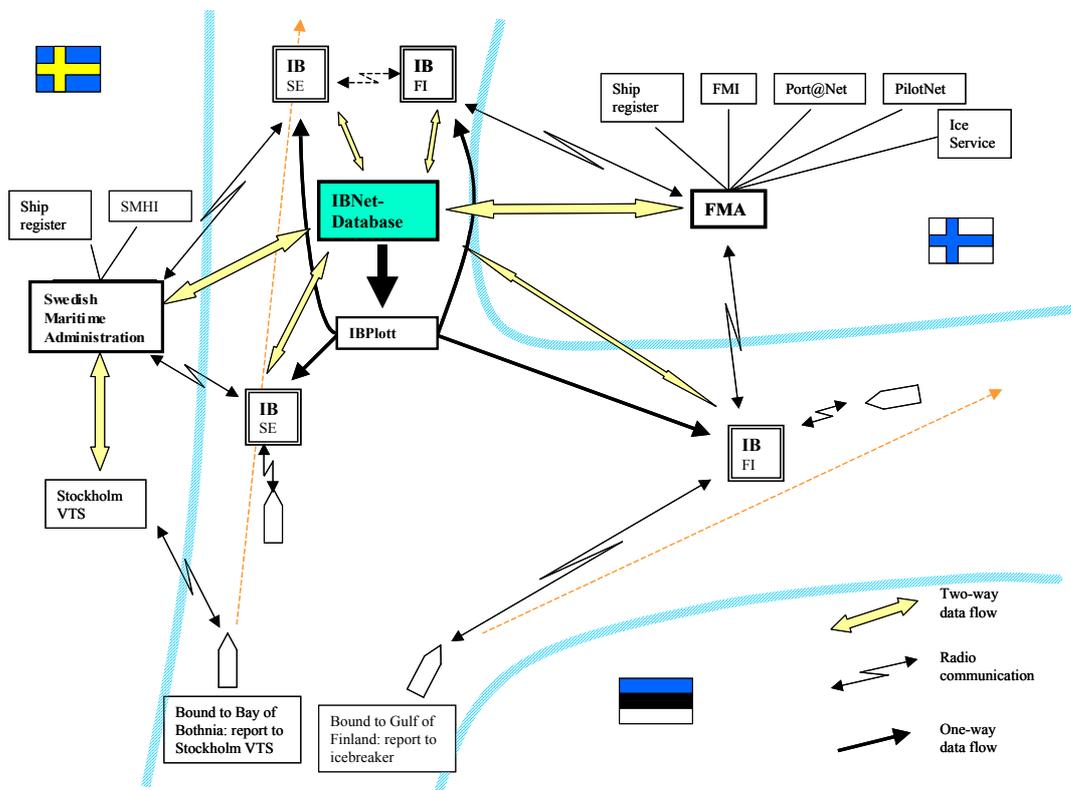
Figure 35   The Finnish-Swedish co-operation model and the information flows in the
IBNet system (reproduced from (Juva 2002)).

Vessels bound to Finnish harbours in the Gulf of Finland have to report directly to the
icebreaker, which is in charge of that area. Reporting is required in good time before
entering the ice covered waters. Also the Traffic Division gets advance notices of traffic
flows from harbour offices.

Sweden

Sweden has five state icebreakers, three *Atle*-class icebreakers (similar to the Finnish
icebreakers *Urho* and *Sisu*), one bigger Arctic class icebreaker, *Oden* (see Figure 36), and
one lake icebreaker, *Ale*, see Table 7. When necessary, e.g. during a hard winter, the
Swedish Maritime Administration may use the AHTS-icebreakers[26] (see Figure 37) *Tor
Viking*, *Balder Viking* or *Vidar Viking* for icebreaker duties. Additionally, buoytender-
vessels *Baltica* and *Scandica* as well as municipal and private icebreaking tugs are rented,
if this is necessary.

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[26]   AHTS-icebreaker = a vessel combining the roles of an icebreaker and an Anchor Handling/Tug/Supply
vessel

Figure 36   Icebreaker Oden (photo: T.Leiviskä)

Table 7   Icebreakers available for use in Sweden[27]

Icebreaker	Built	Displacement (ton)	Power (MW)	Speed (kn)	L_{OA} (m)	B (m)	T (m)	Bollard pull (ton)
Atle	1974	7 900	16,2	18,5	104	23,8	7,3/8,3	160
Frej	1975	7 900	16,2	18,5	104	23,8	7,3/8,3	160
Ymer	1977	7 900	16,2	18.5	104	23,8	7,3/8,3	160
Oden	1989	13 000	18,0	15	108	29,4	7,0/8,5	250
Ale	1973		3,5	14	49	13	5,4	
Tor Viking II	2000	5 900	13,5	16	83,7	18	6,50	200
Balder Viking	2000	5 900	13,5	16	83,7	18	6,50	200
Vidar Viking	2001	5 900	13,5	16	83,7	18	6,50	200
Baltica	1982		2,7	15	54,9	12	3,7	30
Scandica	1983		2,7	15	54,9	12	3,7	30

The mutual co-operation between Swedish and Finnish icebreakers is close. The location of the ports of these countries on both sides of the Bothnian Sea and Bothnian Bay has made it possible to assist the neighbour, when the wind has blown ice masses on the other side of the sea and thus decreased the need for icebreakers along the own side of the sea.

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[27] Data sources: see appendix 2.

Figure 37   AHTS-icebreaker Tor Viking II (photo: T.Leiviskä)

Russia

At the operational level the icebreaker assistance in Russia works much in the same way as in Finland. The icebreakers are in control and they make the decisions at sea. Due to the ice conditions the assistance distances are much longer and more difficult than in Finland, sometimes even along the whole Gulf of Finland. Therefore vessels are often collected into convoys which are assisted by one bigger icebreaker and some smaller ones. These convoys may include up to 10-20 vessels, and the waiting times at the assembly points may be long.

Finland has an agreement on icebreaker co-operation with the Russians, but so far, in practice, the co-operation has been limited, as the Russians operate in the Gulf of Finland independently. Requests for extra icebreaker capacity are difficult to answer, because on severe winters the need for extra icebreakers is concurrent in both countries. The biggest difference between the Finnish and the Russian operations is that in Russia the harbours are in charge of their own icebreaker assistance the same way as they are in charge of towing, etc.

In the winter 2002-2003, which was considered as severe in the eastern part of the Gulf of Finland, the Port Authority of St. Petersburg had 10 icebreakers in use, see Table 8 below. Due to the lively traffic in the St. Petersburg area and the difficult ice conditions a large maximum number of around 120 ships waiting for icebreaker assistance was reached in mid-January (Kudryavtsev 2003). However, strong efforts in unraveling the traffic jam were made by the Russian icebreakers, so the number of ships waiting for IB

assistance could be reduced remarkably till the beginning of February and thereafter. The restrictions that were set on ship traffic were as following: from 22.12.2002 ice class LU1 and from 13.01.2003 ice class LU2 and power 3500 hp (Kudryavtsev 2003), may have also helped in this respect.

Smaller port icebreakers, see Tables 8-9 and Figure 38 e)-f), assisted the cargo vessels between the receiving buoy of the St. Petersburg to the port and vice versa. Bigger icebreakers, see Figure 38 a)-d), were used as liner icebreakers to lead and assist the one-way convoys. Periodically one or two port icebreakers were given to the liner icebreaker service to ensure the movement of the convoys (Kudryavtsev 2003).

Table 8   Russian icebreakers and their recent operating periods for assistance of cargo ships to the Russian ports in the eastern part of the Gulf of Finland (Kudryavtsev, 2003), (Tsoy 2003)

Name of icebreaker	Period in use	Icebreaker belonging to
Liner icebreakers		
Ermak	01.01.2003 - 08.05.2003	Port Authority of St. Petersburg
Kapitan Sorokin	11.12.2002 - 04.05.2003	Port Authority of St. Petersburg
Port icebreakers		
Semyon Dezhnev	17.11.2002 - 29.04.2003	Port Authority of St. Petersburg
Ivan Kruzenstern	18.11.2002 - 15.05.2003	Port Authority of St. Petersburg
Kapitan Izmaylov	25.11.2002 - 14.05.2003	Port Authority of St. Petersburg
Kapitan Zarubin	04.12.2002 - 08.05.2003	Port Authority of St. Petersburg
Port icebreakers taken on lease by the Port Authority of St. Petersburg		
Mudyug	09.12.2002 - 06.05.2003	
Karu	14.02.2003 - 21.04.2003	
Liner icebreakers leased by the company INTERGATE CHARTERING		
Kapitan Dranitsyn	07.02.2003 – 10.04.2003	
Liner icebreakers leased by J/S NORTH-WESTERN FLEET from KUGI of Leningrad Region operated under the management of the Quarter of ice-breaking operations Port Authority of St. Petersburg		
Kapitan Plakhin	28.11.2002 – 20.04.2003	

Main data of these icebreakers is presented in the following table:

Table 9   Icebreakers in use by Russia in the Baltic Sea[28]

Icebreaker	Built	Displacement (ton)	Power (MW)	Speed (kn)	L_{OA} (m)	B (m)	T (m)	Bollard pull (ton)
Yermak	1974	20 241	26,5	19,5	134,8	26	11,0	285
Kapitan Sorokin	1977/91[29]	17 147	16,2	18,5	138	26,5	8,5	186
Kapitan Dranitsyn	1980	14 900	16,2	19	132,4	26,5	8,5	186
Mudyug	1982/86[7]	7 744	7,0	16,1	111,4	22,2	6,5	106
Karu	1958	3 540	5,5	15	74,2	17,4	6,4	70
Semyon Dezhnev	1967	2 718	4,1	14,5	67,7	17,05	4,74	53
Ivan Krusenstern	1967	2 718	4,1	14,5	67,7	17,05	4,74	53
Kapitan M.Izmaylov	1976	2 045	2,6	13	56,3	16,0	4,2	33
Kapitan Zarubin	1978	2 240	4,7	14	77,6	16,3	3,25	59
Kapitan Plakhin	1977	2 240	4,7	14	77,6	16,3,	3,25	59
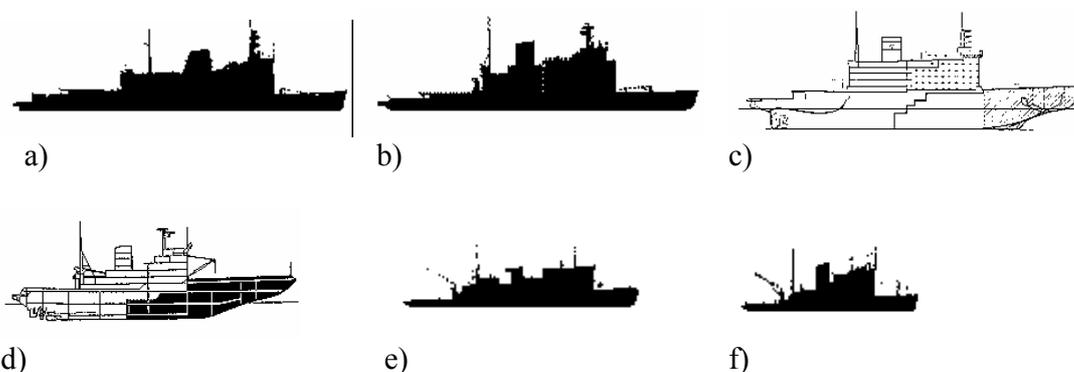
Figure 38   Russian icebreakers: a) Ermak, b) Kapitan Dranitzin, c) Kapitan Sorokin,
d) Mudyug, e) Kapitan Zarubin and f) Kapitan M. Izmaylov

Estonia

Estonia has currently only one icebreaker, *Tarmo*. It was built in 1963 as the first ice-breaker of a series of three Finnish icebreakers, the other two being *Apu* (1970), see Figure 34 a), and *Varma* (1968). In 1986 Finland sold one of its icebreakers, IB *Karhu*, to the ESCO-owned port of Muuga. For a certain period of time it had also the name *Kapitan Chubakov*, but later on it was renamed to *Karu*. In 2002 the Port of Tallinn sold *Karu* to Russia.

The level ice thickness is usually thinner on the southern coast of the Gulf of Finland, i.e. on the northern coastline of Estonia, than on the Finnish coast. Due to the prevailing south-western winds the ice conditions are in general not as difficult as on the Finnish coast. However, a long period of northern winds may change the situation. Therefore the

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[28] Data sources: see appendix 2.
[29] A major conversion to the bow of the icebreaker was made changing the displacement, the overall length (L_{OA}) and the breadth, at waterline, (B_{WL}) of the vessel. The performance in ice was also changed.

need for a well functioning icebreaker system with several icebreakers is more occasional than in Finland. Still, on a severe ice-winter, like that in 2002-2003, when cold northern winds move the ice on the Estonian coast, the lack of efficient icebreakers may endanger the traffic of Estonian ports.

Finland has agreed of the icebreaker co-operation also with Estonia. However, at the moment the co-operation is still rather limited on the operation level. In winter 2002-2003 Estonia operated icebreaker *Tarmo* in the approach to Tallin, but chartered also one of the AHTS-icebreakers, *Balder Viking*, to assist winter navigation in this area due to the difficult ice conditions and the heavy traffic. The Finnish icebreaking tugs, *Zeus* and *Protector*, were chartered to assist traffic to the Estonian ports in the Gulf of Riga.

Latvia

Icebreaker *Varma* (a sistership to IB *Apu* and IB *Tarmo*) assisted traffic to the port of Riga in the winter 2002-2003.

4.7   ICE PASSPORT

Although not included in the Finnish-Swedish winter traffic system, this description of the winter navigation system on the northern Baltic Sea is not quite complete without a description of the Ice Passport in Russian waters. This document or manual, which is prepared for a certain ship by a competent organisation, is intended to give support for operational decisionmaking onboard. It includes information for the ship navigating in ice and for icebreakers assisting them. The main theme in Ice Passport is the guidance given for the navigator concerning safe speed in specified ice conditions. It gives also advice concerning safe distance to the assisting icebreaker, estimation of the side compression strength as well as other general recommendations for the navigator. The Ice Passport was introduced in Russia in the 1970'ies, and it's principles have been described e.g. in (Maksutov & Popov 1981), (Likhomanov et al 1993) and (Likhomanov et al 1998).

The concept of giving information of safe speed limits for a certain ship in predescribed ice conditions for the navigator is useful. A navigator who is familiar with the contents of Ice Passport and is using that tool for decision support in ice covered waters can increase his/her ability to avoid problems and accidents, which are caused by unawareness or lack of information. However, it does not solve the problem of getting the correct and precise information of ice properties along the ship route, which is needed e.g. for the use of the limiting speed curves of the Ice Passport. Although it does not eliminate the possibility of human or organisational errors, see e.g. (Reason 1990) or deliberate deviation from the guidance provided, it is a step towards safer winter navigation in ice conditions, which in some extreme cases may be more severe than the ship's ice class and structural condition is generally applicable for.

5 HAZARD IDENTIFICATION OF WINTER NAVIGATION

5.1 GENERAL

Hazard identification is the first step in risk analysis (when the objectives and scope of the analysis have been defined) . The aim of hazard identification is to identify as many relevant hazards as possible. Experience from past year's accidents and incidents should be used, but creative elements should also be included in the identification process. In this study the past experience is first reviewed in the light of damage reports and accident statistics. Some case histories are included, too.

Navigation has been practised for a very long time. Thus, most hazards of navigation are rather well known. Listed categories of different marine accidents are already available. An example of such a list is presented in Table 10, which is reproduced here from (IMO 2000). Most of the listed accident types are not uncommon in winter navigation.

Table 10   Marine accident types (IMO 2000)

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1) **Collision**: striking or being struck by another ship (regardless of whether under way, anchored or moored).
2) **Stranding or grounding**: being aground, or hitting/touching shore or sea bottom or underwater objects (wrecks etc.)
3) **Contact**: striking any fixed or floating object other than those included in 1-2
4) **Fire or explosion**
5) **Hull failure or failure of watertight doors/ports, etc.**: not caused by 1-4
6) **Machinery damage**: not caused by 1-5, and which necessitated towage or shore assistance
7) **Damages to ship or equipment**: not caused or covered by 1-6
8) **Capsizing or listing**: not caused by 1-7
9) **Missing**: assumed lost
10) **Other**: all casualties, which are not covered by 1-9

The presence of the winter conditions and ice may change the causes, nature and consequences of marine accidents in some characteristic way. Additionally, there are some unique types of accidents solely connected to winter navigation in ice-covered waters. A list including special accident and incident types related to winter navigation is presented in Table 11. Although not based on the structure of common marine accidents presented above, this list helps in performing the hazard identification in a structured way. Characteristics of each of the accident types of Table 11 are described later in sub-chapter "5.2 ACCIDENTS AND INCIDENTS OF WINTER NAVIGATION". Selected examples of accident cases for most ice related incident/accident types are also presented.

The identified hazards are mainly focused on the actual ice damage, icing and some other marine accident types. Ice damages could be divided in accident types 3), 5), 6) and 7) of Table 10 above, but in this connection it is deemed more reasonable to gather them under one header, as has been done in Table 11. Icing, for instance, is actually a hazard, which can cause other accident types, like 8) and 9) of Table 10. Ice may have its special causal effects on collisions and groundings, too, so they are both included in Table 11. Fire and explosion are included in Table 11, because winter and ice conditions may affect the consequences of this accident type and especially the attempts to mitigate them. Potential problems in firefighting and evacuation are the main topics in this respect.

Table 11   Winter navigation accident/incident types and some of their consequences

Ice damage
  Damage to ship hull
    Damage to hull plating (outer)
    Damage to hull stiffeners (frames)
    Damage to hull plating (inner)
    Damage to other parts of the hull
    Damage to hull appendages
      Damage to bilge keels
      Damage to other appendages
  Rudder damage
  Propeller damage
  Machinery damage
  Other damage
    Damage to ship systems
    Damage to ship equipment
Icing
  Loss of ship stability
  Loss of freeboard
  Loss of visibility
Grounding
  Powered grounding
  Drift grounding
Collision
  Collision with an other ship
    Bow/bow
    Bow/side
    Bow/rear end
    Side/side
  Collision with an icebreaker
    Bow/bow
    Bow/side
    Bow/rear end
    Side/side
Fire or explosion

5.2   ACCIDENTS AND INCIDENTS IN WINTER NAVIGATION

A hazard can be defined as a situation with a potential to threaten human life, health, property or the environment. The hazards of winter navigation are many and various as can be noticed from the following description of the main types of different winter related accidents. After each accident type description some examples of ice related incidents and accidents from the years 1963-2003 are presented. All of the 21 cases, except one, have taken place in the Baltic Sea. The oldest of them occurred about 40 year ago, but most of the others are from the recent years.

The importance of the lessons to be learned from these cases does not necessarily depend on the date of the individual incident. Technical development has changed many things in ships and their navigation. However, the environmental conditions, their variation and the nature of human and organisational errors are much the same. All of these cases include some elements that may lead to future accidents. Similar types of ice related accidents/ incidents have been described about 80 years ago in (Thomson 1925). A more recent review of incident and accident cases, related to winter navigation in winter 2002-2003 has been presented in (Hänninen 2004).

In addition to the information gathered from past incidents and accidents the hazard identification process should also take into account hazards that may have not yet been realized as accidents or disasters. In this report the implementation of this task is based on the results of a brainstorming group session of selected experts, which was reported recently in (Juva 2002). The results of this alternative way of hazard identification is presented later in the text. However, before discussing these results in more detail, review of the most typical incidents and accidents in winter navigation is made.

5.2.1   ICE DAMAGE OF SHIP HULL

Background

Ice damage of the ship hull is basically a permanent change in the initial geometrical form of the structure. This kind of ice damage definition, which is used by e.g. Appolonov and Nesterov (1995), includes all damage sizes. Thus, everything from very small and harmless dents of plating up to a compression of beset ship beam e.g. by 1.8 m, see (Varges 1988), and leaking ruptures, that can cause the ship to sink, are included within this broad definition.

Ice damage may include destruction to weld connections, dents and cracks in outer plating as well as deformations on the framing system (Babtsev et al 1995). Additionally, the ice has also a wearing effect on the outer plates, which can be noticed also from the wear of paintwork. This effect, which is not dangerous per se, makes the ship hull more susceptible to corrosion. It has also the following indirect effect: If the hull-ice friction is high, the ship's ice resistance is high, so it will get stuck in ice more easily. A ship which

is stuck in ice is more susceptible to the environmental forces, ice pressure etc. which will increase the risk of damage.
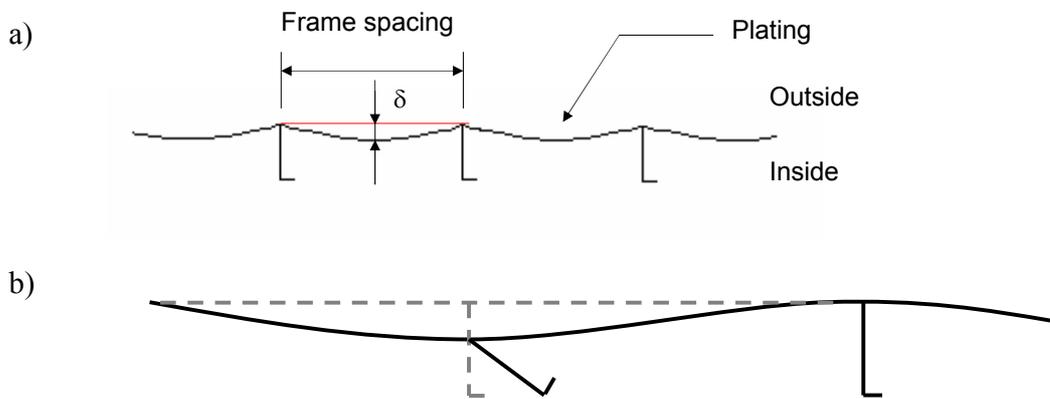

Figure 39   Horizontal cross sections of a vertically framed ship's outer side plating with typical ice damage a) with dents between the frames and b) buckling of the plate and tripping of the frame

One of the main problems in ship hull ice damage is the stochastic nature of ice loads. Ships that are not designed for ice conditions or are only slightly ice-strengthened may be able to operate without trouble for rather long periods, but when they face severe ice conditions, e.g. such conditions that may occur only once in a decade, or even less frequently, they may get into trouble. Ice damages form a serious risk as at worst they may cause the loss of the whole ship. However, the consequences of typical ice damages are not severe. Ice damages have occured quite frequently in ships of winter navigation. According to some observers, see e.g. (Mäkinen 1971), there may even exist such paradoxal effects, that ice damages (of a fleet of vessels) have been 2.5 times larger during a mild winter than during a hard winter. On the other hand, in a recent model for ice load, which takes into account the statistical nature of the phenomenon, see e.g. (Kujala 1994), mean ice load increases when the (equivalent) level ice thickness increases.

Another problem is the fundamental trade-off in engineering design – cost vs. safety. Additional steel weight in a ship due to heavy ice strengthening reduces the cargo weight capacity of the ship and makes the ship more expensive[30]. Several authors, e.g. (Johansson 1967, Timofeyev 1995), present the current principle of plastic design, which is based on the acceptance of small damages, as a method to save transport costs. The Finnish marine accident statistics of the previous 30 years in the Baltic Sea seems to have generally proved that this has been possible without too big sacrifices in safety.

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[30]   In 1971 it was estimated, that the price of a IASuper ice class vessel of 10 000 dwt was 2,6 % higher than without any ice strengthening. The loss of dead-weight (~ cargo capacity) in this vessel size was estimated to be about 200 tons (SST, 1971).

Ice damage of ship hull may be caused by the motion of the ship towards the edge of fast ice, an ice floe or a ridge, but it may also be caused by the motion of the ice towards the ship, see Figure 40. In the former case (a) the impact force is controlled by the velocity, and the local orientation angle of the ship hull surface. Other important parameters in ice impacts are the mass and other characteristics of the ice formation.
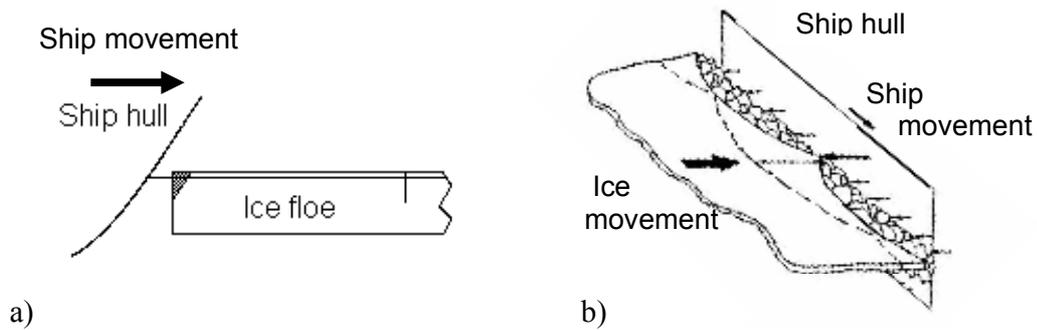

Figure 40   a) Ship moves and hits an ice floe or b) ice is pressed against ship side

In the case of Figure 40 (b), ice is pressed against the ship side. In this case the ship may be moving or stay still. This kind of more static ice loads develop, when there is a slow relative movement of the ice towards the ship. The cases a) and b) of Figure 40 are the two main types of ice contact load cases between ship and ice:

a)   an impact load, which occurs at a moderate or high speed, see Figure 41, and
b)   the slow speed compression of ice against the side of the ship hull

In the former case the relative velocity between ship and ice depends on the ship speed. In level ice the ship speed is restrained by the ice resistance, but in a less difficult ice condition, e.g. in open ice with big floes of sufficient thickness or in ice-free water when approaching the ice edge, the ship speed may easily be much higher, if not reduced in time. According to the Russian scientists, see e.g. (Likhomanov et al 1997), a situation when the ship's straightforward motion is first affected from one ice formation on the other side of the bow, starting a turning motion, and then hitting another ice formation on the other side of the bow, may create the highest ice loads due to the geometry of the bow and the magnitude of the vector projection of the relative impact velocity normal to the surface of ship hull (reflected impact). In the slow speed compression (case b) the ice velocity is below 1 m/s.

Impact loads are used as a basis for the requirements concerning ice strengthening of the ship hull structures. In addition to that, the loading case with ice compression is implicitly included in the Finnish-Swedish Ice Class Rules. However, a lack of a wide scope of research concerning a ship caught in a compressive ice has been noticed by some authors, see e.g. (Hayward 2000).

The longitudinal strength of ice strengthened vessels in the Baltic Sea is not considered as a problem, see e.g. (Sukselainen & Riska 1986). Therefore, in this risk assessment the main emphasis is put on issues related to the local strength.

Ice impact

The effects of the ship speed and local frame angle at the location of ice impact on ice loads have been presented e.g. by Varsta (1983). The magnitude of ice impact loads of type a) can be controlled to a certain extent by the ship speed. In the Finnish-Swedish ice class rules the effect of ship speed on ice impact loads is taken into account indirectly. When calculating the design ice pressure p, the nominal ice pressure p_0 is multiplied by factor c_d, which takes into account the size and the real continuous engine power of the ship (FMA 2002a).

Figure 41   Ice impacts on the side of the ship occur for instance when the ship turns in ice. Here, crushing takes place at the corner of a broken ice floe. (Photo: R. Jalonen)

In the Russian Ice Passport practice the effects of ship speed on ice impact loads are introduced more clearly by establishing diagrams for safe and dangerous speeds in different ice conditions (Likhomanov et al 1993). Ice Passport includes separate safe speed curves for a new and old vessel, which take into account the effects of (standard) corrosion on material thickness. Safe speeds of navigation in ice as a operational risk criteria has been studied also by Koehler (Koehler 1986) and Tunik, who presented a probabilistic assessment of safe speeds for a Polar class icebreaker using two damage criteria (Tunik 2000), see Figure 42.

There is no multi-year ice in the Baltic Sea, but ice impact loads regarding first year ice can be a cause of significant damage, too. If the speed of the ship is too high, an ice impact load leads easily to an exceedance of the strength of the ship structures. This hazard occurs especially often near the edge of the ice covered area (and ice free area) and in an open ice area with some thick and large ice floes, with a considerable mass. If the ice is more concentrated, with no visible water, the ship speed is usually reduced by the ice resistance, so the risk for a high energy impacts is also reduced. This hazard should be taken into account, when e.g. the start of the season for high speed passenger ships, with light hull structures, is considered. Still, it is relevant for all ships with no or only slight ice strengthening. One, more than twenty year old case of the rupture of the bulbous bow of a general cargo ship and the resulting oil outflow on the 1st of May near Helsinki is still a good reminder of this hazard.
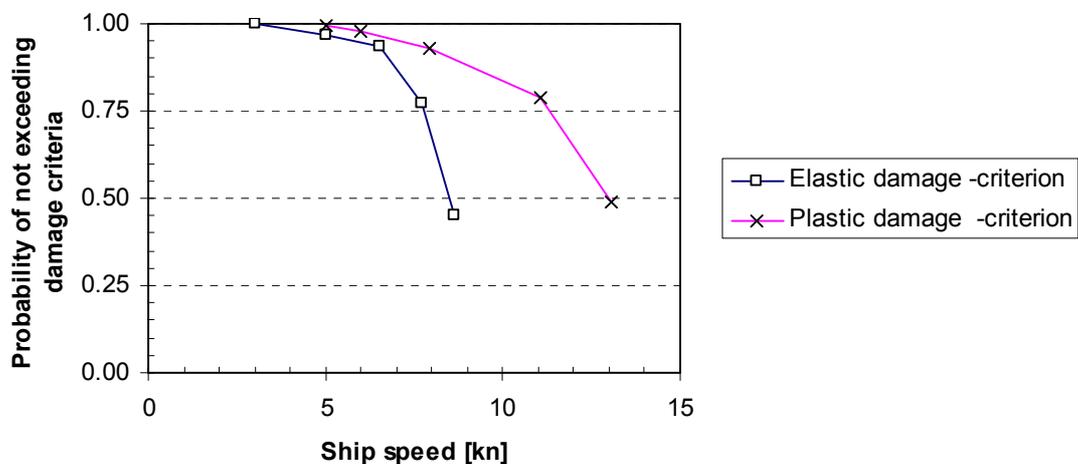
Figure 42 An example of a probabilistic assessment of safe speeds for a Polar class ice-breaker for two damage criteria: a) Elastic damage criteria: elastic stresses up to yield and b) permanent sets in shell plating and ordinary frames up to 0.05 of frame spacing, reproduced from (Tunik 2000).

Propeller induced flow is one possible reason for an ice hull impact. An icebreaker or the ship itself may submerge ice floes, which later rise back towards the water surface behind the icebreaker. If accelerated by the icebreaker's propeller, they may hit the hull of the ship following the icebreaker. This kind of damage scenario has been described e.g. in a Russian journal Vodnyj Transport and its translation in Swedish in (SST 1989).

Ice compression

Compressive ice has caused most of the damages that have been found in the midship area (Kujala 1991). When drifting ice meets a ship's side, ice starts to direct and pressure on it. Wind and current are two environmental reasons for the drift motion of ice. Drift is possible, when there are some ice free areas in the sea ice cover. However, if the sea is totally covered with ice, it is still possible that the ice layer is broken and compressed into

pack ice, if the wind (or current) speed is high enough. The probability of such weather conditions where compressive ice is encountered has been estimated e.g. in (MKL 2004f), where it was assumed that there will be ice compression reducing ship speed on 11 days in Gulf of Finland and Bothnian Sea and on 5 days in the Gulf of Bothnia. It is assumed that these values represent an average. If these estimates are related to the shares of traffic in these sea areas (49 %, 41 %, and 10 %, respectively), it may be assumed that a weighted mean value for days with ice compression in the Finnish waters is 10.4. By comparing this mean value to the average number of days in the period with traffic restrictions (76) we can see that the estimated probability to encounter ice compression in Finnish waters during this period is about 14 %.

The ice velocity can be within the range of about 2 - 3 % of the wind speed. Ice velocity of 0.35 m/s has been recorded at wind speed 10-12 m/s (Leppäranta 1981). Thus, strong wind, e.g. in a winter storm or soon thereafter, the resulting movement of the ice field can cause ship hull ice damage. On other sea areas sea current has also been reported as the main source of driving force of pack ice (Spencer & Hardiman 1993). Ice damage in compressive ice has been recorded also in relatively weak wind speed of 3 m/s (Kujala 1991). Another example of a scenario that may lead to ice damage in compressive ice is given in (Kujala et al 1993), see Figure 43.
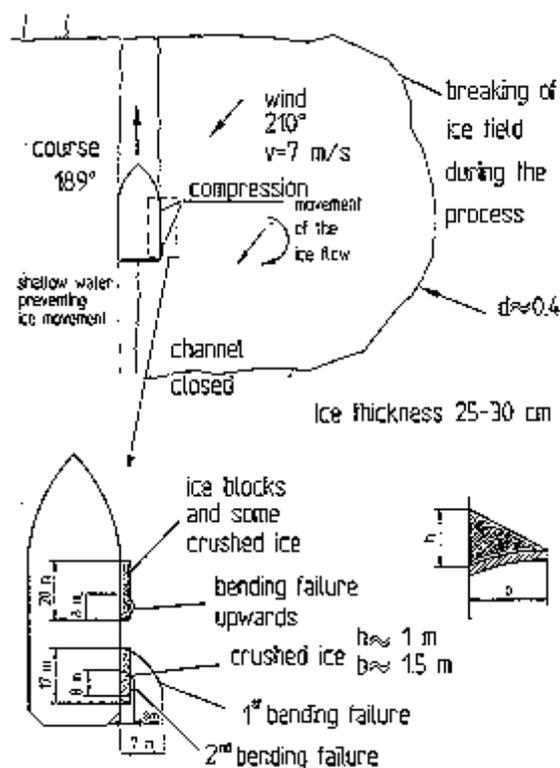

Figure 43   A general description of one incident, when a cargo vessel was exposed to compressive ice, reproduced from (Kujala et al 1993)

When the ice cover is pressed against the side of a strong ship, the ice first starts to fail by crushing, see Figure 44 a). Bending and buckling are two other failure modes, which then come into play leading to the separation of a sector from the ice at the second stage. This sector of ice may be bent upwards, see Figure 44 b), or downwards. If the ice drift against ship side still continues, all the broken ice blocks will form a hummock on the ship side in a later phase of ice-ship interaction, see Figure 44 c).

a)   b)   c)
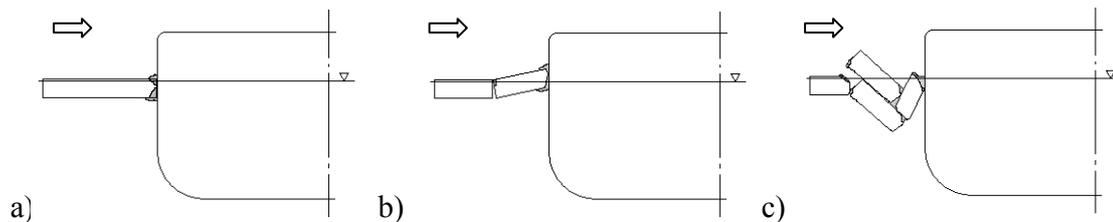
Figure 44   Various phases of the ice-ship interaction in compressive ice, when the ship's side is vertical (frame angle is 0°): a) ice edge starts to be crushed and shear cracks start to be developed, b) the first ice floe is broken and it starts to turn up or down, c) broken ice floes build a hummock on the ship's side.

The heading of the ship related to the direction of the movement of ice is an essential issue concerning the ships ability to come through the condition of compacting ice. A situation with a high lateral pressure on a beset ship hull is probably the most dangerous one and should therefore be avoided, if possible. The ice failure process is strongly connected to the frame angle and friction coefficient of the ship and the shear strength of the ice. An example of the effect of frame angle on the maximum ice load in compressive ice are presented in (Kujala et al 1993), see Figure 45. This kind of relieving effect on the horizontal force has been known by experience for long and it is the reason why e.g. a minimum frame angle of 8° was required in the old ULA ice class category of the Rules of the Russian Register of Shipping (RMRS 1986).
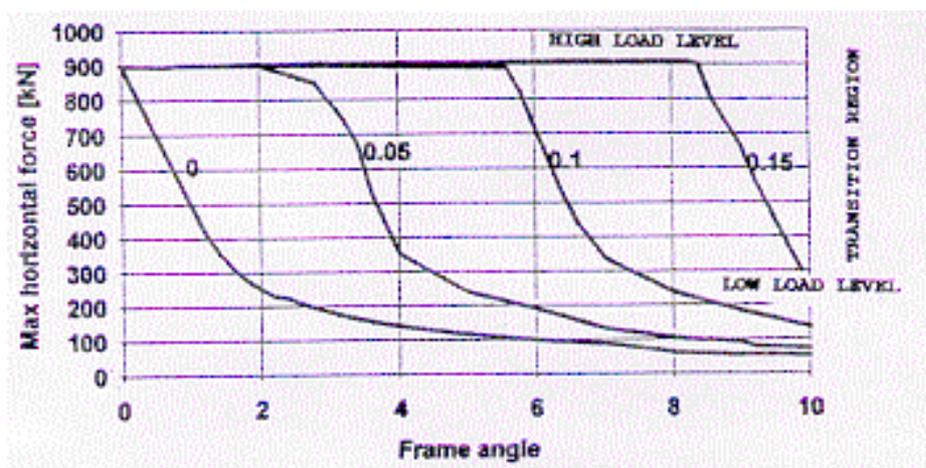
Figure 45   Maximum horizontal force caused by the ice failure process as a function of frame angle and with friction coefficient as a parameter (Kujala et al 1993).

A reduction in the compressive force due to the ship velocity has been found in model tests (Kujala et al 1991). The ship may avoid most of side compression, if the channel that is broken in ice, by the ship or by the icebreaker ahead of the ship, is sufficiently wider than the widest part of the ship and the lateral movement of ice to the broken channel is slow in relation to the ship speed, see Figure 46. Thus, by having a certain speed ahead the ship may avoid ice crushing on its sides. However, if the icebreaker is assisting a long convoy, of e.g. five ships, the length of which may be several nautical miles, and the broken channel is closing due to ice drift, the icebreaker may not have time to reach every beset ship in time, so there is an essential danger of ice pressure (Pohjola 1986). Similar problems elsewhere have been described e.g. by Varges (1988).

Figures 47 and 48 present an other type of ice crushing phenomenon, which may take place at the after part of the parallel middlebody of the ship during turning. This kind of phenomenon can take place also in a curve of a previously broken channel, if its width is too narrow. Thus, a long and wide cargo ship following an icebreaker, which makes a too tight turn considering the dimensions of the assisted vessel. may observe ice loads at the bow and aft shoulders on the outer side of the turn and at midships on the inner side of the turn.

No ice movement
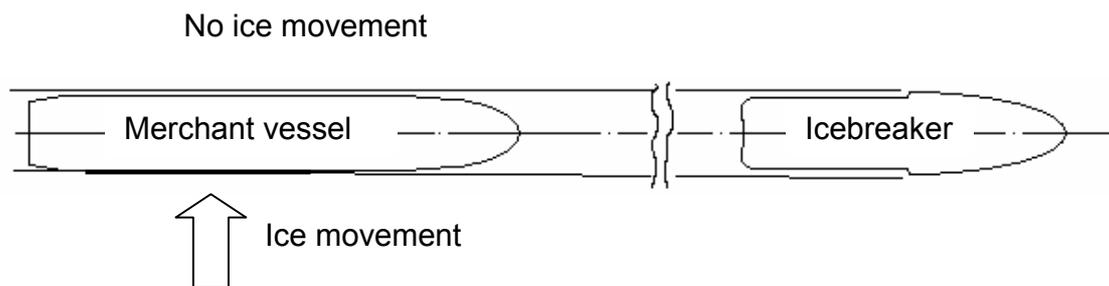
Figure 46   The broken channel behind the ship (or icebreaker) gets quickly narrow in compressive ice. Pressure on ship side can be avoided almost totally, if close towage and sufficient ship speed in relation to lateral ice velocity can be used.

Ice crushing on ship side
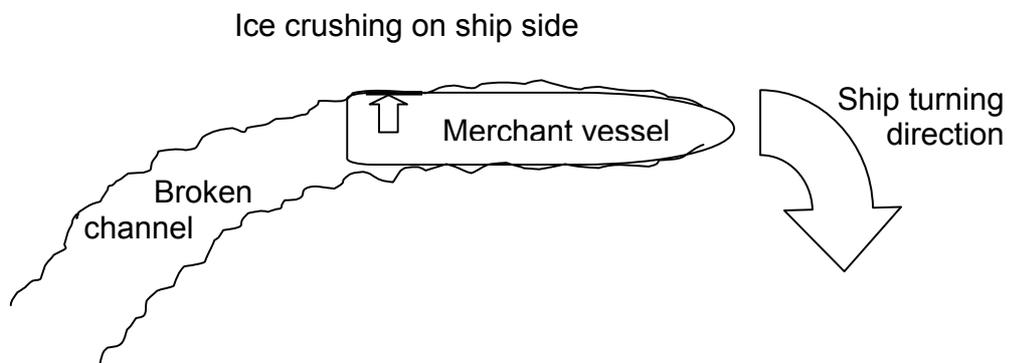
Figure 47   Local crushing, depending on the local shape of the frames, may occur on the ship's afterbody, when the ship is turning.

a)

b)

Figure 48 a) Crushed ice along the ship's vertical side b) a close-up picture of the contact with some of the ice removed (photos: R.Jalonen).

In severe ice compression cases ice blocks may pile-up and enter even on the ship's deck, if the freeboard of the ship is low. Ships, which are not equipped with sufficient engine power for difficult ice conditions, get more easily beset in ice. When ice pressure and compression from the side starts, there is not much to do, if icebreaker assistance is not available, see Figure 49.

Figure 49   A cargo ship is beset in ice in a compressive ice condition (photo: FMA)

One possible example of the worst-case scenarios in this respect is presented in Figure 50 b). This photograph was found in (Blenner & Ohrelius 1960, SST 1970 and Enkvist 1974). Unfortunately, none of these references give any further information regarding the whole story (e.g. what? when? where?) of this interesting incident. The development of a situation like that may, with such a large additional "cargo" onboard, destruct ship structures on deck and even sink it, even if the hull would withstand the ice pressure. In shallow water ice floes may also be jammed between the ship and sea bottom. The latter accident scenario is similar to a grounding.

a)   b)
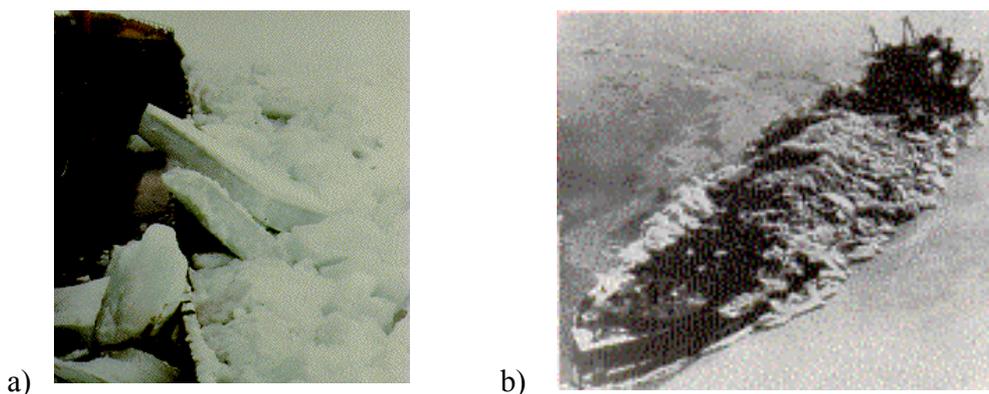
Figure 50   Severe consequences in compressive ice: a) ice blocks entering on the deck of the ship (photo: P. Kujala) and b) a ship buried under ice (Blenner & Ohrelius 1960, SST 1970, Enkvist 1974).

Hull ice damage

A list of the different types of hull ice damage is presented below. It is made here with the support of the sources (Appolonov & Nesterov 1995, Babtsev et al 1995), which are applicable also for our purposes:

- bilge keel tripping and tearing off the hull
- local dents from single ones up to larger areas of goffering in outer plating
- tripping of frames, stringers and web frames
- buckling of stiffeners on the web framing and plate structures
- breaking of stiffeners on plates
- knees and brackets buckling and tear off girders
- tearing of the frames off the outer shell along the welds
- crumpling and swelling of ordinary framing's webs at cross sections of supports
- swells of web framing and plate structures
- cracks and ruptures of welds at the places of framing intersections
- cracks and ruptures of webs and plate structures in the areas of large plastic
  deformations

The main ship classification societies have their own practices regarding hull ice damage and its repair. Some of the societies either approve or disapprove the repair plans (to repair/to postpone the repair/not to repair) of the shipping company by applying a case-by-case judgement at the surveyor's/classification society's discretion, whereas some other classification societies may have also established guidelines in this respect regarding the ship and the location, scope and dimensions of the damage. Even in the latter group there seem to be some differencies in the applied criteria. However, the ship surveyor's experience of ice damage is of utmost importance in the absence of written guidelines including quantitatively determined requirements regarding the necessity of the repair. There is no need to repair each and every small dent regardless of its location on the ship hull, but the principles, what are the limits for those cases when there is a possibility for a bigger risk and what should be done in such cases, should perhaps be established more clearly. A common approach for this kind of policy might be worthwhile.

A distinction between allowed and not allowed ice damage is also made in (Appolonov & Nesterov 1995), which states that single local dents are allowed in external plating, but large (global) areas of goffering are not allowed. In the case of the permanent set of the frames "*a local caving in*" is allowed, but "*a large (global) caving in*" is not allowed. Large ice damages, which are not allowed, are characterized by Appolonov and Nesterov (1995) with a figure, where the damage is extended to an area of eight (8) frame spacings. This type of ice damage is illustrated also in Figure 51.

According to (Benkovsky et al[31]) the Rules of the Soviet Ship Register permits that smooth dents and corrugations are straightened in the next scheduled overhaul, if the dent depths are not greater than 20 % of frame spacing and the ratio of the dent depth to length is not greater than 1:20. In the case of corrugations, the dent depth should not be deeper than five (5) times the thickness of the plating and the ratio of dent depth to frame spacing not greater than 1:20. Unfortunately, it is not known if these old guidelines are still applied in Russia.

An example of the application of the former principle in (Benkovsky et al[31]):

Let us assume that the dent depth is $\delta = 50$ mm, the plate thickness is $t = 15$ mm and the frame spacing is $s = 750$ mm.

20 % of frame spacing: 20 % x 750 mm =   150 mm
The ratio between dent depth and
frame spacing: $\delta / s = 50$ mm / 750 mm = 1: 15

                                50 mm < 150 mm   =>   accepted

However, the latter ratio is   1: 15   > 1:20   =>   not acceptable

In the case of corrugations with 50 mm deep dents:

5 x t = 5 * 15 mm =   75 mm

                                50 mm < 75 mm   =>   accepted

However, the ratio between dent depth and

frame spacing is   1: 15   > 1:20   =>   not acceptable

In both cases the application of the principles in (Benkovsky et al[31]) would accept the dent(s) to be repaired in the next scheduled visit to dock if the depth is less than 37.5 mm (= 750 mm / 20 = s / 20).
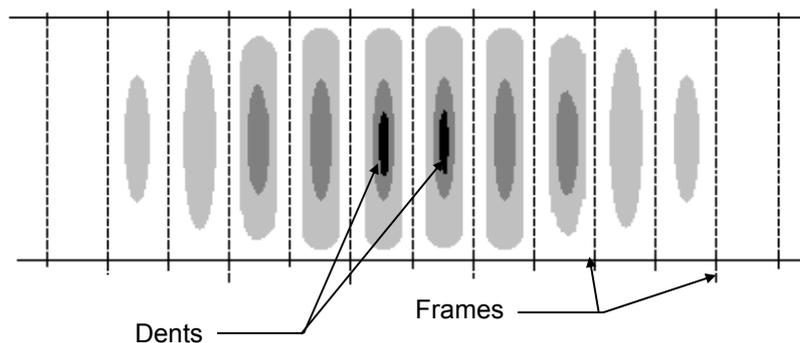
Figure 51   Goffering of a large area of plating like this one, extending to several (≥ 8) frame spacings is not allowed according to Appolonov and Nesterov (1995)

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[31] Unfortunately, no year of publication was found in this reference. However, it is assumed that this book has been published in the 1960's or 1970's.

The allowed dent depth due to hull ice damage can be compared to the applied standards in ship production. The production allowance for plate deformations in welded panel structures should be less than about 20 % of plate thickness. This rule of thumb may be applied, if the frame spacing is about 38 times as long as the plate thickness, the probability for failure is 0.005 and the effects of residual stress are included, see source (VTT 1978) or the original source (ISSC, II:2 1976). Thus, the quality standards for production are clearly above one order of magnitude stricter than those presented in the above example of the criteria for ship repair in the case of ice damage. An other reason for repair is caused by the economical consequences, which in the case of a 100 m long and 5 m deep area with 50 mm deep goffering on both sides of a ship were estimated to be equal to an amount of around 133 tons of additional fuel oil on a ship, which has a fuel consumption of 200 g/kW, see (VTT 1984).

In the Finnish Maritime regulations concerning the observation of hull damages in ships in winter navigation (FMA 1979) the following features of a severe ice damage are given (as a guidance to the inspectors, masters of the icebreakers and pilots):

1) ship side is pressed inside so that frames or longitudinal stiffeners have tripped or broken,
2) plating between frames has been bent inwards so steeply, that fractures have been developed on the surface of the plate
3) a wide area of plating has been bent inwards without the features listed in 1 and 2

Ice damages are usually divided in three main areas of the ship hull: 1) in the ship bow, 2) along the ship sides and 3) in the afterbody. In addition, they can be located a) at the waterline, b) above the waterline, c) below the waterline, d) at the bilge area and in e) the bottom of the ship. For practical reasons the ice strengthened area of the hull, the so-called ice belt, is located to protect the most vulnerable areas of the hull, see Figure 52.

Figure 52   The location of the ice strengthened area on the hull according to the Finnish-Swedish ice class regulation (FMA 2002a)

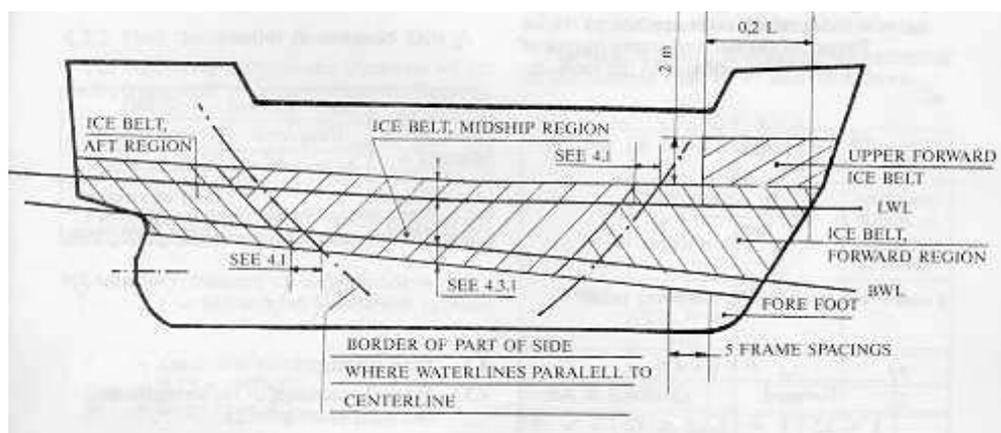Although the bow area dominates among the hull ice damage locations, ice damage can appear on various other locations on the hull, too. The frequency or probability of ice damages in various parts of the ship hull depends on numerous factors. The magnitude of the extreme ice loads depend on the operational time in various ice conditions, the shape and size of the ship and the velocity of the ship. In the Baltic Sea it has been observed that ice loads diminish considerably with an increasing vertical distance from waterline (Kujala 1989)[32], but experience from the most severe ice conditions of Russian Arctic reveals that ice damage is possible even in the bilge strake and in the flat bottom, if the ice conditions are difficult enough (Babtsev et al 1995)[33].

Operational issues are important, too. Careful operation of ships has been stated as a probable explanation for the fixed ice pressure at midships for ships of various sizes with lower ice class by Johansson (1967), "… when laying still the ice cannot possibly know, whether the shipside belongs to a small or big ship and what the machinery output is". The sea area with its typical ice conditions has a strong influence on the failure probabilities, i.e. ice damages (Kujala 1994, Karavanov 1993).

The relative distribution of the ice damage locations may depend on several factors, e.g. on the way the ship is operated and on the icebreaker assistance (if available, and to what extent). In ice strengthened ships operating in the Baltic Sea the hull ice damages are most frequently located in or just below the ice strengthened area, see (Kujala 1991) and (Hänninen 2004).

Figure 53   Typical locations of hull ice damages on Arctic ships presented here with the black areas (Moreynis et al 1998), bow shoulder area is marked here with an additional arrow.

The ship's parallel midbody is rather free from ice damage as shown in Figure 53, which describes the location of hull ice damages on some Arctic ships. It is not known if this matter can be explained by the inclined ship sides which are used e.g. on icebreakers and do have some effect on the ice loads, or by operational practices. According to (Moreynis

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[32]   In the Baltic Sea the most difficult ice obstacles, ice ridges are avoided by route planning. However, if this is not possible they have to be destroyed by the use of propeller flow of the icebreaker (Pohjola, 1986) or, if time is valuable, as it often is, by a high kinetic energy provided by sufficient mass and ramming speed of icebreaker. Ice is broken by mass and force, states director I.Aro of FMA (Montola, 2003).

[33]   It may be necessary to remind that e.g. ice thickness of 0.70-1.20 m, which can be considered as extreme in the Gulf of Finland is classified as medium first year ice in the Russian Arctic (Appolonov et al, 1995).

et al 1998) however, the relative frequency of damage in the parallel midbody in the hull of ships of ULA-class[34] is 30 %, whereas in non-ULA-classes, UL and L1, it is 66 % and 42 % respectively. The parallel midbody area of a ship may be less prone to ice loads, if assistance by a wide and efficient icebreaker is available/required. However, in the case of a too long lasting absence (or failure) of assisting icebreaker, the situation of the merchant ships may change dramatically in a compressive ice field.

The bow shoulder area, marked with an additional arrow in Figure 53, is most prone to ice impact loads due to the hull shape and the customary direction of ship motion (forward), especially if the breadth of the ship is wider than the breadth of the icebreaker or the broken channel. However, if the ice strengthening of the hull structures is appropriate, no problems should appear even in this area.

The hull ice damages are usually just minor dents on the ships outer plating. The denting of hull plating, on a wide area of intervals between several transverse frames causes the goffering, the appearance of a "hungry horse", see Figures 39a, 51 and 54 a) and b). In some cases the frames behind the outer plating are also damaged. The effects of such kind of damages should always be assessed separately, as they may in some cases have influence on the structural safety of the ship. According to Canadian experience: "the failure occurs consistently in the supporting structure rather than in the hull plating. The failure demonstrates itself in the form of tripping and buckling" (DesRochers et al 1994). This kind of finding refers that in Canadian ships the plating is relatively stronger, when compared to the supporting structures.

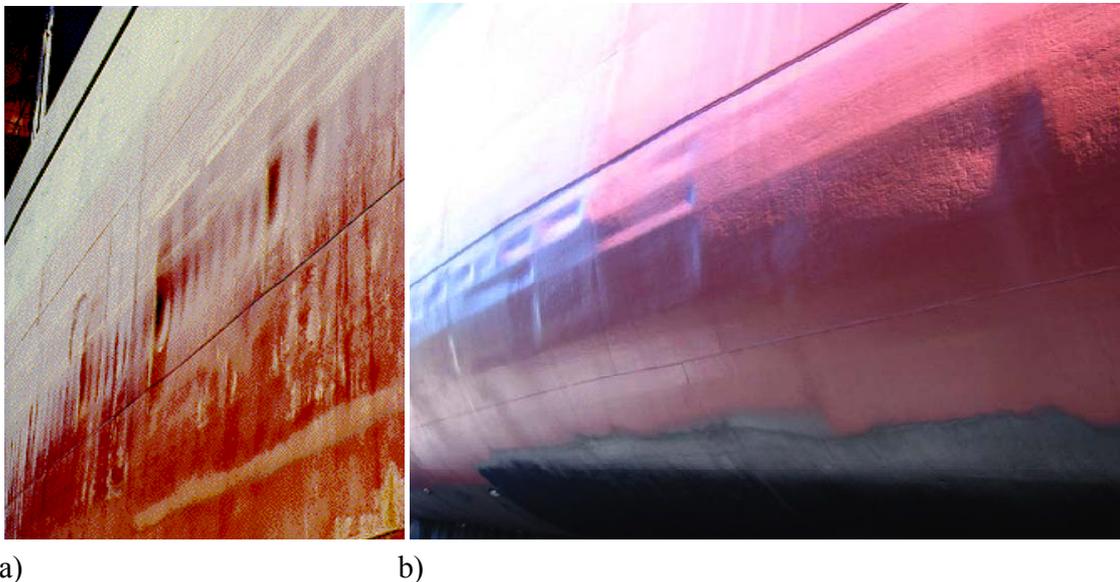a)   b)

Figure 54   Examples of hull ice damage on a) a transversally framed ship side (photo: Kujala) and b) on a longitudinally framed ship's bilge area below the ice belt (photo: Hänninen 2004)

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[34] ULA-category was one of the strong ice categories in the Russian Maritime Register, it is intended for use in Arctic waters.

In the damage statistics of ice strengthened ships in the Baltic Sea 1984-1987, see (Kujala 1991), the typical damages on frames (on 16 ships) varied between 0.8 m and 10 m in length and between 0.5 m and 3.5 m in height. Median value of damage length was 4 m, the median damage height was 1.2 m. Most framing damages occurred in the midship area, especially at the aft end of it. In the more recent ice damage statistics of winter 2002-2003 in the Baltic Sea (Hänninen 2004) bow damage and side damage were the most frequent ones (about 50 % and about 40 %, respectively).

The worst ice damages may cause a rupture of the hull plating and thus make a leakage of water in the ship possible. This kind of ruptures have mainly been connected to corroded and worn plates (Moreynis et al 1998), (Hänninen 2004), typical for older and/or badly maintained vessels. The frequency of leakages in the 2003 statistics of hull ice damages was 6 cases of 27 (Hänninen 2004), thus representing a share of 22 %. In Kujala's data base of 61 ships (31 ships with ice class IASuper, 28 ships with ice class IA and 2 ships with ice class IC) from winters 1984-1987, 29 ships suffered from hull ice damage, but none of these damage cases resulted in a leakage (Kujala 1991).

According to a review of ship hull ice damage in the Russian Arctic (Babtsev et al 1995), based on a large database of more than 800 accidents and wrecks in the period of 1954-1990, as many as 40 % of damages were were followed with water getting inside the hull through holes and cracks. However, experience from the ice covered waters in Russia has also shown, that even large deflections of plating between frames need not necessarily lead to a leakage (Moreynis et al 1998). According to the latter reference the frequency of leakage among all ice damage cases was found to be depending on the severity of ice conditions. The cracks usually form in the joints of framing with plating. A salient feature of the cracks was their small size. However, in rare cases of heavy damages the leakage may be of such size that it causes a severe emergency situation and the need for an immediate repair. A leakage in to the main engine room or in the auxiliary engine room may severely endanger the safety of the whole vessel.

It is not known to the authors, if the accident case of Aspen (SST 1964) is the last hull ice damage leading to a total loss of a merchant vessel in the Baltic Sea. It may be the last of its kind in our waters so far. However, in the eastern Arctic Sea of Russia one ship of the former Soviet Merchant marine was lost, several vessels suffered severe ice damage and many minor damage in October 1983 (ANR 1984/1985). Ship losses due to hull ice damage are not extremely rare in the Arctic waters of Canada either, see e.g. (Kubat & Timco 2003).

In the case of leakage there is a danger of the loss of freeboard and the loss of stability of the ship. There may exist a possibility that the ship sinks, if seawater enters in several watertight compartments. If the subdivided room of the ship at the location of the rupture is used for storage of oil, it may leak out and cause pollution. In extreme cases, such as the Case 2 below, internal structures of the ship may fail.

Case 1: Hull damage due to ice compression (after rudder damage) (SST 1964)

On the 21st of March 1964 an almost twenty year old general cargo ship[35] of around 2600 dwt was sailing in ballast to Riga. Before departure from its previous port on the Swedish coast the ship had received a message from Riga that the ice conditions would not cause any difficulties for the vessel. However, the ice conditions in the Gulf of Riga became worse during the journey and in the night of the 21st of March the ship was assisted by an icebreaker. In the morning it was towed through pack ice, but soon the resistance became too high and the proceeding stopped. The rudder of the ship got some damage and the vessel got an order from its shipping company to get back to Sweden (possibly to a repair yard). Then the icebreaker helped it to turn and started to assist it back in the opposite direction.

At noon the ship was beset in ice again. It was compressed by ice so violently that its both sides, along the whole length, were pressed inwards. Two vertical cracks with a length of 2,5 m and breadth of 5 cm were formed above and below waterline, so seawater started to leak rapidly in to the hold nr. 2. The pumping was started. The icebreaker started to tow the ship and the damaged vessel got extra pump capacity from the icebreaker. The water level in the hold seemed to be stabilized and the speed of the ships was about 6 knots. However, at a later stage the ship started to develop an increasing list angle and the leak intensified. At around 01:00 the captain ordered the crew of the vessel, except the first mate and the main engineer, to abandon the ship. All 20 members of the crew were rescued by the icebreaker, when the ship finally capsized three and a half hours later. A rescue vessel, which was alarmed from Sweden, arrived on the scene, when the ship had already sunk. The ice class of the vessel, if there was any ice strengthening at all, is unknown to the authors.

Case 2: Hull damage due to ice compression (Vapalahti 1997)

On the 22nd of March 1971 a 15 year old general cargo ship of around 3600 tons deadweight was sailing to the Finnish coast of Bothnian Bay in the Quarck area. In the evening a winter storm from north – northeast with force 9 arose [36]. Large masses of drifting ice were moving and the visibility was deteriotrating due to snowfall, which was getting denser. Ice floes started to be pressed and crushed on the ship sides. The assisting icebreaker took the cargo ship bow in its towing notch for towage. However, the bollard on to which the towing line was attached broke and detached from the deck. After a while a new attempt to get the cargo ship moving was made, but it did not succeed. The cargo ship was so tightly pressed by the ice that it did not move anywhere.

The pressure on the cargo ship sides was so strong that they were bent inwards and a small leakage was detected. The compression was continued and the steel structures, frames and decks were deformed. Two frames were totally broken and water started to

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[35] It is not known if this vessel had any kind of ice strengthening. However, it had been built to the highest class of Lloyd's.

[36] Wind force 9 corresponds to wind speed of 20.8-24.4 m/s.

spurt in from the ruptures into three holds. The main deck of the vessel started to get bent and the bulkheads between holds were also buckling manifestly due to strong stresses. As a consequence of the leaks the ship developed a list of 10°. The water depth in hold nr. 2 was two meters at its worst. Fortunately, it was possible to move a pump with great capacity from the icebreaker to the cargo ship. The draught of the cargo vessel could be decreased by emptying the ballast tanks and so it was possible to get the major ruptures over sea water level. Two days after the first phases of this accident the leaking ship was assisted to repair yard. Both sides of the vessel were pressed permanently inwards for a length of 40 m. Although the vessel had been strengthened according to the rules of ice class IA (of that time) did it suffer such a big damage that it had to stay at the repair yard for a period of 40 days. According to Jääsalo (Jääsalo 1979) the ship's ice class would have been IC, if the updated ice class rules of 1971 had been applied.

Case 3: Hull damage due to ice compression (Hänninen 2004)

On the 11th of January, 2003 an oil tanker was on her way with full cargo while she got stuck in compressive ice in the Gulf of Finland. During the compression in the 10-30 cm thick ice field ice blocks piled up against the SB side of this Aframax class vessel, which was not assisted by an icebreaker on that occasion. The ship had an ice class equivalent to the Finnish-Swedish ice class IC. The longitudinally framed flat side plating in the mid-ship area of this ship got permanent deflection in the area of two frame spacing for length of about 100 m with maximum indents being about 30 mm. The damaged area was in the ice strengthened belt about 1.5 m below waterline. According to the ship's master the vertical extension of the ice belt is too narrow.

Ice class IC minimum requirement for the depth of the ice belt is 0,4 m above load waterline (LWL) and 0,5 m below ballast waterline (BWL).

Case 4: Hull damage due to ice loads (Hänninen 2004)

On the 19th of March, 2003, a handymax bulk carrier of around 45 000 dwt with no known ice strengthening (ice class II) was following an icebreaker with full power in ridged and rafted ice. The ice conditions were severe in the eastern parts of the Gulf of Finland, with level ice thickness of 55-75 cm, but the mean speed of the vessel was about 8 knots. The beam of this bulker was about 2.5 m wider than the beam of the icebreaker. The weather data was as follows: temperature –2°C, pressure 1009 mbar, wind W-4.

As a consequence of ice loads on the ship hull both sides of the ship, from fore peak to bow shoulders, became buckled and two fractures and several dents of maximum depth 150 mm were formed on the hull plating. Water started to leak in the foremost hold so that the forward draught of the vessel increased gradually by more than 2.7 m. Around the fractures, which were both located on the same side of the ship, the permanent deformation of the plating was about 200 mm. The length of the fractures was 2 m in horizontal direction. The ship was transversally framed. Two frames were parted due to the fractures.

The ship got an additional emergency pump from the icebreaker, but the pumping was stopped as the water level in the hold could not be changed. Two days later a rescue vessel, which was assisted by another icebreaker, came on to the scene . After some preliminary patching work the vessel was later assisted and towed to open water with the help of three icebreakers and one rescue vessel. However, during its 10-day journey to the ice edge the damaged ship was stopped several times in the prevailing ice conditions, with temperature varying between +2°C and –7°C and wind force varying between 2 and 5 (1.6 m/s – 10.7 m/s). The ship crew left the ship before it was towed to repair yard for docking. The frames, plating and stringers on the damaged area of this about 20 year old ship had to be renewed.

5.2.2 RUDDER DAMAGE

A rudder failure is a failure of the rudder or any part of the the rudder machinery. A rudder failure in ice is caused by the ice load directed on the rudder. This load is a consequence of the relative motion between the ship and an ice block or the edge of level ice. Rudder damage is caused by an ice force that bends or turns the rudder in a violent manner. Most frequently the rudder damage is a twisted rudder stock, see (Kurki 1986). In order to avoid this kind of damage ice class rules include requirements for rudders and manoeuvring devices. Protective devices and appendages, such as a relief valve for the hydraulic system of rudder machinery and an ice knife, see Figure 55, are required in ice classes IASuper and IA. The ice knife or ice horn bends or crushes the ice before it hits the rudder, when the ship is going astern. Rudder stoppers, which limit or prevent the turning motion of the rudder, are recommended for those ships that are operating in heavy ice conditions. Deep trim by the stern is one of the operational risk control options available against the rudder damage (and propeller damage) in ice.
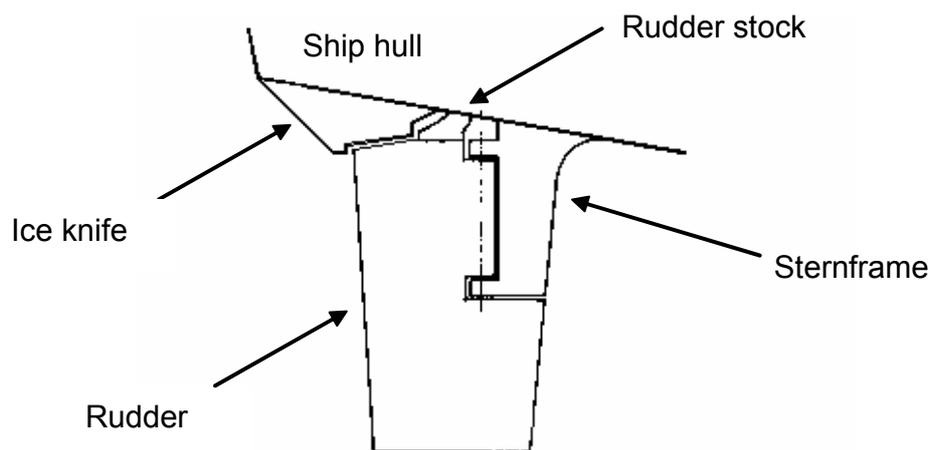

Figure 55   A semi-balanced rudder protected by an ice knife (the expression "ice horn" may also be used in connection with such an appendage that can be seen in Figure 57).

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A typical rudder failure occurs in severe ice conditions due to operational error. When the ship is not anymore able to proceed ahead at constant speed, it gets stopped. In order to make another ram through the obstacle, e.g. an ice ridge, it has to move astern. If the rudder is not kept amidships during the backing phase, it may get damaged, when the ships afterbody impacts ice. A rudder damage is also possible if the ship is not moving astern on a straight course and the impact with ice is oblique. In some cases drifting ice has also been reported as a cause of a rudder failure. It is also possible, although not very probable, that an ice block hits the the rudder, when the ship starts turning when moving ahead. Ice blocks accelerated by the flow from other ship's propeller may also hit the rudder from a certain range of direction.

A serious rudder failure may stop the voyage of the ship. In the accident case nr. 1 above, the ship was ordered to start a return voyage before entering it's port of destination due to a rudder failure caused by ice. If a temporary repair or sufficient towing assistance is not available, a rudder failure may make the ship more prone to hull ice damage. In another worst-case scenario an undetected rudder failure may also act as a cause or contributing factor to a collision or grounding. If the propeller is still working and the ice conditions are not too severe, there may still be some possibilities to manoeuvre the ship, however.

One case of rudder damage was already present in case 1 above. Below is a second one.

Case 5: Rudder damage due to ice load (Hänninen 2004)

On the 22th of April, 2003, a new general cargo ship of ice class IA and a deadweight of nearly 8 000 tons was proceeding in the Bothnian Bay without icebreaker assistance in moderate to heavy ice conditions (level ice thickness being in the range 35-60 cm). The ship was almost in ballast condition with draught forward being about 65 % and aft about 70 % of the full load draught. The weather was fine with wind force 3-4 from N-NE. Occasionally, the ship was stuck in ice, but it could free itself by reversing the pitch.

According to the statement of the master the rudder was kept midships during repeated rams and reversals, the former being performed full power ahead and the latter with a speed between 2 and 3 knots. However, during one repeated ram towards the ice it was noticed that the ship was turning to port with the rudder midships. Starboard rudder was given, but it had no effect. The ship was stopped and the rudder position was checked. It turned out that the rudder was pushed out of its centre position. The owners of the ship and the nearest icebreaker were informed of the condition of the vessel. The icebreaker arrived on the scene about 2.5 hours later. However, after an emergency repair performed by the ships engineers, it could proceed to its close-by destination, with a tugboat helping it to its berth. The rudder stock/tiller connection was slipped and stock in way scored.

5.2.3 PROPELLER DAMAGE

Propeller damage is one of the most frequent types of ice damage. In the old ice damage statistics from years 1962-1970, presented in (Sjöstedt & Hammarsten 1973), propeller

damage represented about 40 % of all ice related damage cases. However, in the damage statistics from 1984-87 (Kujala 1991), the share of propeller damage cases was much lower, being just 8 %. The reason for the low share in the latter case may depend on the limitation of ship types into merchant vessels. A more recent statistics from the Baltic Sea, including all ship types, confirmed that about 40 % of all ice related incident cases in winter 2002-2003 involved a propeller damage (Hänninen 2004).

A propeller damage, when related to ice, can be caused by direct or indirect ice loads on the propeller and its blade(s). Damages may occur especially in certain special occasions, e.g. if a ship with stopped or slowly rotating propeller or a controllable pitch propeller at zero pitch is still moving through ice (Koskinen et al 1999). All ramming operations in difficult ice conditions with repetitive manoeuvres back and forth or icebreaker towage through heavy ice formations may lead to excessive ice loads on the propeller. The ship hull offers hardly any protection, when the ship is moving astern.

Ice load may bend propeller blade(s) or the tip and leading edge of the blade. Trailing edge damage is possible for fixed pitch propellers when the ship is moving astern (and the trailing edge becomes temporarily a leading edge). If the permanent deformation of the blade is small, it may be possible to repair the propeller without changing the blade(s). Propeller ice loads may cause fractures in the blades and pieces of propeller blades can be lost. In some cases with controllable pitch propeller, ice loads have also damaged the pitch controling mechanism. In worst propeller damage cases the whole propeller has been lost.

Additionally, propeller damage can also be caused indirectly, by the fluctuating hydro-dynamic forces due to the ice-blocked flow. In the latter case, which can be especially problematic for propellers working behind A-brackets (supporting propeller shaft) or in a nozzle, the induced heavy vibrations may cause damage to the propeller and e.g. the mechanisms of a controllable pitch propeller. If the propulsion system is not well designed, these loads and heavy vibration may contribute to machinery damage too. Propeller induced vibrations can also lead to progressive damage in the case of a partly deformed or damaged propeller. Fatigue of propulsion system components due to direct and indirect ice loads may become a problem, if not sufficiently taken into account in the design.

In a conventional single propeller ship the propeller is located in a fairly well protected place at the centerline of the ship. In a ship with two propellers less protection is usually available, see Figure 56. The clearance to the hull surface and to the sea level, marked in the figure with black arrows, are needed in order to avoid suction and drifting of ice blocks from the sea surface to the propeller. The most exposed areas of the propeller, the tip and the leading edge of the blade, are marked in Figure 56.

With regard to propeller ice loads, the flow and trajectories of the broken ice pieces along the ship hull and afterbody are crucial matters, when the ship is moving ahead. Usually aft trim is used and the location of the propeller is at a depth deep enough to avoid impacts with ice blocks. However, if the ship is in ballast condition and/or the ship is

backing in ice the risk for propeller damage increases, see Figure 57. If the propeller is near to the water surface, the propeller blades may hit ice floes directly or then the induced flow brings the ice block closer thus enabling a contact.
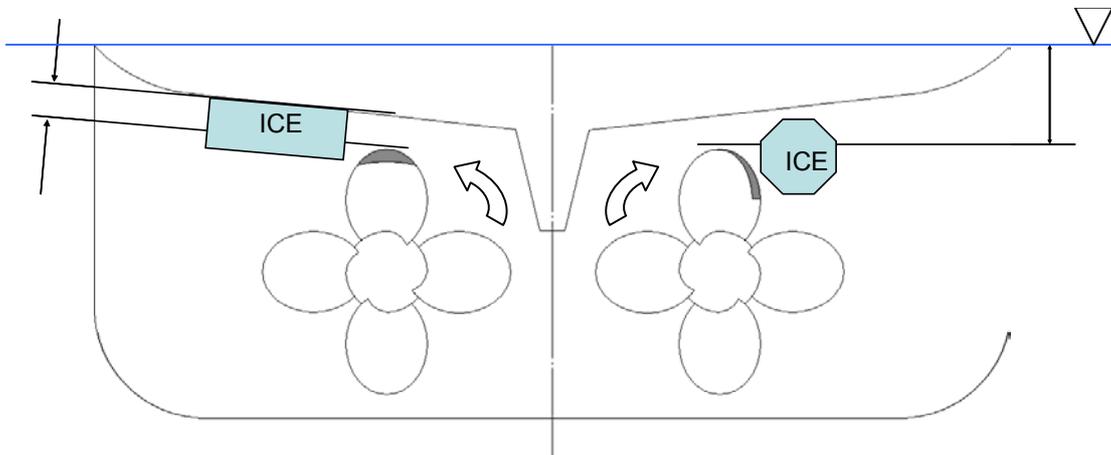
Figure 56   Location of the propeller behind the ship near the centerline. Note! Turning direction of these propellers (outwards) are marked with white arrows.

In addition to separate ice impacts on propeller blades, in the case of a large ice floe, a phenomenon called *propeller ice milling* can occur. In this process all the blades are in contact with ice one after another for a rather long period of time. In order to avoid heavy ice loads a sufficient propeller clearance both to water surface as well as to ship hull is recommendable. Ice strengthening is an essential feature of the propulsors of ice classed ships.

Figure 57   Propeller ice loads are possible, if the ship is in ballast and manoeuvres back and forth are tried regardless of the ice condition (photo: T.Leiviskä).

A damage to the propeller does not by itself endanger the safety of people, environment or ship. However, as an initiating event to an accident scenario it may have more severe consequences. A ship without propulsion is rather helpless and prone to the external forces of the environment. As it is the case with a rudder damage, a serious propeller damage can stop the voyage of the ship. Thus, if sufficient towing assistance is not available, this may make the ship more prone to hull ice damage or drift grounding.

Case 6: Propeller damage due to ice load (Hänninen 2004)

On the 23rd of February, 2002, a rather new roro-vessel of nearly 9 000 dwt with ice class IA Super suffered a propeller damage in the Bothnian Bay. This accident happened in the evening at 21:20 during a voyage about 3.5 hours after departure from port. The ship had been navigating in an old ice channel without icebreaker assistance. Due to an occasional stop the ship was backed with reversed pitch and the main engine was overloaded and stopped. Repeated trials to start the main engine again didn't succeed. The propulsion system was checked and it turned out that the engine could not be started due to the propeller failure. Later on an icebreaker arrived to the scene and the ship was towed to its port of destination, where it arrived at 5:40 in the next morning. The propeller was inspected by a diver. Four days later a towage of the ship to a repair yard was started.

5.2.4 MACHINERY DAMAGE

Machinery damage is not a frequent type of ice damage. If the damage and it's cause are connected to ice, this may be e.g. because of wrong design principles of the propulsion system, i.e. not applying the pyramid strength principle (Koskinen et al 1999), unusually high fatigue loads, heavy vibrations or such operative use of the machinery it is not designed for. According to a checklist presented by Laakso (1984) a safe and reliable propulsion machinery in winter navigation should, in addition to the general require-ments, have the following characteristics:

- full propeller power available at different ship speeds
- continuous power control, ahead/astern
- possibility of rapid reversal of propeller thrust
- stability of propeller speed under ice loads
- protection of main machinery from overloading
- shaftline components dimensioned to withstand ice loads
- allowance for shaft movements during propeller-ice interaction
- tolerance of cold suction air and sea water
- special care applied in the design of sea water utilization for cooling
- ability to operate with little water below the keel

One part of the listed items are connected to the operability of the machinery in winter conditions. This means, that the machinery problems may not necessarily lead directly to a damage. It is a harm, if the ship machinery stops temporarily due to a lack of sufficient

amount of cooling capacity. However, in critical situations the reliability of the full operation of the machinery may have a significant effect on the ship safety. A ship that for some reason is not able to use all components of it's propulsion (or auxiliary) machinery to full extent may become as helpless as a ship with no propeller e.g. in drifting ice.

In some occasions, even the icebreaking tug or the icebreaker may suffer from serious problems with the machinery although at least the latter do usually have redundance for coping with such cases. Winter navigation relies to a considerable extent on the use of a limited number of icebreakers. Therefore, when operating under the pressure of monetary savings, not much redundancy in the number of available icebreakers is available in the most severe winters. Thus, if even one of them is not operable, this lack in the number of assisting units may cause trouble for the safety and steady flow of the traffic in the concerned area of ice covered sea.

In the recent statistics from the winter 2002-2003 including all ship types in the northern Baltic Sea about 3 % of all ice related incidents involved machinery damage (Hänninen 2004). Thus, it may be assumed that machinery damage is not a major problem in winter navigation in the Baltic Sea. However, it can act as a contributory factor to some other accidents.

It is also possible that some problems or difficulties to use the machinery in the desired manner in a sudden situation may be a cause or a contributory factor to an accident. As an example of this kind of effect e.g. Toomey (1994) points to some merchant ships, which may change to heavy fuel during an open water section of a longer transit in ice without being able to stop or manoeuvre in time when needed, when encountering ice edge again.

5.2.5 OTHER ICE DAMAGE

In addition to the damage of ship hull and rudder, ship hull appendages, such as bilge keels and stabilizer fins may also get damaged in ice conditions. The latter are best protected if they can be folded or retracted inside of the hull envelope before entering ice infested areas. Bilge keels are, however, fixed structures and often damaged in ice conditions. According to the recent statistics of ice related accidents/incidents in the northern Baltic Sea in winter 2002-2003 (Hänninen 2004), bilge keel damage was recorded in 7 cases of a total number of 27 hull ice damage cases. Unfortunately, it is not known how many of all these ships did actually have bilge keels.

The structure and attachment of bilge keels to the ship hull are important issues, which are strongly emphasized in the ice class rules. The same design principle, concerning the limitation of damage by controlling the strength of the components of a system (and their joints), as is applied in the case of ship propulsion system, must be used in the case of bilge keels and their attachment to the hull. Bilge keel is a cheap structure, but in some cases, see e.g. (Corlett et al 1987), it's failure has been the source of a much bigger damage.

5.2.6 ICING

Icing is a phenomenon, which means that ice is accumulating ("growing") on the super-structure or deck equipment of the ship. In ships it is most often caused by the cold air temperature and water spray rising from the sea. If the cumulative action of water spray freezing on the upper structures of the ships continues long enough, the additional weight of the frozen water on the ship may endanger its seakeeping ability and stability. Before this happens, it may be a matter of occupational safety or hinder normal deck operations. Comprehensive reviews of icing in marine environment have been presented e.g. in (Lozowski 1988, Makkonen 1988).

Under worst icing conditions whole ships have been lost. The list, which may be developed in icing conditions may also increase the risk of cargo shift. In a critical situation icing may also hamper the use of ship's deck equipment, pilots ladders, lifeboats or other lifesaving equipment. Examples of accrued ice on ship decks, structures and equipment are presented in Figures 58 and 64.

Figure 58   Ice covered outfitting on the forecastle deck of a tanker (photo: Fortum Shipping)

Under unfavourable weather conditions, see Figure 59, the amount of ice accrued on the ship's structures may grow fast. As an example of the effects of severe icing it may be useful to know that during the rescue operation of the crew of cargo vessel Dux II in the 15.1.1963 the draught of icebreaker Ymer was increased by 1 meter (SST 1963). The ferry M/S Peter Pan had to return to Trelleborg instead of proceeding to Sassnitz in 1972 due to the icing covering the windows of the bridge (Lundqvist & Udin 1977). In the latter occasion the wind speed was 17-22 m/s and the temperatures of air and sea were -5°C and +1°C, respectively.
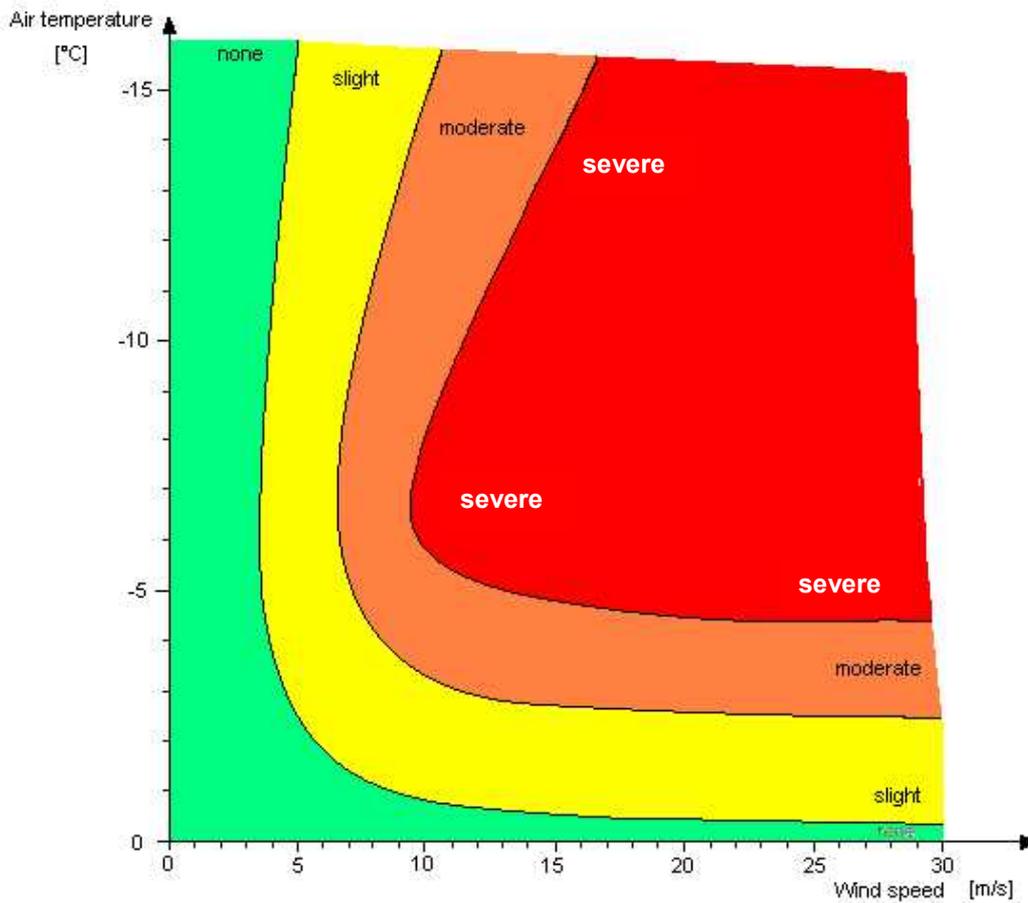
Figure 59   The relation between the severity of icing on ships, wind speed and air
             temperature, reproduced from (Lundqvist & Udin 1977)

The rate of icing depends on several factors: air temperature, water temperature, salinity of the water, wind speed, sea state, speed and course of the ship, ship design etc.. Icing may be avoided or reduced operationally most efficiently by changing the course of the vessel. The areas that are most prone to icing are usually in the bow of the ship. Fire-fighting with water spray in low temperature may have a similar effect as icing. According to Lundqvist and Udin (1977) icing can usually be limited e.g. by:

- seeking shelter in the lee of land until the conditions have changed, or
- change of the ship's course and speed

In the same reference it is stated that the additional time needed for removing the accreted ice from cargo handling equipment and decks in port may be much longer than the extra time consumed on a longer route or due to a speed reduction. Thus, economical benefit may be achieved by selecting the safe alternative.

Case 7: Icing – cargo shift – listing – loss of freeboard – foundering (SST 1963)

On the 18th of January 1963 a general cargo ship sank in mid-January at a distance of 6 nautical miles from the port in the southern Baltic Sea due to icing and consecutive cargo shift. However, the crew of the ship could be rescued to local vessels.

Case 8: Icing-incident (no damage) (HBL 1987, HS 1987)

On the 13th of January, 1987, a fast passenger car ferry with about 400 passengers was on its way to north in open water in the middle of January in the southern Baltic Sea. The stormy wind was blowing very hard from north-east, wind speed being about 20-25 m/s, and the temperature was decreasing down to –10°. Ice started to accumulate on the ships bow deck and on the upper deck structures. In somewhat similar weather conditions about eight years ago, the ship had succeeded in ending its voyage to the port of destination, but with a 20 hours delay. However, this time, when the excessive icing, stormy wind and waves of the winter storm endangered the ships stability and visibility, it was considered better to turn back although one third of the voyage had been already made. The ship returned safely to its port of departure, where the ice removal operation could be started.

5.2.7 GROUNDING

Ship grounding is a typical marine accident, especially in Finnish waters. Its occurrence is not limited to the open water season. Winter time gives new characteristics related to groundings and their causes. This is the reason why it is included in this analysis.

Groundings can be divided in two main types. These are:

a) a powered grounding, when the ship moves with own power on the rock (or strand), or
b) a drift grounding, when the ship drifts on/over the ground due to an external force

In the latter case the ship is not moving under its own power, so it is moved by wind, current or drift ice. If a ship gets stuck in drift ice near to submerged rocks, it may have no way to avoid the grounding. There have been such cases in the history of winter navigation, when an icebreaker has saved cargo ships or passenger vessels from this destiny. Without sufficient icebreaker assistance the outcome of these incidents might have been quite different.

In winter navigation a powered grounding can be caused by ice, if it prevents making the intended and necessary manoeuvre to keep the ship on a safe route. Ice can have sudden and unexpected effects on the manoeuvrability of the vessel. On the other hand, a grounding can also occur, if the ice is treated as an obstacle and, when avoiding it, safe navigation is neglected. A ship may also get grounded on ice floes below its bottom if they can be pressed against the sea bottom. When proceeding across an ice ridge this is possible, if the ridge depth is large enough and the water depth is limited.

There are certain contributory effects that winter may have on the probability of grounding. Snowfall may deteriorate the visibility and in some cases the use of radar too. Icing and fog may have similar effects. Low temperature may stop the aids to navigation from working or the may get covered by snow or ice. Ice blocks have sometimes been reported to make the radar information useless. Channels in ice, broken by an icebreaker may in open sea change their location to unsafe places. It is also easy to get mixed between several leads, especially if the visibility is poor. Thus several possibilities for a grounding accident exist in the winter. In ice channels in fast ice area there may also be some advantage from the ice, as it marks clearly the location of the fairway. However, even in this case all rules of safe navigation should be applied.

Case 9: Powered grounding (Vapalahti 1997) [37]

On the 11th of January 1969 a general cargo ship of about 9 200 dwt grounded in the eastern part of the Gulf of Finland, when it was following a smaller icebreaker in a fairway. The cargo ship had not deviated from the ice channel broken by the icebreaker. However, it appeared later that this broken channel was about 150-200 m aside from the correct waterway. There had been deficiencies in position fixing, when the icebreaker opened this channel. Information regarding these deficiencies were delivered to the cargo vessel just 6 minutes before the grounding took place. It was later insisted that the cargo vessel had very poor possibilities to open a new channel in the prevailing ice conditions.

The speed of the cargo ship had been lowered down to about 6-7 knots when the accident happened. The bottom of the ship had suffered severe damage and water started to enter in holds nr. 1 – 3. In order to avoid sinking in deep water, the ship was assisted by the icebreaker to turn. Then it sailed to a shallow water area near the shore of an island at a distance of 3 nm, where it arrived at 20:00. The leaks were patched up, but at the time when the ship was stopped, the void spaces in two of the cargo holds were almost completely filled with sea water. In addition, the pulp cargo had started to swell and cause further damage inside the ship.

Two days after the accident, when the deck cargo had been removed, the ship was towed back to the port along a new broken channel, which had been checked to have a correct location by another icebreaker. However, during the way back, the cargo ship, using also partly some own power and having still an exceptionally deep draught, hit the sea bottom at a speed of 3-4 knots 70 m on the right side from the correct location of the waterway. However, no more leaks could be found after the latter case. Both groundings happened in a fast ice area and there was a pilot onboard in both occurrences.

Case 10: Powered grounding (FMA 1996)

On the 9th of March 1982 a 12 year old general cargo vessel grounded in the Gulf of Finland in poor visibility, which was caused by dense fog. The navigation in the approach to port was further complicated by effects of the drifting ice floes. According to the pilot

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[37] Note! This case is from year 1969, but lessons that can be learned are not necessarily out of date.

it was impossible to make difference between the echoes from the ice floes and the echo from the radar deflector as everything appeared as similar echoes on the radar. Therefore, the information on the radar monitor was of poor quality for navigational purposes in the prevailing conditions. The ship suffered large bottom damage and water entered e.g. in the machinery room. The ship sunk in shallow water almost down to the level of its main deck and it had to be towed in to the harbour. No damage to the crew was reported.

Case 11: Powered grounding (SHK 1996)

On the 7th of February 1996 a large car-passenger ferry belonging to the ice class IA Super was navigating along the frozen fairway through the Stockholm archipelago with a speed of about 10.5 knots. At one pre-planned turn to the left the ship did not turn as quickly as planned. The manoeuvring mode of the ship was changed to manual control and a 20° rudder angle was applied, but the rate of turning did not increase to the desired level. Therefore the power on the port propeller was decreased and the power on the starboard propeller was increased in order to make the vessel to turn more quickly. The master assessed the situation and ordered the mate to reverse on the port propeller. As even this measure soon turned out to be inefficient he ordered to reverse on both propellers and to start the use of the bow thrusters to avoid an underwater reef which the ship was approaching.

Despite all applied measures the ship grounded, but fortunately at a low speed of about 2.5 knots. Thus, the hull damage was restricted to small material damage in the bulbous bow in the compartment in front of the collision bulkhead. The reason for the ships slow response to the rudder angle and the other applied manoeuvring measures was that the waterline of the ships afterbody, with rather steep frame angles, was leaning all the time against the edge of the broken channel. Thus, the ice edge prevented/retarded the ship from turning at an anticipated rate. The level ice thickness was about 30 cm at the site of the accident.

Case 12: Powered grounding (OM 1994)

On the 4th of March 1994 a large passenger vessel of ice class IA Super was navigating with 1260 persons onboard in the Gulf of Finland. It was proceeding inbound in the frozen approach to the waterway leading to the port with a speed of about 19 knots when it hit underwater rocks at 14:44. The raking damages caused several leaks and water entered also in the machinery room. The ship stopped finally and started to list and sink slowly in deep water. The cause of this accident was, in first hand, related to errors connected to the navigation of the ship and to the use of the electronic radar chart system onboard. An additional factor was the icebreaker approaching along the fairway from the starboard side of the vessel. It was given way by turning the ship's course to right. The information given by the integrated navigation system was not correct at this time, but the operator relied to it and thought that the selected course was safe. The ice buoy that was used for marking the rocks was probably under ice floes at the time of the accident as it was not observed from the bridge.

The evacuation of the vessel was started when an icebreaker and a coast guard vessel had come on the scene at 16:00. As the ship was surrounded by sea ice, some problems were encountered in using the evacuation systems of the ship. The slide system on the other side of the vessel did not open properly to the intended position, due to the presence of sea ice. The life boats and the life rafts were not used. Instead of them, the ship was evacuated by removing passengers and crew members directly to the icebreaker and via the other slide system, on a raft on the other side of the vessel, and then to other ships that had arrived on the scene.

Due to the nature of navigating in ice, with vibrations, noise and some sudden effects on ship motions, it was not immediately realized that a grounding had occurred. However, a command to close the watertight doors was given. The evacuation of the ship was started not until 1 hour 54 minutes after the grounding. It lasted 1 hour and 24 minutes and it could be finalized successfully without any losses of life or injuries. Fortunately, the accident happened in day time and the weather was good, temperature –8°C and wind 4 m/s from E-SE and E. However, the material damage of the leaking, sinking and listing ship, which was towed to shallow water during the evening and night, was extensive.

Case 13: Powered grounding (Moore 1994)

On the 23rd of March 1989 a large oil tanker left the oil terminal with a full cargo load at time 20:54. There had been indications of drifting ice [38] on its originally planned route along the traffic lane, so the master of this vessel with no ice strengthening decided to use a deviating course across the traffic separation zone in order to avoid any ice impacts.

Before leaving the bridge to the third mate the master set the autopilot control on, but he did not mention this to the 3rd mate. The speed of the tanker was increased to 12 knots as it started to cross obliquely the lane for inbound traffic too. There was some ice on this lane also. The radar information which was used for navigation was not correlated with the navigation charts through position fixing. The submerged reef was not presented on the radar screen.

VTS had nearly 18 minutes time to call the tanker on the dangerous course, but at the time of the accident the operator was away for getting a cup of coffee. The VTS radar equipment had been deteriorating for several years without proper maintenance and the system was inoperable up to 28 % of the time. However, after the accident the location of the grounded tanker had been easily found by the VTS radar operator who had previously been thought it was not possible.

As the tanker approached the reef a red signal light blinking at the shore lighthouse was noticed on the bridge. However, delayed attempts to manoeuvre back to the shipping lane did not succeed anymore. The ship rammed on the reef getting ruptures and heavy damage in its bottom. The damage length was about 180 meters. The environmental

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[38] This ice was from a glacier, but it is actually not relevant for this case if we are concerned about risks with vessels with no or just low ice strengthening.

damage caused by this single hull oil tanker ruptures was disastrous [39]. The total volume of the spill was about 42 million m^3. In four days the crude oil had reached a distance of more than 60 km, in 40 days the length of the polluted area had grown to 560 km.

Case 14: Powered grounding (Luukkonen 1999)

On the 11th of January 1991 a roro ship grounded, when it was approaching port on the coast of the Bothnian Sea in heavy snowfall and hard wind. This accident was caused by the problems in understanding the movements of the vessel, but the sudden loss of visibility, irregular and unexpected conditions of sea currents and the dead light of waterway edge mark may have strongly contributed to it. The damaged area of the ship's bottom was about 50 %, so a visit to a repair yard was inevitable.

Case 15: Drift grounding accident (SST 1982b)

On the 16th of January 1982 a motor ship carrying 2750 tons of iron and steel cargo got stuck in ice in the Bothnian Bay. The whole ice field with the ship drifted towards a shallow water area with underwater rocks. Wind speed was 25 m/s. The crew prepared to leave the ship in a lifeboat, but was picked instead up by a helicopter to an icebreaker, which tried to get to the scene in time. However, the ship grounded and got leaks in several tanks.

Case 16: Drift grounding incident (HS 1966b, Vapalahti 1997) [40]

On the 14th of February 1966 a 8 beaufort eastern wind started to move ice from the Gulf of Finland towards the coast of Sweden. Two passenger ships were stuck in the heavy ice conditions near Almagrundet. The whole ice field drifted towards underwater rocks with the jammed ships. An icebreaker was called out to help. It arrived to the scene and managed to free the ships from their hazardous positions in time. One of the passenger vessels used 66.5 hours for the voyage of about 170 nautical miles. The extremely low average speed of 2.6 knots[41] on this trip, long parts of which were made through the sheltered waters of archipelago, tells a lot about the severe ice conditions.

5.2.8 COLLISION

Collisions are rather frequent in winter navigation. However, collisions in ice conditions differ from collisions in open seas. The conditions, which expose ships for collisions are characterized by close manoeuvres of the icebreaker and the assisted cargo ships, navigation in narrow broken ice channels, sometimes with very hard edges, and often reduced visibility. However, as the velocities are often low and ice itself may act as a kind of damper the consequences of these incidents are usually not so severe.

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[39] This was the grounding of Exxon Valdez on the coastal waters of Alaska in 1989.
[40] The actual grounding was fortunately avoided in this case
[41] 2.6 kn < 5 km/h (1 knot = 1.852 km/h = 1852 m / 3600 s = 0.5144 m/s)

Collisions in winter navigation can be divided in different categories, which are:

a) bow/bow collision
b) bow/side collision,
c) bow/rear end collision,
d) side/side collision

These winter-time collision types are presented schematically in Figure 60. One of the most typical collision that belongs to category c) above takes place between a merchant vessel and an icebreaker, when the former is following the latter. This kind of accident may occur if the speed of the convoy is high or moderate and the distance between ships is narrow. If the speed of the icebreaker is now suddenly reduced, e.g. due to a ridge, the operators of the cargo ship may not be able to reduce the speed or stop its motion in time to avoid colliding with the rear end of the icebreaker. Fortunately, structural damage of the towing fork of the icebreaker or the bow of the cargo ship (ahead of the collision bulkhead) are not typically as critical as collision damage on the side of the ship. The lay-out of a conventional ship with the deckhouse at some distance from the ultimate limits of the vessel at fore and at aft acts here as a protective safety feature. However, some new designs may not be as safe in this respect.

a) bow / bow collision

b) bow / side collision

c) bow / rear end collision

or

d) side / side collision
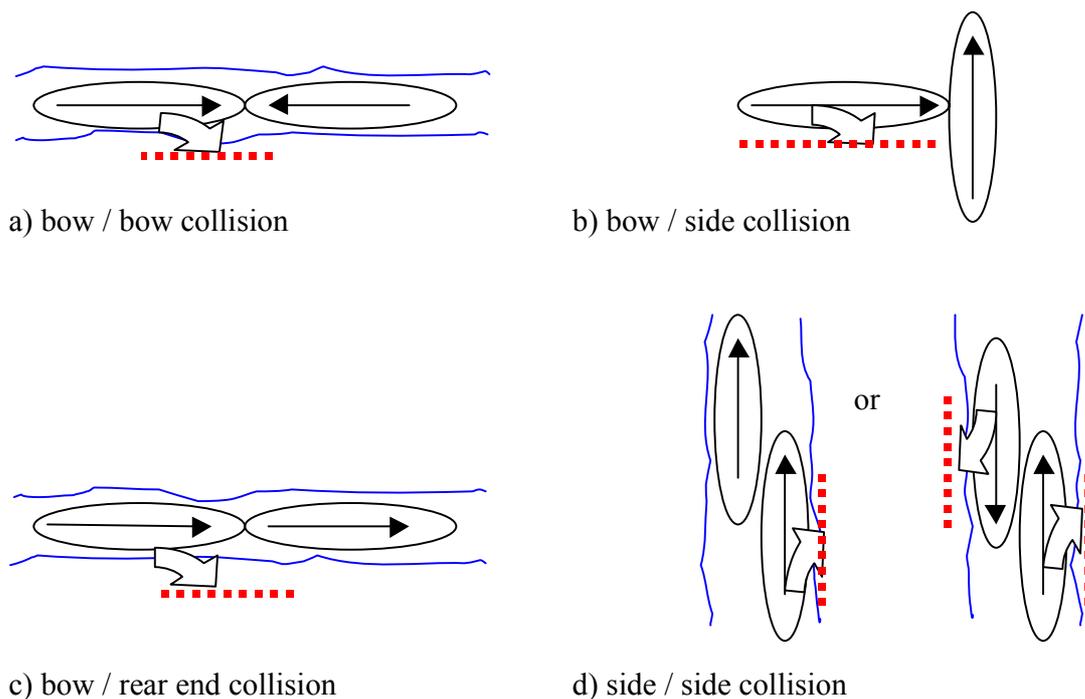
Figure 60   Different types of collision in ice conditions. Collisions of type a, c and d typically occur in narrow ice channels, where strong ice formation at the edge of the channel (marked with the dotted line) restricts the ship from steering clear of the other vessel. Note! This figure includes only the most typical collision types in ice. Other types of ice related collisions are also possible and should therefore not be totally neglected.

It should be pointed out that some collisions do not clearly belong to any of the categories presented in Figure 60. Some collisions may also occur without any clear evasive acts. An example of such additional type is a collision that may happen between two vessels in difficult drifting ice conditions. Such cases have been reported to have occurred in Russian Arctic in 1983 (Järvinen 1984).

The most essential issues characterising these collisions is the presence of ice, which may seriously restrict the attempts to avoid the collision. The ship manoeuvrability in ice is usually much worse than in open water and difficulties in taking into account the often unpredictable behaviour of the ship with respect to the rudder commands may be large. However, the problems with poor manoeuvrability in ice, poor visibility and snow fall having disturbing effects on the use of radar may also sometimes be relevant. The icebreaker's normal operations, cutting a cargo vessel loose, see Figure 61, and taking it in towage, see Figures 62 and Figure 63, are reasons for an increased collision risk, especially in severe ice conditions, when close and fast manoeuvres are often required. Operational experience in ice navigation, the ability to foresee and predict the ship's response to the effects of ship speed, propeller thrust and rudder force, and any changes of them, in different ice conditions, is of great value when trying to avoid collisions. Navigation in ice conditions requires constant vigilance, especially when ships are operating at close range (e.g. in a narrow ice channel).

Figure 61   Multipurpose icebreaker is cutting loose a cargo ship beset in pack ice (photo: T. Leiviskä).

Case 17: Bow / bow collision (see Figure 60a) (FMA 2001)

On the 7th of March 1994 a general cargo ship and a tanker of about 8 500 dwt were on meeting courses in a narrow old ice channel in the Gulf of Finland. It was planned that the tanker with ice class IA would give way and break out from the channel. However, the channel edge was harder than expected and the tanker could not get out from the channel. The distance between these two ships diminished quickly and finally they

collided bow to bow in the ice channel. Fortunately the extent of damage was rather small in both vessels.

Case 18: Bow / side collision (see Figure 60b) (HS 1985)

On the 6th of April, 1985, at around the time of daybreak, a general cargo ship collided on the port side of an other cargo vessel of about 15 000 tdw in the Gulf of Finland. The latter vessel listed and took fire at the afterbody, so its whole crew and three passengers onboard had to be evacuated in a life boat, a life raft and on ice. An icebreaker came on the scene and rescued the people. A helicopter picked 3 persons to hospital. A tug towed the ship in a safer location in shallow water as the danger for ship sinking was imminent. The fire was extinguised on the next day. Then, the ship was towed to a nearby harbour and after that to the repair yard.

Figure 62   The numerous operations when an icebreaker starts or carries out towing tasks will increase the risk of a light collision inevitably.

Case 19: Bow / rear end collision (see Figure 60c) (FMA 1996)

On the 26th of February 1990, a general cargo ship collided in fog on the afterbody of the assisting icebreaker in the Bothnian Bay. The speed of the icebreaker had been stopped intentionally for a while due to a sudden heavy ice formation, which was decided to be broken down by the use of the flow of the icebreaker's bow propeller. The following cargo vessel seemed first to be at a safe distance, so no request to speed drop was given to it by the icebreaker. However, the echo of the IB's radar was reflected from the high superstructure at the afterbody of the cargo vessel, not from the ship hull as anticipated. Thus, the icebreaker was not yet prepared to continue forward, when the bow of the cargo vessel suddenly appeared out from the fog. The icebreaker got some minor damage on its bitts at the aft deck, but the cargo ship got a rupture at bow above waterline.

Case 20: Side to side collision (see Figure 60d) (FMA 1996)

On the 6th of March 1987 a passenger vessel collided with an other in darkness at 03:05 in a snowfall. The ships were passing each other port-to-port at a small distance in a narrow ice channel, so a suction effect due to the pressure fields of the vessels was evident. However, local variations in the ice conditions had also some influence on the motion of the ships, which changed unexpectedly. Ship no. 1 got some material damage on its port side plating. Ship no. 2 got a 20 cm wide and 15 m long rupture above water-line. Lifeboats and the davits of the latter vessel were also damaged.

Figure 63   The cargo ship and the icebreaker are preparing for starting a towage in heavy ice conditions. Operations like this may sometimes lead to bow damage of the merchant vessel (photo: T. Leiviskä).

Case 21: Bow damage during towing (FMA 2001)

On the 15th of March 2000 an icebreaker towed a cargo vessel in heavy ice conditions in the Bothnian Bay. When the towage was finished it appeared that the cargo vessel had a dent and a rupture in its stem. The damage was located totally above the waterline.

Minor bow/aft damages, of more or less severe consequences, like that in the case 21 seem to happen almost each year. Some of them are caused by the rough nature of winter navigation in severe environmental ice conditions. All bow designs of the merchant vessels do not fit closely to its counterpart in the aft of the icebreaker. This seems to be one reason for the rather high number of this kind of small damages. However, by using the close tow (i.e. keeping the bow in the icebreakers towing notch), more serious damage in the ship sides at waterline can usually be avoided.

An icebreaker, which is leading a convoy of one or more merchant ships may often not be able to maintain a steady speed. If the navigators of the following ships are not vigilant, a collision may occur. The operational side of the winter navigation and some possible difficulties related to it have been discussed more thoroughly e.g. by (Pohjola 1986, Toomey 1994). According to the latter, in an escort situation it is not always possible to make progress through ice without temporarily suspending some of the rules of safe navigation. If the communication is sufficient and a common understanding on the manoeuvres is achieved, this may be all right, but still a single ship deviating from the assumed manoeuvres may change the situation to a hazardous direction.

5.2.9 DISCUSSION

A general conclusion drawn from the above examples is that the hazards of the winter navigation and the effects involved may have influence on the probability (or causal factors) of an accident, on the accident process itself, and on the possibilities for evacuation and rescue operations. A list of key words related to the hazards of winter navigation was prepared, see Table 12. The contents of this table is mainly related to environmental factors typical for winter navigation. Thus, all other typical accident causes, such as those related to the following categories:

- Ship design and the location of equipment onboard
- Technical failures in ship equipment
- Issues related to the operation and placement of equipment onboard
- Issues related to the cargo/fuel and cargo/fuel handling equipment
- Issues related to communication, organisation, operational instructions and routines
- Human factors, awareness & assessment of situation, etc.

are not included in Table 12. However, the topics that are presented on the above list are also very important. Therefore, a table including issues under these topics is presented in Appendix 3. An icebreaker assisting a merchant vessel can hardly help it without good communication and mutual understanding between the operators on both ships. For ships passing by in a narrow channel these matters are as important. In the latter case it is of course important also to be aware of the ship's manoeuvring characteristics.

The accidents in winter navigation may include almost any combination of the presented topics as initiating events or contributing factors. However, it has to be admitted that there may still be also some areas that are not thoroughly covered here. Due to the structure of this work, the identified hazards are not necessarily in balance concerning the different issues and phases of the accident process[42]. The accident and incident cases presented above are mainly connected to the causative factors of separate accident scenarios. However, issues connected to the emergency situation itself, procedures and arrangements related to the evacuation, escape and rescue in ice conditions have not been thoroughly handled in this report.

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[42] These are: Causes & contributing factors – Physical process of the accident - Consequences

Table 12   List of key words, initiating events, problems or deviations related to winter navigation hazards (Note! these are mainly related to environmental factors)

Ice
=> Difficulties in keeping the ship moving, speed loss, unexpected loss of speed
=> Difficulties in manoeuvring, unexpected motions of the ship, unexpected restrictions of movements
=> Deviations from the originally planned route
=> Ice impacts due to ship speed & ship motion
=> Noise & vibrations increase
=> Increased time needed for voyage, taking pilot, berthing
=> Increased time and restrictions to rescue units arrival on accident site
=> Difficulties in finding objects or substances (oil) that are below ice cover or under ice floe(s)
=> Difficulties to find shoreline from radar based information
=> Abrasive effects on ship hull painting => increased rate of rusting

Drifting ice
=> Damage or other effects (e.g. change of location) to the aids to navigation
=> Compressive ice: ice loads due to ice movement & pressure
=> Ship stuck in ice / Ship movement with ice
=> Anchoring not possible due to
=> Movement of newly broken channel / old channel from its original location
=> Ice accumulation on the side of the ship, on the deck

Ice blocks, ice floes
=> Extra echoes on radar screen
=> Ice blocks below the ship bottom
=> Echo depth sounder may not work properly
=> Ice block jammed in front of the propeller or between hull appendages
=> Ice in the sea-water intake for machinery cooling system, fire main
=> Ice in the transverse thruster tunnel
=> Ice loads on the propeller
=> Ice loads on the rudder and other appendages
=> Stones from sea bottom sticking fast to ice blocks in shallow water

Snow
=> Difficulties with visual observations
=> Difficulties with radar based information
=> Makes the channel more heavy to navigate

Low temperature
=> All effects of low temperature (e.g. => -35°C in the Gulf of Finland)
=> All effects of temperature changes and temperature differencies
=> Effects on materials: thermal strains, brittleness, thermal expansion
=> Effects on oil viscosity: effects on fuel oil, hydraulic oil, lubricating oil
=> Moisture condensing and/or freezing on cold surfaces
=> Freezing of cargo, deck equipment etc.
=> Difficulties with battery operated devices
=> Hypothermia

Spray ice, icing
=> Difficulties with visual observations (frozen windows on bridge)
=> Weight increase in the upper structures, draught increase, loss of freeboard
=> Deteriorating of ship stability, listing
=> Ice on outer decks and other surfaces, clogged deck drainage pipes, ice on deck equipment, frozen life saving equipment (lifeboats, davits etc.)

Others
=> Darkness
=> Sea smoke from broken channel and other areas of open water
=> Occupational safety matters onboard: equipment & effects on crew members

The evacuation and rescue of people from a ship in hazardous condition can be a big problem in some ice conditions, generally in cold temperature and darkness. It is also difficult in such conditions, when icing is heavy or there is a high concentration of ice drifting in the area. The regulatory life saving appliances of today are generally all designed for ice free conditions and there is not so much experience accumulated from their use in more demanding environmental conditions. A few cases, representing large scale evacuations in ice or cold weather conditions do exist, see e.g. Figure 65 and (OM 1994), but due to the otherwise favourable weather conditions not all of these cases give us valuable direct information concerning the real problems occuring, when the environmental and other conditions are more difficult. Icing of the life-saving equipment, see Figure 64, is just one of the problems, which may be encountered.

Figure 64   Ice on the decks of the ship, lifeboat and davits may seriously hamper the evacuation in case of an accident (photo: Paul Hoffmeyer).

This theme of ship evacuation in ice covered waters is too wide and complicated to be adequately discussed here. Some points of view on the evacuation systems and appliances to be used in ships in ice-covered waters, e.g. a remark concerning the use of a freefall lifeboat in ice covered sea (see an example of that in Figure 79), have been presented in (Jalonen et al 1999). A more recent Canadian overview of evacuation systems for structures in ice-covered waters has been presented in (Wright et al 2003). When applied to the scope of this study, the latter is a valuable, informative and useful reference concerning this topic.

a)   b)
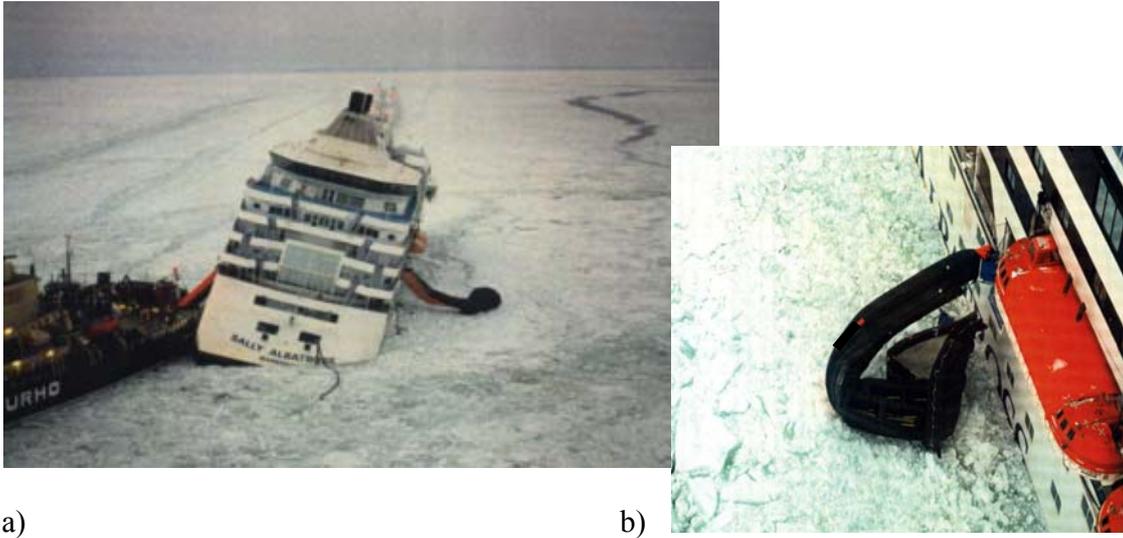
Figure 65   a) Evacuation of about 1200 persons from M/S Sally Albatross was per-
              formed after a grounding accident in winter 1993-94 with the help of IB
              Urho and some other vessels not visible in this figure.[43] b) The bending/
              twisting of the MES's[44] slide on the starboard side of the vessel prevented
              its use in the prevailing ice conditions[45] (photos: OM 1994).

Other interesting areas of issues are the material properties of ship structures and
equipment in cold temperature, such as 0°C - -35°C. Steel structures may develop cracks
more easily when they are loaded in extreme temperatures if the steel alloy has not been
selected with the sufficient range of temperature in mind.

Firefighting may be a serious problem in such low temperature conditions, e.g. if there is
frozen water in the fire mains or if water used for firefighting freezes on the decks and
outfitting. It may seriously deteriorate the stability of the ship, if large quantities of water
remains on the decks due to the freezing of the scuppers, see Figure 61. Cargo or cargo
handling related damage and accidents may also occur due to low temperature. Some of
the topics related to this matter are dealt shortly in (Gard 2001).

Hazards may be complicated due to several links between contributing accident factors.
Disasters include usually a chain of accidents/events. A fire may ignite in a collision.

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[43]   The conditions for this operation were favourable due to the good weather conditions, day-light and
       stable ice condition (without ice drift).
[44]   MES = Marine Evacuation System
[45]   Note! In the accident of Sally Albatross in 4.3.1994 the lifeboats of the ship were not used, so no
       experience of their use in this kind of ice conditions was obtained. A freefall lifeboat onboard, which is
       quite frequent in several modern cargo ships, would probably be dangerous in a situation like this, so an
       alternative means for evacuation would be needed. In this type of ice condition around the ship, broken
       ice with small ice blocks and floes, evacuation of a large number of people on the ice field surrounding
       the ship would probably have been dangerous, almost impossible. If the ship can be moved in level ice
       and the people onboard can get safely down on it, the evacuation might be possible. However, the
       problems in a rescue operation would be very difficult, its success depending on many other factors.

Containers may fall in the sea, where they bring up further hazards to navigation and the environment. In the latter case new problems will be brought up, if the fallen containers stay partly submerged at the water surface but are perhaps not clearly visible due to ice.

5.3 WINTER NAVIGATION HAZARDS IDENTIFIED BY AN EXPERT GROUP

The identification of the hazards related to winter navigation has been conducted also using a brainstorming expert group session method, see (Juva 2002, VTT 2002). In this hazard identification process the hazards of winter traffic in the Gulf of Finland were identified in one brainstorming group session. Eight selected experts from Finland were used as consults in the session. These experts, representing various stakeholders in shipping and its infrastructure, including authorities and shipping companies, are listed in the appendix 1 of reference (VTT 2002).

In the brainstorming session the biggest hazards in relation to winter navigation in the Gulf of Finland were considered to be the issues presented in Table 13 which is adopted from Juva (2002). This list has been constructed and arranged according to the discussions carried out by the participating experts of the brainstorming session. Some of the issues that were pointed out in the brainstorming session have been combined to reduce overlapping. Therefore, the order in the list may not be absolute but at least indicative.

The list which is presented in Table 13 is based on the comments recorded in the brainstorming session. Thus, it must be kept in mind that the results reflect the opinions of the participants. The prioritisation takes into account both the frequency and the consequences of the accident scenarios. However, the connection between these two dimensions of risk should be considered as subjective (Juva 2002).

Table 13   Prioritised list of hazards in relation to winter navigation in the Gulf of Finland (VTT 2002 and Juva 2002). These numbered issues (1-15) are explained in more detail later in the text.

1   Heavily increasing tanker traffic
2   Increasing traffic volumes between Helsinki and Tallinn
3   Single bottom tankers
4   Rescue operations in heavy ice conditions
5   Vessels unable to give way according to regulations because of heavy ice conditions
6   Oil combatting measures in ice conditions
7   Crews which are unfamiliar with ice conditions or inexperienced in winter navigation
8   Lack of escort towing
9   Getting stuck in compressive ice
10   Occasional disruptions in icebreaker activities
11   Problems in radio communication
12   Navigation errors, which happen when trying to avoid difficult ice conditions
13   Lack of routing system in ice conditions
14   Cold weather, rapidly changing ice conditions
15   Icing

1. **The heavily increasing tanker traffic** was considered to be the biggest risk in winter navigation in the Gulf of Finland. The biggest fear is that the traffic is handled with tankers that have inadequate ice strengthening and engine power compared to the ice conditions. When this is combined with a large tanker size, ridging and drifting ice field, and narrow and shallow fairways, the risk of a massive oil disaster becomes high. The possibility of inadequate icebreaker assistance still increases the risks of grounding, sinking, ice damages and oil spills.

   Accident scenarios: A powered grounding or a drift grounding of a large crude oil tanker due to ice conditions. Consequence: an oil spill from one cargo tank.

2. **The increasing traffic volumes between Helsinki and Tallinn** were considered hazardous. This traffic is heavy also during the winters even though the fast passenger vessels do not operate in ice. The ice conditions on the other hand make the avoidance manoeuvres slow, difficult and sometimes even impossible. Also, if the give-way vessel is in lighter ice conditions it may not be willing to give way and loose the benefit of the lighter ice conditions. When taking into account the east-west traffic the risk of collision becomes high. If the traffic volumes keep increasing, also the collision risk increases. The worst case scenario would be a collision between a tanker and a passenger vessel which, in the worst case, could have massive consequences like fire, hundreds of lives lost and a massive oil disaster.

   Simplified accident scenarios: A collision between two ships on the Helsinki-Tallinn route. The collision occurs between a cargo ship and a tanker, between two cargo ships or a tanker and a passenger vessel so, that both ships catch fire. Accident cause: insufficient manoeuvres to avoid collision in ice conditions.

3. **The use of single bottom tankers** was considered to be another significant risk. At the moment only 20 % of the world's tanker capacity is double hulled. The single bottom increases the consequences of even smaller accidents. Also, the single hulled tanker fleet is often quite old and this increases the risk of spill accidents.

   Simplified accident scenarios: Grounding. A tanker without double bottom or double hull.

4. **Delays of rescue operations** due to heavy ice conditions were also found to be an important risk factor. In case of an accident, the rescue units might have difficulties to reach the accident site fast enough, or maybe even at all. This could delay the rescue operations and the consequences could escalate into a disaster. Ice slows down evacuation, fire-fighting and oil combatting. In addition, the lifeboats and liferafts are designed for open water use. Ice cover itself doesn't prevent air rescue operations but normal winter conditions like snowstorm, winds and freezing can do so.

   A simplified accident scenario: The development of an accident reaches a critical condition, when evacuation of the ship, extra capacity for firefighting or some other

extraordinary rescue operation is required. Accident escalation occurs due to the slow mobilization and arrival of the rescue units on the scene due to difficult ice/weather conditions.

5. **The vessels that are unable to give way** according to the regulations because of heavy ice conditions are also found to create a hazard. This can happen in passing situations in channels or at crossing routes. If the give-way vessel is unable to give way as expected according to the regulations, the collision risk increases. Factors such as overestimating own icegoing capacity, underestimating the severity of the ice conditions, insufficient machine power, inadequate communication between closing vessels, and crew inexperience in ice navigation can lead into this kind of situation.

   A simplified accident scenario: Two ships in the same ice channel are approaching each other from the opposite directions or in connection with an overtaking manoeuvre. A collision occurs because ice conditions prevent or retard normal evasive actions.

6. **The ineffectiveness of oil spill combating measures** in ice conditions also creates a obvious hazard. In case of an oil spill in ice, there are no means available to collect more than small amounts of the oil from the water or to prevent the oil from spreading with the ice. Therefore, oil spills in ice may have significant environmental effects.

   This risk was not assessed by the use of a risk matrix in (Juva 2002).

7. **Inexperience with ice** of foreign crews or visitors, or even Finnish crews without adequate experience in winter navigation increase the risk of all types of accidents because without experience it is difficult to take into account the special features and needs of ice navigation. Negligence and wrong attitudes may be one background factor related to this potential problem.

   This risk was not assessed by the use of a risk matrix in (Juva 2002).

8. **Lack of escort towing.** The fact that, at the moment, escort towing is not applied to all tankers in the Gulf of Finland was also seen as a concern. The tugs are too few and too weak compared to the traffic volumes and the size of the tankers operating in the gulf. When taking into account also the fact that the ice conditions are difficult every winter and the fairways are rocky and shallow, the grounding risk increases significantly if escort towing is not applied properly.

   Simplified accident scenarios: Grounding due to insufficient escort assistance. Minor damage or major damage.

9. **Getting stuck in compressive ice or in an drifting ice field** was also seen as a hazard. After getting stuck the vessel might suffer ice damage in compressive ice or might drift to rocks with the moving ice. It is important to prevent vessels from

getting stuck or to get help quickly if it happens. Adequate ice class and engine power are the means to prevent vessels from getting stuck. Adequate icebreaker assistance combined with adequate hull strength prevents damages if a vessel, for some reason, does get stuck.

Simplified accident scenarios: A ship is beset in ice. Hull ice damage due to compressive ice. Minor damage or major damage. Drift grounding due to ice drift.

10. **Occasional disruptions in the icebreaker activities** in the whole Gulf of Finland area are seen to be hazardous. The present winter navigation system causes waiting times in ice and assistance is given based on the need. Therefore some vessels are bound to attempt to proceed independently in ice conditions in order to avoid long waiting times and financial losses. These factors increase the risk of ice damages and groundings.

    Simplified accident scenarios: Ice damage due to insufficient icebreaker assistance. Grounding due to insufficient icebreaker assistance.

11. **Problems in radio communication** cause several problems. Lack of radio communication, excess of communication (disturbance) and language problems are known problems. Finnish icebreakers have complained that there are no free VHF channels for their use during wintertime because of the excessive radio traffic. Language problems also cause misunderstandings. There should be strict rules for the use of VHF channels and English should be the only language used in radio traffic in the whole Gulf of Finland area without exceptions.

    Simplified accident scenarios: A collision between icebreaker and assisted cargo ship due to insufficient communication. Grounding due to insufficient assistance from VTS.

12. **Navigation errors,** which happen when trying to avoid difficult ice conditions, increase the risk of groundings. Searching the easiest routes through ice often leads to unusual selections of course and other manoeuvres. If the navigator is not up to his task the possibility of navigation error increases. Navigation error may also be caused by technical or logical errors in navigation equipment, lack of education, defective co-operation on bridge, etc.

    A simplified accident scenario: A grounding due to an error in navigation. Accident cause: avoidance of ice formations. Oil spill from fuel tank..

13. **The lack of the routing system in ice** was also considered to increase the collision and grounding risks. Icebreakers control the traffic in ice conditions and if all instructions are followed the situation is under control, but the system requires adequate communication and experience in winter navigation. Also, in wintertime navigation the opposite traffic flows are not separated from each other. Vessels try to find the easiest routes through the ice cover and therefore manoeuvring and

navigation differs from the open water season. Inexperience in these conditions increases the risk of groundings and collisions.

Simplified accident scenarios: A grounding or collision due to the wintertime non-existence of traffic separation scheme.

14. Cold weather creates a hazard by increasing the amount of ice and changing the ice conditions rapidly. The vessels run into ice earlier than presumed or the ice conditions are more severe. Also, cold weather can cause malfunctions in equipment which are not specifically designed for operation in low temperatures. Improving the ice information and the distribution of this information would increase safety.

Simplified accident scenarios: A ship proceeds and enters into ice (impact with ice) with full (open water) speed. Hull ice damage in ship bow. Minor damage or major damage.

15. Icing of the structures reduces vessel stability and can even lead to capsizing. Icing is a natural phenomenon which can not be avoided by rules, but with proper measures it can be avoided or controlled and the consequences reduced. Changing the course and speed and also starting the removal of ice early enough should be adequate counter-measures. Inexperience in icing and lack of knowledge of the countermeasures in-creases the risk significantly.

Simplified accident scenarios: A dangerous list angle develops due to heavy icing, the ship founders due to heavy icing.

Not all possible winter navigation hazards are included in the list above. Only the top fifteen hazards considered most significant in (Juva 2002) were selected on it. Several more hazards were mentioned in the brainstorming session. They have all been collected into fault trees constructed and presented in (Juva 2002).

Fault trees were constructed based on the expert opinions expressed in the brainstorming session and relevant accident statistics. Separate fault trees were constructed for different accident categories (grounding, collision, ice damage and icing). The accident fault trees were meant to be general and cover all possible accident scenarios. Their purpose was to visualise the accident scenarios, the factors influencing them, and mutual connections between them. The material and comments from the brainstorming session regarding the different factors are summarised under the fault trees and are fully listed in (Juva 2002).

Examples of such fault trees, related to hull ice damage, and other ice related accidents/ incidents are presented in Appendix 4. It should be strongly emphasized, that the structure of the simple models of various accident/incident types in Appendix 4, and the numerical values of probability/frequency of basic events included in them, are given just as examples, which are a subject to further discussion among the experts of winter navigation and other relevant stakeholders. After a throughout discussion it should be possible to establish an acceptable structure and contents for this kind of accident model.

Then, conclusions and recommendations based on their future use can be recommended. This does not mean that the probability of each initial event would be just a matter of voting. Reliable statistics are prefered and should be used whenever available and reasonable to be used. On the other hand scientific modelling based on first principles should be given precedence. If not readily available such tools should be developed. In reality, more practical approaches for risk assessments are also used.

Realistic accident/incident models of winter navigation are more complicated than the fault tree models in Appendix 4. The lack of consequence modelling is the most obvious deficiency. However, the presented models can serve in the role of awakening discussion concerning the development of better models that could be used in the future. In order to be able to model the consequences, physical damage models are also needed.

6 RISK ASSESSMENT

6.1 GENERAL METHODS

Risk can be assessed qualitatively and quantitatively. In these two cases the assessment can be based on various methods. The risks can be assessed in a qualitative way, e.g. in an expert meeting, where both the probability and the degree of the consequences of the corresponding risk are assessed individually based on the experience and understanding of the experts. The result of the risk assessment can be presented using a risk matrix, see Figure 66. In the qualitative risk assessment the two dimensions of the risk matrix, the frequency (or the probability) and the severity of the consequences are expressed by verbal means. In quantitative risk assesment the verbal scales of risk matrix are changed to numerical ones.

Frequency:				High risk
Often				
Sometimes				
Seldom				
Very seldom	Low risk			
Consequence:	Insignificant	Moderate	Remarkable	Catastrophical

Figure 66   An example of a qualitative risk matrix

When the risk is determined quantitatively, it should be done by combining the numerically assessed frequency (or probability) and consequence. The risk is often expressed as the product of the likelihood (of an undesired occasion at the end of an event tree) and the negative consequences connected to it. The probability of an accident is usually expressed as the number of potential accidents per a certain time period, e.g. one case per ten or hundred years. However, in the case of a very low probability, say 0.000 001, it may sometimes be more convenient to use more familiar figures or units to make the risk communication more understandable. If necessary, in such cases the risk might be expressed as the risk for a whole fleet of vessels.

On the other hand, if the probability is much higher, e.g. several times per one year it is usually easier to understand. When analysing accident or incident statistics we speak of frequency, but when making assessments concerning future, we should always use the word probability. Thus, if there has not occured a single accident of a certain type in a

certain time period, this does not mean that the probability of such an accident would be zero. Although the frequency of such an accident in the period of observation may be nil, the probability may have a higher value.

In some cases the probability of an accident and its consequences can be assessed by using values of accident frequency based on statistics. In this study this kind of approach is used. However, there is also a more scientific way to proceed. It starts by developing first the accident model, continues then by the assessment of the probability of the initiating events, and, finally, by calculating the outcome. In the last phase, physical and mathematical models are prefered. However, the latter method may need a lot of time to be used, as the required models may not be readily available.

The consequences of an accident can be loss of life, damage to the environment and material damage, leading to repair costs or loss of property, as depicted below in Figure 67. In the case of risk analysis the loss of life is not sure, it is always potential.

Risk = Probability × Consequences
{ Loss of life
Environmental damage
Material damage & Loss of property }
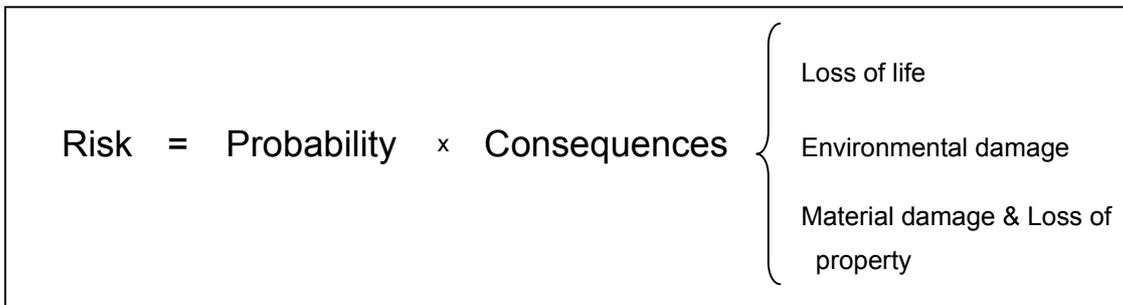
Figure 67   The definition of risk applied in this study

6.2   ACCIDENTS AND THEIR FREQUENCY IN WINTER NAVIGATION

A traditional approach to assess the risks of winter navigation is to limit the scope of assessment to ice damages, which are damages to ship hull, propeller(s) and rudder(s). These kind of damage assessments have been reported e.g. in (Thomson 1925, Johansson 1967, Sjöstedt & Hammarsten 1973, Kujala 1991, Kubat & Timco 2003 and Hänninen 2004). However, winter navigation influence maritime risks on a much wider spectrum than the scope of pure ice loads. There are several factors, like low temperature, ice, snow, icing, darkness and low visibility, that make winter navigation risky. Therefore, in this study, at the phase of hazard identification, a holistic view on the risk was applied.

A division of marine accidents from periods January-April and May-December is made in Figure 68. This data, which is based on a past extract from the DAMA-database for marine accidents in Finland in 1990-1997, includes accidents in all sea areas (Gulf of Finland – Bay of Bothnia). A limitation of this data is that it is restricted only to those cases, which have been reported to the maritime authorities in Finland.

According to this accident statistics, grounding is the most frequent accident. This statistics supported also the common belief that collisions in Finnish waters occur more

frequently in winter period than in the other, practically ice free season. According to these data the collision frequency has been about 4-5 cases per year and the grounding frequency about 9-10 cases per year in the rather mild winter periods January-April of 1990-1997. Grounding in dense snowfall and collision between an icebreaker and the ship it is assisting, seem to be the most common accidents in wintertime.
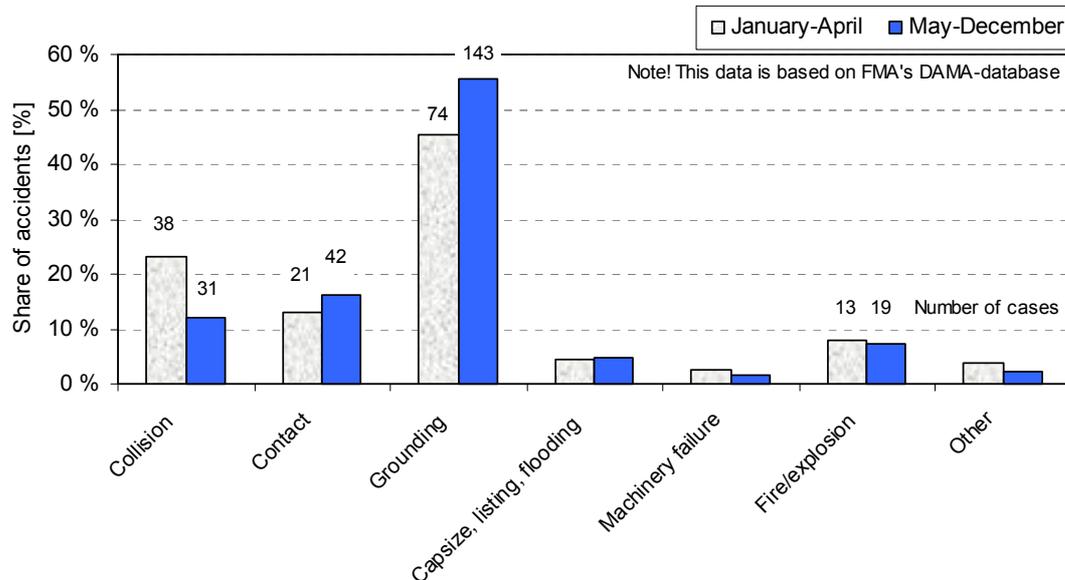
Figure 68   Distribution of the frequency of various marine accidents in winter / other seasons in Finnish waters (source of data: DAMA database Finland, January 1990 - May 1997).

In the yearbooks of the Finnish Board of Navigation (FMA 1971-1990) statistical information of the number of marine accidents caused by various reasons are given. According to this statistical information the number of marine accidents has varied between 1-16 per winter. Similarly, in the marine accident database DAMA, maintained by FMA, the accident cases related to ice, snow etc. by cause (or other information) can be picked up. This kind of selective process was performed for years 1991-2003. The results are presented in Figure 69 with the older data. It should be noticed, however, that there is almost a complete non-existence of hull ice damage cases in the DAMA-database. For some reason, minor hull ice damages, such as dents on the hull etc. are not included in DAMA. Therefore, the marine accidents represented in Figure 69 consist mainly of collisions, propeller damage and groundings, which are closely related to the prevailing environmental conditions of the site and time of accident.

In a mild winter, when the ice cover is limited, say to Bothnian Bay, only a limited number of ships operating in that particular area of Baltic Sea are exposed to the ice conditions. When the winter is harder and consequently the area covered by ice is larger, more ships will be exposed to the hazards of ice. In this case it is rather straightforward to assume that the frequency of ice related accident/incident cases is related to the severity of the winter. This relation is confirmed in Figure 69. The number of ice related

accidents seem to be somehow related to the maximum extent of ice cover, although the correlation is not strong, nor is it linear, and the deviations can be great. The extent of ice cover is one of the main parameters when the severity of the winter is assessed.
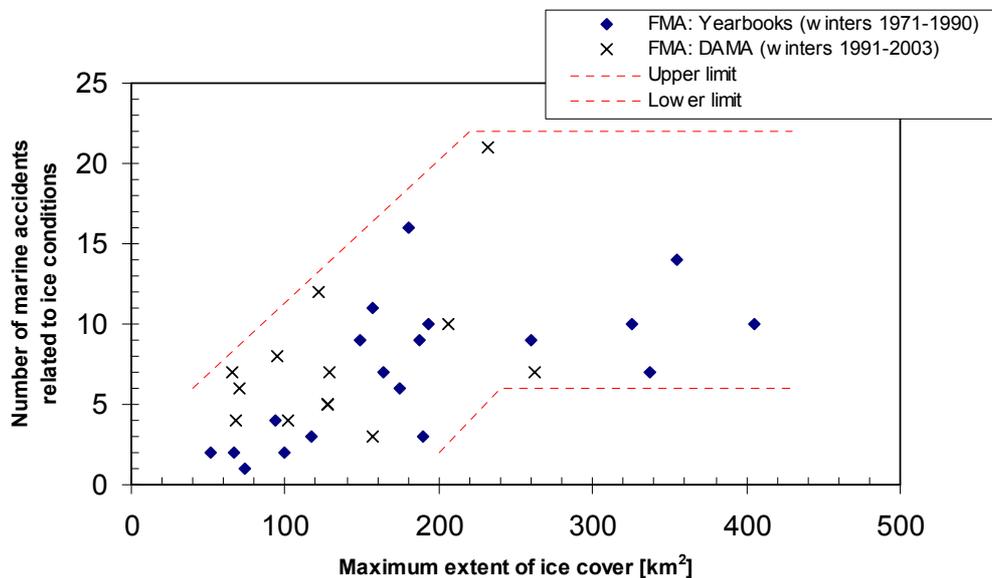
Figure 69 The number of marine accidents caused by severe ice conditions or otherwise connected to the environmental conditions of winter in Finnish waters vs. the maximum extent of ice cover in the Baltic Sea in years 1971-1990 (source: (FMA 1971-1990)) and in years 1991-2003 (source: FMA/ DAMA database). Note! Hull ice damage cases are not included in either series.

Some general conclusions may be drawn from Figure 69. When the area of maximum extent of ice cover in the Baltic Sea is below 120 000 km^2, the number of ice related marine accidents is rather low (< 8). However, when the area of ice cover exceeds about 140 000 km^2, the number of ice related marine accidents seems to have a clearly higher mean value. It can be also noticed that in the latter case the deviations are great. Different criteria may explain the higher number of cases in mild winters in years 1991-2003, when compared to the 1971-1990 data. The difference in the data of these two time periods may also be caused by some unknown factor.

In reality, the absolute value of the total number of accidents related to ice conditions is clearly higher than the number of reported and registered accident cases in the DAMA-database statistics of the Finnish Maritime Administration. The smallest hull damages, if we can use the word "damage" of the smallest permanent deformations, may not always be noticed by the operator of the ship. Even if some slight ice related damage is noticed, information concerning each case may not always be delivered to the authorities. Another problem comes from the timing of ship visits in drydock. Ice damage may be revealed some years after its formation. The hull ice damages on a ship in a drydock do not reveal the date of their formation. Thus, the result may be a cumulative damage. However, the

ship's crew usually has useful information concerning the probable date(s) of the incidents/accidents, which may have caused the deformations.

The Ship Laboratory of HUT collected data from ice related incidents in the winter 2003. In this study ice related accident/incident information was collected straight from the shipowners and shipping companies (in addition to the authorities). The total number of accident/incident cases surpassed much the number of cases in winter 2002-2003 in Figure 69. Based on the experience from winter 2002-2003 it may be concluded, that the total number of ice related accidents/incidents may be about 4-5 times higher than the number of accidents/incidents presented in Figure 69.

The above finding reveals one of the main problem from the risk analysis point of view: how to get a sufficient and reliable coverage for the accident/incident statistics, when all the information is distributed on a wide, international scope of flag states, classification companies, insurance companies, shipping companies, ships and crew members. The only way to get such a statistics is to continue efforts to collect data from the listed quarters. In addition to the marine accident database DAMA, a working database for marine incidents, which has been suggested e.g. in (Soininen 1999 or Nyman & Soininen 2000) would certainly help in gathering such information. Unfortunately, the establishment of such a system has not yet been realized in Finland.

6.3   ICE DAMAGE RISK ASSESSMENT: Frequency

This risk assessment is based partly on the previous experience. Therefore it is useful to take a look at relevant data. In the winter 2003 information regarding ice related incidents and accidents were gathered by Hänninen (2004). A summary of the corresponding accident incident data separated according to the type of accident/incident is given in Appendix 5. Main part of this accident data is related to the traffic information regarding ships arrivals in Finnish, Estonian and Russian ports, which is estimated to be around 19 000 in the ice-season (2002-2003).

Rough estimates of the distance in ice to the main ports (and back to the edge of the ice covered area) and the thickness of level ice along the routes to these ports were made as average values for the whole winter. In the case of the traffic to Finland Russia and Estonia, the average distance from ice edge to port and back to ice edge was estimated to be about 161 nautical miles, when weighted with the number of port visits for the December-April period. By applying a similar weighting to the level ice thickness along the assumed ship routes, an average value of about 0.33 m was obtained[46]. Thus, the following relative accident/incident frequencies, see Table 14, were obtained. The

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[46] Note! In the case of ship arrivals to and departures from the ports of Finland in January-April 2003 the average distance from ice edge to port and back was estimated to be about 127 nautical miles and the average ice thickness about 0.3 m. Here it is assumed that the ships arrive to the port from the edge of the ice covered area and when leaving they are assumed to proceed back to the edge of the ice covered area.

calculation of the accident/incident or damage frequency, e.g. in the case of collision accidents/incidents is performed as follows:

20 collisions / (19 000 arrivals × 161 nautical miles × 0.33 m) = 20×10^{-6} (cases / (nm × m))

Table 14   Ice related accident/incident rates [47] of cargo and passenger vessels divided in different accident/incident types in winter 2002-2003. The number of cases may differ from those presented in Appendix 5 because of slightly different selection criteria.

Accident/incident type	Number of cases	Frequency	(cases / (distance * H_{ice}))
Hull ice damage	20	20×10^{-6}	(cases / (nm × m)) [48]
- frame damage	*3*	*3×10^{-6}*	*(cases / (nm × m)) [49]*
- fracture or rupture	*5*	*6×10^{-6}*	*(cases / (nm × m)) [49]*
Collisions	19	19×10^{-6}	(cases / (nm × m)) [50]
Groundings	2	2×10^{-6}	(cases / (nm × m)) [51]
Propeller damage	29	29×10^{-6}	(cases / (nm × m))
Rudder damage	8	8×10^{-6}	(cases / (nm × m))
Machinery malfunction/damage	2	2×10^{-6}	(cases / (nm × m)) [52]
Other	2	2×10^{-6}	(cases / (nm × m))
Total	82	82×10^{-6}	(cases / (nm × m)) [53]

According to Hänninen (2004) roughly 10 % of all the ships visiting Finnish ports in winter 2002-2003 had some sort of ice related damage. It should be emphasized that these damages include almost all classes of damage severity, but most of the cases were just minor damage. All of the vessels with fractures and ruptures were more than 20 years old, except one about 15 year old ship in ice class IB.

It should be emphasized that the frequencies or accident rates above are indicative only. The real accident/incident frequencies may be higher than those presented in Table 14 above due to the fact that all cases regarding to ships operated in the northern Baltic Sea in winter 2002-2003 may not have been included in this study. This database of 85

[47] Note! The calculated frequencies are very rough and indicative estimates, they are calculated for just one specific year and for one generic ship, which is representing the average vessel of the whole traffic. The accident frequency is calculated by dividing the number of cases by the product of number of voyages, average distances travelled in ice and the average ice thickness. It should be stressed that the category hull ice damage includes a large variety of ice damages from small dents to a bit larger ares of goffering and also some cases with cracks and ruptures.

[48] Note! Three (3) merchant ships with both propeller damage and hull ice damage are also included here. However, three vessels with cumulative damage from a long period of time and/or with operations in the Arctic, see (Hänninen 2004), were left out of Appendix 5 as well as from this analysis.

[49] Note! These cases are included in the number of "Hull ice damage" above.

[50] Note! Three collision accidents/incidents between and icebreaker and a cargo ship in Sweden are not included in the calculation of the collision frequency due to the lack of corresponding traffic data.

[51] Note! One (1) of these two groundings is included in the group "Hull ice damage" in Appendix 5.

[52] Note! One (1) vessel is not included here due to the ship age, which was over 90 years.

[53] The total number of accident/incident cases with some damage presented here differs from the summary table in Appendix 5 due to the slightly different principles applied when selecting these cases.

accidents/incidents and damages of cargo and passenger vessels and 17 cases of other ships may be too small for giving a sufficient basis for drawing reliable conclusions about the quantitative level of risk. Therefore, it is recommended to continue the collection of data of ice related accidents and incidents in the future to form a more solid base for risk assessment. In the meantime the results of this analysis can be used with caution.

From the ice damage database presented by Kujala (1991), we can obtain the following information:

- 61 ship database
- 28 ships in ice class IA Super (46 %)
- 31 ships in ice class IA (54 %)
- 2 ships in ice class IC
- 4 years period of observations (including years 1984-1987)
- 321 km^2 maximum extent of ice cover (= average value for years 1984-1987)
- Data concerning the 59 vessels in ice class IA Super or IA:
  -- 1072 voyages[54] per winter => 18 voyages in winter / ship
  -- 30 hull ice damages, 6 rudder damages and 5 propeller damages

This data is used in this risk analysis for support and comparisons when assessing the frequency and consequences of some ice related accidents/incidents.

The number of port visits, consisting of ship arrivals and departures, is used as a reference when calculating the accident frequency as already shown before. The number of port visits is based on the statistics concerning ship arrivals and departures in Finnish ports during the period of traffic restrictions in those ports. This data, which is based on the traffic statistics of FMA (FMA, 2004e) was presented in Table 5.

In some cases the data for all winters 1982-2003 is used. The ice damage statistics that is presented by Kujala (1991) is from four winters 1984-1987. Corresponding figures for these cases can be found in the bottom of Table 5. The accident/incident statistics presented by Hänninen (2004) is just from one winter, 2003. In some cases all relevant accident and incident data of the latter database are used. In such cases the corresponding (estimated) number of port visits is 19 000. This value is not included in Table 5, because it is based on different traffic data limited to certain winter months, January-April, and it is extended to ports outside the borders of Finland (e.g. Tallinn and St. Petersburg), see Table 3. However, if the accident and incident data is limited to such cases that took place in the Finnish waters in winter 2003, the corresponding number of port visits during the time of traffic restrictions can be found from Table 5.

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[54] It should be noted here, that in (Kujala 1991) the number of voyages is expressed as the number of visits to port. Therefore, the distance travelled in ice per one visit is two times the distance from port to the ice edge measured along the route of the ship.

6.3.1 HULL ICE DAMAGE RISK ASSESSMENT: Frequency

<u>Winter 2003</u>

The hull ice damage frequency based on the winter 2002-2003 statistics, see (Hänninen 2004) was presented in Table 14 above. Its numerical value which is valid for a generic[55] cargo or passenger ship in winter navigation is:

Generic ship: 20 hull ice damages / (19 000 port visits × 161 nm × 0.33 m) =

$$\underline{20 \times 10^{-6} \text{ hull ice damage cases} / (\text{nm} \times \text{m})}$$

By making the corresponding selections and assumptions for the hull ice damage data from winter 2002-2003 the following frequencies are obtained:

Ice class categories IA Super & IA [56]*:*

11 hull ice damages / (0.85 × 19 000 port visits × 161 nm × 0.33 m) =

$$\underline{13 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$$

Based on a rather short and rough comparison of the hull damages in ships of different ice class categories it was deduced by Hänninen (2004) that the hull ice damage frequency of ships in ice classes IC or II (= no strengthening) is about nine times higher than that of ships in ice classes IA Super or IA. If the number of the remaining hull ice damage cases of cargo (and passenger) ships in the ice classes lower than IA and IASuper is used the following estimate of the hull ice damage frequency is obtained:

Ice class categories IB, IC and II:

9 hull ice damages / (0.15 × 19 000 port visits × 161 nm × 0.33 m) =

$$59 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m}) = \quad \underline{60 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$$

However, it should be stressed that for the lowest ice classes the damage frequency may be even higher. Using the figures of the two lowest ice classes[52] we get:

Ice class categories IC and II:

6 hull ice damages / (0.04 × 19 000 port visits × 161 nm × 0.33 m) =

$$149 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m}) = \quad \underline{150 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$$

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[55] A generic ship is a hypothetical ship representing the relevant distribution of all the merchant ships and ship types in traffic in the sea area including all ice class categories.

[56] It is assumed here that the proportions of the ships in different ice class categories, which was presented in (Hänninen 2004) is valid: a) IA Super & IA ~ 85 %, b) IB, IC & II ~ 15 %, c) IC & II ~ 4 %.

Thus, the comparison of the hull ice damage frequencies above suggests that the damage frequency of the lower ice class vessels in ice class categories *IB, IC and II* is about four to five (59/13 = 4.5) times higher and in ice class categories *IC and II* more than ten (149/13 = 11.5) times higher than the corresponding value for vessels in ice classes IA Super and IA. However, it should be stressed here that it is not known precisely what are the proportions of different ice class vessels in the whole traffic. Another reason for uncertainty in this comparison is the possibility of unreported damage.

The hull ice damage frequencies for winter 2002-2003 calculated as above may under-estimate the effect of ice strengthening on the damage frequency due to the assumed pronounced relative representation of the ships in higher ice classes in the group of vessels making longer voyages in thicker ice. This is a natural consequence of the policy of traffic restrictions (see Appendix 1). Therefore, the real effect of the low ice class on the damage frequency is probably more significant than presented here. It should be reminded, too, that the result of this kind of a comparison is naturally specific to the nature and severity of the winter.

Winters 1984-1987

If we assume that the average ice thickness and the average length of a voyage in ice are both directly related to the maximum extent of ice cover[57] and that the distribution of ship arrivals in Finnish ports is similar in the winters 1984-87 and 2003, we can estimate the corresponding frequency of hull ice damages based on the data presented by Kujala (1991). Thus, the following rough estimate of the hull ice damage frequency for winters 1984-87 is obtained:

Ice class categories IA Super & IA:

30 hull ice damages / (4 winters × 1072 voyages/winter × 127 nm × 0.3 m × $(1.384)^2$) =

$$96 \times 10^{-6} \text{ cases } / (\text{ nm} \times \text{m})$$

The latter frequency is about sevenfold when compared to the former hull ice damage frequency which is based on the winter 2002-2003 data. One probable reason for this difference may be the possibility that all hull ice damage data is simply not reported in the latter data base, which should include precise and full information concerning a very large population of ships. The data from years 1984-87 (Kujala 1991) is based on a limited number of ships in one country. The damage frequency for winter 2002-2003 is based on a rough estimate of all ship arrivals in ports in the area in December-April. The estimated average length of the distance traveled in ice as well as the estimated average ice thickness along the routes of the vessels involved in the comparison may be one additional source of uncertainty.

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[57] Thus, the relationship between maximum extents of ice cover gives us the following correction factor: $(321 \text{ km}^2 / 232 \text{ km}^2) = 1.384$. When both the ice thickness and the extent of ice cover are taken into account, this correction factor has to be applied twice.

The winters 1985, 1986 and 1987 were generally colder than winter 2003. Thus, it can be assumed that the ice was thicker, the extent of ice cover larger and the ice conditions were probably more difficult during the former period than in winter 2003. It is uncertain if the relation between these parameters and the maximum extent of ice cover is linear. Several simplifications and differencies in the approach and other differencies in the data sets may explain some part of the difference in the calculated damage frequencies.

If the number of hull ice damage cases in Kujala (1991) is related to the number of ship arrivals during the period of traffic restrictions in winters 1984-1987 and the 85 % representation of vessels in these ice classes, see (Hänninen 2004), is still valid the following result is obtained:

Ice class categories IA Super & IA:

30 hull ice damages / (0.85 × 14 846 voyages in ice × 127 nm × 0.3 m × (1.384)^2) =

$$\underline{33 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$$

This latter frequency of hull ice damage is more close to the corresponding frequency for winter 2003 although it is still more than 50 % higher than the latter. So it is shown here that if the hull ice damage cases concerning merchant ships in ice classes IA and IASuper are selected and related to the assumed proportion of these ice class vessels visiting Finnish ports in the time period of traffic restrictions[58] a more solid base for a comparison is obtained. Due to the difference between the hull ice damage frequency in winters 1984-1987 and the corresponding frequency for winter 2003 it is recommended here that a range instead of a certain single value should be used.

Summary: Hull ice damage

As a summary of the above analysis it is conluded here that for a generic ship:

- An average frequency range of **20 × 10^{-6} - 33 × 10^{-6}** hull ice damage cases / (nm × m) may be used for the present (2002-2003) patterns of traffic and distributions of ice classes[59] in the northern Baltic Sea. It should be pointed out, however, that there are several factors of uncertainty affecting on the above frequency: e.g. ship design, structural design and operation.

- If the effects of different ice classes on the frequency of hull ice damage in the northern Baltic Sea are taken into account, the frequency range is much wider than presented above: **13 × 10^{-6} – 150 × 10^{-6}** hull ice damage cases / (nm × m).

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[58] The data concerning ship arrivals and departures in Finnish ports and the ice class distribution of these vessels in the time period of traffic restrictions is based on the statistics of the FMA.

[59] The following percentages of port arrivals of ships belonging to different ice classes (or equivalent) were recorded in Finland in winter 2002-2003 (Hänninen 2004): IA Super 32 %, IA 54 %, IB 11 %, IC 1 % and II 3 %.

Low values in the latter range are valid for a generic ship in ice classes IA Super and IA, whereas the higher end is valid for a generic ship in ice classes IC and II.

It should be taken into account also, that the ice conditions in various times and various parts of the Baltic Sea, e.g. in the Bothnian Bay and in the Gulf of Finland, differ a lot from each other. Therefore, the estimated frequencies above may be valid only for general purposes when considering the whole traffic during winter, not for a certain vessel on a certain voyage. Ships in the same ice class category may differ from each other as do their operators, and there may be many other factors having considerable influence on the damage frequency. Availability of icebreaker assistance should also taken into account when considering the above values of damage frequency more thoroughly. According to the damage data presented by Hänninen (2004) in three cases representing about 18 % of the hull ice damage cases of merchant ships the cause of the damage was ice compression.

Ice thickness has an effect on the ice loads on ship hull. This effect has been discussed e.g. by Kujala (1994) who suggests that e.g. the increase in ice resistance due to thicker ice leads to a slower ship speed thus changing the exponential relationship between ice thickness and ice impact load on ship hull, $F_{ice} \sim h_{ice}^{1.7}$, towards a more linear relationship in practice.

Calculation of more accurate estimates of hull ice damage frequency is possible. It is a tedious task, however, requiring more data than was collected and analysed in this study. Not all shipping companies with relevant ships operating in the area were included in the study of Hänninen (2004). The underreporting due to various reasons may also cause some bias to the results. Some part of the hull ice damage cases may not have been reported and some of them may have remained unnoticed. Therefore, more effort and resources should be used to gather data in co-operation with domestic and foreign shipping companies, maritime administrations, classification societies, insurance companies and ports to get more complete and precise information on the ships and their movements in ice, information concerning the ice conditions as well as detailed information of the hull ice damage. Common criterion for hull ice damage should also be agreed and established.

6.3.2 HULL ICE DAMAGE RISK ASSESSMENT: Consequences

In general, the consequences of the ice related accidents and incidents of winter 2003, which were reported in (Hänninen 2004), were not severe in general. However, without assistance service and extra pump capacity from icebreakers, one leaking cargo ship with hull ice damage might have been lost. The damage of this single vessel, which had no ice strengthening [60], represents about 4 % of all recorded cases. Fractures caused by ice damage were found in 6 merchant vessels, representing a share of 29 %, but most of them were in older ships, which were in bad repair. Frame damages were found in 3 vessels, which forms a share of 14 % of all hull ice damage cases.

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[60] See the description of this accident in Case 3 in the previous text

Structural damage / damage to the ship

It has been emphasized on several occasions that even the fulfilling of the requirements of the Finnish-Swedish ice class IA Super does not guarantee that the ship will remain intact in all possible environmental conditions in the Baltic Sea. About 53 % of the reported hull ice damage cases in merchant ships in winter 2002-2003 were found in ships belonging to ice class IA Super and IA.

In the older data from 1984-87, see (Kujala 1991), frame damage was found in about 16 % of the ships of ice class IA Super. The corresponding percentage in ice class IA was 23 %. Ice damage on plate was found in 26 % of the IA Super-ice class vessels and in 54 % of the IA-ice class vessels. No leaking ruptures were found among the ice damage cases of this older database.

Research during the previous years, see e.g. (Kujala 1994) has shown that the ice loads have a highly probabilistic nature. Based on the damage statistics of winter 2002-2003 (Hänninen 2004) it is estimated here that the current level of hull ice damage risk concerning one generic ship representing a fleet of cargo and passenger vessels (with a representative distribution of ice classes) is roughly as follows:

a) Ice damage of hull plate: 20×10^{-6} cases / (nm × m)
b) Ice damage of hull frames: 3×10^{-6} cases / (nm × m), a sub-group of case a) representing a 15 % portion of all hull ice damages
c) Ice damage of hull plate (rupture): 5×10^{-6} cases / (nm × m), a sub-group of case a) representing a 25 % portion of all hull ice damages

Based on an unofficial and rough estimate of the repair costs of more than 10 hull ice damage cases in the northern Baltic Sea in winter 2002-2003 the average repair cost was estimated to be around 45 000 €. Surprisingly, this estimate agrees well with the corrected[61] average compensation paid by Finnish insurance companies due to the 430 ice damage cases in the years 1959-70. The large variation in the repair costs of ice damages should be taken into account. Based on the information given in (Beckman 1971) the largest single compensation paid in 1971 due to hull ice damage could be calculated to be about 22.5 times higher than the average compensation.

According to the Russian experience along the Northern Sea Route in 1983 (Babtsev et al 1995), the character of the damage on transport vessels and icebreakers due to ice loads in the extremely difficult ice conditions was:

- dents, goffering in   35 vessels,
- dents with cracks in   37 vessels,

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[61] According to Beckmann (1971) the total compensation sum of the 430 ice damages in years 1959-1970 was FIM 17.7 million. By using the monetary correction index for years 1971 and 2002 which is 6.595 and the exchange rate 1€ ~ 5.94573 FIM the current value of those compensations is about 19.6 M€. Thus, the current value of the average of the compensations of the old ice damages is: 19.6 M€ / 430 = 46 000 €.

- hole(s) or rupture(s) in   29 vessels and
- loss of ship in   1 case (= 1 ship)

Thus, depending on the nature of the influence of the crack on the watertightness of the ship, it may be concluded that about 3 % of the ice damage cases with a loss of watertight integrity resulted in the loss of the ship.

A recent Canadian study (Kubat & Timco 2003) presents information from a database of 125 ice damage events. Of all vessels included in that study, whether with just a small puncture or a larger hole, three vessels from 64 sank. These numbers gives us an approximative sinking ratio of almost 5 %. However, it should be pointed out that all of the sunken vessels were damaged in ice conditions, where an impact with multiyear ice is not out of question.

Thus, it may be estimated that the risk of a total loss of a generic ship is approximately around 3 – 5 % in such cases, when there is a crack or a hull plate rupture due to ice damage. The size of the vessel and the watertight subdivision of the ship hull are not reported by the previous authors. It is not known if the sunken ships in these cases have been two-compartment ships, withstanding leaks in two watertight compartments. It is possible that this is not the case. Therefore, it is believed that the above range does not strikingly underestimate the probability of a total loss. However, due to the scarcity of data there is much uncertainty in the following estimate:

In the hull ice damage cases of all merchant vessels there were five cases with rupture or fracture. Therefore, the probability of a fracture or rupture for a generic ship is estimated by calculating:

Generic ship: Fracture/rupture

5 / (19 000 voyages in ice × 161 nm × 0.33 m) = 5×10^{-6} cases / (nm x m)

The probability of a total loss in this group of ships is estimated by calculating:

Generic ship: Total loss

(0.03 – 0.05) × 5 / (19 000 voyages in ice × 161 nm × 0.33 m) =

$$0.15 \times 10^{-6} - 0.25 \times 10^{-6}   \text{cases} / (\text{nm} \times \text{m})$$

There was only one case with rupture in the group of merchant vessels of ice class categories IA Super and IA. Therefore, we may estimate the probability of total loss in this group of ships by calculating:

Ice class categories IA Super & IA: Total loss

(0.03 – 0.05) × 1 / (0.85 × 19 000 voyages in ice × 161 nm × 0.33 m) =

$$0.03 \times 10^{-6} - 0.06 \times 10^{-6}   \text{cases} / (\text{nm} \times \text{m})$$

In the group of merchant vessels in ice classes IB, IC and II there were four cases with a rupture or fracture. Therefore, we may estimate the probability of total loss in this group of ships by calculating:

Ice class categories IB, IC & II: Total loss

(0.03 – 0.05) × 4 / (0.15 × 19 000 voyages in ice × 161 nm × 0.33 m) =

$$0.8 \times 10^{-6} - 1.3 \times 10^{-6} \quad \text{cases} / (\text{nm} \times \text{m})$$

Thus, we can present the following summary of these rough estimates concerning the risk of total loss of a generic ship due to hull ice damage in the northern Baltic Sea:

- The probability of total loss of a generic ship due to hull ice damage in the northern Baltic Sea is assumed to be roughly about **$0.1 \times 10^{-6} - 0.3 \times 10^{-6}$** cases / (nm × m).

The uncertainty due to the low number of damage cases with large damage and the limitation of the data of this study in damages in one winter should be taken into account when conclusions based on these results are made.. If the applied linear relationships can be accepted, the above level of risk of total loss due to hull ice damage is equivalent to about 0.4 – 1 total losses in a period of 22 years, if related to the actual ship traffic to and from Finland, to the estimated distances traveled in ice and to the rough estimates on the average ice thickness in winters 1982-2003.

It should be also noted that older cargo ships with corroded hulls are naturally in the greatest danger in this respect. In such a ship group or in the case of ships with no ice strengthening at all the risk for a total loss due to hull ice damage exceeds clearly the presented range. Therefore, the role of the classification societies and the administrators of flag states and port states in setting and keeping high standards on the structural condition of ships is of utmost importance. Substandard ships must be prevented from becoming a hazard to the safety in winter navigation.

Fatalities / potential for loss of life

No lives have been reported to be lost in the above ice related accidents. Therefore, the corresponding estimate of risk for loss of life is assumed to be clearly less than the risk of a total loss. A rough assumption of a proportion of 10 - 33 % of the probability of the total loss cases might be a reasonable estimate:

Generic ship:

- A rough estimate of the probability of an accident with some loss of life in the case of hull ice damage of a generic ship in the northern Baltic Sea is considered to be in the range of about **$0.01 \times 10^{-6} - 0.1 \times 10^{-6}$** cases / (nm × m)

When multiplied with the sum of the product of the annual number of ship arrivals in Finnish ports, the estimated average of traveled distance in ice and the estimated average of ice thickness in years 1982-2003 the range of risk level calculated by using the above range of probability is equal to about 0.03 – 0.3 cases of hull ice damage in merchant vessels with one or more fatalities as a consequence. This result is not in contradiction with the observation of the accident data.

Environmental damage / potential for pollution

The risk of an environmental damage, e.g. oil outflow from an oil tanker due to a hull ice damage in the Baltic Sea depends on several factors, e.g. on the structure (double hull/ single hull)[62], age and ice class category of the vessel. Environmental conditions, such as ice conditions, wind speed and direction as well as the quality and quantity of icebreaker assistance do have significant influence on this risk. According to the Finnish statistics from years 1982-2001 (in the period January-April) there was only one case of a ship accident with an oil spill which was caused by ice damage. In this case 6 tons of spilled oil was collected from the harbour.

In the references of hull ice damages in the Baltic Sea (Kujala 1991, Hänninen 2004) or in the Canadian or Russian Arctic (Babtsev et al 1995, Kubat & Timco 2003) there was not presented any cases, where both the outer and the inner sides of a double hull had been breached during ship-ice interaction. According to (Peresypkin & Tsoy 2001) a statistical analysis of more than 200 cases of heavy ice damages of cargo ships in navigation under ice conditions along the Northern Sea Route showed that the ice hole penetration does not practically exceed 0.5 m. The reason for this observation should be examined thoroughly in order to find the theoretical grounds and boundary conditions for this matter.

Although not all of the above evidence is from the Baltic Sea, it may be concluded that the probability of such an occasion, with ice damage rupturing the inner plating of a double hull vessel, is very low. However, in order to get more clarification to this problem it is recommended to develop methods to assess the risk for an oil outflow in this case, too. A more concentrated effort, with a specified case ship and all the necessary information concerning the route etc. would be needed for such a study.

According to Hänninen (2004) four tankers did suffer some hull ice damage during the winter 2002-2003 in the northern Baltic Sea:

In a tanker in the ice class category IA the damage was limited to some structural deformation, about 20-30 mm deep dents in the plating just below the ice belt and in the bilge area. Some frames and brackets in the forepeak were buckled, too. Some cracks and buckling was observed in the junction between frames and stringers above and below the ice belt. This kind of damage should be considered as a minor one. No oil leaks were reported.

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[62] Note! Several other issues in the design of the ships such as the design of structural details may also have a significant effect on the risk.

In an other case the side of a tanker in ice class IC was slightly deformed in compressive ice . The plating got dents 1.5 meters below waterline. Maximum dent depth in the 18 mm thick plating was about 30 mm. The spacing of the longitudinal frames is 800 mm and the frame span is 3.2 m. The damage of the second tanker is classified as a minor damage. No oil leaks were reported.

The third tanker was also in compressive ice but it drifted and grounded due to the ice movement. The ship suffered only minor damage. The fourth tanker suffered some damage on its side(s) but the date and other details of this case are not known. Therefore, the severity of the hull ice damage of this 42 m wide vessel in ice class IA is not so easy to assess. However, it seems that in most cases there was only minor damage and no oil leaks were reported.

It might be an useful exercise to make the necessary calculations to assess the ice loads in the above hull ice damage cases and then calculate the corresponding deformation and damage in the case of lower/higher ice class vessel and to repeat the calculations for a double hull tanker. This kind of approach would be the only way to create new knowledge which is required for the risk assessments concerning the risk of environmental damage. The risk level of oil spill in the case of hull ice load depends to a great extent on the ship design. Therefore it is not a very reliable method to assess it by using historical accident frequency as a basis when the number of accidents is so low.

According to the analysis of the data presented in (DNV 1999) the probability of pollution in the case of a serious contact accident is about 7 % for a generic merchant ship. However, this proportion is much higher, about 30 % for oil tankers. Thus it can be noticed that the risk of pollution is more than fourfold when compared to a generic vessel. Unfortunately, this reference (DNV 1999) does not specify the numbers of ships, accidents and pollution cases for the two design alternatives (single hull/double hull) in the data which is relevant for years 1978-1998.

Generic ship: Pollution

In the case of a generic vessel the probability of an oil leak is assumed here to be about 5-10 % of the frequency of a fracture or a rupture due to a hull ice damage. Based on this information the assessed probability of pollution is:

(0.05 – 0.10) × 5 / (19 000 voyages in ice × 161 nm × 0.33 m) =

$$\underline{0.25 \times 10^{-6} - 0.5 \times 10^{-6} \quad \text{cases} / (\text{nm} \times \text{m})}$$

- The rough estimate of the probability of an oil leak from a generic ship due to hull ice damage in the northern Baltic Sea is about **0.25×10^{-6} – 0.5×10^{-6}** / (nm × m).

When applied to the actual number of ship arrivals in Finnish ports, the estimated average of traveled distance in ice and the estimated average of ice thickness in winters 1982-2003 the range of risk level can be assessed quantitatively to be equal to about 0.7 – 1.4

cases of hull ice damage in merchant vessels with an oil spill as a consequence. This result is not in contradiction with the observations of the Finnish accident data in 1982-2003, with one case with an oil leak in the port of Raahe. However, it should be stressed here again that there are many uncertainties in the above risk level.

A ship with a double hull has probably a lower probability of total loss, probability of loss of life and probability of an oil leak in hull ice damage than a ship with a single hull. The quantitative difference in the risk of these two types of ship design in the case of a tanker or any other ship is not assessed in this study.

6.3.3 PROPELLER ICE DAMAGE RISK ASSESSMENT: Frequency

<u>Winter 2003</u>

The propeller ice damage frequency based on the winter 2002-2003 statistics is presented in Table 14. It includes 29 propeller ice damage cases which occured on merchant ships in all ice classes. So, the rough estimate of the propeller ice damage frequency, related to the travelled nautical miles in ice and to the average ice thickness, is:

Generic ship:

29 propeller ice damages / (19 000 arrivals × 161 nautical miles × 0.33 m) =

$\quad$ 29×10^{-6} propeller ice damage cases / (nm × m) = $\quad$ $\underline{30 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$

If calculations are performed only for cargo and passenger ships in the ice class IA Super and IA in winter 2002-2003 the following propeller damage frequency is obtained:

Ice class categories IA Super & IA:

17 propeller ice damages / (0.85 × 19 000 voyages in ice × 161 nm × 0.33 m) =

$\quad$ $\underline{20 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$

If calculations are performed only for cargo and passenger ships in the ice class IB, IC and II in winter 2002-2003 the following propeller damage frequency is obtained:

Ice class categories IB, IC & II:

12 propeller ice damages / (0.15 × 19 000 voyages in ice × 161 nm × 0.33 m) =

$\quad$ 79×10^{-6} cases / (nm × m) = $\quad$ $\underline{80 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$

<u>Winters 1984-1987</u>

The ice damage database related to years 1984-87 of Kujala (1991), contained 5 propeller ice damage cases. The corresponding accident frequency, related to the travelled nautical miles in ice (of the fleet of 59 ships) and to the average ice thickness, was around:

Ice class categories IA Super & IA:

5 propeller ice damages / (4 years × 1072 voyages/year × 127 nm × 0.3 m × $(1.384)^2$) =

$$16 \times 10^{-6} \text{ cases / (nm × m)}$$

The propeller damage frequency, which is based on the 1984-87 damage statistics, is lower than the former one. There are several possible reasons for this difference, e.g. the different ice strengthening of the ships in these two studies. If the number of propeller damages in winters 1984-87 is related to the total number of ship arrivals and departures in Finnish ports, the corresponding frequency will be even lower:

5 propeller ice damages / (0.85 × 14 846 voyages in ice × 127 nm × 0.3 m × $(1.384)^2$) =

$$5 \times 10^{-6} \text{ cases / (nm × m)}$$

Another possible reason for the large difference in propeller ice damage frequencies in winters 1984-87 and 2003 may be the familiarity of operators in navigation in ice conditions. The data from winter 2003 includes damage cases from a larger variety of ship operators all of whom may not be accustomed in winter navigation. A long period of mild winters before winter 2003 may have also had some deteriorating effect on the operators ability to avoid hazardous manoeuvres. Another reason for the difference may be e.g. the fact that all cases of propeller ice damage are probably not included in the 1984-87 statistics. As a consequence of these or some other reasons the variation in the assessed risk of propeller ice damage seems to be large.

Theefore, it is recommended that the collection of propeller ice damage data is continued in order to form a wider base for statistical analysis and to reduce the uncertainty connected to a small sample size. There may be some more important parameters affecting the frequency of propeller damage in ice than the distance travelled in ice conditions. The frequency of encountering difficult ice conditions and the need to perform repeated rams and especially movements astern are assumed to be the key questions in this respect.

<u>Summary</u>

As a summary of the above analysis it may be stated that:

- Propeller ice damage frequency of a generic ship in the northern Baltic Sea is on average about **30×10^{-6}** damage cases / (nm × m).

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About 60 % of the damaged propellers in merchant ships was found in vessels in ice class IA Super and IA.

Various manoeuvres in difficult ice conditions caused propeller damage also for six (6) tugs and one icebreaker operating in the Baltic Sea in winter 2002-2003. Most of these vessels were in ice class IA, but at least one was in ice class IA Super. It is not a rare phenomenon that propeller blade failures occur on tugs during a hard winter. This fact may have some effect on the rescue and salvage capacity of the coast states in the case of a major marine accident.

6.3.4 PROPELLER ICE DAMAGE RISK ASSESSMENT: Consequences

The consequences of propeller ice damage are not treated separately here, because all other than material damage is included in the assessment of the other ice related accident types. The median of the estimated repair cost of about 12 propeller damages is in the range 80 000 – 100 000 €, but the two highest propeller damage cost estimates were in the range of 600 000 – 1 000 000 €. It should be reminded that in about 10 % of the cases with propeller damage there was also some hull ice damage to be found.

6.3.5 RUDDER ICE DAMAGE RISK ASSESSMENT: Frequency

The number of rudder damage cases was equal to the number of propeller damage cases in the older ice damage statistics from years 1984-87 of Kujala (Kujala 1991). However, in the ice damage statistics from winter 2002-03 (Hänninen 2004), the number of rudder failures related to ice was only about one third of the number of propeller damage cases.

<u>Winter 2003</u>

Thus, based on the results of the more recent damage data it may be assumed that

8 rudder damage cases / (19 000 voyages × 161 nm × 0.33 m) =

$$\underline{8 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})}$$

<u>Winters 1984-1987</u>

Using the older data for winters 1984-1987 from Kujala (1991) we get:

6 rudder damage cases / (4 years × 1072 voyages/year × 127 nm × 0.3 m × $(1.384)^2$) =

$$\underline{19 \times 10^{-6} \text{ cases} / (\text{nm} \times \text{m})} ,$$

or, if calculated otherwise

6 rudder ice damages / (0.85 × 14 846 voyages in ice × 127 nm × 0.3 m × $(1.384)^2$) =

$$7 \times 10^{-6} \text{ cases } / (\text{ nm} \times \text{ m })$$

Summary

Thus, it may be proposed that

- the frequency of rudder ice damage for a generic ship in the northern Baltic Sea is on average about $7 \times 10^{-6} - 20 \times 10^{-6}$ damage cases / (nm × m)

6.3.6 RUDDER ICE DAMAGE RISK ASSESSMENT: Consequences

The consequences of rudder ice damage are not treated separately here, because all other than material damage is included in the assessment of the other ice related accident types.

6.3.7 RISK ASSESSMENT OF MACHINERY DAMAGE IN ICE: Frequency

In the ice damage statistics from winter 2002-03 (Hänninen 2004) the number of machinery damage cases was about 1/10 of the number of hull or propeller ice damage cases. However, it is not known to the authors if there has been more of such damage cases, or in how many cases the crew has been able to repair the damage at sea. Thus, there is uncertainty in the following estimate on the frequency of this kind of damage cases, related to the ship's travelled nautical miles in ice and to the average ice thickness. It is assumed that the real number of damage cases may be fivefold to the reported value:

- the frequency of machinery damage in ice for a generic ship in the northern Baltic Sea is on average in the range of about $2 \times 10^{-6} - 10 \times 10^{-6}$ damage cases / (nm × m)

There is considerable uncertainty in the above assessment due to the limited number of accident/incident cases. An enlargement of the database of machinery damages in ice and interviews of the ship crews is strongly recommended to be done in order to form a more reliable basis on the estimates of the frequency of this accident type.

6.3.8 RISK ASSESSMENT OF MACHINERY DAMAGE IN ICE: Consequences

The consequences of machinery damage in ice are not treated separately here, because it is assumed, that all other than material damage is included in the assessment of the other ice related accident types.

6.3.9 COLLISION RISK ASSESSMENT: Frequency

Collisions and other impact type of accidents, which occur in narrow ice channels or in operations connected to icebreaker assistance, are included in the ice related accidents/ accidents of this study. These type of accidents occuring in winter are the most common collision accidents in Finnish waters and their influence on the statistics can be clearly identified, for instance in monthly accident statistics (FMA 2001), see Figure 70. Nearly 70 % of all the collisions in Finnish waterways in 1990-2000 occured during the period January-March.

Winters 1982-2003

The data from winters 1982-2003 includes a total number of 76 collision accidents and other incidents with ship-to-ship contact or impact in Finnish waters. It is based on the reported cases in the databases in (FMA 1996, FMA 2001 and the Finnish DAMA). The distribution of this data in to different categories of ice related collision accidents and incidents is presented in Table 15. The data from winters 1982-2003 includes in total 59 collisions, if the 15 occurrances during towage and two allisions with light bridges over ice channels are excluded. It should be stressed here that in this study a collision is defined as an impact between two (or more) vessels, which may be underway, anchored or moored. A special case typical for winter navigation with the other ship stopped due to ice conditions is included in this broad definition of collision, too. About 50 % (= 29 / 59) of these collisions were minor incidents between the merchant ship and the assisting icebreaker.

Table 15   Ice related accidents and incidents: collisions and other ship-to-ship contact accidents in Finnish waters in winters 1982-2003, based on (FMA 1996, 2001) and the DAMA-database 1990-2003.

Ships involved:	Type of accident or incident:	Cases	Share
Icebreaker and the assisted vessel 58 %	Impact on the aft end of the icebreaker	20	26 %
	Impact on the assisted vessel	9	12 %
	Structural damage during towage	15	20 %
Other vessels 42 %	Bow/bow collision in ice channel	10	13 %
	Bow/aft collision in ice channel	7	9 %
	Collision, when aside (overtaking)	6	8 %
	Collision, when aside (passing by)	2	3 %
	Other collision	4	5 %
	Collision/allision with a light ice bridge or ice channel ferryboat	3	4 %
Note! In about 95 % of these cases there was no damage or only minor damage		76	100 %

According to the above data the average number of these collision accidents and other ship-to-ship contact incidents in Finnish waters has been about 2.7 - 3.5 cases per winter depending on the definition of collision that is used. There is some variation between different winters as can be seen from Figure 71. However, there seems to be no obvious trend in this statistics. When compared to the previous period of winters 1982-2002, the number of cases has been exceptionally high in winter 2002-2003. The reason for this

jump in the collision statistics is unknown unless it is caused by the increase in traffic, see Figure 72 a).
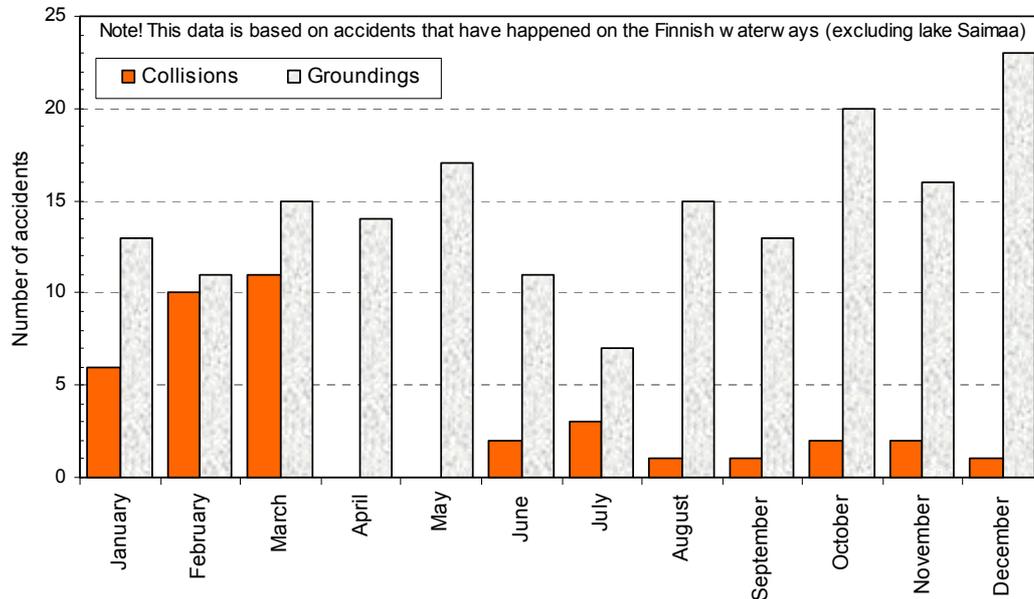
Figure 70   Ship collisions and groundings at the Finnish sea waterways in 1990-2000 excluding open sea areas and inland waterways (FMA 2001).
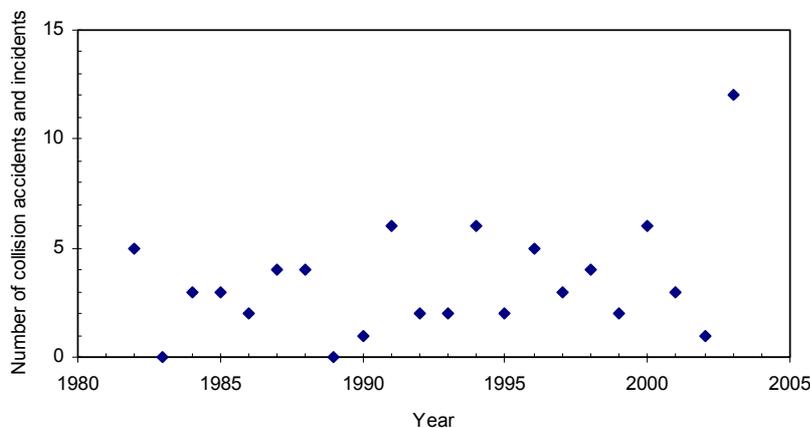
Figure 71   Ice related collision accidents and incidents contact with some or no damage in Finnish waters in winters 1982-2003 based on the accident/incident reports sent to FMA.

About 95 % of all these incidents with ship-to-ship contact in connection to winter navigation in Finnish waters in years 1982-2003 resulted in no damage or just minor damage. The whole database includes only one vessel, which was declared as a total loss due to the collision damage and the fire, ignited by the collision. However, this badly damaged ship was repaired afterwards and taken back in operation.

When the above number of 59 collision accidents and incidents is related to the 153 703 ship arrivals and departures concerning Finnish ports during the period of traffic restrictions in years 1982-2003 and is divided by two we can calculate the average frequency of ice related collisions per one port visit[63] in ice:

59 collision accidents/incidents in ice / (153 703 arrivals and departures / 2) =

$$768 \times 10^{-6} \text{ cases / port visit} = \underline{770 \times 10^{-6} \text{ cases / port visit}}$$

By using the Finnish collision accident and incident data from winters 1982-2003 (59 cases) and relating it to the estimated average distance traveled in ice, the estimated average ice thickness and the corresponding number of port visits, we get:

59 collision accidents/incidents in ice / $(2.75 \times 10^{6}$ port visits $\times$ nm $\times$ m $)$ =

$$\underline{21 \times 10^{-6} \text{ cases / (number of port visits} \times \text{nm} \times \text{m)}}$$

Winter 2002-2003

According to the accident/incident statistics collected in (Hänninen 2004) a total number of 22 ice related collisions occured in the winter period 2002-2003. About 45 % of these reported cases occurred in icebreaker assistance. About 75 % of the collisions between two merchant ships occured in the Gulf of Finland, but about 70 % of the collision in the assistance of an icebreaker occured in the Bay of Bothnia, which may be an indication of difficult operating conditions.

The collision data from winter 2002-2003 is based on the information from the northern Baltic Sea, not only from the Finnish (ice-covered) waters. Based on this data we can calculate:

19 collision accidents/incidents[64] / (19000 port visits) = $\underline{1000 \times 10^{-6} \text{ cases / port visit}}$

The above underlined values are comparable and not very far from each other. If the number of collision accidents and incidents in the winter 2002-2003 data is related to the number of port visits and the estimated value of the average distance traveled in ice and the estimated average ice thickness we get the following frequency of:

19 collision accidents/incidents in ice / (19 000 port visits $\times$ 161 nm $\times$ 0.33 m) =

$$\underline{19 \times 10^{-6} \text{ cases / (number of port visits} \times \text{nm} \times \text{m)}}$$

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[63] Note! Here one port visit includes the voyage and arrival to the port and the departure and voyage from the port.

[64] As it was explained earlier, three of these cases were not included into further analysis due to the lack of the corresponding traffic data.

This result for winter 2003 and the corresponding result for winters 1982-2003 which was calculated using the data from Finnish waterways are very close to each other. The above estimates are calculated for a generic ship. Therefore, the calculated frequency is not recommended for use if the collision risk of a certain ship making a visit to a certain port at a certain time of winter is assessed. In such cases more information is needed for the collision risk assessment. It should be emphasized once again, that there are several factors affecting the collision accident/incident frequency and the applied risk model may be too simple.

As assumed, some correlation between the number of ship arrivals and departures and the number of collision accidents and incidents in ice conditions (per winter) can be observed, see Figure 72 a). However, the effect of the severity of ice conditions, characterized here by the maximum extent of ice cover in the Baltic Sea, on the number of ice related collisions (and incidents) per winter or on the relative accident/incident frequency is not so clear, see Figures 72 b) and c).

The collision data for winter 2002-2003 from Sweden and Russia includes six collisions, three collisions in both cases. In the latter case the number of ship arrivals was assumed to be 2525, so a rough estimate of the collision frequency per port visit would be about:

3 collisions / 2525 port visits = $\quad\quad\quad\quad\quad\quad\quad\quad$ $\underline{1188 \times 10^{-6} \text{ cases / port visit}}$

The above value is quite near the corresponding value for winter 2002-2003 in Finland, which is based on 10 collisions (and ship-to-ship contact incidents) and 16 891 arrivals and departures, which give:

10 collisions / (16 891 arrivals and departures / 2) = $\quad$ $\underline{1184 \times 10^{-6} \text{ cases / port visits}}$

It should be stressed that it is not known precisely if the criteria for recorded collisions in the statistics are the same in Finland, Russia and Sweden. Unfortunately, the number of ship arrivals and departures in Swedish ports (with traffic restrictions due to ice) in winter 2002-2003 is not known, so the collision frequency related to the three collisions related to winter navigation in Sweden is not calculated here.
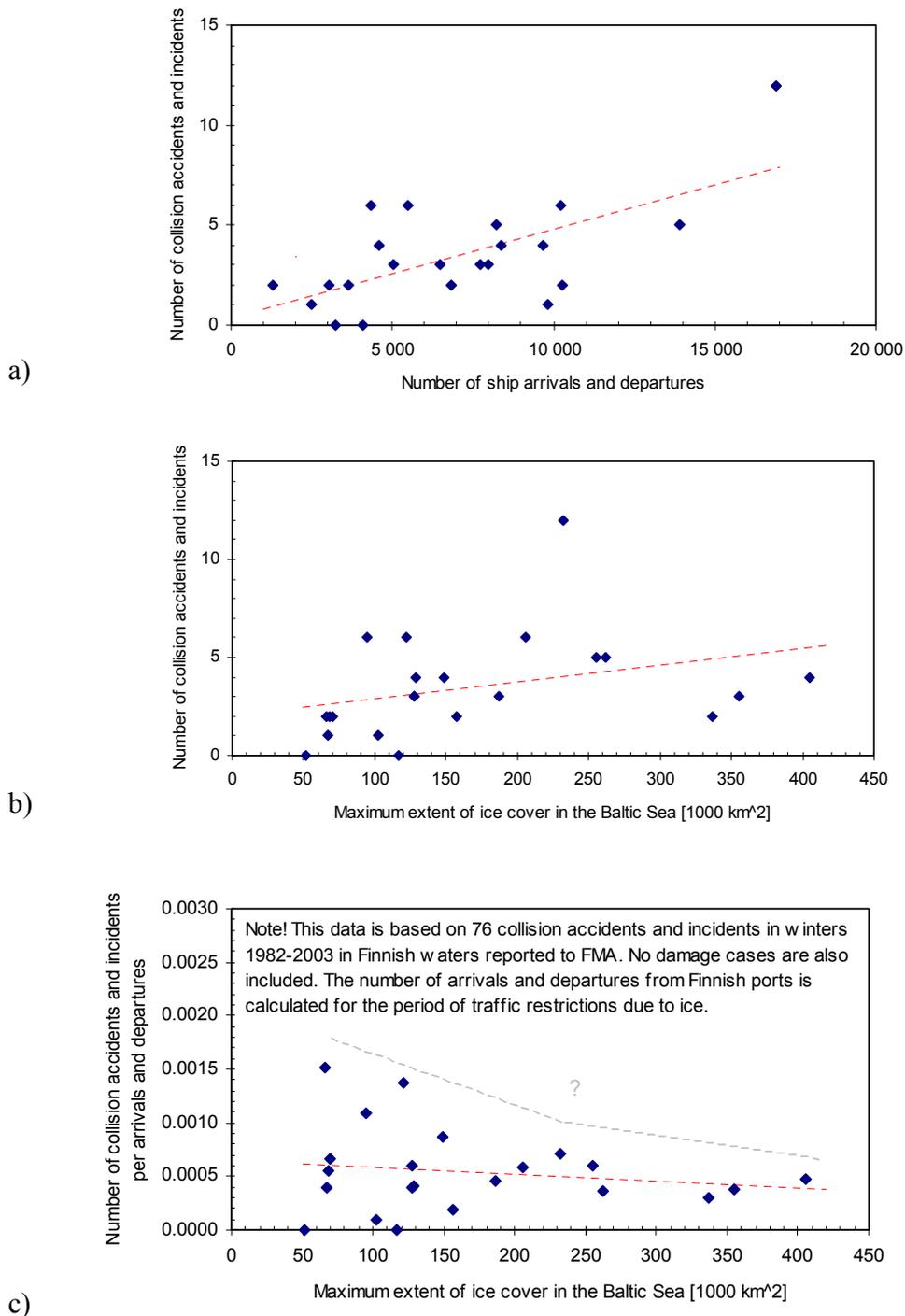
a)

b)

c)

Figure 72   a) The relationship between the number of ice related collision accidents/
incidents and the number of voyages (arrivals and departures), b) the number
of accident/incidents and the maximum extent of ice cover, c) collision
accident/incident frequency (per a single one-way voyage) plotted against the
maximum extent of ice cover.

Summary

Although the relationship between the average distance traveled in ice, the average ice thickness encountered and the number of collision incidents/accidents is not so clear the following rough estimates of the collision accident/incident probability for a generic merchant vessel in winter navigation are presented:

- The probability of ice related collision accident/incident for a generic ship in the northern Baltic Sea is in the range: 800×10^{-6} - 1200×10^{-6} collisions per port visit[65]. If the ice conditions are taken into account by relating the collision probability to the average distance traveled in ice and the average ice thickness, the following probability is obtained: 20×10^{-6} cases / (number of port visits $\times$ nm $\times$ m).

It should be reminded that the standard deviation of the collision frequency is high and several additional factors having possible influence on the collision frequency in ice should be analysed in more detail. Experience of the ship operator with the manoeuvring capability of the vessel in various ice conditions may be one of the key issues in this respect. Another important factor is the operator's general experience in winter navigation.

Information regarding the deceleration rate of different ship types in different ice conditions should be collected and analysed. Results of such analysis could be used as a basis for setting standards for safe distances when ships proceed in ice conditions. It is understood by the authors that this kind of analysis and recommendations concerning the recommendable distances between ships in a convoy proceeding in ice are included in the Russian Ice Passport system. On the other hand, all ships have information regarding the stopping distance in open water. Stopping distance in ice conditions is probably not any longer than what it is in open water conditions, if the same propeller power is available.

6.3.10 COLLISION RISK ASSESSMENT: Consequences

Fortunately, the consequences of the collisions in ice conditions have been mainly limited to small damages or no damages. Icebreakers do not have a bulbous bow, which could cause severe underwater damage to the assisted ships. On the other hand ice blocks and the icebreaker's towing fork, see figure 62, act as protective barriers too. Thefore, e.g. the outcome of the numerous rear-end collisions, caused by the assisted vessels hitting the aft end of an icebreaker has usually been minor damage or no damage at all. Another reason for the outcome of the collisions being generally not so bad in ice conditions is the absence of small craft, which are perhaps the most vulnerable objects of collision accidents at sea.

About 1 % of all reported collisions of Finnish and foreign vessels in Finnish waters in years 1978-1990 resulted in the total loss of the ship (VTT 1997). Large damage was the consequence of about 6 % of all collisions.

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[65] This range of the rate of ice related collisions is equal to one collision per 833-1250 port visits.

Structural damage / damage to the ship in collision

There seems to be only one collision that has lead to a total loss in winter navigation in Finnish waters in the period 1982-2003. Therefore, only a very uncertain risk estimate of the frequency of this kind of an accident is obtained:

1 total loss / 59 collisions = 0.017 cases / collision

The share of the cases with major damage in winters 1982-2003 seems to be smaller than in the slightly older data from 1978-1990. If we assume here that the share of collisions with major damage in winter navigation is about 6 % of all collision cases, the following estimate of risk in this category is obtained:

0.06 cases / collision

The relation between the above probabilities of a total loss and a major damage is about 0.30. This ratio is higher than the average value of 0.20 (number of total losses/number of serious casualties), which can be calculated in the case of collision accidents from the data presented in (DNV 1999).

If the above risk estimates are applied to the winter 2003 data, the following results are obtained:

Major damage estimate (2003):

(19 000 port visits × 161 nm × 0.33 m) × 0.06 × 20 × 10^{-6} cases/(port visits × nm × m) = 1.2

Total loss estimate (2003):

(19 000 port visits × 161 nm × 0.33 m) × 0.017 × 20 × 10^{-6} cases/(port visits × nm × m) = 0.34

With the data from winters 1982-2003 we obtain:

Major damage estimate (1982-2003):

(2.75 × 10^{6} port visits × nm × m) × 0.06 × 20 × 10^{-6} cases/(port visits × nm × m) = 3.3

Total loss estimate (1982-2003):

(2.75 × 10^{6} port visits × nm × m) × 0.017 × 20 × 10^{-6} cases/(port visits × nm × m) = 0.9

At least one of the collisions in winter 2003 could be classified as a major damage. Unfortunately the severity of all the collisions in the northern Baltic Sea in winter 2003 is not known. Therefore it is not possible to assess the validity of the above collision risk assessments. Much more data is needed for such an assessment.

However, based on the limited amount of accident data concerning major damages in collision accidents in ice the risk estimates are extended upwards. Thus, the following very rough estimates of the consequences of collisions in ice, ending up to a major damage or to a total loss, are obtained:

- about 1.2×10^{-6} collisions/(port visits $\times$ nm $\times$ m) with **major damage**

- about 0.3×10^{-6} - 0.4×10^{-6} collisions/(port visits $\times$ nm $\times$ m) ending up to a **total loss**

Fatalities / potential for loss of life

Based on the accident statistics and data concerning all ship types presented in (DNV 1999) it is assumed here that there is some loss of life in about 9 % of the collisions which are classified as serious casualties. It is assumed here that serious casualty is equal to an accident with major damage. Thus we get the following rough risk estimate for ice-related collisions with some loss of life:

- about 0.1×10^{-6} collisions/(port visits $\times$ nm $\times$ m) with some **potential loss of life**

When related to the total number of arrivals and departures from Finnish ports in the winter periods 1982-2003 the above estimated range gives us about 0.3 collision cases with some loss of life for this time period.

Environmental damage / potential for pollution

Some environmental damage is assumed to occur in about 13 % of the collisions that are classified as serious casualties. This ratio is calculated in the case of collision accidents from the data presented in (DNV 1999). Thus we get a rough estimate of

- about 0.16×10^{-6} collisions/(port visits $\times$ nm $\times$ m) with some **pollution**

When adjusted to the total number of arrivals and departures in Finnish ports in the periods of traffic restrictions in 1982-2003 the above estimate gives us about 0.4 collision cases with some environmental damage. According to the data published by FMA (2001) the collisions in Finnish fairways in 1990-2000 have not resulted in pollution.

It should be pointed out that the above risk estimates are based on the assumption of a generic vessel. Ships are different and the risk of pollution is higher for certain ship types and so is the case with the risk of fatalities. Analysis of the historical risk levels (DNV 1999) in the case of a serious collision accident reveal that on certain ship types the risk of fatalities may be about 2-3 times higher than the average level of all ships or the risk for pollution may also be 2-3 times higher than average.

Discussion

The above estimates are based mainly on historical data from a limited time period (1982-2003) and the assumption that the relation between the collision frequency and the

number of ship arrivals (and departures) is linear. Several factors, e.g. some new trends in icebreaker design and operation, e.g. exposing the side of the icebreaker to impacts of the assisted vessel, may have effects on collision frequency and the severity of the collision consequences. The magnitude of such effects are yet unkonown. Similar effects are possible if the buffering effect of ice floes in the channel behind the icebreaker is totally absent or radically reduced as has been claimed to be possible by the developers of some other type of designs, see e.g. (Varges 1988).

If the collision damage is limited in the upper parts of the ship hull, there will normally be no leaks and the damage has usually been limited mainly to the steel structures. However, in collisions with high kinetic energy there is a possibility of other losses, too. In some cases a fire or an explosion may be ignited as a consequence of a collision. These risks are probably strongly related to the cargo and the design of the ship, which are not considered here separately in the case of a generic vessel.

One major concern is connected to the scenario when the vessel is not able to stop or change course in time and hits therefore the other ship ahead of it. When the number of big tankers with a large mass is increasing in the Baltic Sea, this may increase the number of such collision cases, where major damage or total loss is unavoidable. An other factor increasing the collision risk is the increase in velocity.

6.3.11 GROUNDING RISK ASSESSMENT: Frequency

The number of ship groundings in Finland is relatively high in October-December, with the maximum in December, see Figure 70. This is the darkest month of early winter, with rain and falling snow often complicating the navigation in narrow fairways with many turns. In many cases it is noted that snowfall has hampered both the visual observations and the use of radar although these may not be the only contributing factors of an accident. According to the available information, 22 collisions and 13 groundings of the data from 1990-2000, presented in Figure 70, occured in the presence of ice (FMA 2001). Thus, about 25 % of all groundings in January-April period in the winters 1990-2000 were ice- or snow-related groundings. The seasonal grounding frequency, which is based on this data, is about 1.2 groundings per winter. It should be noted that the winters 1990-2000 were rather mild, so this database is extended. Therefore, the data concerning the number of groundings in the presence of ice in winters 1982-1994, presented in (Lahtinen 19999), and the data for winters 1995-2003 from the Finnish DAMA database are combined, see Figure 73. This data is comprised of 44 groundings in 22 years, i.e. the average number of ice related groundings per winter is 2.
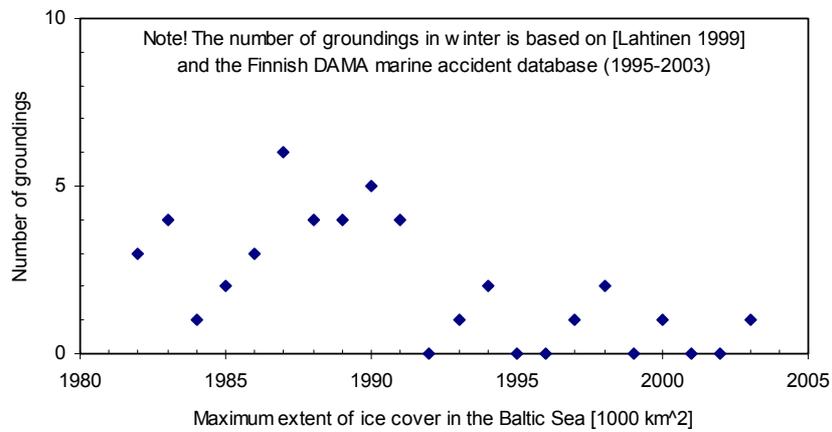
a)
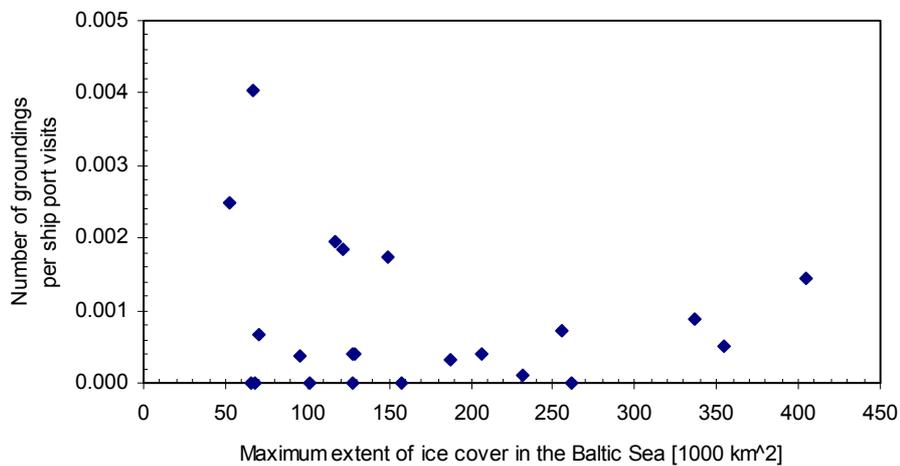
b)

Figure 73   a) The number of groundings in the presence of ice or in heavy snowfall in Finland in years 1982-2003 and b) The frequency of ship groundings related to the number of port visits plotted against the maximum extent of ice cover in the Baltic Sea in years 1982-2003

Based on the data presented in Figure 73 a) it can be deduced that the number of winter and ice related groundings was higher in winters 1982-1991 than in winters 1992-2003. In Figure 73 b) the frequency of groundings (related to the number of port visits in the time of traffic restrictions) is plotted against the maximum extent of ice cover in the Baltic Sea in years 1982-2003. The variation in the relative grounding frequency is high in both cases (a) and (b).

By using the above Finnish grounding statistics from years 1982-2003 the following grounding frequency in the presence of ice or during snowfall is obtained:

0.25 × 44 groundings / (153 703 voyages / 2) = 143×10^{-6} cases / port visit, or

0.25×44 groundings / (2.75×10^6 port visits $\times$ nm $\times$ m) = $\underline{4 \times 10^{-6} \text{ cases / (nm} \times \text{m)}}$

According to the accident and incident statistics of winter period 2002-2003 (Hänninen 2004) a total number of 2 groundings of merchant ships occurred in ice in the northern Baltic Sea. Both of these cases were drift groundings with just rather minor damage. Thus, using this data the estimated grounding frequency for a generic merchant ship is obtained:

2 groundings / (19 000 voyages) = 105×10^{-6} cases / port visit, or

2 groundings / (19 000 port visits $\times$ 161 nm $\times$ 0.33 m) = $\underline{2 \times 10^{-6} \text{ cases / (nm} \times \text{m)}}$

The latter underlined value is smaller than the former one, which may be explained by the recent development in the navigation equipment and several other safety related improvements related to the operation of the ships. Due to the variation between the frequencies above the following range of frequency for ship grounding in the presence of ice or heavy snowfall is given:

- about 2×10^{-6} - 4×10^{-6} ice or snow related grounding cases / (nm $\times$ m)

6.3.12 GROUNDING RISK ASSESSMENT: Consequences

Structural damage / damage to the ship

According to the grounding statistics in (Luukkonen 1999) less than 20 % of the ice related grounding cases have more serious consequences than a minor loss of watertight integrity. Therefore it is assumed here that in about 20 % of all groundings in ice or in heavy snowfall can be classified as serious casualties.

According to the worldwide marine accident statistics from years 1995-1999 presented by IMO, see e.g. Jalonen (2003), it was assumed that about one quarter (25 %) of groundings with serious damage end up with a total loss of the vessel. Based on the data presented in the Lloyd's World Casualty Statistics (1993-2002) and in (DNV 1999) the ratio between the annual average number of total losses and serious casualties in the accident category wrecked/stranded can be calculated. It is 0.23. Based on this and the above results it can be calculated further that about 5 % ($0.20 \times 0.23 = 0.046$) of all groundings end up with a total loss. The last value seems to be in some contradiction with the grounding risk assessment for all ships made in (VTT 1997), which states that the risk of a total loss in a grounding is 1.5 % (= 0.015) in the Finnish Sea transportation. When the risk of a total loss in a grounding in the northern Baltic Sea is considered, the latter value (0.015) seems to be a more reasonable alternative to be used due to the influence of local conditions on the results. So, as in (VTT 1997) it is estimated also here that:

- roughly about 1-2 % of all groundings of a generic ship in winter navigation in the Northern Baltic Sea will lead to a total loss

Fatalities / potential for loss of life in grounding

Based on the analysis of the data in reference (DNV 1999) it can be estimated that about 1-2 % of all serious grounding cases will lead to one or more fatalities. Historical data from the years 1968-1995 concerning 789 groundings of Finnish vessels with at least some damage, see (VTT 1997) does not exceed this risk estimate. Some recent grounding cases from Norway in years 1999 and 2004, not included in the above analysis, show that the risk of loss of life in grounding is real. If the above percentage is applied to the above estimated frequency of serious casualties in grounding, it can be estimated that about

- 0.2 – 0.4 % ($0.20 \times 0.01 = 0.002$, $0.20 \times 0.02 = 0.004$) of all groundings of a generic ship in winter navigation in the Northern Baltic Sea will cause one or more fatalities

Environmental damage / potential for pollution in grounding

Based on the analysis of the data in reference (DNV 1999) it can be estimated that in about 10 % of all serious groundings of a generic ship (which is not a single hull tanker) there will be some pollution as a consequence. In the analysis that is made by Lahtinen (1999) a slightly lower proportion, 6.5 % of groundings leading to some leak of oil, is obtained. The former value is based on 251 oil spills in worldwide ship groundings, but the latter value is specific for ice conditions in the Finnish waters. Therefore a range including both values is used as a basis for this risk level:

- 6-10 % of all groundings of a generic ship in winter navigation in the Northern Baltic Sea will cause some pollution

According to the analysis of the data from years 1978-1998 presented in (DNV 1999) the risk of an oil spill in the case of oil tankers is fourfold when compared to the avarage level of a generic ship. It should be pointed out that this ratio is based on grounding accidents of all tanker designs, so the representation of single hull tankers in the whole population is assumed to be remarkable.

Summary

Thus, with all the above assessments made for a generic ship we get the following rough estimates consequences for a grounding in ice conditions (or in a snowfall):

- about 2×10^{-6} - 4×10^{-6} ice or snow related grounding cases / (nm $\times$ m)

- about 0.4×10^{-6} - 0.8×10^{-6} groundings with serious damage / (nm $\times$ m)

- about 0.03×10^{-6} - 0.06×10^{-6} groundings with a total loss / (nm $\times$ m)

- about 0.004×10^{-6} - 0.02×10^{-6} grounding cases with loss of life / (nm $\times$ m)

- about 0.01×10^{-6} - 0.4×10^{-6} groundings with pollution / (nm × m)

It should be noted that the above risk assessments are valid only for the groundings in ice conditions or in such environmental conditions, when the winter may have some effects on the probability of the accident.

6.3.13 RISK ASSESSMENT OF ICING: Frequency & Consequences

In the accident and incident statistics of winter period 2002-2003 by Hänninen (2004) no icing incident cases were presented. This kind of accident has become rather rare and no reported accident cases are known, at least in the past 10-15 years, according to DAMA (FMA) or the Swedish Maritime Administration. However, it would not be realistic to totally exclude this risk totally from the group of winter navigation risks.

It is not known to the authors, if there is any clear definition for an icing incident. The minimum amount of ice weight on a ship to cause an accident or to act as a contributory factor with e.g. cargo shift in swell is not so easy to be determined. An occupational accident may be caused just by a tiny frozen puddle on the deck.

Icing incidents/accidents occur in open sea areas in certain weather conditions (see Figure 59), when the combined effects of wind, waves and the ship motion get the sea spray trajectories hit the ship structures. Therefore, the risk for an icing accident is probably not related to the distance travelled in ice during normal winters. During most severe winters the risk for icing becomes low if the whole sea is covered with ice.

It is assumed that the risk level of icing is constant. Icing risk should be related to the probability of the weather conditions and the ship design. Due to the lack of information and data regarding to the frequency of the weather conditions and the frequency of icing incidents, the following rough estimate (this is an uncertain assumption) of an icing incident frequency is presented for the whole traffic in winter in the northern Baltic Sea:

- about 1 - 5 icing related incidents / year

Nowadays, warnings for icing conditions are issued in weather reports, if needed, so it is probable that the conditions susceptible to icing risk can be avoided in most cases. Therefore, incident cases may not develop to accidents as easily as some decades before. If they do, the accident frequency is assumed to be low, however, and limited mainly to smaller vessels (length < 100 m). Thus, for all vessels operating in the northern Baltic Sea we may assume very roughly:

- about 1 - 3 icing related accidents / 30 years

The above time period and the corresponding estimate of icing accidents gives us the following rough estimate of icing accident frequency in the northern Baltic Sea on annual basis:

- about 0.03 – 0.1 icing accidents / year

Unlike other ice related accident types, the icing accidents are most probable in the case of small vessels, such as fishing vessels, pilot boats etc.. However, even bigger vessels may suffer from icing, especially if they are fast and/or suffer from deck wetness. E.g. any small container feeder with a bad bow design and a low freeboard, with full cargo and the majority of the containers on deck might be an ideal object to the risk of icing, if the destination is in the northern parts of the Baltic Sea. If icing is not avoided by a change of course or a speed reduction it may be connected to other problems with ship stability. Therefore, this accident may often end up with the loss of the ship.

Unawareness of the operators onboard of the hazards of icing or inability to react to it, connected to some other contributing factors, e.g. poor stability and low freeboard of the ship may lead the vessel to an accident. Due to the typical weather conditions for severe icing, with temperature below –5°C and wind speed in excess of 10 m/s, the possibilities of the ship crew to evacuate the ship successfully and to survive are not good, especially, if survival suits are not available or the crew is not familiar with using them. In bad weather the possibilities of external rescue units to enter the accident site in time are not as good as otherwise. Based on the considerations above it is assumed that the probability for an icing accident with severe outcome is 33 % of all icing accidents. Thus we get the following rough estimate for a generic ship in the:

- about   0.01 – 0.03   icing accidents with a total loss / year

It is assumed here that there is some loss of life or severe injuries and some oil leaks connected to all cases of total loss caused by ship icing.

6.4   RISK CONSEQUENCES IN WINTER NAVIGATION

The consequences of ice related accidents and incidents have not been exceptionally severe in the Baltic Sea during the recent 30 years. This statement is based on the review of marine accidents statistics in Finland and the empirical knowledge of the authors concerning the other northern coast states of the Baltic Sea. Of the about 100 ice related incidents and accidents recorded in winter 2002-2003 (Hänninen 2004), not a single case is known to have resulted in any loss of life or injuries. Neither was any environmental damage documented in relation to these cases. Thus, the consequence of ice related marine accidents has been limited to material damage and repair costs.

The main result of this study, the risk of winter navigation, is assessed here separately considering the different types of accidents. Another division is made according to the damage directed to a) the people, b) the environment and c) the property (ship and cargo). Below, in Table 16, the results of this risk assessment are presented as a function of the severity of the winter. Based on the analysis made in this report with all its assumptions a rough risk estimate for the hull ice damage is given below in the case of a mild winter, a

normal winter and a severe winter, considering all merchant ships operating in the area of Finnish, Estonian and Russian waters (in the Gulf of Finland) per winter:

Table 16   Selected representative values for a mild, normal and severe winter and the corresponding risk level of a hull ice damage in the northern Baltic Sea

	Mild winter	Normal winter	Severe winter
Maximum extent of ice cover during winter	94 000 km^2	160 000 km^2	265 000 km^2
Number of port visits in Estonia, Finland and Russia (in ice conditions)	13 000	16 000	20 000
Average ice thickness encountered	0.13 m	0.23 m	0.38 m
Average distance from ice edge to port & back	65 nm	111 nm	184 nm
	Mild winter	Normal winter	Severe winter
Estimated risk: Hull ice damage in	2 - 4	8 - 13	> 28 – 46 ships per winter

The assessed risk in the case of hull ice damage is presented also in in the form of a two-dimensional risk matrix in Figures 74 a), b) and c). These assessments, as well as the risk assessments related to the other ice related accident/incident types, which are presented in the risk matrixes in Appendix 6, are based on the results of this study and the results of an earlier study, which has been reported in (Juva 2002 and VTT 2002).

It should be emphasized, that most of these risk assessments are based mainly on historical data or the rather subjective views of the assessors. One of the most important assumption connected to all of the presented quantitative assessments in this risk analysis is that significant changes in the ships involved, in the ice class and hull condition, or in the operation of the vessels are not taken into account. However, from the technical point of view there are possibilities for such studies. A more theoretical approach, requiring several case studies for different ship types, development of ultimate load scenarios for double hull structures and corresponding FEM calculations, and other calculations, would be needed for such research work. The areas of biggest uncertainty are marked and equipped with a question mark in Figures 74 a), b) and c). New tools for assessing the risk contributing factors related to human/organisational questions have also been developed and presented e.g. in (Vivalda et al 1999).

Figure 74   a) Risk matrix for structural hull ice damage: Risk to people onboard.[66].
Note! This is the estimated risk considering all ship traffic.

Figure 74   b) Risk matrix for hull ice damage: Risk to the environment[66]. Note! This is
the estimated risk considering all ship traffic.

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[66] Note! The risks assessed here are coded according to the numbers in Table 11. The area with a question
mark inside shows the main area of current uncertainty.

Risk matrix: **Risks connected to hull ice damage**

Risk control option(s):   As applied in winters 1982-2003

General risk level of this accident/incident type

Assessed risk level is lower

Probability:			Area of intolerable risk	Worst risk
P4 Several times per winter	ALARP-area	S: 9-1 ← S: 10-1 →		
P3 1 year < One time in < 10 years			← S: 9-2 →	
P2 10 years < One time in < 50 years				?
P1 Less than one time in 50 years	Slightest risk	Area of negligible risk		
Consequence:	**C1**	**C2**	**C3**	**C4**
	Minor	Moderate	Remarkable	Catastrophical
P. People				
X S: Ship	No damage to ship	Small damage to ship	Severe damage to ship	Total loss
E: Environment				

Scenario:
9-1   The ship is stuck in ice. Structural failure due to compressive ice. Minor damage to ship.
9-2   The ship is stuck in ice. Structural failure due to compressive ice. Large damage to ship.
10-1   The ship operates independently in severe ice conditions. Ice damage due to lacking icebreaker assistance
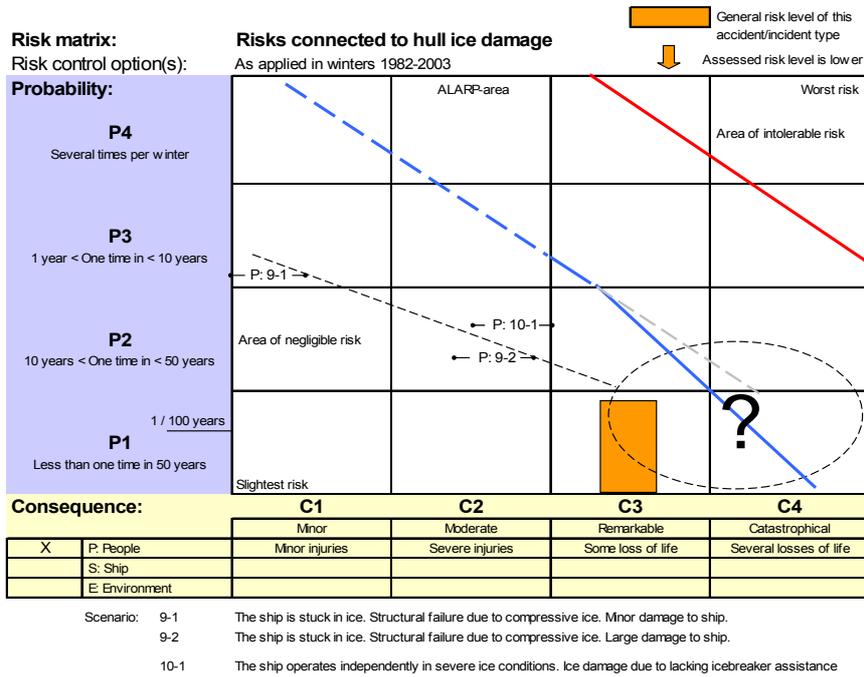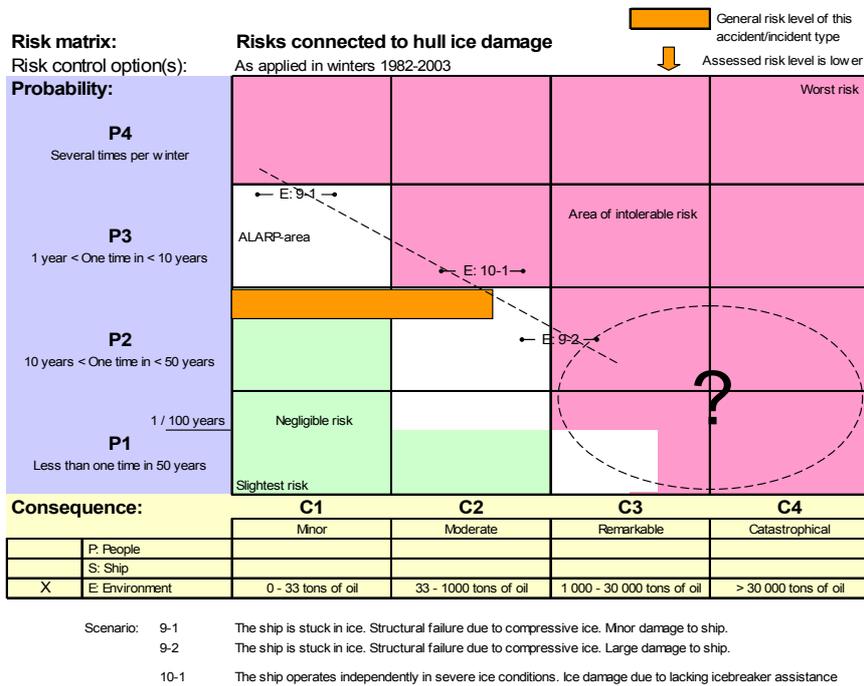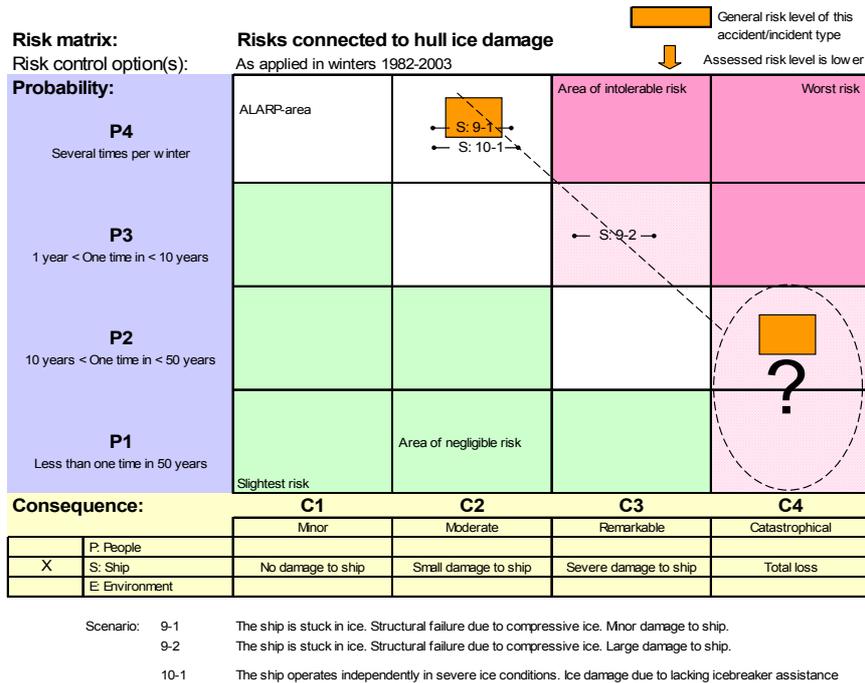
Figure 74   c)   Risk matrix for hull ice damage: Risk to ship[66]. Note! This is the estimated risk considering all ship traffic.

One area, which requires more research, is the survivability of the people onboard in the case of an accident, which escalates so that an evacuation is unavoidable. All obvious problems in the evacuation and rescue in extreme weather and ice conditions have not been deeply and thoroughly discussed here due to the wide scope of this risk assessment study. Survivability and its deteriorating in the case of some typically difficult environmental conditions in winter should be examined. New reasonable risk control options for this purpose should be investigated and developed, if necessary.

The costs of the ice damage repairs are not exceptionally high, in general. The average repair cost (per ship) of the damage that is estimated for ships in a group of vessels representing about one third of the ~100 cases in winter 2002-2003, is in the range of 100 000 - 150 000 euro. However, in some few cases the repair costs of the damage may easily rise up to an extensive sum of money. Among the accidents of winter 2002-2003, in at least ten cases the estimated repair cost was over 100 000 euro. Total costs of an ice related damage, which necessitates a visit to a repair yard, are probably considerably higher than this. A rough estimate of the total costs is twofold, when compared to the repair costs (Jalonen 2003). In a marine accident in winter navigation the total costs may be even higher, as the time to get the ship to the repair yard may be much longer than in the ice-free period. More powerful tugs are needed, so the cost for towage is also higher.

According to the statistics of the Swedish Club from years 1988-1997 which was presented in (Hernqvist 1998), the 33 ice damage cases of this database of 1681 hull & machinery claims represented a 2 % share of the number of all cases. The costs of these ice related claims represented also a 2 % share of the total cost. The average cost of an

ice damage was about 350 000 USD, which is about 84 % of the average cost of all claims. It should be noted here that the average deductible in 1997 for hull & machinery claims was approximately 100 000 USD. Damage, which falls below the deductible is in most cases not brought to the Club's attention (Hernqvist 1998). The risk of damage to cargo in ice related accidents should be assessed separately.

Although the general impression of ice related accidents emphasizes strongly just the economical consequences related to the repair of structural (material) damage, it should not be forgotten, that each initial event or minor incident may, under a bit changed circumstances lead to more severe outcome. This reasoning is clarified in Table 17, which presents the worst case scenarios. In this study, the assessment of the probability of ice related accidents/incidents was based mainly on historical data, so a more precise assessment of the probability of the worst case scenarios is recommended to be performed in the near future.

6.5   RISK ACCEPTANCE CRITERIA

One important issue connected to the risk in general as well as the risk matrixes above, is the concept of risk acceptance or risk tolerability. Although some criteria for individual risk and societal risk related to loss of human life have been published, see e.g. (IMO MSC 72/16) and (Skjong 2003) the problems involved in the value of life are difficult. The tolerance limits in the case of human losses and environmental damage will probably develop continuously to a more demanding direction. This may be explained by the general growth of the gross domestic product per person per year and the life quality.

Approaches to take into account the effect of growth of welfare and life quality on the risk acceptance have been presented by e.g. (Skjong & Ronold 1998), in order to derive a general risk acceptance criteria in the case of human losses. In the case of oil spills risk acceptance has been discussed e.g. in (SEALOC 1998) and in (Friis-Hansen & Ditlevsen 2003). In this risk analysis the following risk acceptance criteria are applied: IMO MSC 72/16, in the case of the life loss of a crew member of a generic ship, and the criteria applied by (SEALOC 1998) when considering the transportation of dangerous goods.

It is always useful to find out the opinions of other stakeholders. The value of a clean nature is not necessarily a measurable quantity. Problems will probably develop if the gain from some operation and the negative consequences of risks involved (or the costs to have them in control), are separated and directed to completely different stakeholders. Such problems may be defeated by the application of Kaldor-Hicks Compensation Principle: "*A policy is to be socially beneficial if the gainers receive enough benefits that they can compensate the losers fully and still have some net gain left over*", see e.g. (Nathwani et al 1997).

Table 17   Ice related accidents/incidents and their worst possible consequences

Ice damages			
Hull damage	Rupture of plating	Loss of hull watertightness	Capsizing
	Damage to structures	Loss of hull watertightness	Sinking
		Loss of hull strength	Further damage
			Structural failure & fractures
			Breaking apart
			Oil spill
Rudder damage (or failure)	Reduced controllability	Possibility of hull damage in compressive ice	
		Possibility of grounding	(see Grounding)
		Possibility of collision	(see Collision)
Propeller damage (or failure)	No propulsion	Possibility of hull damage in compressive ice	
		Possibility of grounding	(see Grounding)
		Possibility of collision	(see Collision)
Thruster damage (or failure)	Reduced controllability	Possibility of grounding	(see Grounding)
		Possibility of collision	(see Collision)
Appendage damage	Rupture of appendages (e.g. bilge keel)	Loss of hull watertightness	Sinking
		Structural failure / fracture	Breaking apart
			Oil spill
Other ice related accidents/incidents			
Icing	Weight accumulation	Loss of stability, cargo shift	Capsizing
	Loss of freeboard	Possibility of green water loads	Sinking
	Loss of visibility	Possibility of collision	(see Collision)
		Possibility of grounding	(see Grounding)
Collision	Damage to hull plating	Loss of hull watertightness	Sinking/Capsizing
	Damage to hull structures	Loss of hull strength	Breaking apart
	Damage to outfitting	Partial loss of LSAs	Oil spill
		Partial loss of anchors & deck equipment	Fire/explosion
Grounding	Rupture of plating	Loss of hull watertightness	Sinking
	Damage to bottom		Capsizing
			Oil spill

The shipping industry as well as the national administrators and the classification societes seem to be rather accustomed to the occasional, minor structural hull ice damages, which are rather frequent in the winter navigation. These damages could be avoided by designing stronger ship structures, but the cost of this in the form of reduced payload may be higher than the cost of repair. On the other hand, in the light of accident statistics, the prevailing standards and level of winter navigation system in Finland and Sweden seem to be have been adequate so far to prevent major accidents, which could lead to environmental damage or loss of life. However, it should be reminded that this situation may change if some of the main parameters in the winter navigation are changed. It should also taken into account that the limited amount of data and the simplified linear risk models applied above may not be able to illustrate the full picture of the risk in

winter navigation. Therefore, these matters should be studied in full depth and width. The estimated risk levels based on this risk analysis are still uncertain in the case of hazards listed in the column at the right end of Table 17. More comprehensive risk models are needed to deal with the problem.

6.6   NEW RISK MODEL FOR THE WINTER NAVIGATION SYSTEM

Main elements of the winter navigation system, relevant information connected to it and the existing links and relations between the various issues in it are presented as a conceptual model in Figure 75 a). Most of the elements that are presented in this figure are directly or indirectly connected to the risks of winter navigation. Thus, Figure 75 a) may be understood as a collection of input data for the risk models. The connection to the risk models is presented in the form of the large arrows on the right side of the figure.
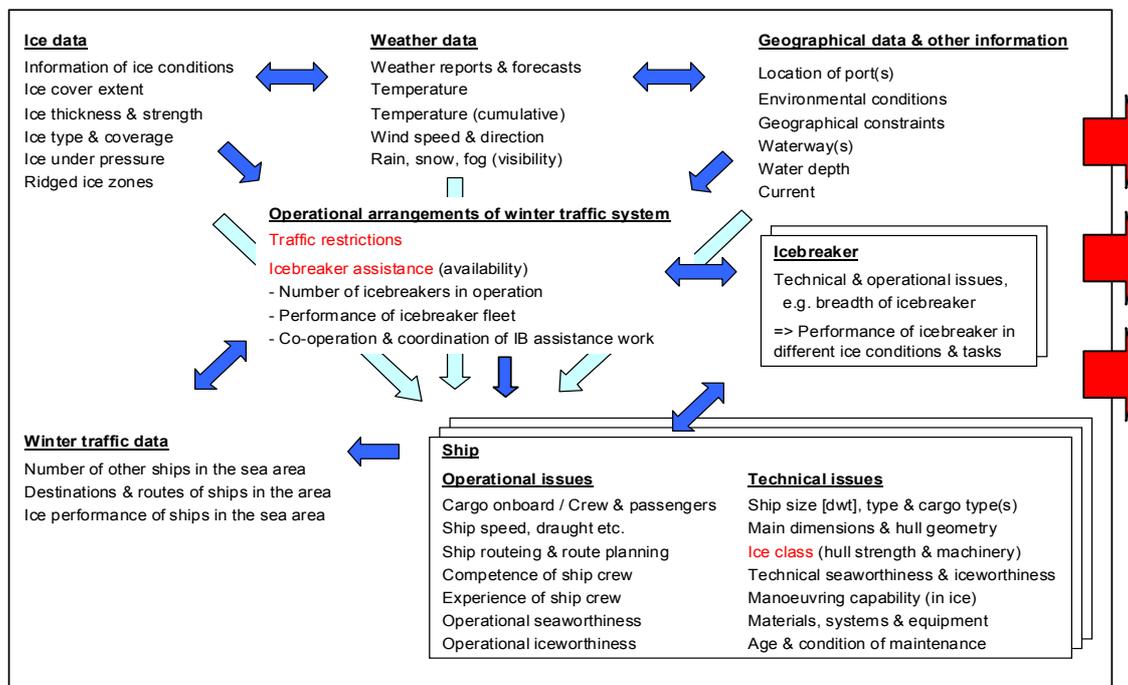
Figure 75 a) Input data needed for risk models of the winter navigation system

There are several factors affecting the system of winter navigation in the Baltic Sea. Firstly, there are the geographical and the environmental conditions. During the cold winter an ice cover will grow on the sea. However, the extent of the ice cover, see Figure 13, and its properties will vary a lot due to differences in meteorological conditions in the winters.
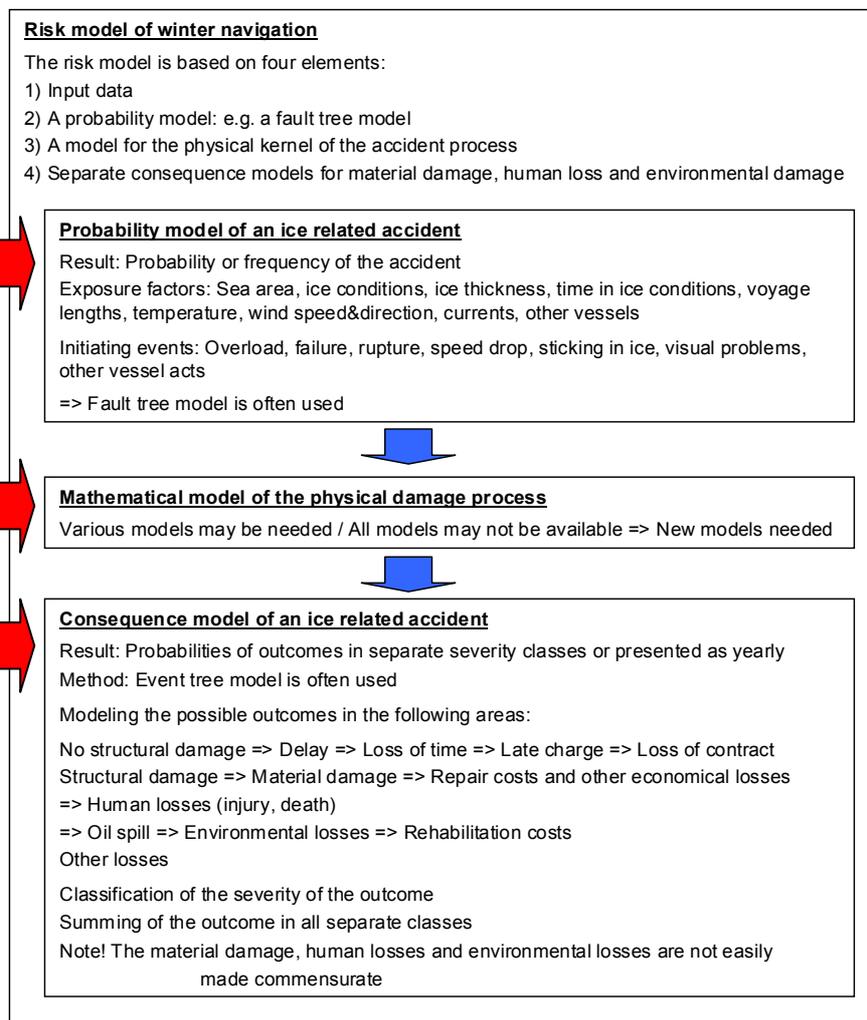
Figure 75 b) A general risk model of the winter navigation. Note! The total risk model of winter navigation system includes models for all relevant accident risks.

The outcome of this complicated system, consisting of the winter navigation system and the general risk model is, from the Administrator's point of view, the safety, which is measured indirectly by its opposite, the risk, and on the other hand the smooth flow of the ship traffic. The latter is much more easy to measure, e.g. by the evenness of the cargo flow. Deviations of the evenness are measured using a short time unit, e.g. in hours, when the ship arrives at port late of its schedule. Risk, on the contrary, is much more difficult to measure and verify, especially if the probability connected to it is small.

The main elements of this model are the severity of winter, which depends on the weather data and the ice data, winter traffic data, to and from the ports along the coast(s) plus the transit passages. It includes a large variety of different ships with a variable capacity, strength and power to operate in various ice conditions and the icebreaker fleet assisting

the merchant vessels, which need assistance. The complexity and the dynamics of this model make it difficult to present a quantitative model. Main controls of this model, available for the administrator, are the number of icebreakers and the traffic restrictions, which are based on the ice class and ship size (deadweight, as a measure of cargo capacity) of the merchant ships. From the industry's logistics point of view this kind of resrictions concerning ship size declared by the administrator may lead to a reduced level of efficiency, because the industry and its customers do usually prefer a steady flow of cargo instead of large separate quantities of cargo delivered at long time intervals.

The nature of model for the probability of ice related incidents /accidents is a complicated one, see Figures 75 and 76.
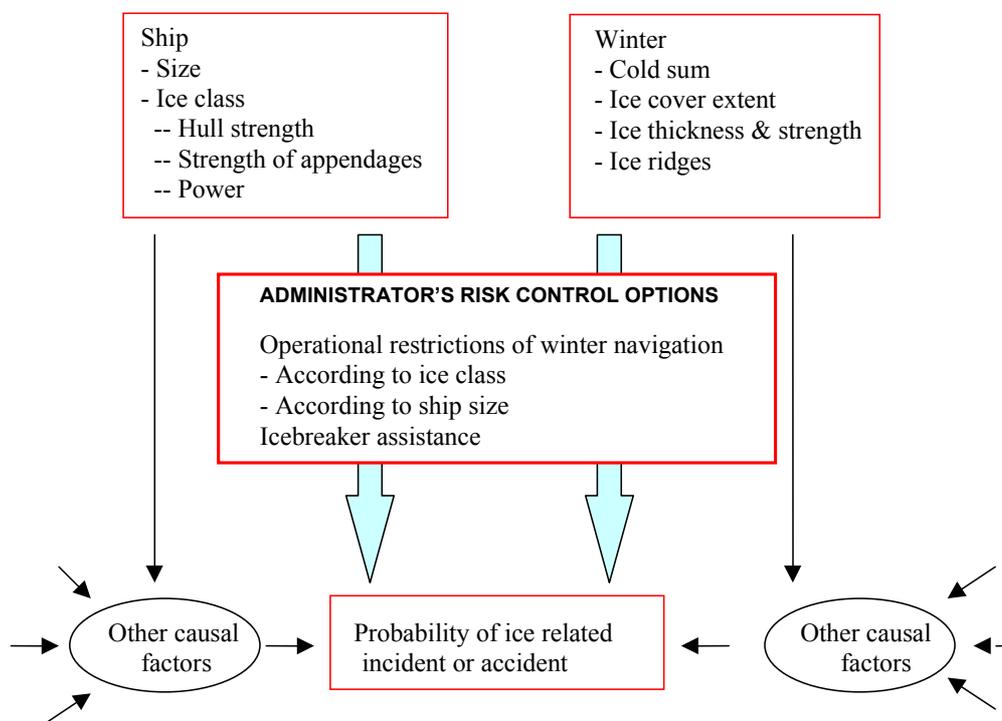
Figure 76   Factors having influence on the probability of ice related accidents

The experience of consequences of the ice related accidents in the Baltic Sea during the last 30 years has been rather promising. No large scale disasters have happened so far. In the time period 1971-1990 a total number of 135 ice related accidents was recorded by the Finnish Maritime Administration. This gives us an average of 7 cases per year. The consequences of these ice damages have been generally minor. The number of more serious hull damages in the same time period has been much smaller, roughly about 5 %

of the above cases. As far as it is known by the authors, only one or two ice related merchant ship losses[67] have occurred in the area in the last 40 years.

However, as it is emphasized in connection to the assessment of the probability of this kind of accidents, the dynamics of the system and the many affecting factors make the assessment difficult, especially in an environment under changes. The traffic patterns change, cargoes and their volumes change and so do the ships that are used for the transport. Ice class rules, which govern the ice strengthening and powering of the ships have been changed four times, in 1965, 1971, 1985 and 2002, in the last 40 years period.

It is not exactly known, what are the worst possible ice conditions in the Baltic Sea regarding ship safety. A common agreement for determining them might be useful. It is not known, if ships in the Baltic Sea have been exposed to the maximum ice loads involved with the most unfavourable conditions. It is difficult to estimate how large these extreme ice loads could be. Impact loads are better known due to the measurements that have been performed on various ships.

The ice loads in impacts depend on ship size, speed and the local shape of hull. The possible consequences of certain ice loads depend on the ship type, ship size and ship structures. Age of the ship and, in case of poor maintenance, excessive corrosion may have a considerable influence on the strength of the sructures. For these reasons it is a tedious task to generate a general risk model of winter navigation, being able to model the consequences of ice related accidents on a precise and reliable level in a changing environment (changing traffic patterns, ship types, cargoes and cargo volumes, new operators, portfolio of ice classes etc.). The restricted time reserved for this study was sufficient to conclude this work with a much more simple model.

A winter navigation risk model for a specific ship would differ from the above general risk model. On one hand such an approach giving more specific and hopefully more reliable results is more straightforfard, but on the other hand the price for using it has to be paid in the amount of necessary input data. In order to be able take into account e.g. differences in ice thickness and ice strengthening of the ship hull a collection of more sophisticated risk models are needed. One example of a conceptual model applying this kind of approach is presented in Appendix 7.

The risk model in Appendix 7 is presented in order to give some outlines for the development of the physical models that could be used for assessing the risk of structural damage. When the mechanisms between relevant input parameters, such as the environmental conditions, and the structural damage can be presented as a reliable formula or a calculation process, then it is much easier to assess all damage, potential environmental damage and human losses. Repeating calculations with different input parameters, e.g. data concerning structural design, valuable information of their effects can be produced.

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[67] The first on was the loss of Aspen in compressive ice in the Gulf of Riga in the winter 1963-1964, see case 1 in the ice related accident case descriptions. It should be pointed out also, that this ship was built in 1945. The second one was Salla, which burnt after collision with Abakanles in the Gulf of Finland in 1985.

This kind of approach is more laborious than e.g. the use of qualitative expert assessments, but according to the authors the former method is the only way to tackle and solve the problems connected to the risks with low probability and large consequences. Therefore, this approach is recommended as a basis for further research and development.

Although the knowledge and understanding regarding ice loads on ships has been developed a lot during the past years, see (Kujala et al 1994), this research has been mainly targeted on the reliability of ship, not necessarily so much on the safety (Varsta & Hanhirova 1997). The differences between reliability and safety are small, however. All problems concerning ship ice interaction and ice loads on ship have not yet been solved. The ultimate consequences of a certain high wind speed, e.g. a storm with $v_{wind} > 20$ m/s, and drift ice condition with a huge amount of ice (~ 40 km) drifting on to a ship with vertical sides and a double hull structure are not easily assessed.

The safety aspects, that have been taken into account in such studies as (Soininen 1983) and to a certain extent in the studies of (Kujala 1991), (Kujala 1994b), (Hänninen 2004) have to be strongly emphasized in the future research on ice loads on ship hull. An interesting approach to this topic has been presented e.g. in (Timofeyev 1995). In order to be able to assess the risks of winter navigation on a scientific basis, more research work is needed. Co-operation between researchers and various organisations is also needed.

7 RISK CONTROL OPTIONS

Maritime authorities have some tools to regulate the winter navigation, as it was indicated earlier. Traditionally, the Finnish icebreakers have been operated by the FMA and thus it has been easy to control the operational restrictions set by the same authority. Operational restrictions of winter navigation comprise of those, which are related to the ship size (based on deadweight, which is a measure of the cargo capacity of the vessel) and the ice class, by which the hull strength, strength of propeller(s) etc. and the machinery power of the vessel are regulated. One other important risk control option, related to winter navigation, is of course the ice information service of the Finnish Institute of Marine Research, which publishes the ice charts, as well as the weather reports and forecasts of the national weather service, The Finnish Meteorological Institute (FMI).

In the case of an accident, there are also several organisations being able to assist the ship and the persons aboard. Icebreakers, icebreaking tugs and patrol ships do have equipment for towing the ship. They have also extra pump capacity in case of leakage and some of them have also firefighting equipment that can be used in emergencies. In the case of an oil spill it is the Finnish Environment Institute (SYKE), and its Environmental Emergency Response Unit, which has a certain, although limited capability to collect spilled oil in ice conditions.

Thus, the following risk control options for winter navigation have been recognized:

	Operational	Structural
• Icebreaker assistance	x	(icebreakers)
• Ice class (= ice strengthening)		x
• Ice class restrictions	x	
• Ice charts	x	
• Weather forecasts	x	
• Oil spill combatting resources	x	(equipment)
• Firefighting equipment	x	(equipment)

When the ice conditions get more difficult during the winter, the number of ships operating in the northern areas of the Baltic Sea will be limited by the use of operational restrictions for ships of low ice classes and small size. Several examples of these limits and their development are given in the previous chapters. The number of ice related incidents and accidents gets lower partly purely due to the fact that the number of operating ships in the area is reduced. However, these restrictions do not usually step in force in the earliest days of the winter. So, the way how the winter proceeds and the necessary lag of time between the prevailing ice conditions and the coming into force of the tightening restrictions have also their effects in the number of these occasions.

Therefore, the ice strengthening, i.e. the ice class of the vessel, has also its own effect on the probability of ice related accidents. Ships with a low ice class are not allowed to operate in severe ice conditions. This kind of restrictions can be made by the authorities, managing the icebreakers, as well as by the operators of these merchant ships, the shipping companies, and the cargo owners and the insurance companies. Shipping is one of the oldest businesses dealing with risk-taking. From the administrators point of view, the number of ships operating in difficult ice conditions has to be limited from the the weakest ones. This is done in order to be able to guarantee icebreaker assistance for the ships with the best possibilities to operate safely and to keep the cargo and passenger traffic going on without troubles.

The restriction concerning the ice class and size of the assisted vessels forms a powerful tool, because most of the operators are not usually willing to put their vessels on the risk of being stuck in ice for long periods. However, these restrictions may have also such kind of an effect that ships with a low ice class may not have much ice damage during the most severe winters.

7.1 RESTRICTIONS TO TRAFFIC

A straightforward conclusion based on the findings regarding effects of ice class on the frequency of hull ice damage (Hänninen 2004), it might be assumed that a total restriction of traffic from ships in ice classes IC and IB, and below, would eliminate more than 90 % of the hull ice damages. However, in some of these cases the ice loads might have caused damage in vessels of ice class IA, too. On the other hand, the maximum ice loads are related to the equivalent ice thickness and distance travelled in ice, see (Kujala 1994). Therefore, if traffic restrictions concerning smaller ships in lower ice classes would not have been declared, the number of damage cases in the lower ice classes would probably have been clearly higher.

The ice damage statistics of a certain winter is a result of the winter navigation system affected by several parameters the values and combination of which are unique for each winter. The traffic restrictions are connected to the ice conditions, shares of ships in different ice classes and icebreaker assistance. Thus, it is difficult to assess quantitatively the efficiency of each risk control option separately.

Figure 77   Traffic restrictions are issued to some navigational areas and ports in the northern Baltic Sea due to difficult ice conditions (photo: M. Lensu).

It has been the duty of the Finnish Maritime Administration to take care of the safety management of winter navigation in Finnish waters, by providing icebreaker assistance, by issuing ice class rules and by declaring restrictions to navigation, if this has been considered necessary. If there is strong pressure to issue exemptions from resrictions to navigation, all their grounds should be transparently documented. Inclusively, in

connection with this kind of deviation from the regulatory principles, the possible increase in risk level should be assessed and balanced, e.g. with more efficient icebreaker assistance.

7.2   ICEBREAKER ASSISTANCE

Icebreaker assistance is an essential feature of winter navigation in the northern parts of the Baltic Sea. Even strong and powerful ships belonging to ice class IA Super do some-times need icebreaker assistance. As it has been refered by several authors, e.g. (Siivonen 1979), (Edelman 1986) and (Riska 2002), that this ice class, the highest one in the Finnish-Swedish ice class system, does not guarantee a total absence of ice damages in the Baltic Sea. According to (Hänninen 2004) about 10 % of the hull ice damage occured during icebreaker assistance. Unfortunately, there is no such information available that could be used in relation with this information to get a reliable numerical estimate of the effect of the icebreaker assistance.

Figure 78   Icebreaker Urho tows a merchant vessel in an old channel (photo:M.Lensu).

If an average ship speed of 10 kn in ice for a generic merchant vessel without icebreaker assistance is assumed and the mean voyage length in ice in winter 2002-2003 of about 120 nm is taken into account, the calculated average time in ice is about 12 hours. When multiplied with the number of port visits we get a rough estimate of the total time of all merchant vessels in ice, which is about: 2 × 10 000 ×12 hours = 240 000 hours. The total assistance time of the Finnish icebreaker fleet in winter 2002-2003 was about 12 000 hours. This is 5 % of the former value (240 000 hours). Even if the this rough estimate of the average time proportion (5 %) of the generic ship operated in the assistance of an

icebreaker and the 10 % proportion of hull ice damages occuring when the icebreaker is assisting would not be correct to state that the icebreaker assistance doubles the risk for hull ice damage. Icebreaker assistance is needed in the most difficult ice conditions, where the probability of damage is highest. Therefore it may be more correct just to assume that:

- the risk for hull ice damage is assumed to be much higher for a ship, which is not assisted by an efficient icebreaker than for a ship which gets assistance

The statement above can be justified by the experience from winter navigation in the northern Baltic Sea.

It should be reminded however, that icebreaker assistance may not be efficient in all possible ice and weather conditions. In the worst environmental conditions most of the merchant ships at sea may need the assistance of an icebreaker. However, the number of icebreakers is limited and it is not always possible to assist all vessels simultaneously. There are differencies in the main dimensions and engine power and other design features of icebreakers, which may make them more or less efficient for some modes of assistance operations. Comparisons between different types of icebreakers (Ierusalimsky & Tsoy 1994), have revealed surprisingly large differences in efficiency between icebreakers with different bow design but equal engine power. In critical ice conditions, e.g. such that prevailed in the previously described ice compression cases 1 and 2, any kind of deficiencies in icebreaker operability may be critical for safety.

Figure 79 A ship beset in compressive ice waiting for icebreaker assistance (photo:FMA).

Some other new icebreaker designs have been introduced in the northern Baltic Sea in the 80's and 90's. In this connection it may be necessary to point out that mission based design, see e.g. (Soininen 1990), is of utmost importance and that big differencies in design may produce an urgent need for the operators to get thoroughly acquainted with new operating methods required with the novelties in various ice conditions. Manoeuvres with a new type of icebreaker in close proximity of a merchant vessel, e.g. an oil tanker that has a large kinetic energy, can be critical, if collision risk is considered. Fortunately, most of the impacts have been with low energy and directed to the best protected parts of the vessels, the bow, ahead of the collision bulkhead, or the aft, which in icebreakers is protected by the structures of towing fork. However, in some new and more revolutionary icebreaker designs other efficient safety barriers may be needed.

Finally, we shall refer to the texts in (Siivonen 1979), which reminded that:

"*It was pointed out in the general definitions that even class* IA Super *could not withstand undamaged in all ice conditions along our coasts.*",

and to that in (Edelman 1986), which explains that:

"*It must be realized however that our aim has not been to make ships strong enough to withstand heavy jamming in the worst possible conditions.*"

and

"*Our regulations are intended for ships which are assisted by icebreakers in the Northern Baltic*".

Thus, efficient icebreaker assistance can be considered as an indispensable requirement for the safety of the winter navigation in the northern Baltic Sea. In order to be efficient the icebreakers should not be designed for fullfilling just one criterion, but to be able to guarantee safety in harsh and most severe ice conditions. This means that they should be able to withstand all ice loads, and to a certain extent collisions, too, without loosing their capability to assist winter navigation.

7.3   ICE CLASS

In the older ice damage data from 1984-87 (Kujala 1991), frame damage was found in about 17 % of the ships of ice class IA Super. The corresponding percentage in ice class IA was 23 %. Ice damage on the outer side plate was found in 26 % of the IA Super-ice class vessels and in 54 % of the IA-ice class vessels.

Based on a rough comparison of hull ice damages of ships in winter 2002-2003, see (Hänninen 2004), the following assumption can be made:

- the hull ice damage probability of ships in ice classes IC or II (= no strengthening) may be roughly about ten times higher than in ice classes IA Super or IA

This relation is specific to the severity of the winter, however and contains many simplifying assumptions. We might assume that in extremely severe ice conditions with ever increasing ice loads the probability of ice damage will approach 100 % in all ice classes. When more incident/accident data is gathered applying a systematic method, the possibilities to take into account the severity of the winter will increase. A sufficient database should include incident/accident data, verbal and illustrated descriptions of the incidents as well as the damage at least from mild, normal and severe winters. It should also include reliable information concerning the whole traffic data. This kind of database would support on its side the efforts to prepare a more reliable basis for quantitative assessment of the influence of the ice class on the risk

7.4   ICE CHARTS & WEATHER FORECASTS

The information concerning ice conditions and the weather is of great value for the winter navigation. Decisions concerning ship routeing should be based on reliable and up-to-date information. In winter navigation it is recommended to take full advantage of the use of leads and other areas that are more easy to navigate. It is extremely difficult to make a quantitative assessment of the general efficiency of ice charts, see Figure 80, and weather forecasts, see Figure 81, although it is clear that they provide important information for the seafarers. Therefore, it is assumed only roughly that their effect may drop the probability and consequences of ice related accidents/incidents by some percents.

On the other hand, the costs connected to these risk control options are minimal (when compared some other risk control options), so full use of them is recommended.

7.5   OIL SPILL COMBATTING RESOURCES

At the moment the possibilities to combat oil spills in ice covered seas are rather limited. Therefore, there is a need for development of equipment that would perform well and efficiently in the various ice conditions that can be considered in this respect. The requirements of a suitable equipment for this kind of work in Finland have been dealt e.g. by Jolma (1999 and 2002) and Lahtinen (1999). A recent view on this matter has been presented also in (LVM, 2003), where the possibilities to combine icebreaking and oil combatting tasks were discussed.

Recently, some new oil combatting equipment designed to be used in ice conditions has been installed to a modified buoy handling vessel *Seili* in Finland and similar type of modification work (to a vessel to be eqipped with an oil collecting equipment) of some other vessels shall be done in the years 2004 and 2005 (HS 2004). However, although this addition to the equipment is necessary, it is probably not sufficient in the case of a major accident.

Figure 80   An example of an ice chart with an overview of the ice conditions in the
             Baltic Sea area in the 12.3.1987 (FIMR 1987) by the courtesy of J.Vainio.

Figure 81 An example of a sea weather forecast for the southern Baltic Sea (FMI 2004).

7.6   FIREFIGHTING EQUIPMENT

At the moment the possibilities to assist in combatting ship fires in ice covered seas are rather limited. Some of the new icebreakers and icebreaking tugs are equipped with the equipment needed for this purpose, but not all of them. Therefore, it is recommended to install such equipment for all those icebreakers, that might need it, if a separate study concerning the costs and benefits involved would support such a decision. The availability of extra pump capacity is important in the case of a flooding.

7.7   OTHER OPTIONS

The above risk control options were limited to the scope that is controlled by the Administrator. However, there are several other effective risk control options, many of them especially on the side of the other parties of winter navigation. As it has been stated earlier, the operative side, e.g. the shipping companies, is important. This risk assessment was a limited one, so the benefits of e.g. an experienced ship crew and all other risk contributing factors are beyond the scope of this study.

The Ice Passport system, which is used in Russia, has been an alternative risk control option when compared to the present Finnish-Swedish winter navigation system. The Ice Passport is a large, informative document, based on thorough theoretical calculations and considerations of the strength of the vessel and the ice loads it may encounter. At its best it will probably give good advice for the navigators of the ship concerning what the ship can tolerate. It has several advantages, such as the valuable information to the operators concerning safe and dangerous speeds in some specified ice conditions. The information about safe distances between ships in a convoy in various ice conditions seems to be a valuable tool, too.

However, one problem with the Ice Passport seems to be the correct definition of the prevailing ice conditions. The assessment of the local ice thickness for instance is not an easy task, unless the ship is stopped and someone goes on the ice and measures the thickness. The combination of a low ice class and a human or organisational error, deliberate deviations from the allowed and safe speed level are also realities, which may be difficult to exclude totally. In a typical situation, when the ice condition is severe enough to stop the ship and ice starts pressing hard on the side of the vessel, as in Figure 79, the structural strength of the ship may become a crucial question. Waiting times for icebreaker assistance may become long in difficult ice conditions. According to an interview of the Head of ice operations at the St. Petersburg maritime administration from last winter regarding the requirements for entering the port of St Petersburg, "*the main reason for introducing additional restrictions to navigation was the lack of initiative from the ship owners in obtaining ice certificates and passports for vessels calling at St Petersburg*" (FP 2003).

Training and getting both theoretical and practical knowledge of the peculiarities of winter navigation is another risk control option. In some cases such a combination might be a very useful risk management tool, but not without some other risk control options (RCO's).

Advice from an experienced icebreaker captain and real-time (online) measurements of stresses on ship hull are other RCO's, which are parallel to the Ice passport. However, a quantitative assessment of the benefits of such RCO's, or their comparison to the Ice Passport system would be a very difficult task. Therefore, theoretical work, calculation methods and computer programs for these kind of comparisons should be developed.

8   RESULTS

The results of this risk analysis are based on information about ice- or winter-related marine accidents and incidents, a large portion of which was gathered during winter 2002-2003. However, older ice related accident/incident and damage statistics was also utilized. In addition to the information concerning past accident cases several other resources were used. One source of information was a recent study, during which a hazard identification process performed by a panel of experts was realized.

The main results of this risk assessment are as follows:

The recent historical risk level concerning ice related accidents in the last 30 years in the northern Baltic Sea is low. Accidents and incidents, such as hull ice damage or propeller ice damage may occur rather frequently, but the consequences have been generally limited to minor material damage. This finding is not a new one, it is familiar to all persons who are involved with winter navigation. During a period of 20 years with rather normal winters (1971-1990) the average number of ice related accidents in Finnish waters was annually about 7. Over 95 % of these accident or incident cases had consequences that could be classified as minor damage or no damage at all. Structural damage due to ice loads on ship hull have been observed, but the "damage" is often just a dent on the side plating. No ships have been lost in the Finnish waters due to this reason during that period or after it.

The number of ice related accident and incident cases depends on the extent of ice cover, but in a rather interesting way. In mild winters the number of cases is low, because of the absence of ice cover along the main routes of navigation. When the maximum extent of ice cover increases a level above 120 000 – 140 000 km^2, the number of ice related accidents can increase to it's full magnitude, see Figure 69. At this stage there is enough ice to cause troubles, and due to the partly open sea areas the dynamic effects of the drifting ice and pack ice can be a reason to big troubles. When the sea areas get totally frozen, the mean ice thickness along shipping routes grow, but the adverse effects of dynamic ice masses do not necessarily grow as much if wind speed remains at a normal, low level.

Based on the damage statistics from winter 2002-2003 in the northern Baltic Sea and the corresponding traffic patterns, proportions of merchant ship ice classes and number of assisting icebreakers the following rough estimates of ice related accident/incident probabilities[68] have been made:

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[68]   Note! These frequencies are related to one generic ship, the length of the distance travelled in ice and the average ice thickness. Estimated number of damage cases for one winter can be obtained by multiplying the presented frequency by the number of port visits, average distance traveled in ice and the mean ice thickness. The estimated number of accidents/incidents considering all traffic is obtained in a similar way.

Table 18   The probability of various types of accidents/incidents for a generic vessel
            (all consequence classes included) assessed in this risk assessment based
            mainly on the accident/incident statistics in winter 2002-2003.

Type of accident/ incident	Probability of accident / incident	Probability of total loss	Probability of fatalities	Probability of pollution
	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
per (distance traveled in ice conditions [nm]) $\times$ (ice thickness [m])				
Hull ice damage	20 - 33	$0.2 - 0.3$	$0.01 - 0.1$	$0.25 - 0.5$
Collision	~ 20	$0.3 - 0.4$	~ 0.11	~ 0.16
Grounding	2 - 4	0.02-0.08	$0.004 - 0.016$	$0.12 - 0.4$
Note! In the case of collision and grounding only such cases that take place in the ice conditions or are directly or indirectly related to ice or snowfall are included.				

8.1   RISK OF A FATAL ACCIDENT

Thus, based on these results it can be stated that in the case of a generic ship collision is
deduced to form the greatest risk when the risk of a casualty with fatalities is considered.
The estimated risk level is equal to about one collision with at least one potential fatality,
or 10 injuries, in about 12-13 years depending on the winters. Here it is assumed that the
winters in the near future do not differ from those in the period 1982-2003.

The assessed risk of a fatal accident in winter navigation in the northern Baltic Sea as a
function of the severity of the winter is presented in Figure 82 in the case of hull ice
damage, collision and grounding. Although the collision risk is highest, the hull ice
damage is not so far below it. According to the collision and grounding statistics
presented earlier e.g. in Figures 69 and 70 the assumption of the relationship between the
severity of the winter and the accident frequency may not be correct. Therefore, the
dotted parallelograms which have drawn in Figue 82 to illustrate both the uncertainties of
the risk estimates and the change of the risk in relationship with the severity of the winter
have been adjusted to be more even.

The risk of a fatal accident in the case of a grounding seems to be rather low, when
compared to the collision and hull ice damage. However, a few fatal accidents may
dramatically change the assessed risk. The quantitative risk assessment carried out in this
report did not take into account e.g. the recent fatal grounding cases in Norway (in 1999
and in 2004). Therefore, in the case of ship grounding the height of the dotted
parallelogram which expresses the uncertainty of the assessed risk extends to a larger
area than in the case of hull ice damage and collision. It is the view of the authors that the
risk of a fatal grounding may be underestimated if solely based on statistics. However,

due to the typical characteristics of this accident the risk of a fatal accident in this case seems still, even if adjusted upwards, to remain below the corresponding risk levels of collision and hull ice damage.

The number of people onboard was not taken into account as the target of this risk analysis was a generic ship. So, the assessment of the number fatalities was not made. This task requires a separate, more comprehensive study to be made, including an assessment of the evacuation in winter conditions. There are many sources of uncertainty in the above assessment, however. Several assumptions have been made. Due to the timetable of this study the necessary theoretical methods for a more detailed analysis have not been yet fully developed or applied.
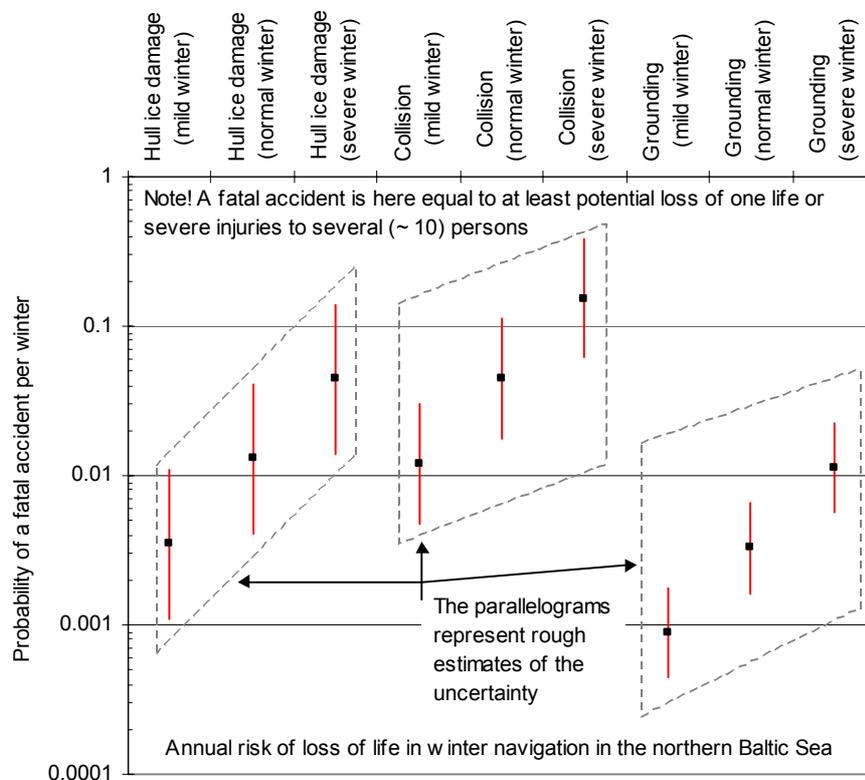
Figure 82   Risk of a fatal accident in winter navigation in the northern Baltic Sea in the case of hull ice damage, ice related collision and grounding. Estimates are presented separately for a mild, a normal and a severe winter[69]. Note! This risk level represents the risk considering the whole winter navigation, it is not the risk of a single ship.

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[69] It is assumed here that the environmental and traffic parameters of these winters are as in Table 16.

8.2   RISK OF POLLUTION

The probability of an environmental damage in the case of a generic ship is estimated to be at greatest in the case of hull ice damage and grounding. According to this risk assessment the risk of pollution is almost the same in the three accident types, see figure 83. The combined risk level is equal to about one oil spill per ~ 2 years, if spills of all size categories due to hull ice damage, collision and grounding are all taken into account.

The risk of a major environmental disaster in ice conditions is not possible to be assessed with the traditional method of using accident/incident statistics, as there is a lack of data concerning relevant cases. It is the opinion of the authors that such a risk assessment taking into consideration the ship design and the ice class category should be performed within a longer time and by using the best available theoretical tools. This was not possible within the scope of this analysis. The need for a broader co-operation with many organisations is also recognized so this kind of a more focused and more detailed risk analysis should possibly be performed as an application of a Formal Safety Assessment (FSA), where the risk of pollution in winter navigation could form one part of the wide risk entity.
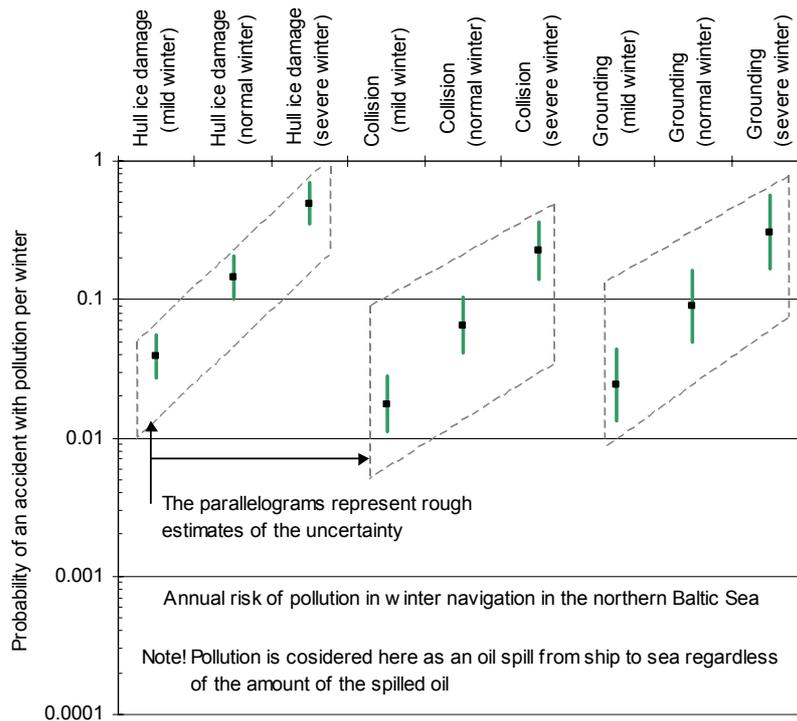
Figure 83   Risk of an accident/incident with pollution in winter navigation in the northern Baltic Sea in the case of a hull ice damage, an ice related collision case and an ice related grounding case. Estimated risk level (an accident/ incident with pollution per winter) is presented here separately for a mild, normal and severe winter[67].

8.3   RISK OF TOTAL LOSS

The assessed quantitative risk of a total loss in winter navigation in the northern Baltic Sea is presented in Figure 84.
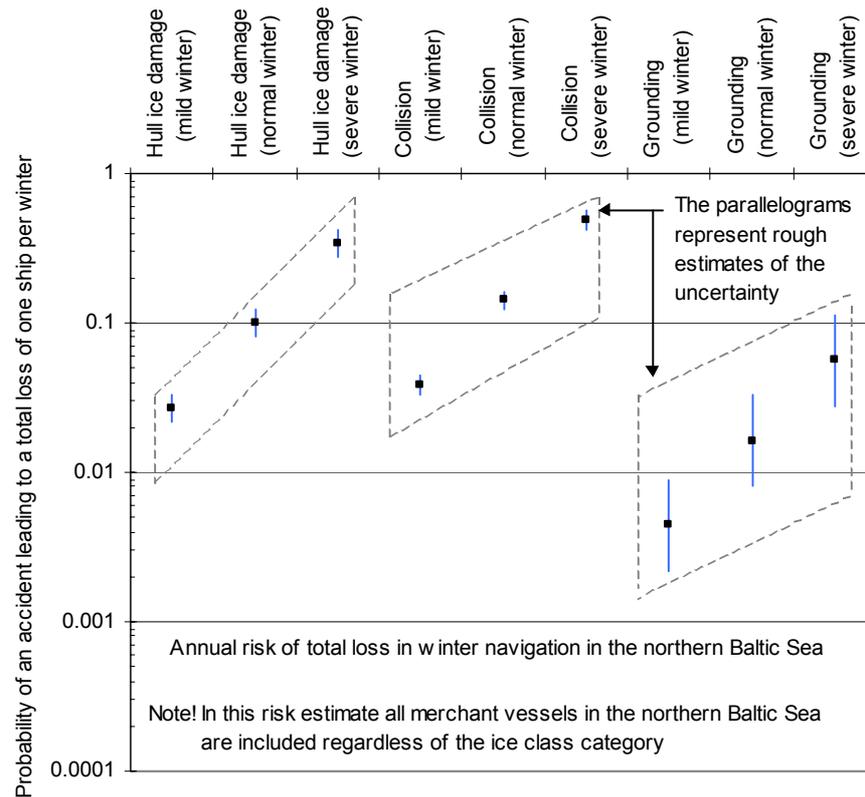
Figure 84   Risk of a total loss of a generic ship in winter navigation in the northern Baltic Sea in the case of hull ice damage, ice related collision and grounding. Estimated risk level (a total loss per winter) is presented here separately for a mild, normal and severe winter[67]. Note! This risk level represents the risk considering the whole winter navigation, it is not the risk of a single ship.

The risk assessment of a total loss in the case of an ice related grounding, where the ship drifts on rocks due to ice drift, is included in the above assessment. However, there is a lack of sufficient information concerning hull damages in such cases. This scenario is an important one, but without sufficient knowledge or related research results it's more detailed analysis and assessment is left for the future.

8.4   RISK OF OTHER DAMAGE

The probability of propeller ice damage (all consequence classes included) is not included in Table 18 above as it does not directly have other that material and economical consequences. In this risk assessment it is estimated that the probability of a propeller damage in ice is roughly about:

- 30×10^{-6} propeller ice damage cases / (nautical mile × m)

In the mild winter[70] this risk would be roughly equal to about 3 cases of propeller damage, in the normal winter to about 12 cases of propeller damage and in the severe winter to about 42 cases of propeller damage. The last values, based mainly on the damage statistics from winter 2002-2003, seem to be high if compared with the data from winters 1984-1987, but it should be taken into account that the basis of the new risk assessment is wider including several ships in low ice classes. It should be noted that some of these propeller damage cases may act as a contributing factor to a hull ice damage or a drift grounding, if the ice field moves and there is no immediate assistance available

The probability of a rudder ice damage in winter navigation in the northern Baltic Sea is estimated to be (all consequence classes included) about:

- 8×10^{-6} rudder ice damage cases / (nautical mile × m)

In a mild winter this risk would be roughly equal to possibly 1 case of rudder damage, in a normal winter to about 3 cases of rudder damage and in a severe winter to about 11 cases of rudder damage.

The probability of a machinery damage in ice in winter navigation in the northern Baltic Sea is estimated to be (all consequence classes included) about:

- 0.6×10^{-6} - 6.3×10^{-6} rudder ice damage cases / (nautical mile × m)

This risk is roughly equal to about one case of machinery damage in about 1-14 mild winters, in a normal winter to about 0-3 cases and in a severe winter up to about 9 cases of machinery damage.

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[70] See definitions of these three types of winter in Table 15.

9   SUMMARY

In this report, the risk of winter navigation in the northern Baltic Sea has been assessed. This work started with the description of the object of the study. Winter navigation is a large system with many operators: the authorities (FMA), icebreakers, a large number of shipping companies and their fleets of vessels with (or without) various ice classes. The environment is an essential element in this context. Consecutive winters are not like each other and the routes of low pressure areas from the Atlantic ocean to the east have an important role controlling the conditions of winter. Thus, local time-dependent conditions do have a large effect on the risks.

A general conclusion of the traditional winter navigation in the northern Baltic Sea, such as it has been e.g. in the period 1975-2000, is that it is connected to a rather small risk level. The average frequency of ice related accidents, incidents and damages among the ships in winter navigation is significant, but, on the other hand the expected consequences are generally not severe. The risk of loss of life seems to be low, if the accident statistics from the past years is reviewed. However, just considering a few real accidents in unfavourable winter conditions, the need for the development of life-saving appliances, evacuation and rescue methods is obvious.

The risk for a hull ice damage for a generic ship, related to the product of the average length of voyage in ice and the average ice thickness, was assessed quantitatively on the basis of similar accidents/incidents in winter 2002-2003. It's numerical value for a generic ship is about

- 21×10^{-6} cases / (travelled length in ice in nautical miles $\times$ ice thickness in meters)

The risk for a hull ice damage leading to a total loss of the ship is assumed to be in the following range:

- $0.2 \times 10^{-6} - 0.3 \times 10^{-6}$ cases / (travelled length in ice in nautical miles $\times$ ice thickness in meters)

Older vessels with weared/corroded hull structures or vessels with a low ice class are at special risk.

- The repair cost per ice related accident damage is in the range of 100 000 - 150 000 € on average, but the variation between different cases is large

The total risk of winter navigation is composed of three main categories. These are: the risk to people, risk to the environment and the risk to the property. If the results of this risk analysis are put together we can present the assessment of the risk in these three different areas in the form of a table, where the probability/frequency of three different consequences is presented as a function of the severity of the winter. This is done in Table 19 below:

Table 19 The risk of winter navigation in the northern Baltic Sea. Note! This risk assessment includes the risk of ice damage, the risk of collision and the risk of grounding (when ice or heavy snowfall is a contributing factor). The characteristic parameters for the mild, normal and severe winter are assumed to be the same as in Table 16.

	Fatalities (one or more)*	Pollution (minor-)	Total loss
Mild winter	One time in 40-75 years	One time in 8-17 years	One time in 12-20 years
Normal winter	One time in 10-20 years	One time in 2-5 years	One time in 3-5 years
Severe winter	One time in 3-6 years	**Yearly**	**One time in 1-2 years**

* Note! It is assumed here that one fatality is equivalent to 10 injuries

As can be seen from Table 19 the risk of pollution or material damage (= damage to property) is higher than the risk for people. If the assessed values of the risk level in each category is correct, it seems to be somewhat higher than what might be expected. Therefore it is important to assess the validity of this assessment and to use effectively the available risk control options.

There are many uncertainties and assumptions that have influence on the results which are presented in Table 19. One of the major sources of error are probably the assumption of the linear relationship between all parameters and the continuity. Here it is assumed for instance that the proportions of the ships in different ice class categories remain the same as they have been in winter 2002-2003. Thus, when calculating the quantitative estimates of the risk that are presented in Table 19 it is assumed that the winter navigation is carried out by a large fleet of vessels with certain percentages of these vessels belonging to ice classes IA Super, IA, IB, IC and II.

Some of these vessels are better prepared to encounter the hazards of winter navigation than the others due to the differencies in the design and operation so it is possible to state and expect that the risk is not equally distributed to all these ships if the operating time and area is the same. Thus, it is more probable that the ship suffering a total loss due to hull ice damage in a severe winter is one of the vessels in the ice class category II than a vessel with an ice class IA or IA Super. However, even the latter may get badly damaged e.g. in a collision or grounding. Old and corroded vessels are at special risk even if they have managed to keep their class. Port State Control and

Another important assumption, which the risk estimates in Table 19 are based on, is that the risk control options, ice class, traffic regulations and icebreaker assistance are in use as they have been in use in the previous period of about 20 years in Finland. The risk models used do not allow major changes in the effects of the risk control options although some parameter studies are possible to be performed.

The traditional risk control options for winter navigation[71] are efficient, but the intrinsic possibility of a common cause accident due to suddenly changing extreme weather

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[71] Icebreakers, traffic restrictions and ice strengthening of merchant ships

conditions may hamper all efforts as it affects simultaneously on all merchant vessels in a sea area. Therefore, the importance of reliable ice and weather reports/forecasts and their reasonable use for ship route planning and scheduling is obvious.

This kind of risk assessment, which concerns such a large and complicated system as the winter navigation on a rather large sea area with several hundreds of different ships, is problematic in that sense that it is quite heterogeneous and, on the other hand, the system is highly dynamic. Thus, the sensitivity of the risk model for small disturbances may be high. Therefore, there is risk of winter navigation needs more research.

10   RECOMMENDATIONS

Due to the limitations set for this work the development of a full risk model for winter navigation has not yet been completed. The scope of risks in winter navigation is wide. Many problems in the area are not solved yet. Thus, instead of an approach utilizing purely scientific basis there has been left still some room for approximations, assumptions and subjective views in this risk assessment. Therefore, this risk assessment should be considered as a preliminary work. During this study it was found that there are some important topics with lack of reliable/sufficient information. One of them concerns the probability of the most dangerous ice damages, e.g. hull ice damages with ruptures and leakages in the watertight compartments of the ship. The acquisition of reliable information related to this topic is an important matter. Therefore it is recommended that

- the collection of detailed winter related accident and incident data is continued so that the scope and depth of information for future risk analysis is increased.

Ship owners, both domestic and foreign, classification societies, insurers and national regulatory bodies should be encouraged to get all information and data concerning incidents, accidents and damage combined to form a strong and reliable basis for future risk analysis. Data from a large number of ships representing all ice classes should be collected using a systematic method. Relevant data includes the operating area of the ship, the number of days navigating in ice during mild, normal and severe winters and the ice conditions encountered. This is a straightforward method to reduce uncertainty in the risk assessments in the future. Confidentiality of some of the information should not be a hinder for the work for safety.

It is also recommended, that the prevailing weather and ice conditions at the time of any ice related accident should be documented in a more detailed way. A more detailed description of the situation, including the existence, and method, or lack of icebreaker assistance is also needed.

Ice compression was the contributing factor in about 20 % of the hull ice damage cases in winter 2002-2003. A theoretical study concerning the ultimate strength and safety of a vessel in compressive ice, including the rupture of outer hull as well as the rupture of the

inner hull would greatly increase the knowledge. Experiments and theoretical modeling are useful tools to be applied when creating new knowledge in this area. Therefore,

- theoretical and experimental studies concerning the ultimate strength of ship structures in compressive ice should be performed

This is important in order to increase understanding what is possible and what is not in the case of worst case scenarios. In addition to that

- the behaviour of a ship, e.g. a large tanker, in drift ice / compressive ice conditions, and the ice-ship interaction should be studied, e.g. by performing model tests, to clarify and reveal possible mechanisms that can be dangerous for the environmental safety

and to increase the accuracy of the risk assessments

- the probability of extreme environmental conditions, e.g. combinations of hazardous ice conditions, stormy winds, low temperature, etc. should be gathered to form a basis for assessing the probability of compressive ice, drift grounding and icing.

Finally,

- Formal Safety Assessment, FSA, for winter navigation is recommended

This would be a demanding task, however, and should therefore to be realized at least as a long term project (e.g. at least 3-5 years) to have good opportunities to develop sufficient databases, to design and perform the necessary experimental work, if needed, and to develop the required theoretical tools. A stepwise approach to reach the goal with close co-operation with the relevant authorities and other organisations would probably be useful and recommendable in this respect. International co-operation is also important to come to terms concerning the risk involved in winter navigation in the Baltic Sea and sufficient methods to manage it.

The nature of the risk of winter navigation is complicated. With a scientific approach and patient work the prerequisites for it's understanding and it's quantitative assessment can be improved. In the meantime, risk assessments based mainly on accident/incident statistics and expert judgements are applicable.

11   ACKNOWLEDGEMENTS

12   REFERENCES

ANR, 1984/1985: Merchant Marine meets Ice with new Tactic. Arctic News Record – Fall/Winter 1984/1985, p. 34.

Appolonov, E. & Nesterov, A, 1995: The investigation of ice damages and increasing of demand to the ice strength of Arctic vessels. 13th International Conference on Port and Ocean Engineering under Arctic Condition, August 15.-18. 1995, Murmansk, Vol. 1, p. 42-51.

Appolonov, E., Nesterov, A, Stepanov, I. & Timofeev, O., 1995: The Way of Reglementation for Allowable Ice Condition for Navigating in Ice in the Frame of Demands to the Arctic Class of Arctic Ships. 13th International Conference on Port and Ocean Engineering under Arctic Condition, August 15.-18. 1995, Murmansk, Vol. 1, p. 52-61.

Arpiainen, M., Bäckström, M. and Suojanen, R.-A., 1999: Revolutionary oblique icebreaker. POAC'1999, Vol. 2, pp. 552-560.

Babtsev, V.A., Batskich, Y.M. and Trjaskin, V.N., 1995: Damages of Icebreakers and Transport Vessels in Russian Arctic. 13th International Conference on Port and Ocean Engineering under Arctic Condition, August 15.-18. 1995, Murmansk, Vol. 2, p. 3-20.

Beckman, L.: Ice damages have increased. Navigator nr. 12, 1971, pp. 16-17.

Benkovsky, D., Galver, G., Korobtsov, I. and Oganezov, G.: Technology of Ship Repairing. MIR Publishers, Moscow, p. 21. (Note! Printing year is not given!)

Blenner, H. & Ohrelius, B.: Isbrytare. Stockholm, 1960. (In Swedish)

The Baltic Sea University, 2004. Baltic University Programme, Environmental Science. Presented (2.2.2004) in the internet web-page: http://www.balticuniv.uu.se/environmentalscience/ch5/chapter5_g.htm

Corlett, E.C.B., Colman, J.C. & Hendy, N.R.: Kurdistan - The Anatomy of a Marine Disaster. The Royal Institution of Naval Architects, RINA 1987, p. 1-20.

Daley, C., Tuhkuri, J. and Riska, K.: The role of discrete failures in local ice loads. Cold regions Science and Technology 27 (1998), p. 197-211.

DesRochers, C., Crocker, E.J., Bayly, I., 1994: Post-yield Buckling of Stiffened Panel Structures. The Society of Naval Architects and Marine Engineers, Icetech '94, Calgary, Canada, March 1994, p. K1-K11.

DNV, 1999: Historical Risk Levels in the Maritime Industry. Det Norske Veritas, Technical Report No. 99-2028, Revision no. 01, Hovik, Norway, 1999, 63 p. + app. 35 p.

Drebs, A., Nordlund, A., Karlsson, P., Helminen, J., Rissanen, P., 2002: Climatological Statistics of Finland 1971-2000. Finnish Meteorological Institute, Climatic Satistics of Finland 2002:1,Helsinki, 2002.

Edelman, G., 1984: Updating the Finnish-Swedish Ice Class Rules. VTT Symposium 52, Ship Strength and Winter Navigation, organized by the Technical Research Centre of Finland, Ship Laboratory, Espoo, January 10-11, 1984.

Enkvist, E. 1974: Ships resistance in ice. Styrelsen för vintersjöfartsforskning, Forskningsrapport nr 5, Sjöfartsverket Sverige & Sjöfartsstyrelsen Finland, Helsingfors, 1974. (In Swedish).

EUCC, 2002: Baltic Sea Regional Overview. EUCC - The Coastal Union, September 2002. Presented in internet, web-page:
http://www.coastalguide.org/icm/baltic/index.html

Federley, H., 2004: Ship traffic in foreign trade during period of traffic restrictions in winters 1982-1990. E-mail message dated 25.2.2004.

FIMR, 2002: Finnish Institute of Marine Research – Variations in sea water level. The Internet Web-page of Finnish Institute of Marine Research, 14.12.2002 at address: http://www2.fimr.fi/fi/palvelut/aallokko-vedenkorkeus/vedenkorkeusvaihtelu.html (In Finnish)

FMA 1971-2002: The yearly statistics. Finnish Maritime Administration, Several issues, one for each year 1971, 1972, … , 2002. (In Finnish)

FMA, 1979: Observation of hull ice damages in ships in winter navigation. (Talviliikenteessä olevien alusten runkovaurioiden tarkkailu.) Merenkulkulainsäädäntö. 24/Talvimerenkulku, Annettu merenkulkuhallituksessa 9.4.1968. Merenkulkuhallitus, Valtion painatuskeskus, Helsinki 1979, s. 1183-1184. (In Finnish).

FMA, 1996: Accident analysis 1982-1994; Groundings and collisions. Finnish Maritime Administration, Department of Fairways, Helsinki 1996 (In Finnish).

FMA, 2001: Accident analysis 1990-2000. Finnish Maritime Administration, Publication 7/2001, Helsinki 2001 (In Finnish).

FMA, 2002a: Finnish-Swedish Ice Class Rules. Finnish Maritime Administration, Bulletin No. 13/1.10.2002. Finnish Maritime Administration, Helsinki.

FMA, 2002b: Sea Ice Nomenclature, English-Finnish-Swedish-Estonian-Russian. Merenkulkulaitos, Merenkulkulaitoksen julkaisuja 5/2002, Helsinki, 2002.

FMA, 2004a: Shipping statistics. January, March and April 2003. Finnish Maritime Administration, 2003. ISSN 1236-1178. (In Finnish and Swedish)

FMA, 2004b: 9. Ship traffic to Finnish ports. Updated 29.1.2004. Available (6.2.2004) in internet-page: http://www.fma.fi/palvelut/tietopalvelut/tilastot/kk/kk9.htm

FMA, 2004c: Ship traffic to Finnish ports in years 1960-2002. Updated 5.5.2003. Available (6.2.2004) in internet-page:
http://www.fma.fi/palvelut/tietopalvelut/tilastot/alus/mltw.htm

FMA, 2004d: Sea transportation growth over 6 million tons, passenger traffic slightly declined. FMA Publications, Updated 31.1.2004. Available (6.2.2004) in internet-page: http://www.fma.fi/tietopalvelut/tiedotteet, (In Finnish)

FMA, 2004e: Ship traffic in foreign trade during period of traffic restrictions in winters 1990-2003. Updated 9.3.2004. Available (16.3.2004) in internet-page: http://www.fma.fi/palvelut/tietopalvelut/tilastot/talvil.htm. (In Finnish)

FMA, 2004f: Development of the Winter Navigation in Finland. A simulation tool for the assessment of the need for icebreakers. Finnish Maritime Administration. Publication 2/2004, 9.2.2004. (In Finnish)

FMI, 1988: Climatological data 1987. Finnish Meteorological Institute, Helsinki, 1988.

FMI, 2002/2003: Climate review. Finnish Meteorological Institute, November 2002 – April 2003. (In Finnish)

FMI, 2003: Finnish Meteorological Institute – Weather and Climate – Climate statistics – Storms in Finland. The Internet Web-page of Finnish Meteorological Institute,

21.11.2003 at address: http://www.fmi.fi/saa/tilastot_20.html and
http://www.fmi.fi/saa/tilastot_21.html (in Finnish).

FMI, 2004a: Finnish Meteorological Institute – Weather and climate – Climate statistics
– Months. The Internet Web-page of Finnish Meteorological Institute, available on
31.1.2004 at address: http://www.fmi.fi/saa/tilastot_65.html,
http://www.fmi.fi/saa/tilastot_66.html, http://www.fmi.fi/saa/tilastot_51.html,
http://www.fmi.fi/saa/tilastot_52.html, http://www.fmi.fi/saa/tilastot_57.html and
http://www.fmi.fi/saa/tilastot_58.html. (in Finnish)

FMI, 2004b: Finnish Meteorological Institute – Weather and climate – Climate statistics
– Stormdays in sea areas, days of hard and gale-force wind. The Internet Web-page of
Finnish Meteorological Institute, available on 22.1.2004 at address:
http://www.fmi.fi/saa/tilastot_20.html. (in Finnish)

FP, 2003: St Petersburg gets tough on ice. Fairplay, News Focus, April 24, 2003, p. 23.

Friis-Hansen, P. & Ditlevsen, O., 2003: Nature preservation acceptance model applied to
tanker oil spill simulations. Structural Safety, Vol. 25, 2003, p. 1-34.

Furman, E., Dahlström, H. & Hamari, R., 1998: ITÄMERI – luonto ja ihminen.
Kustannusosakeyhtiö Otava, Helsinki, 1998. (In Finnish)

Gard, 2001: Operations in extremely cold climates. Gard Loss Prevention Circular No.
10-01, December 2001.

Grönvall, H. & Korhonen, O., 1983: Oceanography. Otava, 1983. (In Finnish)

Hammer, W., 1972: Handbook of System and Product Safety. Prentice-Hall Inc., 1972,
351 p.

Hayward, R., 2001: Plastic Response of Ship Shell Plating Subjected to Loads of Finite
Height. A thesis submitted to the School of Graduate Studies in partial fulfilment of
the requirements for the degree of Master of Engineering, Faculty of Engineering and
Applied Science, Memorial University of Newfoundland, May 2001.

HBL, 1987: Icing forced Finnjet to turn back. Huvudstadsbladet, 14.1.1987. (In Swedish)

HELCOM, 2003: Equivalence of ice classification rules. Agenda item 4, Document Code
4/1. Annex to the draft HELCOM Recommendation. Helsinki Commission, Ice
Expert Working Group, Fourth Meeting, St. Petersburg, Russia, 18 November 2003.

Hernqvist, M., 1998: Main engine damage. 22nd CIMAC Congress, Copenhagen, May
1988. The Swedish Club Highlights, available 2.1.2004 at:
http://www.swedishclub.com/lossprevention/publications/highlights9807.pdf

HSE, 2002: Marine Risk Assessment. Offshore Technology Report 2001/063. Prepared
by Det Norske Veritas for the Health and Safety Executive, HSE Books, 2002.

HS, 1966: Oil is imported in Finland by force, even in a "rustbucket" - other ships have to
wait. Helsingin Sanomat, 13.2.1966 (In Finnish).

HS, 1966b: Assistance only for merchant ships; Bore's difficult voyage back to home
took three days. Helsingin Sanomat, 17.2.1966 (In Finnish).

HS, 1985: Salla's tanks intact, no oil pollution threat. Helsingin Sanomat, 7.4.1985 (In
Finnish).

HS, 1987: Finnjet returned to Germany. Helsingin Sanomat, 14.2.1987 (In Finnish).

HS, 2004: Seili is the first Finnish oil combatting vessel suitable for ice conditions.
Helsingin Sanomat, 20.2.2004 (In Finnish).

Hänninen, Samuli, 2004: Incidents and accidents in winter navigation in the Baltic Sea,
winter 2002-2003. To be published in the series of: Winter Navigation Research

Board, Research Report No __, Finnish Maritime Administration, Swedish Maritime Administration, Helsinki, 2004.

Hänninen, Samuli, 2003: Discussions with S. Hänninen and review of the incident/accident data in autumn 2003. (In Finnish)

Ierusalemsky, A. & Tsoy, L., 1994: The Efficiency of Using Non-Traditional Hull Lines for Icebreakers. The Society of Naval Architects and Marine Engineers, Icetech '94, Calgary, Canada, March 1994, p. S1-S10.

IMO, 2000: Reports on marine casualties and incidents. International Maritime Organization, MSC/Circ.953, MEPC/Circ.372, 14 December 2000.

IMO, 2002: Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process. International Maritime Organization, MSC/Circ.1023, MEPC/Circ.392, 5 April 2002.

IMO MSC 72/16: Formal Safety Assessment - Decision parameters including risk acceptance criteria, Submitted by Norway. International Maritime Organization, Maritime Safety Committee, 72nd session, Agenda item 16, MSC 72/16, 14 February 2000.

IMR, 1987: Ice Chart N:o 40. Institute of Marine Research, Helsinki, 12.3.1987.

ISSC II:2, 1976: Non-linear structural response. Report of Committee II:2, Proceedings of the 6th International Ship Structures Congress, Boston.

Jalonen, R., Lax, R., Häkkinen, P., Sukselainen, J., Hellevaara, M., 1999: Effects of the developing technology on the maritime safety. Helsinki University of Technology, Ship Laboratory, Report M-245, Otaniemi, 1999. (In Finnish)

Jalonen, R., 2003: Risk analysis of a ROPAX-vessel in powered hard grounding. Licentiate thesis. Helsinki University of Technology, 144 p. + app. 129 p. (In Finnish)

Johansson, B. M., 1967: On the Ice-Strengthening of Ship Hulls. International Shipbuilding Progress, Vol. 14, No. 154, June 1967.

Jolma, K., 1999: Preparedness for prevention in 2005 and 2010. The Finnish Environment Institute, 30.3.1999, Helsinki, 78 p. (In Finnish)

Jolma, K., 2002: Combatting environmental damage in Finland and in the Baltic Sea. The Finnish Environment Institute, 9.4.1999, Helsinki, 12 p. (In Finnish)

Juva, M., 2002: An analysis of safety of winter navigation in the Gulf of Finland using the FSA-method. HUT, Department of Mechanical Engineering, M.Sc. thesis, 165 p. (in Finnish).

Järvinen, T., 1984: Några synpunkter om arktisk sjöfart. NSTM'84, Ålesund, 1984. (In Swedish)

Jääsalo, H., 1979: The Development of Winter Navigation in Finland. Ice, Ships and Winter Navigation Symposium in Oulu University 1977-12-16 … 17 in Connection with the 100 Year Celebration of Finnish Winter Navigation, Finnish Board of Navigation, 1979.

Kalliosaari, S.: Ice winter: 1996/97, 1997/1998, 1998/1999, 1999/2000, 2000/2001, 2001/2002, 2002/2003. Each available in internet (8.2.2004) from the web-page of the Finnish Institute of Maritime Research: http://www2.fimr.fi/fi/palvelut/jaapalvelu/jaatalvi.html (In Finnish)

Kaplan, S., 1997: The Words of Risk Analysis. Risk Analysis, Vol. 17, No. 4, 1997, p. 407-417.

Karavanov, S., 1993: Analysis of Particular Features of Ship Damages to the Structures of Icebreaking Ships and the Recommendations on the Increase of the Reliability. Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17.-20. August 1993, Hamburg, Vol. 1, p. 319-327.

Koehler, P.E., 1986: Safe Speed of Ships in Arctic Waters. International Polar Transortation Conference, Vancouver, 4-8 May 1986, Vol. 2, p. 734-743.

Koskinen, P., Edelman, G., Soininen, H., Jussila, M. & Weyde, J., 1999: The Development of New Baltic Machinery Ice Class Rules. Proceedings of the 15th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC '99, Helsinki, August 23-27, 1999, Vol. 2, p. 776-789.

Kubat & Timco, 2003: Vessel damage in the Canadian Arctic. Proceedings of the 17th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC '03, Trondheim, Norway, June 16-19, 2003, p. 203-212.

Kudryavtsev, 2003: Icebreaker assistance for the Russian ports of the Gulf of Finland during winter navigation 2002-2003. Information delivered to the HELCOM IEWG, 2003.

Kujala, P., 1989: Probability based safety of ice-strengtened ships in the Baltic Sea. Licentiate thesis. Helsinki University of Technology, 109 p. + app. 13 p.

Kujala, P., 1991: Damage statistics of ice-strengthened ships in the Baltic Sea 1984-1987. Winter navigation research board, Research report No 50, Finnish Board of Navigation.

Kujala, P., Goldstein, R., Osipenko, N. & Danilenko, V., 1991: A Ship in Compressive Ice - Preliminary model test results and analysis of the process. Report from the joint Finnish-Soviet research project. Helsinki University of Technology, Faculty of Mechanical Engineering, Laboratory of Naval Architecture and Marine Engineering, Report M-111, Otaniemi, 1991.

Kujala, P., Goldstein, R., Osipenko, N. & Danilenko, V., 1993: A Ship in Compressive Ice - Analysis of the ice failure process. Report from the joint Finnish-Russian research project. Helsinki University of Technology, Faculty of Mechanical Engineering, Ship Laboratory, Report M-165, Otaniemi, 1993.

Kujala, P., 1994: On the Statistics of Ice Loads on Ship Hull in the Baltic. Acta Polytechnica Scandinavica, Mechanical Engineering Series No. 116, Helsinki 1994, 98 pp. Published by the Finnish Academy of Technology.

Kujala, P., Tuhkuri, J. & Varsta, P., 1994: Ship-Ice Contact and Design Ice Loads. The Society of Naval Architects and Marine Engineers, Icetech '94, Calgary, Canada, March 1994, p. A1-A19.

Kurki, H., 1986: On the dimensioning of the ship rudder. Master's thesis. Helsinki University of Technology, 80 p. + app. (In Finnish)

Laakso, J., 1984: Arctic Shipping, Safe and reliable propulsion machinery for arctic ships. Arctic News Record – Summer 1984, p. 57-59.

Lahtinen, J., 1999: A method to recover oil under the level ice. Licentiate thesis. Helsinki University of Technology, 69 p. + app. 16 p.

Leppäranta, M., 1981: On the Structure and Mechanics of Pack Ice in the Bothnian Bay. Finnish Maritime Research, No. 248 pp. 3-86, Helsinki 1981.

Leppäranta, M., Palosuo, E., Grönvall, H., Kalliosaari, S., Seinä, A. & Peltola, J., 1988: Phases of the Ice Season in the Baltic Sea (North of latitude 57° N). Finnish Institute of Marine Research, Finnish Marine Research N:o 254, Supplement 2, Helsinki 1988.

Likhomanov, V., Timofeyev, O., Stepanov, I., Kashtelyan, V. and Tsoy, L., 1998: Ice Passport for Icebreaker "Pierre Radisson" and Passport's Concept: Further Development. Proceedings of the Eight International Offshore and Polar Engineering Conference, Montreal, Canada, May 24-29 1998, , Vol. II, p. 566-571.

Likhomanov, V.A., Polferov, S. Yu., Stepanov, I.V., Timofeyev, O. Ya., Faddeyev, O.V., 1993: Principles for the development and prospective use of the ice passports. The 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17.-20. August 1993, Hamburg, Vol. 1, p. 219-226.

Lozowski, E., 1988: Marine icing. IAHR Ice Symposium 1988, Sapporo.

Lundqvist, J.-E. & Udin, I., 1977: Ice Accretion on Ships; with special emphasis on Baltic conditions. Winter Navigation Research Board, Research Report No 23, Swedish Administration of Shipping and Navigation, Finnish Board of Navigation, Norrköping, 1977.

Luukkonen, 1999: Damage statistics of groundings in the Finnish territorial waters. Helsinki University of Technology, Ship Laboratory, Report M-240, Espoo 1999. (In Finnish)

LVM, 2003: Final Report of the Multipurpose-Icebreaker Working Group. 31.12.2003. (In Finnish).

Makkonen, L., 1988: Formation of spray ice on offshore structures. IAHR Ice Symposium 1988, Sapporo.

Maksutov, D. and Popov, Yu., 1981: Development and Implementation of Ship ice Certificates. The Society of Naval Architects and Marine Engineers, Spring Meeting, Star Symposium, Ottawa, Ontario, June 17-19 1998, p. 83-86.

Montola, M., 2003: Ice is broken by the mass force. Meriväylä, News from the Finnish Maritime Administration, nr. 3/2003, p. 6. (In Finnish)

Moore, W. H., 1994: The Grounding of Exxon Valdez: An examination of the Human and Organizational Factors. Marine Technology, Vol. 31, No. 1, January 1994, pp. 41-51.

Moreynis, F., Lichomanov, V., Karavanov, S., Zubkova, A., Ponomarev, S., Stepanov, V, Timofeev, O. & Krupina, N., 1998: Requirements to Environmental and Structural Safety of Ships. INSROP Working paper, no. 119-1998, I.5.11.

Mäkinen, P., 1971: Winter navigation in the Bay of Bothnia. A translation and summary of a study for the Maritime Foundation (1968/69). Svensk Sjöfartstidning, nr. 2/1971, p. 18-20. (In Swedish)

Nathwani, J.S., Lind, N.C. & Pandey, M.D., 1997: Affordable Safety by Choice: The Life Quality Method. Institute for Risk Research, University of Waterloo, Waterloo, Ontario, Canada.

Nyman, T. & Soininen, H., 2001. Confidential incident reporting. University of Turku, Center for Maritime Studies and Research, Publications B : 120, Turku. 79 p., ISBN 951-29-1933-8. (In Finnish)

OM, 1994: Investigation report concerning the grounding of M/S Sally Albatross in the Gulf of Finland off Porkkala in the 4th of March 1994 and the hazardous situation

induced. Ministry of Justice, Investigation Board of M/S Sally Albatross, Major accident investigation report N:o 1/1994. (In Finnish)

Peresypkin, V. & Tsoy, L., 2001: Northern Sea Route navigation risk assessment. Preliminary Proceedings of the Joint EU * Russia * Canada * US Workshop, A Common Approach to Collaborative Technological Research for Arctic Development, Brussels, Belgium, 25-27 October 2001, p. 485-509.

Pohjola, J., 1986: Icebreaker operations. INSKO, 37-86, 1986, XII p. 1-10. (In Finnish)

PoT, 2004a: Port of Tallin. Cargo key figures. Available 6.2.2004 at internet web-pages: http://www.ts.ee/statistics/cargo_key_figures.shtml

PoT, 2004b: Port of Tallin. Passenger key figures. Available 6.2.2004 at internet web-pages: http://www.ts.ee/statistics/passenger_key_figures.shtml

Ranki, E., 1984: Optimum strengthening of ship hull against arctic ice. Arctic News Record, Spring 1984, p. 49-52.

Reason, J., 1990: Human error. Cambridge University Press, New York, 1990, 250 p.

Riska, K. et al, 1983: Ice load and pressure measurements onboard I.B. Sisu. POAC 1983, Helsinki.

Riska, K., 2001: Factors affecting tanker traffic safety in winter in the Gulf of Finland. A lecture in the Sea Safety Seminar 3.5.2001, Finlandia-house, Helsinki. (in Finnish)

RMRS, 1986: Rules for the Classification and Construction of Sea-Going Ships; 26.3.1 Requirements for the shape of hull. Russian Maritime Register of Shipping, 1986, p. 188.

Storey, N., 1996: Safety-Critical Computer Systems. Addison-Wesley Longman Limited, 1996, 453 p.

Suokas, J. & Rouhiainen, V. (eds.), 1993: Quality Management of Safety and Risk Analysis. Elsevier Science Publishers, Amsterdam, 291 p.

Salonen, M., 2003: Icebreakers do not assist weak vessels. Meriväylä, News from the Finnish Maritime Administration, nr. 1/2003, p. 10. (In Finnish)

SEALOC 1998: TR1193 – SEALOC. Final report of the Project funded by the European Commission under the Transport RTD Programme of the 4th Framework Programme. Available 31.3.2004 at internet web-page:
http://europa.eu.int/comm/transport/extra/final_reports/waterborne/sealoc.pdf

Seinä A. et al, 2001: Ice seasons 1996-2000 in Finnish Sea Areas, Report Searies of the Finnish Institute of Marine Research, No. 43, 2001.

SHK, 1996: The grounding of passenger ferry Silja Symphony in the 7th of February 1996 at the lighthouse of Södernäs, AB province. Board of Accident Investigation, Sweden, Stockholm, 1996. (In Swedish)

Siivonen, O., 1979: The Development of Finnish Ice Class Rules. Ice, Ships and Winter Navigation Symposium in Oulu University 1977-12-16 … 17 in Connection with the 100 Year Celebration of Finnish Winter Navigation, Finnish Board of Navigation, 1979.

Sjöstedt & Hammarsten, 1973: Isskador på fartyg i Östersjön, Bottenhavet och Bottenviken – Statistisk analys av skadefrekvenser (in Swedish). Styrelsen för vintersjöfartsforskning, Sjöfartsverket Sverige & Sjöfarts-styrelsen Finland, Forskningsrapport nr3, Stockholm, 1973.

Skjong, R. & Ronold, K., 1998: Societal indicators and risk acceptance. 17th International Conference on Offshore Mechanics and Arctic Engineering, 1998.

Skjong, R., 2003: Evaluation Criteria. In "Design for Safety: An integrated approach to Safe European roro ferry design. SAFER EURORO (ERB BRRT-CT97-5015) SU-01.03, Thematic Network: DESIGN FOR SAFETY, Public Final Report, January 2003", p. 21-44.

SMHI&IMR, 1982: Climatological Ice Atlas for the Baltic Sea, Kattegat, Skagerrak and Lake Vänern (1963-1979). Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, Institute of Marine Research, Helsinki Finland, Norrköping 1982.

Soininen, H., 1989: Mission-based Approach in Modern Icebreaker Design. POAC 1989, Luleå, Sweden, 12-16 June 1989, p. 764-773

Soininen, H., 1999: A confidential incident reporting system for Finnish shipping - Preliminary Study. Maritime Institute of Finland, Maritime Research News, Vol. 14, Nr. 2 / 1999, p. 5-7.

Spencer, D. & Hardiman, K., 1993: Effect of Lateral Ice Pressure on Ship Resistance. Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17.-20. August 1993, Hamburg, Vol. 1, p. 272.

SST, 1963: Compass around. For bravery (of Ymer) in the sea. Svensk Sjöfarts Tidning, nr 11? / 1963, p. 650. (In Swedish)

SST, 1964: When Aspen sunk in the bottom (of the sea). Svensk Sjöfarts Tidning, nr 29 / 1964, p. 1652. (In Swedish)

SST, 1970: Compass around. Svensk Sjöfarts Tidning, nr 2 / 1970, p. 16. (In Swedish)

SST, 1971: Sweden and Finland get common ice class. Svensk Sjöfarts Tidning, nr 14 / 1971, p. 6. (In Swedish)

SST, 1982b: Shipwrecks. Svensk Sjöfarts Tidning, nr 3 / 1982, p. 2. (In Swedish)

SST, 1989: Icebreaker "Mudjug": New bow gives worse characteristics. Svensk Sjöfarts Tidning, nr 14 / 1989, p. 17. (In Swedish)

Storey, N., 1996: Safety-Critical Computer Systems. Addison-Wesley Longman Limited, 1996, 453 p.

Sukselainen, I.J. & Riska, K., 1986: Current Problems in Arctic Vessel Research. International Polar Transortation Conference, Vancouver, 4-8 May 1986, Vol. 1, p. 41-65.

Thomson, 1925: Ice navigation and damage in the Baltic. Lloyd's Register Technical Association, Paper read 7th January, 1925

Timofeev, O. Ya., 1995: Reliability Estimate of Ice Belt Construction of Ice Class Ship and Ice-Resisting Structures. 13th International Conference on Port and Ocean Engineering under Arctic Condition, August 15.-18. 1995, Murmansk, Vol. 1, p. 124-134.

Toomey, P. R. M., 1994: "A Master Mariner's perspective on the performance of icebreakers". The Society of Naval Architects and Marine Engineers, Icetech '94, Calgary, Canada, March 1994, p. V1-16.

Tsoy, L., 2003: Operation of icebreakers in the Baltic Sea (Challenges of winter navigation in the Gulf of Finland), presentation on the Bizkon seminar 11.3.2003.

Tunik, A., 2000: Safe Speeds of Navigation in Ice as Criteria of Operational Risk. International Journal of Offshore and Polar Engineering, Vol. 10, No. 4, December 2000, p. 285-291.

Vainio, J., 2003: Personal e-mail correspondence on 21.11.2003. (In Finnish)

Vapalahti, H., 1997: Finnish ship accidents 1953-1973. Judicor Oy, 176 p. (In Finnish)

Varges, G.: Revolution in Polar shipping -Thyssen/Waas in the Arctic. IAHR Ice Symposium 1988, Sapporo, Japan, p. 721.

Varsta, P., 1983: On the mechanics of ice load on ships in level ice in the Baltic Sea. Technical Research Centre of Finland, Publications 11, 1983.

Varsta, P. & Hanhirova, K.: Ship safety. Helsinki University of Technology, Ship Laboratory, Report M-217, Espoo 1997. (In Finnish)

Vivalda, C., Paalsson, I., Reis, A., Vie, H.: Evaluation of Assessment Methods and how to integrate Human and Organisational Factors. EU 4th Framework Programme, Transport RTD Programme, Concerted Action on FSEA, Final Report of Workshop B, WSB - 01, Revision 1, 22.06.1999.

VTT, 1978: Deformations in ship structures caused by welding. Valtion teknillinen tutkimuskeskus, Laivalaboratorio Metallilaboratorio, Espoo, Lokakuu 1978. (In Finnish)

VTT, 1984: Effects of surface roughness on ship's operating costs. Technical Research Centre of Finland, research notes 303, Espoo, 1984. (In Finnish)

VTT, 1997: Safety of maritime transport in Finland. Mapping of accidental risk. Report VAL A V5SU01429/1, Tampere, 16.6.1997. (In Finnish)

VTT, 2002: The implementation of the VTMIS system for the Gulf of Finland. Research report no. VAL34-013153, 15.5.2002.

Walday, M., Kroglund, T. and Norwegian Institute for Water Research (NIVA), 2002: Seas around Europe, The Baltic Sea – the largest brackish sea in the world. European Environment Agency, Europe's biodiversity – biogeographical regions and seas. This document was available on the 3.12.2003 at the Internet Web-page: http://reports.eea.eu.int/report_2002_0524_154909/en/page141.html

Webster's, 1996: Webster's Encyclopedic Unabridged Dictionary of the English Language. Random House, Gramercy Books, New York, 1996, 2230 p.

Wright, B.D., Timco, G.W., Dunderdale, P. & Smith, M., 2003: An overview of evacuation systems for structures in ice-covered waters. Proceedings of the 17th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC '03, Trondheim, Norway, June 16-19, 2003, p. 765-774.

Zubov, N. N., 1938: The Maximum Thickness of Perennial Sea Ice. Meteorologiya I Gidrologiya, No. 4, p. 123-131., August 15.-18. 1995, Murmansk, Vol. 1, p. 124-134.

APPENDICES

ICE CONDITIONS, TRAFFIC RESTRICTIONS AND ICE EDGE IN THE GULF
OF FINLAND IN 1997-2002

The following data of the traffic restrictions and descriptions of the winter conditions in
the Gulf of Finland is based on the references [Seinä et al 2001] and [Kalliosaari 2003].

The winter proceeds so that the ice edge expands from the eastern part of the Gulf of
Finland towards west during the winter months. Thus, the traffic restrictions also develop
so that the most stringent restrictions are placed on the easternmost ports on the Finnish
side. The traffic separation schemes are located outside the clustered Finnish ports and
thus it would be natural to relate the icebreaking zone, traffic restrictions and traffic
separation schemes in some way. As discussed later, one alternative to treat the traffic
separation schemes is that when the winter proceeds, the separation schemes are replaced
with icebreaking zones which include traffic restrictions and icebreaker escort. In order to
gain insight how the winter and traffic restrictions usually proceed, winters 1996-97 to
2001-02 have been analysed here. The average location of the ice edge over the winter
period is presented in Figures 1, 3, 5, 7, 9 and 11.

The average longitude of the ice edge has been estimated from the ice charts published by
the Finnish Ice Service (Finnish Institute of Marine Research). These ice charts are
produced daily and published officially two times a week [Vainio 2003]. The ice edge
does not actually lie directly in the north-south direction but it bend mores to the North-
west-Southeast direction. The longer the winter proceeds and the ice edge moves towards
west, the more the ice edge also bends to the Northwest-Southeast direction. When the
ice edge is still far in east, in the beginning of the winter, the ice edge lies quite well in
the north-south direction.

The longitudes of the main harbours in the Gulf of Finland are: St. Petersburg 30°15',
Hamina 27°12', Kotka 26°56', Loviisa 26°15', Porvoo 25°35', Helsinki 24°57', Kantvik
24°21', Inkoo 24°00', Koverhar 23°13' and Hanko 22°58'.

Winter 1996–1997

The winter was warmer than normally and the ice season was a mild one. Freezing was minimal until mid-December, when new ice formed in the eastern Gulf of Finland. This was approximately one week later than normally. The freezing continued normally up to the end of December. At the beginning of January, the weather cooled off and freezing accelerated. At the beginning of February a cooler period started, during which the winter's maximum ice conditions, covering 128 000 km^2, were reached on February 18. In the Gulf of Finland there was ice eastwards of the longitude of Helsinki, and in the northern Baltic Sea Proper a narrow belt of new ice had formed beyond the coastal areas. In mid-March the weather cooled off again, and by March 24 the ice cover was almost as extensive as on February 18. After this slow melting set in, but the weather remained cool. In the western Gulf of Finland the ice break-up at the turn of April and May was approximately one week later than normally. The eastern Gulf of Finland was ice-free by late April, about one week later than normally. In the coastal and inner archipelago of the Gulf of Finland the ice season was 2-28 days shorter than in a normal winter.

The maximum fast ice thickness was 10-20 cm (-24 cm) in the western Gulf of Finland and 10-40 cm (-15 cm) in the eastern Gulf of Finland. On the outer sea areas of the Gulf of Finland the maximum ice thickness was 15-50 cm (-5 to -25 cm). The maximum distance that vessels had to navigate through ice between the harbour and the ice edge was 1 nautical mile (-44 nautical miles) at Hanko and 101 nautical miles (-57 nautical miles) at Hamina.

Figure 1   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 1996–97.
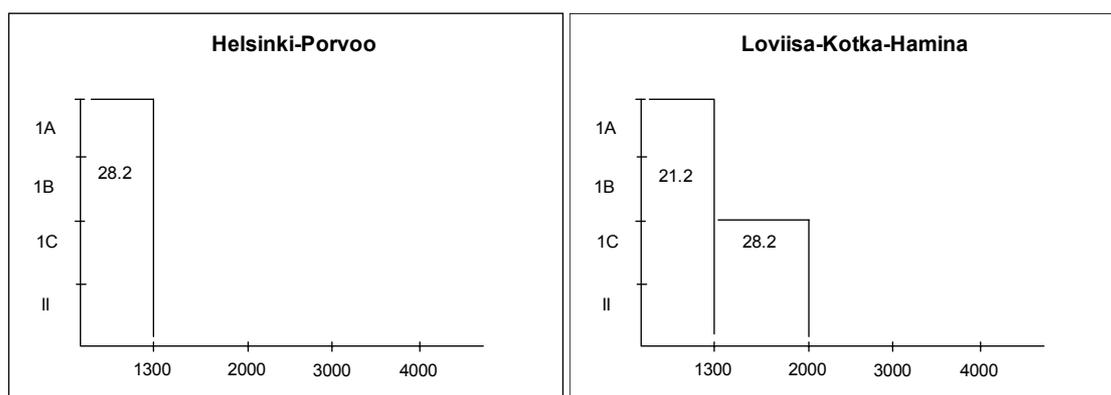
Figure 2   Traffic restrictions to Finnish ports in the Gulf of Finland in winter 1996–97.

Winter 1997–1998

The winter was warmer than normally and the ice season was mild. In the eastern Gulf of Finland freezing began in early December, one week later than normally. Mild ice conditions continued until Christmas, when new ice formed rapidly. The ice cover, however, also decreased rapidly. At the turn of December-January freezing started again, but the ice cover, once again, decreased rapidly. Variable ice conditions continued until late January, when strong freezing set in: on the 1st of February half of the Gulf of Finland was ice-covered. After this the ice cover increased slowly. By mid-February, some ice had also formed in the outer sea areas of the western Gulf of Finland. The ice cover decreased until early March, after which the ice cover started to increase. On March 11, the maximum conditions were reached with ice coverage of 129 000 km^2. In the Gulf of Finland the ice edge reached the line Utö-Ristna. Some days later the ice cover started to decrease. The spring was relatively cool, causing the ice to melt later than on average. The western Gulf of Finland was ice-free in late April, 1-1,5 weeks later than normally, and the eastern Gulf of Finland in late May, also 1-1,5 weeks later than normally. In the archipelago of the eastern Gulf of Finland the ice season was three weeks longer than on average.

The maximum fast ice thickness was 20-30 cm (-26 cm) in the western Gulf of Finland and 30-13 cm (-16 cm) in the eastern Gulf of Finland. On the outer sea areas of the Gulf of Finland the maximum ice thickness was 15-70 cm (-3 to +10 cm).

The maximum distance that vessels had to navigate through the ice between the harbour and the ice edge was 10 nautical miles (-35 nautical miles) at Hanko and 133 nautical miles (-25 nautical miles) at Hamina.

Figure 3   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 1997–1998.
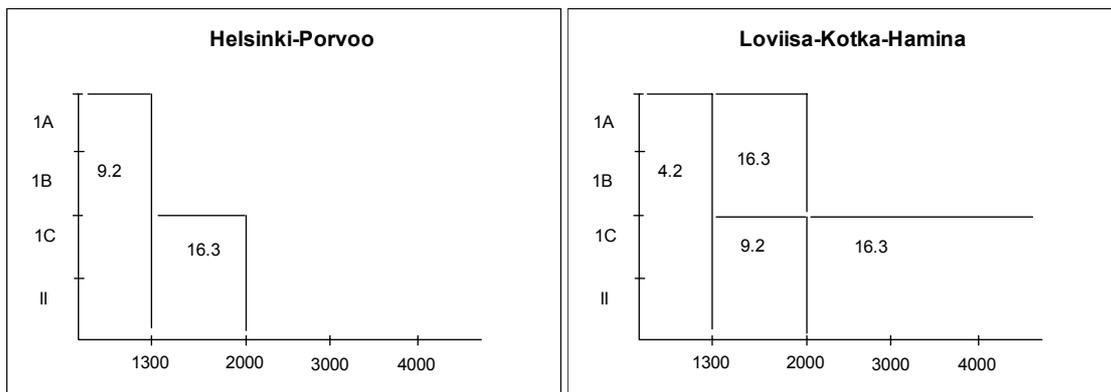
Figure 4   Traffic restrictions to Finnish ports in the Gulf of Finland in winter 1997–98.

Winter 1998–1999

The winter started with cold weather and the ice season was a normal one. The ice season started already in early November with exceptionally low air temperatures. On the other hand, air temperatures were exceptional high in April. On the coasts of the eastern Gulf of Finland, freezing began in late November, three weeks earlier than normally. In early December rapid freezing occurred, but this phase did not last long, and mild ice conditions continued until Christmas, when new ice formed rapidly. The ice cover, however, also decreased rapidly. At the turn of the year, freezing started again, but once again the ice cover decreased rapidly. These variable ice conditions continued until mid-January, when strong freezing started. In early February rapid freezing set in again, and on February 11 the maximum conditions were reached with ice coverage of 157 000 km^2.

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The Gulf of Finland was completely ice-covered. Within a few days the ice cover started to decrease. The spring was relatively mild, and in April there were exceptionally high air temperatures. May turned out to be a cool month. The western Gulf of Finland was ice-free in mid-April, and the eastern Gulf of Finland in late April, both at the normal time. On the coast of the western Gulf of Finland, the duration of the ice season was normal, but in the east it was 1,5 weeks longer than on an average winter. On the outer sea areas, the ice season was 1-1,5 weeks longer than normally.

The maximum fast ice thickness was 45-50 cm (+6 cm) in the western Gulf of Finland and 50-55 cm (+2 cm) in the eastern Gulf of Finland. In the outer sea areas of the Gulf of Finland the maximum ice thickness was 10-50 cm (-5 to -10 cm).

The maximum distance that vessels had to navigate through the ice between the harbour and the ice edge was 22 nautical miles (-23 nautical miles) at Hanko and 152 nautical miles (-6 nautical miles) at Hamina.
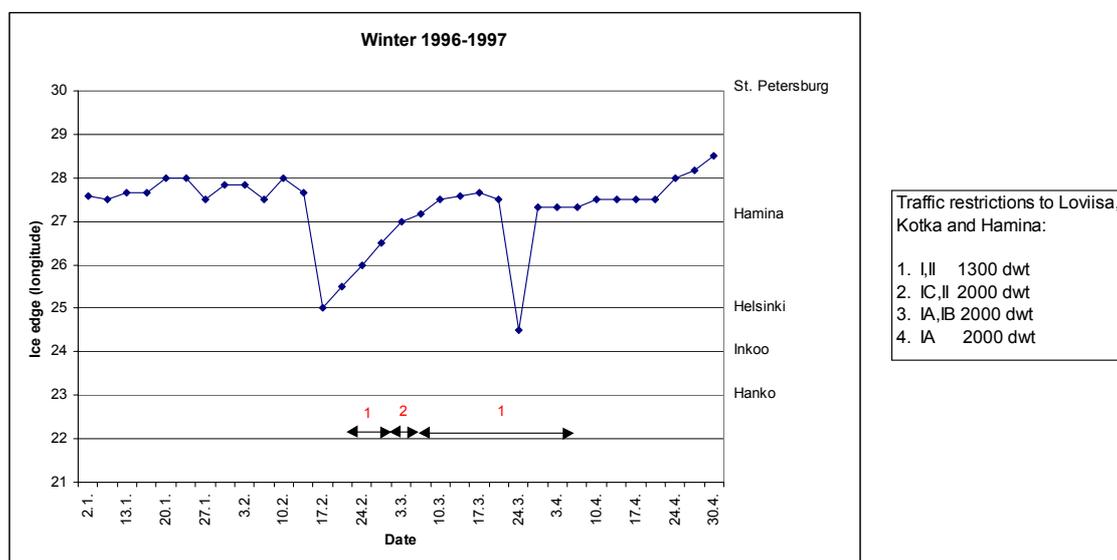

Figure 5   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 1998–99

Helsinki-Porvoo

1A

1B   9.2

1C   15.2

II

1300   2000   3000   4000

Loviisa-Kotka-Hamina

1A   15.2

1B   18.1   9.2   15.2

1C   1.2   9.2

II

1300   2000   3000   4000

Hanko

1A

1B   15.2

1C

II

1300   2000   3000   4000
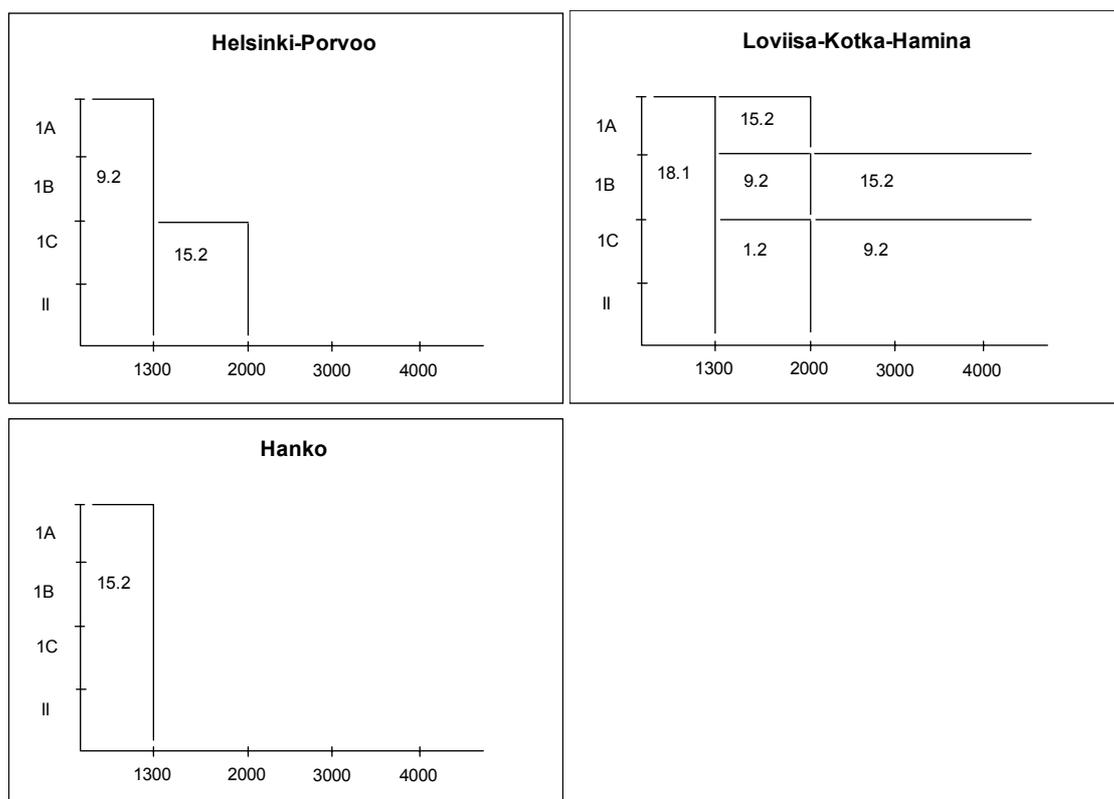
Figure 6   Traffic restrictions to Finnish ports in the Gulf of Finland in winter 1998–99

<u>Winter 1999–2000</u>

The winter turned out to be a warm one and the ice season was a mild one. Along the coasts of the eastern Gulf of Finland, freezing did not begin until in early January, two weeks later than normally. The mild ice conditions continued until after mid-January, when strong freezing started. In mid-February rapid freezing started again, and on February 24th maximum conditions were reached with ice coverage of 95 000 km^2. The outer sea areas of the Gulf of Finland were ice-covered from the east to the longitude of Loviisa. The ice cover already started to decrease on the following day. In early March, the outer sea areas of the Gulf of Finland were almost completely open. On March 9 a new freezing period commenced, lasting until mid-March. Hereafter the ice cover started to decrease. The spring was relatively mild, with exceptionally high air temperatures in late April. May turned out to be a normal month. The western Gulf of Finland was ice-free in mid-April, and the eastern Gulf of Finland in late April. In both cases this was 1,5 weeks earlier than normally. On the coast of the western Gulf of Finland the duration of the ice season was approximately one month shorter, and in the east it was 2,5 weeks shorter than on average. In the outer sea areas, the ice season was approximately two months shorter than normally.

The maximum fast ice thickness was 9-31 cm (-29 cm) in the eastern Gulf of Finland. On the outer sea areas of the Gulf of Finland the maximum ice thickness was 5-40 cm (-23 to

-28 cm). The maximum distance that vessels had to navigate through the ice between the harbour and the ice edge was 2 nautical miles (-43 nautical miles) at Hanko and 62 nautical miles (-96 nautical miles) at Hamina.
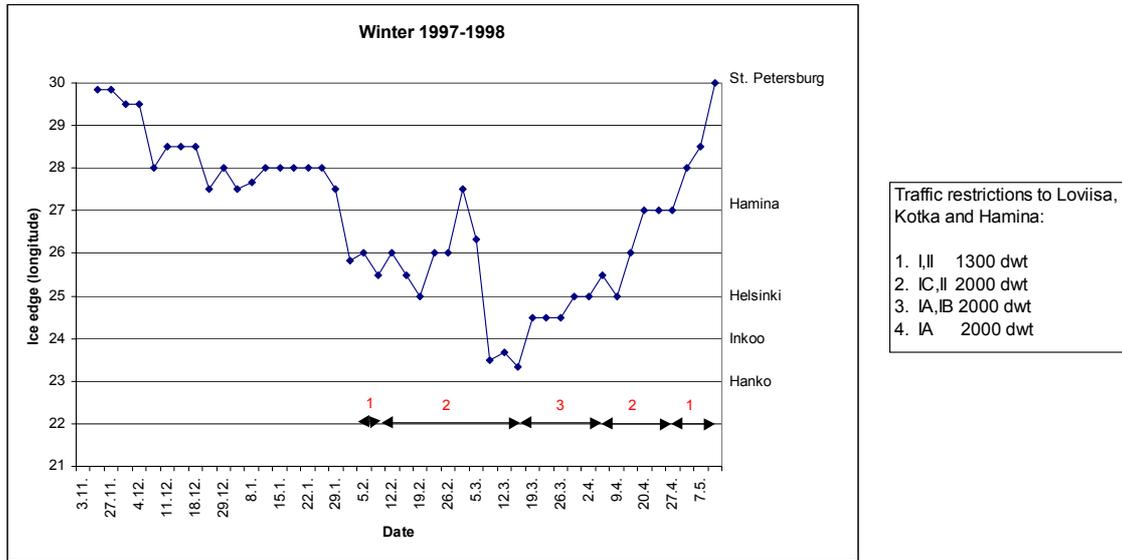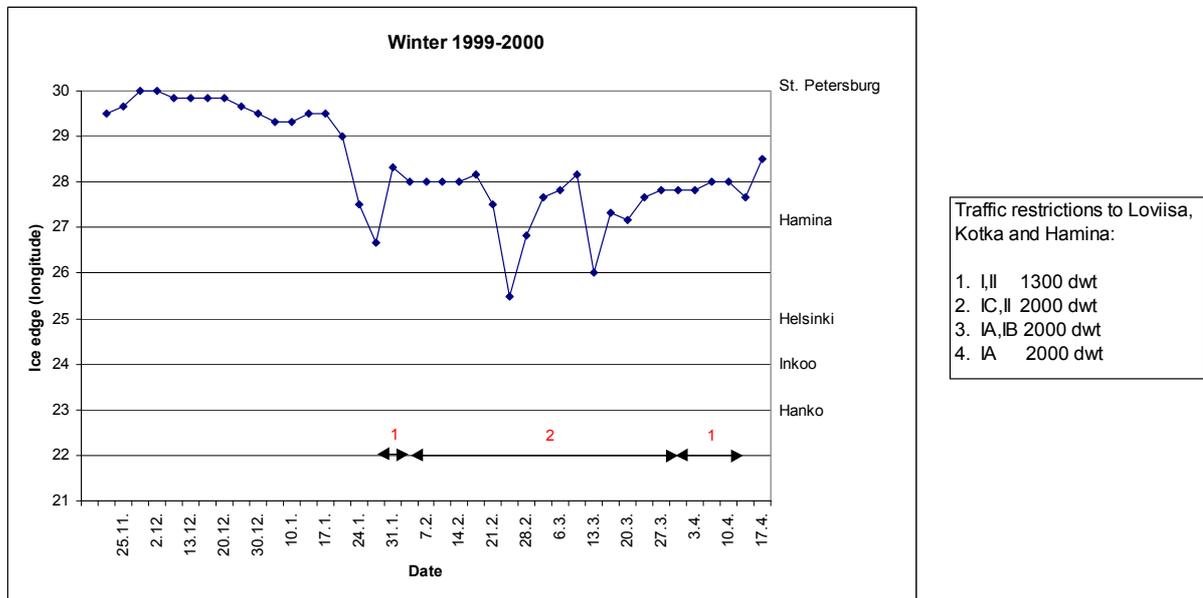

Figure 7   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 1999–2000.
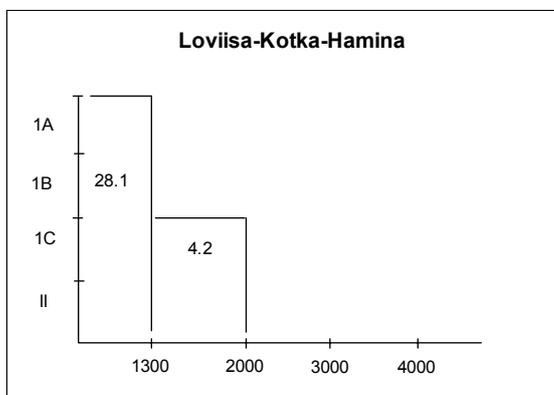
Figure 8   Traffic restrictions to Finnish ports in the Gulf of Finland in the early months of winter 1999–2000.

Winter 2000–2001

The beginning of the winter 2000-2001 was delayed by several weeks due to the warm autumn in 2000. However, in the St. Petersburg area the freeze-up started at about the usual time. The January was rather mild, but during a cold period in early February covered the archipelago with ice and thereafter there was ice at sea from St. Petersburg to the island of Gogland (Suursaari). Later in February ice was packed east of the line Nerva – Seskar. Cold northern winds made new ice growing in all sea areas and at the end of February a there was a 30-40 nm wide zone of thin new ice along the coast of southern Finland. The ice cover reached now to the longitude of Jussarö.

The weather was rather unsettled in early March with short mild and colder periods. The extent of ice cover decreased untill a cold spell started in mid-March. The ice cover in the Baltic Sea reached it's maximum extent on March 26th, which is extremely late. The maximum ice thickness was about 30 cm in the western parts of the Gulf of Finland and 35-50 cm in the eastern parts. At the central sea area in the GoF the thickness was 10–45 cm. At it's largest the ice edge was reaching a line from Naissaar to 18 nm southwest from of Bengtskär and then to Kökar. Then, in April the weather started to get warmer and by the turn of the month Gulf of Finland was ice free, corresponding to the average situation. The ice season in the GoF was more than 4 weeks shorter than on average.
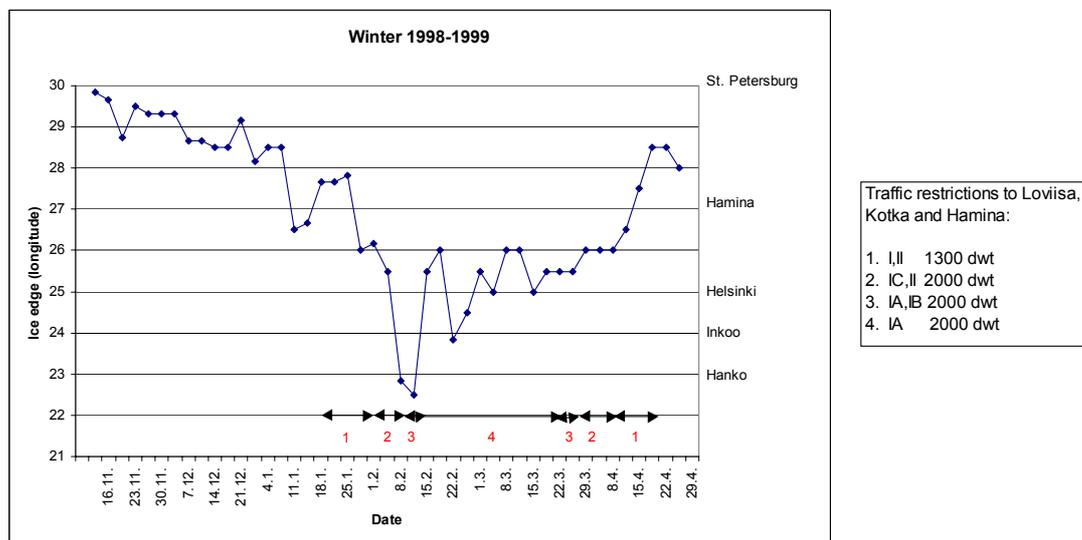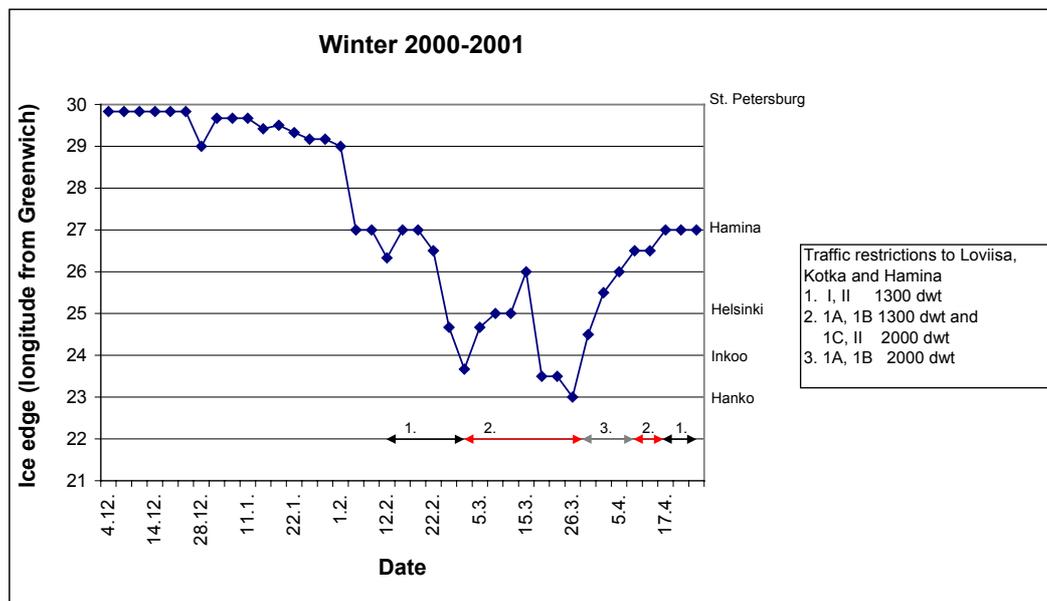

Figure 9   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter 2000–2001
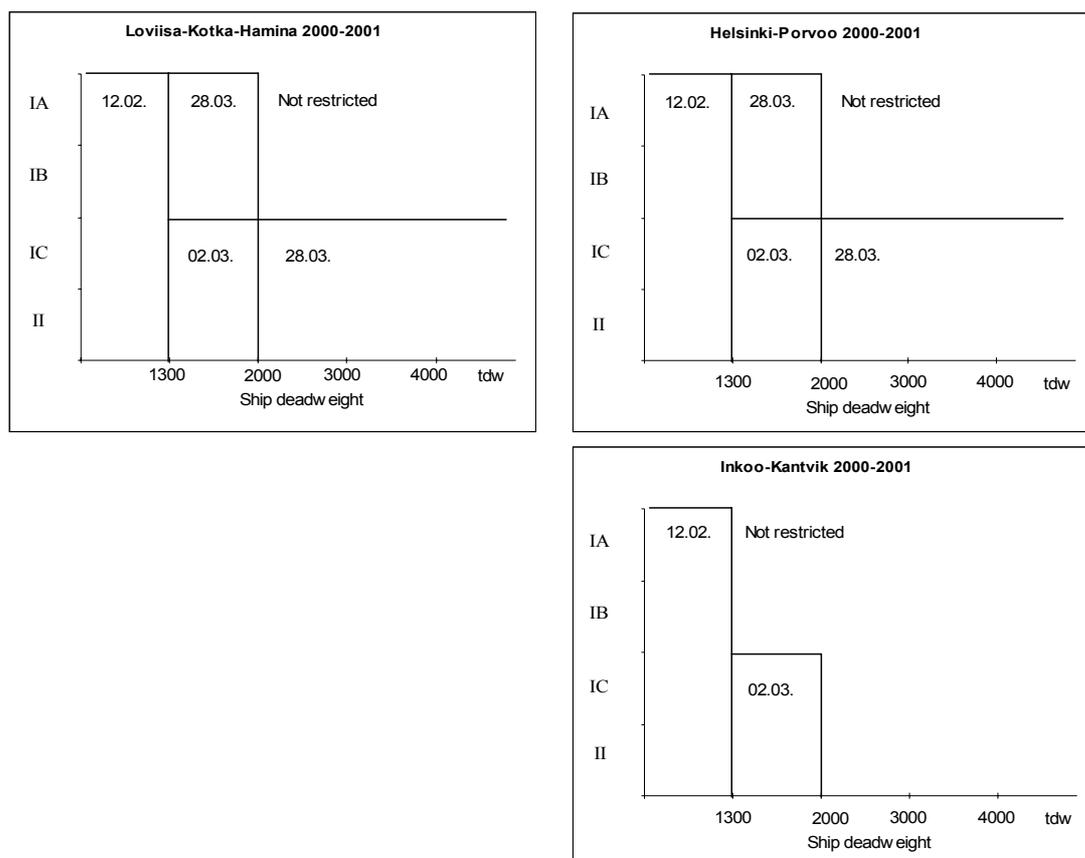
Figure 10   Traffic restrictions to Finnish ports in the Gulf of Finland in the early months of winter 2000–2001.

Winter 2001–2002

The freeze-up of the northeastern part of the Gulf of Finland, in the Vyborg Bay, started in the second half of November, slightly earlier than usual. Ice conditions started quite normally in the eastern part of the GoF the ice-cover forming as usual from St. Petersburg to the island of Gogland by the year's end. Mild weathers prevailed in January, so the ice did not extend further than to the outer islands. In February the weather was variable and there was ice cover east of the island Motshnyj (Lavansaari). Weather was warmer than usual in April, thus making the the western part of the GoF ice-free in mid-April and the eastern part of it by the end of it, corresponding to the long period average.

In the western Gulf of Finland the maximum ice thickness reached 25 – 30 cm, in the eastern parts of it the maximum ice thickness was 35 – 45 cm. However, at more open sea area the maximum thickness was about 10 – 45 cm. The length of the ice season was about one week shorter than average in the GoF. The maximum extent of ice cover in the Baltic Sea was 102 000 km^2 in winter 2001-2002.
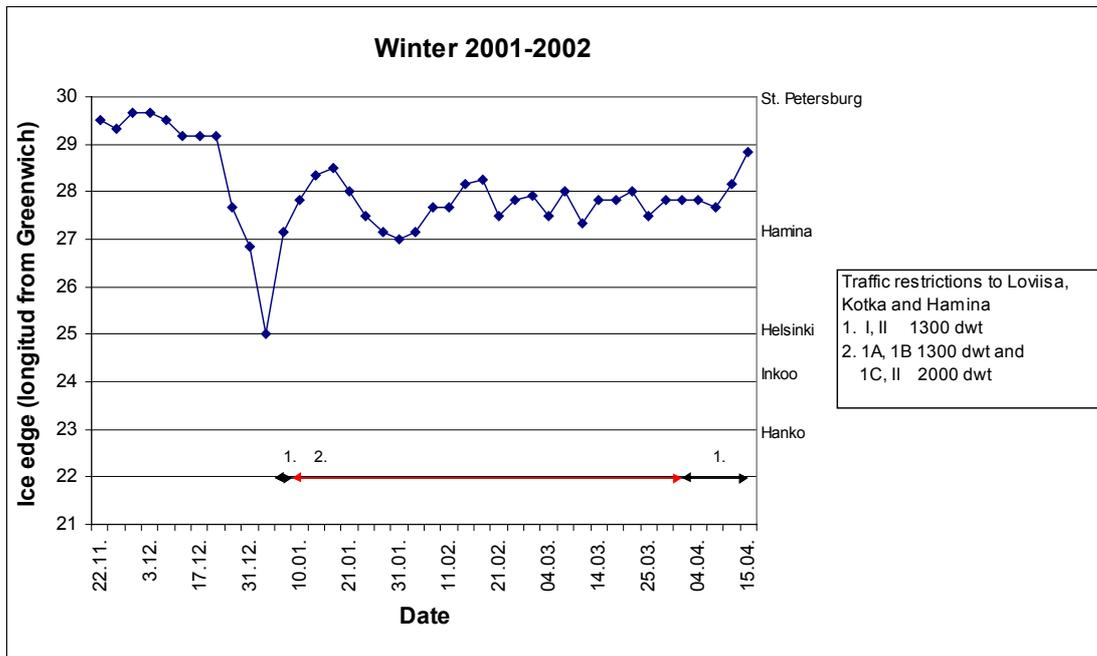
Figure 11   Ice edge and traffic restrictions to Loviisa, Kotka and Hamina in winter
2001–2002.
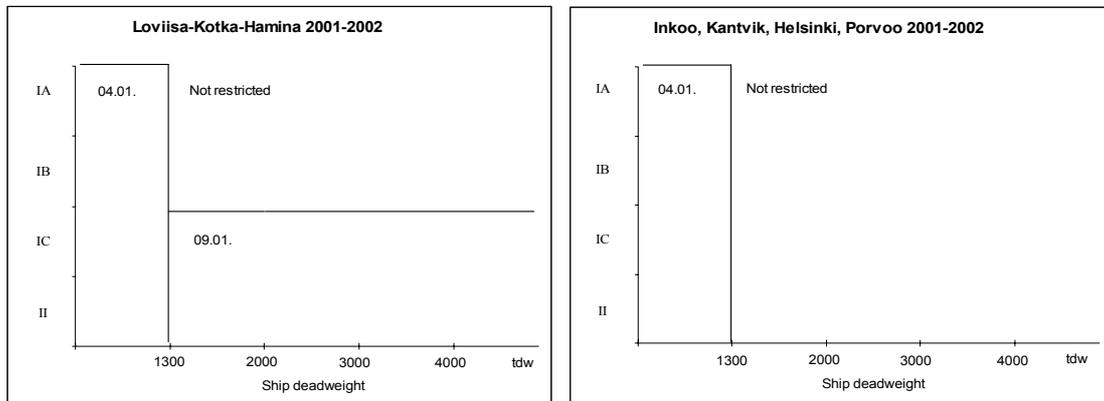
Figure 12   Traffic restrictions to Finnish ports in the Gulf of Finland in the early months
of winter 2001–2002.

Summary

Most of the winters analysed here were mild and thus no very general conclusions can be drawn. The ice class 1C was required for the ports of Loviisa to Hamina in every year and in 1999 the requirement was ice class 1B. In 2003 the requirement was raised to ice class 1A. In general, the decisions about the traffic restrictions followed the ice edge, but with some delay. This is natural because, before a restriction comes into force, there must be time to inform all the potential ships bound to the Baltic Sea. The analysis showed, however, that it is feasible to plan the interaction between the traffic separation schemes and the icebreaking zones so that one always changes to the other. This requires, however, willingness of all the port states to deploy icebreakers when the icebreaker zone comes into force.

REFERENCES FOR ICEBREAKER DATA

B&N and SMA: Efficient and beneficial high-capacity ice-breaking in a new combination of offshore activities. Sjöfartsverket/Isbrytningsavdelningen & B&N Nordsjöfrakt AB (publ). Available in internet (20.11.2003) at web-page: http://www.sjofartsverket.se/tabla-a/pdf/a14_4.PDF

FMA, 2001: Icebreakers - the guards of the winter navigation throughout the year. Finnish Maritime Administration, Edita, 2001. Available in internet (27.8.2003) at web-page: http://www.fma.fi/palvelut/tietopalvelut/esitteet/jaanmurto_fi.pdf (In Finnish)

Dick, R. A. and Laframboise, J.E., 1989: An empirical review of the design and performance of icebreakers. Marine Technology, Vol. 26, No. 2, April 1989, pp, 145-159.

Harjula, A., Siirilä, T., Eronen, H. and Lohi, P.: Multipurpose icebreaker MSV Botnica, Basic design aspects. POAC 1999, Vol. 2, pp. 568-577.

HELCOM, 2003a: Adequacy of emergency capacity during winter; towing capability of the Finnish icebreakers and large buoy tender vessels. Helsinki Commission, Ice Expert Working Group, Second Meeting, Document code 8/1, Submitted by Finland, Helsinki, Finland, 17-18 June 2003.

HELCOM, 2003b: Adequacy of emergency capacity during winter. Helsinki Commission, Ice Expert Working Group, Second Meeting, Document code 8/2, submitted by Sweden, Helsinki, Finland, 17-18 June 2003.

HELCOM, 2003c: Adequacy of emergency capacity during winter. Helsinki Commission, Ice Expert Working Group, Second Meeting, Document code 8/3, submitted by Russia, Helsinki, Finland, 17-18 June 2003.

Hieronymi, E., 1993: Ice impact on ship hulls. The 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17.-20. August 1993, Hamburg, Vol. 1, p. 307-318.

Johansson, B. & Liljeström, G.: Oden - Icebreaker Technology for the Year 2000. SNAME Transactions, Vol. 97, 1989, pp. 53-83.

NGPRV, 2003: Visit to Scandinavian Icebreakers. U.S.Department of Transportation, Maritime Administration, Office of Shipbuilding and Marine Technology, New Generation Polar Research Vessel, Issue 1, June 2003.

Nyman, T., Riska, K., Soininen, H., Lensu, M., Jalonen, R., Lohi, P. and Harjula, A.: The ice capability of the multipurpose icebreaker Botnica - Full scale results. POAC 1999, Vol. 2, pp. 631-643.

Riska, K., Leiviskä, T.,Nyman, T., Fransson, L., Lehtonen, J., Eronen, H., Backman, A.: Ice performance of the Swedish multi-purpose icebreaker Tor Viking II. POAC 2001, Vol. 2, pp. 849-865.

Soininen, H., Nyman, T., Riska, K., H., Lohi, P. and Harjula, A.: The ice capability of the multipurpose icebreaker "Fennica" - Full scale results. POAC 1993.

SST, 1982a: Heavy buoys, harbour icebreaking, jobs for the new workship. Svens Sjöfarts Tidning, nr. 11, 1982, p. 16. (In Swedish)

Oesterle, B., 1988: Icebreakers from the whole world. Steiger, Berlin, 1988. (In German)

Sodhi, Devinder S., Northern Sea Route reconnaissance study : A summary of icebreaking technology. Special Report 95-17, 239 p., June 1995. Available in internet (8.2.2004) at web-page: http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/NSR.pdf

Vapalahti, H., 2003: Finnish illustrated list of ships 2003. Judicor Oy, May 2003, 736 p. (In Finnish/English)

Contributing factors to maritime accidents

Typical marine accident causes can be classified according to the following categories, which are similar to used in the accident database DAMA, which is used e.g. by the FMA.

External factors, not directly related to ship

A01 Heavy storm, natural catastrophe
A02 Drift or other ship handling difficulties due to wind, current etc.
A03 Collision to a floating object that could not be observed or avoided in time
A04 Failure in external aids to navigation
A05 Failure in sea chart or publication
A06 Technical failure in other vessel (including tugs)
A07 Operational error of other vessel
A08 Technical failure in external cargo loading, unloading or bunkering equipment. A failure in quay, channel lock, or bridge structures
A09 Operational error in operation of cargo loading, unloading or bunkering equipment. An operational error in using port equipment or channel locks.
A10 "Blow-up" or other external conditions in connection to oil drilling.
A11 Difficult ice conditions
A12 Icing on deck structures or deck cargo

Ship structures and the location of equipment onboard

B01 Insufficient structural strength of ship
B02 Deteriorated structural strength of ship due to repair welding or other welding work, or due to corrosion
B03 Deteriorated stability of the ship due to the construction
B04 Poor manoeuvring characteristics of the ship
B05 Engine room lay-out / location of the equipment has caused a danger of leakage or fire
B06 Poor location or arrangement of the cargo space or store
B07 Poor location or arrangement of other space, not bridge
B08 A difficult space to enter for cleaning, maintenance or inspection
B09 Other conditions connected to ship construction or maintenance

Technical failures in ship equipment

C01 Technical failure in navigation equipment
C02 Technical failure in manoeuvring equipment
C03 Technical failure in propulsion machinery
C04 Technical failure in auxiliary machinery
C05 Technical failure in anchoring equipment / deck equipment
C06 Technical failure in control devices / remote control devices / automatic control devices / warning systems
C07 Technical failure in cargo handling equipment
C08 Technical failure in redundant systems / safety devices / inert gas system / fire extinguishing system
C09 Technical failure in drilling equipment
C10 Other technical failure

Issues related to the operation and placement of equipment onboard

D01 Unpractical design of the bridge, missing or wrongly located devices
D02 Wrong or illogical design or location of controls
D03 Device not located in a suitable place for use
D04 Device unfit / bad / weared / difficult to use
D05 Other factors related to the design / operation of the device. Man-machine interaction problems.

Issues related to the cargo / fuel and cargo / fuel handling equipment

E01 Self-ignition of the cargo / fuel
E02 Missing inert gas system / or other fire / explosion prevention system
E03 Stability contrary to the rules (wrong location of cargo, missing ballast etc.)
E04 Defective securing of cargo
E05 Leakage of liquid cargo (barrels, containers, tanks, etc.)
E06 Leakages in cargo or fuel pipes / hoses
E07 Other factor related to cargo or fuel

Contributing factors to maritime accidents, list continued

Issues related to communication, organisation, operational instructions and routines

F01   General instructions missing / deficient
F02   General methods of operation unknown / not practiced sufficiently
F03   Safety instructions missing / deficient
F04   Safety instructions known, but not followed
F05   Safety instructions not followed in connection with welding
F06   Welding work lead to fire although safety instructions were followed
F07   Lifesaving equipment testing and exercising instructions not followed
F08   Protective equipment not used
F09   Organisational / instruction / knowledge level too low
F10   Instructions for inspection / maintenance not followed
F11   State of stability not known / ship without accepted stability calculations
F12   Unsuitable methods of leadership, personal problems etc.
F13   Ship or bridge not sufficiently manned (missing helmsman, lookout etc.)
F14   Areas of responsibility or task assignment unclear
F15   Bridge routines non-existing or deficient
F16   Bridge routines not followed
F17   Sea charts / publications not updated
F18   Errors in co-operation / procedures with tugs, shore organisation etc.
F19   Other factors related to organisation, safety regulation, routines or communication

Human factors, awareness & assessment of situation, etc.

G01   Insufficient formal competence for duty (training, certifications etc.)
G02   Insufficient practical competence for duty (experience, local knowledge of waters, use of devices etc.)
G03   Task / operation poorly designed (cargo, night navigation, route planning, anchoring etc.)
G04   Available means of getting warning not sufficiently used
G05   Alternative systems for navigation not used. Wrong assessments of navigational lights, lighthouses etc.
G06   Available aids for navigation or publications not sufficiently used
G07   deficient positioning of own vessel, not marked in sea chart
G08   Wrong assessment of other vessel's movements / intentions
G09   Wrong assessment of own vessel's movements (current, wind etc.)
G10   Aim to perform task / operation under non-favourable conditions
G11   Right side of the waterway / channel not used
G12   Excessive situational speed
G13   Sickness, fatigue, overstrain etc.
G14   Falling asleep on the watch
G15   Alcohol or other intoxicating substance
G16   Other cause related to persons

Other factors

ANN   Other known reason
UKJ   Reason unknown (not announced, impossible to determine etc.)

Note! LTA = Not sufficient (considering the conditions

Static hull ice damage

Note! The structure of this fault tree and the numerical values included in it are not final estimates of the corresponding probabilities. They are presented here only to act as a catalyst to a discussion enabling the development of a fault tree model with a broad acceptance.

Stuck in ice

Note! The structure of this fault tree and the numerical values included in it are not final estimates of the corresponding probabilities. They are presented here only to act as a catalyst to a discussion enabling the development of a fault tree model with a broad acceptance.

Dynamic hull ice damage

Note! LTA = Not sufficient (considering the conditions)

Dynamic hull ice damage — 6.48E-02

AND

Impact force of high energy impact exceed hull strength — 0.068

High energy impact with an ice block/obstacle — 0.960

AND

Hull strength LTA — 0.15

Impact force higher than expected — 0.45

OR

Ice class LTA — 0.05

Classification requirements LTA — 0.05

Hull strength less than classification — 0.05

OR

Ship speed is higher than what should be allowed considering — 0.40 strength

Ice obstacle stronger/larger than expected — 0.05

OR

Missing knowledge or intuition of ice loads vs. ship speed — 0.35

Violation against good seamanship or ice passport's — 0.05 advice

OR

Impact with an ice block which is accelerated by IB — 0.050

Impact with a large ice floe in open water or ice edge — 0.310

Impact with a large ice floe in old channel — 0.10

Impact with a large ice floe in a new broken channel — 0.50

OR

No sufficient ice chart information available onboard — 0.05

Organizational error in arranging ice detection — 0.05

Ice edge / large floe is not detected in time although tried — 0.21

OR

Human error in actual ice detection — 0.10

Technical failure of ice detection equipment — 0.01

Environmental factors hamper ice detection — 0.10

Note! The structure of this fault tree and the numerical values included in it are not final estimates of the corresponding probabilities. They are presented here only to act as a catalyst to a discussion enabling the development of a fault tree model with a broad acceptance.

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Icing accident

Note! The structure of this fault tree and the numerical values included in it are not final estimates of the corresponding probabilities. They are presented here only to act as a catalyst to a discussion enabling the development of a fault tree model with a broad acceptance.

Winter navigation accidents and incidents in winter 2002-2003 based on (Hänninen 2004)

Source of data:

Damage types:		Sea areas:				Source of data:	
HB	Hull damage; bilge	RU	Rudder damage	AS	Archipelago Sea	BPr	Baltic Proper	FMA	Finnish Maritime Administration
HD	Hull damage	CL	Collision	AW	Arctic waters	GoF	Gulf of Finland	HUT	Helsinki University of Technology
HR	Hull damage; rupture	C	Contact	BoB	Bay of Bothnia	GoR	Gulf of Riga	SMA	Swedish Maritime Administration
PR	Propeller damage	GR	Grounding	BSe	Bothnian Sea	Sai	Saimaa	OTHER	Ship owners, insurance comp., newspapers, news agencies etc.

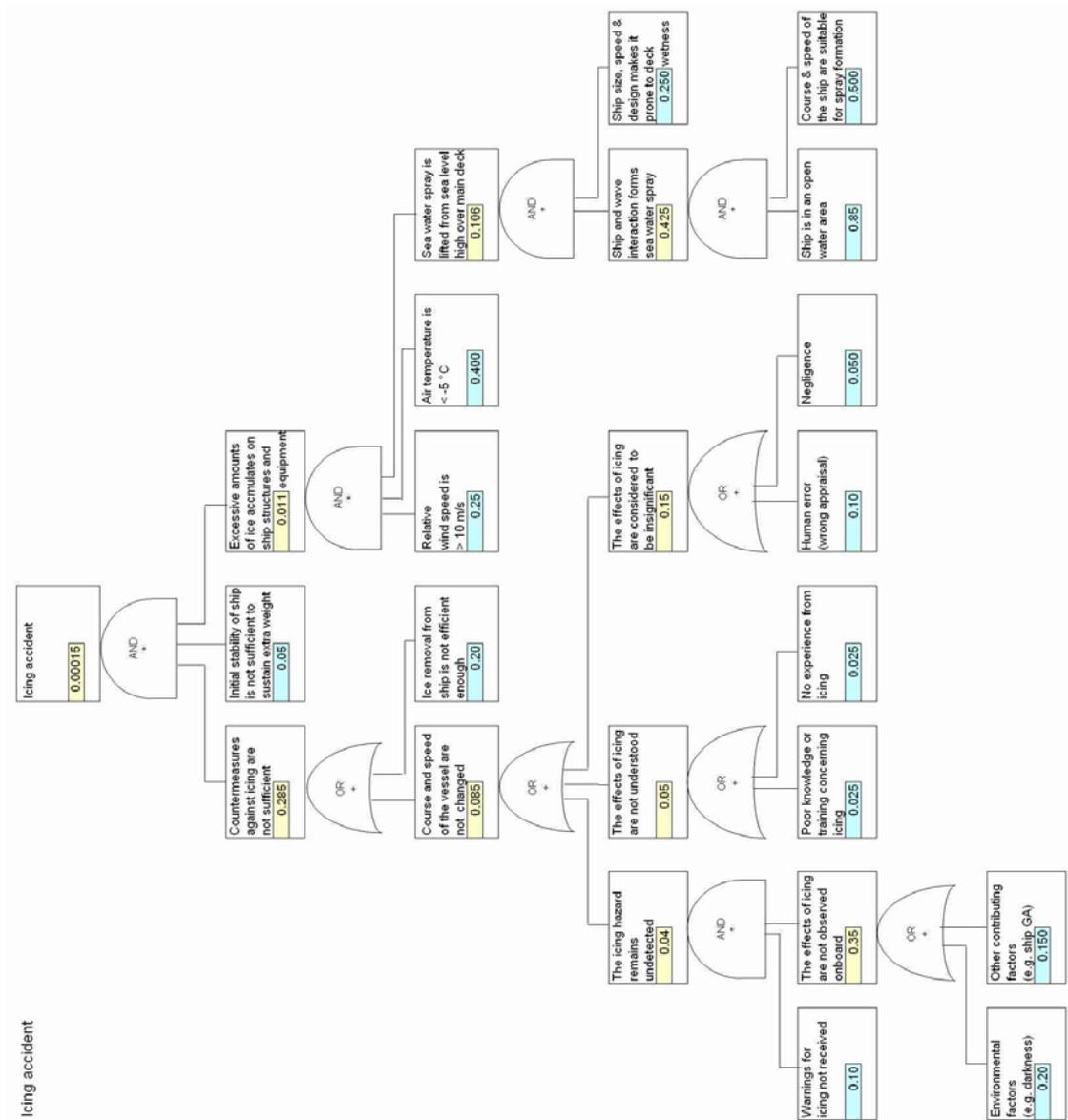| Case	Date			Ship type	L [m]	B [m]	T [m]	DWT	P [kW]	Ice class	Year build	Damage	Sea Area	Ice conditions	Source
Hull ice damage															
1	03	1	15	Bulk carrier	95.8	16.5	5.4	3 925	2 800	IAS	1986	HD	GoF	In ice	FMA
2				Ferry	201.8	32.6	6.8	4 650	31 800	IAS	1993	HD, HB	AS	In ice	HUT
3				Bulk carrier	137.2	21.6	8.2	13 370	6 250	IAS	1995	HU, HB	GoF	In ice	Other
4	03	2	27	Bulk carrier	143.4	18.6	7.5	10 935	4 413	IA	1985	HD	GoF	In ice	FMA
5	03	2	15	Tanker	160.9	23.1	10.1	22 700	7 930	IA	1984	HD	GoF	In ice	HUT
6				Tanker	232	42	20.3	96 350		IA	1994	HD	-	In ice	FMA
7				Dry cargo	118.3	18	7.4	7 210	3 680	IA	1972	HD	GoF	In ice	FMA
8	03	1	8	Tanker	99.6	17.1	6.5	6 200	3 230	IA	1989	HD, GR	GoF	Compressive ice	Other
9	03	3	2	Ferry	128.9	19.7	5	1 500	8 825	IA	1966	HR, HB, HD	BoB	In ice	HUT
10	03	1	26	Reefer	149	21.5	7	8 900	5 880	IB	1984	HD	GoF	IB assist.	Other
11	03	1	17	Dry cargo	89.6	13.2	5.7	2 800	1 200	IB	1989	HR	GoF	In ice	Other
12	03	1	18	Dry cargo	140	16.8	6.7	5 845	1 430	IC	1987	HD	GoF	IB assist.	Other
13	03	1	11	Tanker	242.4	40	14	51 160	11 000	IC	1993	HD	GoF	Compressive ice	Other
14	03	1	13	Dry cargo	81	11.8	4.4	1 855	1 280	IC	1978	HR	GoF	In ice	FMA
15	03	3	25	Bulk carrier	199.6	29	11.7	44 363	9 630	II	1982	HD	GoF	IB assist.	Other
16	03	1	18	Dry cargo	114	13.2	5.5	2 480	-	II	1969	HR	GoF	Compressive ice	FMA
17	02	12	12	Dry cargo	81	12	4.4	1 855	1 280	II	1982	HR	Sai	In ice	FMA
18	03	3	4	Trawler	-		-			-	-	HD	BPr	In ice	Other
19	03	2	5	Trawler	33.5	7.5	3.5	350	750	IC	1968	HD	BSe	In ice	FMA
20	03	1	2	Trawler	-		-			-	-	HD	GoF	In ice	Other
21	03	1	21	Tug	28.8	8.3	3.8	240	1 240	IA	1968	HD	GoF	Compressive ice	HUT
Contact															
1				Ferry	169.4	27.6	6.3	34 390	15 760	IAS	1989	C	GoF	In ice	FMA
2	03	1	5	Dry cargo	71.4	11.3	3.9	1 840	590	II	1984	C	GoR	In ice	FMA
Grounding															
1	03	4	5	Dry cargo	78.7	12.3	5.1	2 590	1 100	II	1974	GR	BPr	In ice	Other
2	03	4	11	Icebreaker	83.5	19.4	6.75	5 209	10 200	-	1979	GR	GoF	In ice	Other

Winter navigation accidents and incidents in winter 2002-2003 based on (Hänninen 2004)

Source of data:

Damage types:		Sea areas:				Source of data:	
HB	Hull damage; bilge	RU	Rudder damage	ARP	Archipelago Sea	BPR	Baltic Proper	FMA	Finnish Maritime Administration
HD	Hull damage	CL	Collision	ART	Arctic waters	GOF	Gulf of Finland	HUT	Helsinki University of Technology
HR	Hull damage; rupture	C	Contact	BBO	Bay of Bothnia	GOR	Gulf of Riga	SMA	Swedish Maritime Administration
PR	Propeller damage	GR	Grounding	BSE	Bothnian Sea	SAI	Saimaa	OTHER	Ship owners, insurance comp., newspapers, news agencies etc.

Case	Date			Ship type	L [m]	B [m]	T [m]	DWT	P [kW]	Ice class	Year build	Damage	Sea Area	Ice conditions	Source
Propeller damage															
1				Cargo ferry	175	28.7	7.4	11 600	23 000	IAS	1994	PR	-	In ice	Other
2	03	2	2	Bulk carrier	95.8	16.5	5.4	3 925	2 800	IAS	1986	PR, HD	BoB	In ice	HUT
3	03	4	22	Dry cargo	120	15.2	7	7 795	3 840	IA	2002	PR	BoB	In ice	FMA
4	03	4	1	Cargo ferry	153.4	28.2	5.82	2 880	15 300	IA	1981	PR	GoF	In ice	Other
5	03	3	25	Dry cargo	108.5	15.9	5.8	5 257	2 880	IA	1999	PR	BoB	In ice	FMA
6	03	3	20	Dry cargo	108.5	15.9	5.8	5 257	2 880	IA	2000	PR	BoB	In ice	FMA
7	03	3	20	Cargo ferry	86.3	16.8	4.2	990	4 030	IA	1971	PR	GoR	Ice channel	FMA
8	03	3	6	Cargo ferry	71	16.3	4.2	880	2 820	IA	1971	PR	GoF	IB assistance	FMA
9	03	3	2	Cargo ferry	71	16.3	4.2	880	2 820	IA	1971	PR	GoR	In ice	FMA
10	03	2	27	Dry cargo	108.5	15.9	5.8	5 257	2 880	IA	1999	PR	BoB	In ice	FMA
11	03	2	18	Cargo ferry	122.3	19.8	6.2	5 760	7 500	IA	1998	PR	GoR	In ice	Other
12	03	1	26	Cargo ferry	145.6	23.3	8.8	13 100	10 550	IA	1996	PR	GoF	In ice	FMA
13	03	1	25	Cargo ferry	74.2	16.6	3.8	726	2 650	IA	1972	PR	GoR	In ice	FMA
14	03	1	11	Dry cargo	99.8	14.7	7	4 200	-	IA	1984	PR	GoF	In ice	Other
15				Dry cargo	82.5	12.5	5.3	3 000	2 040	IA	2000	PR	-	In ice	Other
16				Dry cargo	117.3	18.2	7.1	6 870	5 760	IA	1998	PR	-	In ice	FMA
17				Passenger ship	158.9	25.2	5.6	1 700	19 100	IA	1992	PR, HB	GoF	In ice	HUT
18	03	4	17	Dry cargo	88.8	12.8	6.7	2 620	1 180	IB	1976	PR	GoF	In ice	Other
19	03	1	30	Reefer	75.4	13.2	5.1	2 225	1 370	IB	1980	PR	GoF	In ice	Other
20				Dry cargo	80	13.8	5.4	2 900	1 460	IB	1972	PR	GoF	In ice	Other
21				Tanker	182.6	27.3	11.2	37 000	9 460	IB	2001	PR	-	In ice	FMA
22	03	4	1	Cargo ferry	188.9	23.7	5.9	6 300	13 200	IB	1986	PR, HB	BPr	Ice channel	FMA
23	03	2	20	Dry cargo	86.3	13	5.6	2 600	1 470	IC	1977	PR	GoF	In ice	FMA
24	03	1	28	Dry cargo	81	11.8	4.4	1 855	1 280	IC	1978	PR	GoF	In ice	Other
25	03	1	15	Dry cargo	119	13.4	3.8	3 000	1 280	IC	1989	PR	GoF	In ice	Other
26	03	4	30	Passenger ship	292.5	38.8	7.8	7 500	35 200	II	2003	PR	GoF	In harbour	FMA
27	03	2	22	Dry cargo	81.6	13.4	5	2 500	1 950	II	1975	PR	GoR	In ice	FMA
28	02	12	3	Dry cargo	134.6	21.5	7	9 450	7 200	II	2003	PR	BoB	In ice	FMA
29				Dry cargo	93.1	-	-	5 340	3 825	II	1993	PR	-	In ice	FMA
30	03	3	24	Icebreaker	67.7	18.3	6.1	2 700	3 970	-	1971	PR	GoF	In ice	Other
31	03	4	1	Tug	40.4	9.8	4.3	175	2 700	IA	1965	PR,HB	GoR	In harbour	Other
32				Tug	30.5	9	4.6	300	1 470	IAS	1968	PR	AS	In ice	Other
33	03	1	15	Tug	28.5	8.1	4.6	150	1 000	IA	1964	PR	GoF	In ice	Other
34	03	1	23	Tug	29.1	9	3.6	300	2 650	IA	1989	PR	GoF	In ice	FMA
35	03	2	27	Ferry*	23.3	6.8	3.6	300	750	-	1992	PR	GoF	In ice	Other
36	03	3	5	Tug	26.4	8	3.6	245	550	IA	1966	PR	GoF	In ice	Other

* This is a ferry converted from another ship type

Winter navigation accidents and incidents in winter 2002-2003 based on (Hänninen 2004)

Source of data:

Damage types:		Sea areas:					FMA	Finnish Maritime Administration
HB	Hull damage; bilge	RU	Rudder damage	ARP	Archipelago Sea	BPR	Baltic Proper	HUT Helsinki University of Technology
HD	Hull damage	CL	Collision	ART	Arctic waters	GOF	Gulf of Finland	SMA Swedish Maritime Administration
HR	Hull damage; rupture	C	Contact	BBO	Bay of Bothnia	GOR	Gulf of Riga	OTHER Ship owners, insurance comp.,
PR	Propeller damage	GR	Grounding	BSE	Bothnian Sea	SAI	Saimaa	newspapers, news agencies etc.

Case	Date			Ship type	L [m]	B [m]	T [m]	DWT	P [kW]	Ice class	Year build	Damage	Sea Area	Ice conditions	Source
Rudder damage															
1	03	4	10	Cargo ferry	162.6	20.6	6.7	8 708	12 600	IAS	2001	RU	BoB	In ice	FMA
2	03	2	26	Cargo ferry	162.6	20.6	6.7	8 708	12 600	IAS	2001	RU	BoB	In ice	FMA
3	03	2	14	Bulk carrier	90.4	13.6	5.7	4 200	2 400	IA	1999	RU	BoB	In ice	FMA
4	02	12	15	Cargo ferry	107.5	17	6.1	4 450	2 960	IA	1989	RU	BSe	In ice	Other
5				Tanker	161	23	8.6	17 080	6 600	IA	1994	RU	-	In ice	FMA
6	03	4	2	Dry cargo	100	15.9	4.9	3 725	3 280	IA	2001	RU	GoF	In ice	FMA
7	03	2	28	Reefer	140	16.6	4	4 500	1 940	IC	1996	RU	GoF	In ice	Other
8	03	1	18	Dry cargo	108.4	15	5	2 500	1 030	II	1986	RU	GoF	In ice	FMA
9	03	3	13	Other	76.9	11.6	3	1 300	5 200	-	1992	RU, HD	GoF	In ice	Other
Machinery damage															
1	03	2	14	Dry cargo	132.2	15.9	7.1	8 300	3 960	IA	2000	EN	BoB	In ice	FMA
2				Dry cargo	135.1	20.7	8.7	10 500	4 840	IA	1984	EN	-	In ice	FMA
3	03	1	3	Ferry	23.2	5.4	1.9	-	310	-	1909	EN	BPr	In ice	FMA
Collision															
1a	03	3	14	Tanker	124.8	17.2	7.1	8 000	4 100	IA	1993	CL	GoF	In ice	Other
1b	03	3	14	Tanker	134.7	19.6	8.3	10 620	4 000	IA	1986				
2a	03	3	12	Dry cargo	134.5	16.5	7.1	8 950	5 280	IA	2000	CL	GoF	Ice channel	FMA
2b	03	3	12	Tanker	140.7	21.2	7.3	11 500	6 000	IA	1982				
3a	03	3	11	Dry cargo	102.2	15.2	5.1	4 140	2 440	IA	1986	CL	GoF	Ice channel	FMA
3b	03	3	11	Bulk carrier	130.3	17.3	6.9	6 000	4 500	IAS	1977				
4a	03	3	5	Dry cargo	130.2	15.9	7.5	9 070	3 960	IA	1998	CL	GoR	In ice	FMA
4b	03	2	27	Bulk carrier	89.7	13.6	5.7	4 025	2 010	IA	1994	CL	GoF	Ice channel	Other
5a	03	2	24	Bulk carrier	89.7	13.6	5.7	4 025	2 010	IA	1994	CL	GoF	Ice channel	Other
5b	03	2	24	Tanker	178.8	25.3	11	28 640	-	IC	1986				
6a	03	2	6	Dry cargo	103.5	16.2	6.1	4 450	2 990	IA	1991	CL	GoF	Ice channel	FMA
6b	03	2	6	Cargo ferry	122.3	19.8	6.2	5 760	7 500	IA	1998				
7a	03	2	1	Bulk carrier	179.4	25.7	11.1	31 850	9 450	IA	1980	CL	GoF	Ice channel	FMA
7b	03	2	1	Dry cargo	109.7	17.8	7.2	6 920	3 360	IA	1996				
8a				Dry cargo	82.3	12.6	4.9	2 600	1 200	IB	1987	CL	-	Ice channel	FMA
8b				Tanker	101.4	15.9	6.25	4 650	2 940	IA	1980				
9	03	3	10	Dry cargo	77.3	12.8	5.5	2 400	1 210	IA	1970	CL	GoR	Ice channel	FMA
10	03	2	27	Tanker	178.8	25.3	11	28 640		IC	1986				
11	03	2	18	Dry cargo	104.9	16	6.3	4 150	2 940	IA	1989	CL	GoF	Ice channel	FMA
12	03	1	18	Dry cargo	100	16.5	5.3	4 700	2 800	IA	2001	CL	GoF	Ice channel	FMA

Winter navigation accidents and incidents in winter 2002-2003 based on (Hänninen 2004)

Source of data:

Case	Date			Ship type	L [m]	B [m]	T [m]	DWT	P [kW]	Ice class	Year build	Damage	Sea Area	Ice conditions	Source
Collision in IB assistance															
1a	03	2	10	Dry cargo	100	14.6	6.4	5 500	2 600	IA	1997	CL	BoB	IB assistance	FMA
1b	03	2	10	Icebreaker	104.7	23.85	8.3	9 660	16 200	-	1975				
2a	03	2	4	Bulk carrier	98.9	13.8	5.75	4 550	2 880	IA	1999	CL	BoB	IB assistance	FMA
2b	03	2	4	Icebreaker	99	24.2	8	9 130	21 850	-	1986				
3a	03	1	30	Tanker	100.8	12.5	6.5	4 300	3 180	IA	1998	CL	BoB	IB assistance	FMA
3b	03	1	30	Icebreaker	99	24.2	8	9 130	21 850	-	1986				
4a				Dry cargo	82.3	12.6	4.9	2 600	1 200	IB	1987	CL	GoF	IB assistance	FMA
4b				Icebreaker	83.5	19.4	6.75	5 209	10 200	-	1979				
5a				Bulk carrier	159.1	27.2	6.7	14 000	-	IAS	1986	CL	BoB	IB assistance	HUT
5b				Icebreaker	99	24.2	8	9 130	21 850	-	1986				
6				Icebreaker	-	-	-	-	-	-	-	CL	BoB	IB assistance	SMA
7				Icebreaker	-	-	-	-	-	-	-	CL	BoB	IB assistance	SMA
8				Icebreaker	-	-	-	-	-	-	-	CL	BoB	IB assistance	SMA
9	03	3	28	Dry cargo	108.4	15	5	3 070	1 030	II	1978	CL	GoF	IB assistance	Other
10	03	2	14	Dry cargo	77.3	12.8	5.5	2 400	1 210	IA	1970	CL	GoR	IB assistance	FMA

Summary

				Merchant ships				
	Merchant ships total	Other ships	Total	IA Super	IA	IB	IC	II
Hull ice damage	17	4	21	3	6	2	3	3
Cumulative hull damage	3		3	2	1			
Propeller damage	29	7	36	2	15	5	3	4
Rudder damage	8	1	9	2	4		1	1
Machinery damage	2	1	3		2			
Collision	12		12					
Collision in IB assistance	10		10					
Grounding	1	1	2					
Contact	2		2					
	84	14	98	9	28	7	7	8

Note! One case in the group "hull ice damage" could also be placed in the group "grounding"
One case in the group "propeller ice damage" could also be placed in the group "hull ice damage"
Three other cases in the group "propeller ice damage" could also be placed in a group "bilge keel ice damage"
One case with a ship in the group "other" in the group "rudder ice damage" could also be placed in the group "hull ice damage"

RISK MATRIX FOR WINTER NAVIGATION:
Hull ice damage / Risk to people

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
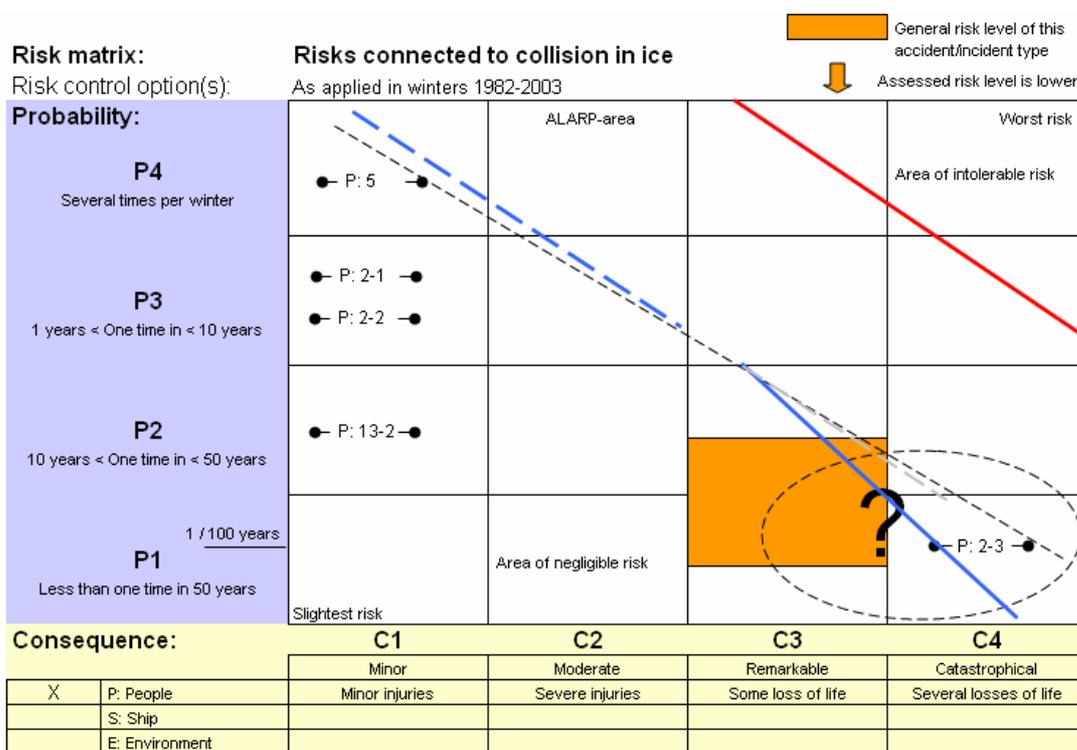
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The risk acceptance criteria are characterized here by the two inclined dashed lines (blue and red), which are fitted here with the assumption of a fleet of 2000 ships in winter navigation in the northern Baltic Sea. The applied risk acceptance criteria are based on the societal risk acceptance criteria proposed in IMO MSC 72/16, where the expressed limit for the intolerable risk in frequency of one or more fatalities is 1/100 ship-years and the limit for the negligible range is 1/10000 ship-years. In this risk matrix the risk criteria is extended to severe and minor injuries by maintaining the slope of the line.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
   P4: 1 time per year   - 10 times per year   ~ several times per year
   P3: 1 time per 10 years - 1 time per year, **P2**: 1 time per 50 years - 1 time per 10 years
   P1: 1 time per 250 years - 1 time per 50 years ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Collision / Risk to people

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
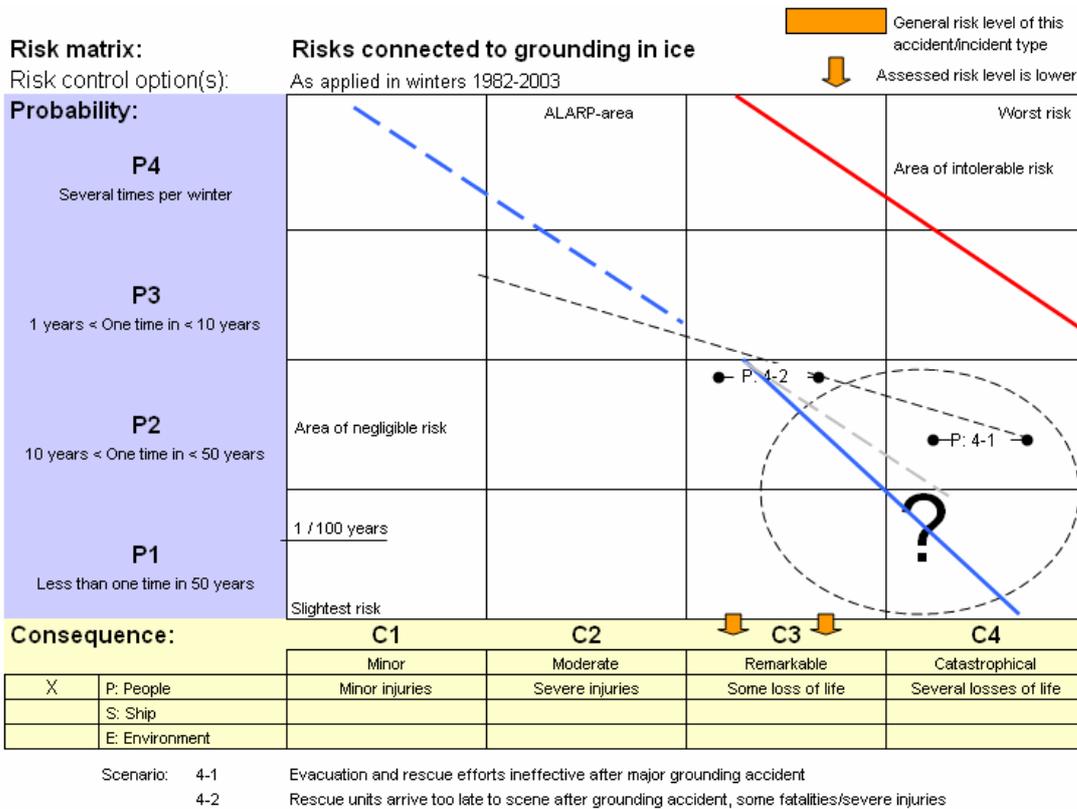
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The risk acceptance criteria are characterized here by the two inclined dashed lines (blue and red), which are fitted here with the assumption of a fleet of 2000 ships in winter navigation in the northern Baltic Sea. The applied risk acceptance criteria are based on the societal risk acceptance criteria proposed in IMO MSC 72/16, where the expressed limit for the intolerable risk in frequency of one or more fatalities is 1/100 ship-years and the limit for the negligible range is 1/10000 ship-years. In this risk matrix the risk criteria is extended to severe and minor injuries by maintaining the slope of the line.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
  P4: 1 time per year   - 10 times per year   ~ several times per year
  P3: 1 time per 10 years - 1 time per year, **P2**: 1 time per 50 years - 1 time per 10 years
  P1: 1 time per 250 years - 1 time per 50 years ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Grounding / Risk to people

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
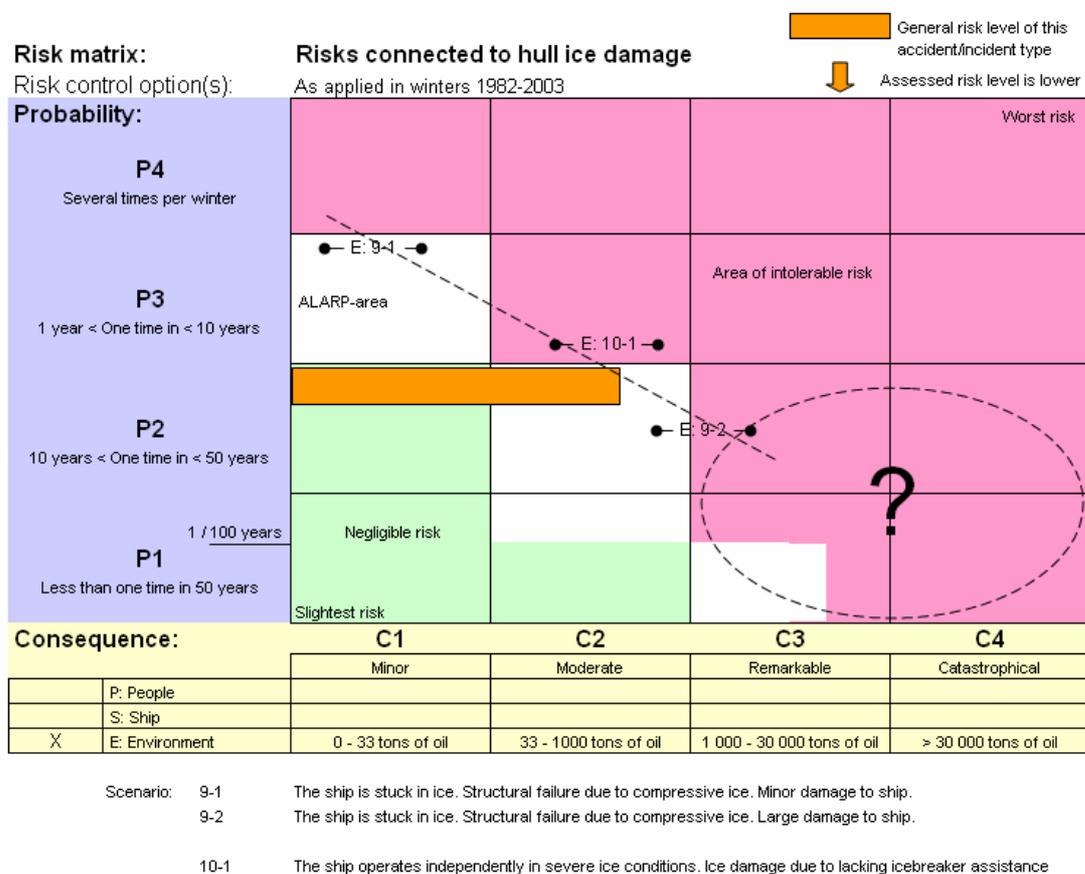
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The risk acceptance criteria are characterized here by the two inclined dashed lines (blue and red), which are fitted here with the assumption of a fleet of 2000 ships in winter navigation in the northern Baltic Sea. The applied risk acceptance criteria are based on the societal risk acceptance criteria proposed in IMO MSC 72/16, where the expressed limit for the intolerable risk in frequency of one or more fatalities is 1/100 ship-years and the limit for the negligible range is 1/10000 ship-years. In this risk matrix the risk criteria is extended to severe and minor injuries by maintaining the slope of the line.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
P4: 1 time per year - 10 times per year ~ several times per year
P3: 1 time per 10 years - 1 time per year, **P2**: 1 time per 50 years - 1 time per 10 years
P1: 1 time per 250 years - 1 time per 50 years ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Hull ice damage / Pollution risk

	Scenario:	9-1	The ship is stuck in ice. Structural failure due to compressive ice. Minor damage to ship.
		9-2	The ship is stuck in ice. Structural failure due to compressive ice. Large damage to ship.
		10-1	The ship operates independently in severe ice conditions. Ice damage due to lacking icebreaker assistance

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
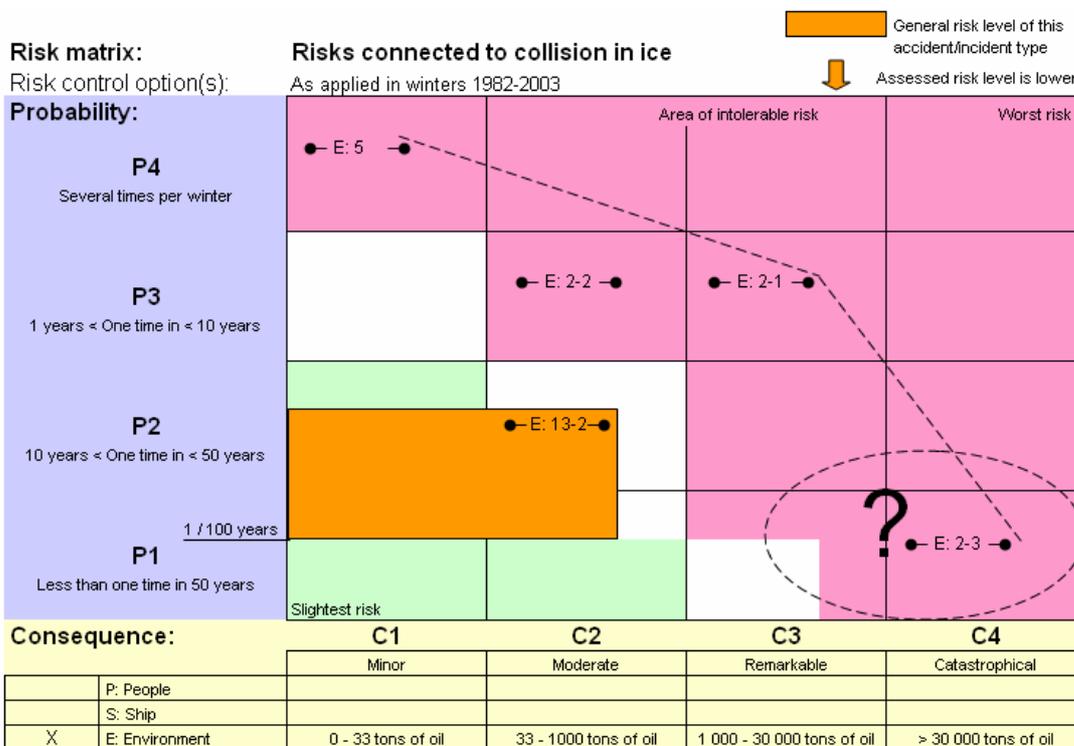
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment. It should be stressed here that the risk of a remarkable (C3) or catastrophic (C4) oil spill is not assessed here.

The acceptable risk level is characterized here by the light green area, in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). The risk acceptance criteria applied here is based on (SEALOCK 1998) and partly on the views of the authors. The former criteria are used when the amount of spilled oil is >100 t, and the latter when the amount of spilled oil is <100 t. The expected amount of spilled oil in this study is 0 - 300 t.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
P4: 1 time per year   - 10 times per year   ~ several times per year
P3: 1 time per 10 years   - 1 time per year, **P2**: 1 time per 50 years   - 1 time per 10 years
P1: 1 time per 250 years - 1 time per 50 years   ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Collision / Pollution risk

	General risk level of this accident/incident type
	Assessed risk level is lower

Risk matrix: Risks connected to collision in ice
Risk control option(s):   As applied in winters 1982-2003

Probability:

Area of intolerable risk   Worst risk

P4
Several times per winter
● E: 5 ─●

P3
1 years < One time in < 10 years
● E: 2-2 ●   ● E: 2-1 ●

P2
10 years < One time in < 50 years
● E: 13-2 ●

1 / 100 years

P1
Less than one time in 50 years
Slightest risk
? ● E: 2-3 ●

Consequence:	C1	C2	C3	C4
	Minor	Moderate	Remarkable	Catastrophical
P: People				
S: Ship				
X E: Environment	0 - 33 tons of oil	33 - 1000 tons of oil	1 000 - 30 000 tons of oil	> 30 000 tons of oil

Scenario:
- 2-1   A collision in ice conditions between a cargo ship and a tanker
- 2-2   A collision in ice conditions between two cargo ships (neither of which is a tanker)
- 2-3   A collision between a passenger vessel and a tanker in ice conditions with a fire as a consequence
- 5   Two ships collide with minor structural consequences when approaching each other in ice channel, either in an encounter or an overtaking manoeuvre, which does not succeed. Breaking out of channel difficult due to ice.
- 11-1 A collision between icebreaker and an assisted vessel, in assistance operations
- 13-2 A collision between two ships due to the traffic separation scheme, which is not in use in ice conditions

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.

The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment. It should be stressed here that the risk of a remarkable (C3) or catastrophic (C4) oil spill is not assessed here.

The acceptable risk level is characterized here by the light green area, in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). The risk acceptance criteria applied here is based on (SEALOCK 1998) and partly on the views of the authors. The former criteria are used when the amount of spilled oil is >100 t, and the latter when the amount of spilled oil is <100 t. The expected amount of spilled oil in this study is 0 - 300 t.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
   P4: 1 time per year   - 10 times per year   ~ several times per year
   P3: 1 time per 10 years   - 1 time per year, **P2**: 1 time per 50 years   - 1 time per 10 years
   P1: 1 time per 250 years - 1 time per 50 years   ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Grounding / Pollution risk
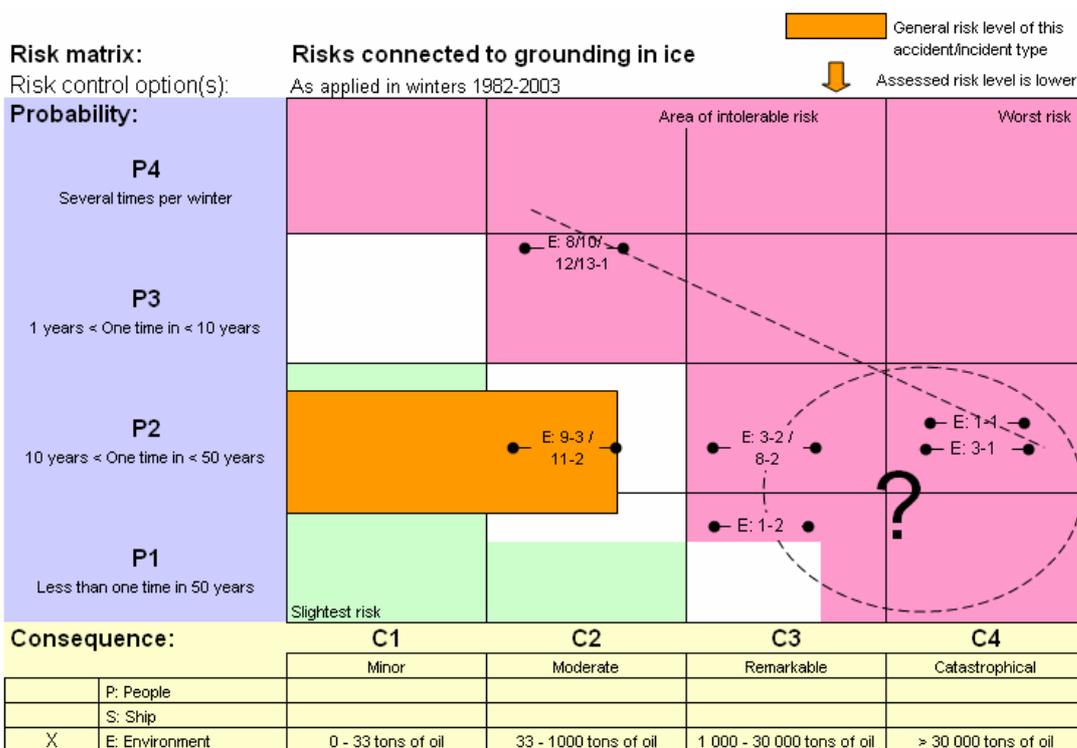
Scenario:
- 1-1 Powered grounding of a large oil tanker, related to ice conditions
- 1-2 Drift grounding of a large oil tanker, related to ice conditions
- 3-1 Powered grounding of a single bottom oil tanker
- 3-2 Powered grounding of an oil tanker with single hull
- 8-1 Drift grounding of a cargo ship (not due to ice) Small damage
- 8-2 Drift grounding of a cargo ship (not due to ice) Severe damage
- 9-3 Drift grounding of a cargo ship due to ice drift
- 10-2 The ship operates independently in severe ice conditions. Grounding due to lacking icebreaker assistance
- 11-2 Grounding due to misunderstandings in communication with IB or other ships
- 12   Grounding due to avoiding of difficult ice conditions. (Navigational error)
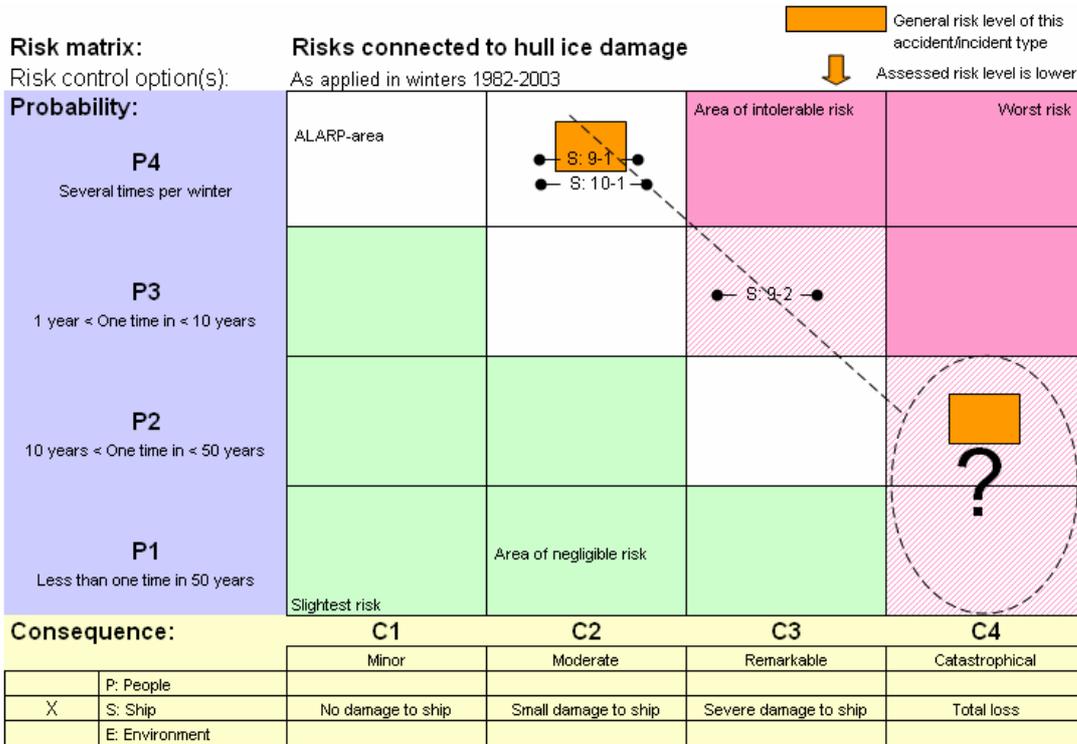- 13-1 Grounding due to missing traffic separation scheme in winter

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.

The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment. It should be stressed here that the risk of a remarkable (C3) or catastrophic (C4) oil spill is not assessed here.

The acceptable risk level is characterized here by the light green area, in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). The risk acceptance criteria applied here is based on (SEALOCK 1998) and partly on the views of the authors. The former criteria are used when the amount of spilled oil is >100 t, and the latter when the amount of spilled oil is <100 t. The expected amount of spilled oil in this study is 0 - 300 t.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the scale for the upper part is different to the lower half.

RISK MATRIX FOR WINTER NAVIGATION:
Hull ice damage / Risk to ship

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
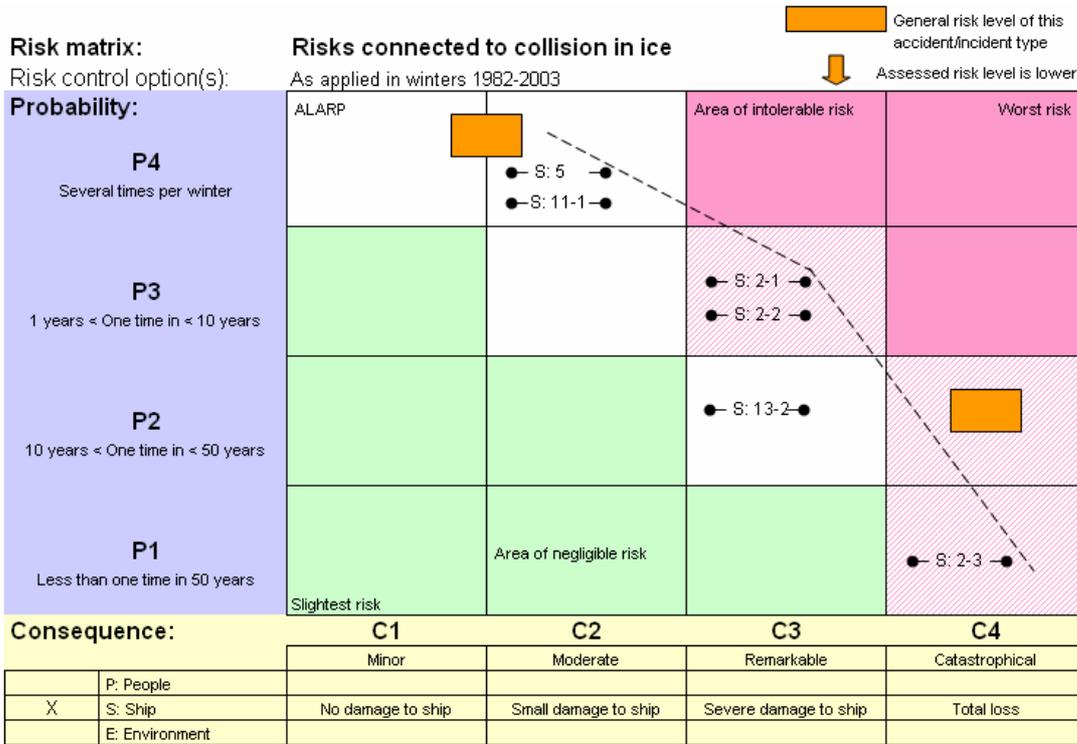
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The acceptable risk level is characterized here by the light green area(s), in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). As there are no widely accepted risk criteria for structural damage or total loss of the ship (to the knowledge of the authors), the risk acceptance criteria presented here are based on the subjective views of the authors. Money that is paid on the insurance & repair costs can be used as a criteria, but a cost-benefit study is not included in this study.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:

P4: 1 time per year - 10 times per year ~ several times per year
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RISK MATRIX FOR WINTER NAVIGATION:
Collision / Risk to ship

				General risk level of this accident/incident type
				Assessed risk level is lower

Risk matrix:
Risk control option(s):

Risks connected to collision in ice
As applied in winters 1982-2003

Probability:	ALARP		Area of intolerable risk	Worst risk
P4 Several times per winter		● S: 5 ● ● S: 11-1 ●		
P3 1 years < One time in < 10 years			● S: 2-1 ● ● S: 2-2 ●	
P2 10 years < One time in < 50 years			● S: 13-2 ●	
P1 Less than one time in 50 years	Slightest risk	Area of negligible risk		● S: 2-3 ●

Consequence:		C1	C2	C3	C4
		Minor	Moderate	Remarkable	Catastrophical
	P: People				
X	S: Ship	No damage to ship	Small damage to ship	Severe damage to ship	Total loss
	E: Environment				

Scenario:	
2-1	A collision in ice conditions between a cargo ship and a tanker
2-2	A collision in ice conditions between two cargo ships (neither of which is a tanker)
2-3	A collision between a passenger vessel and a tanker in ice conditions with a fire as a consequence
5	Two ships collide with minor structural consequences when approaching each other in ice channel, either in an encounter or an overtaking manoeuvre, which does not succeed. Breaking out of channel difficult due to ice.
11-1	A collision between icebreaker and an assisted vessel, in assistance operations
13-2	A collision between two ships due to the traffic separation scheme, which is not in use in ice conditions

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.
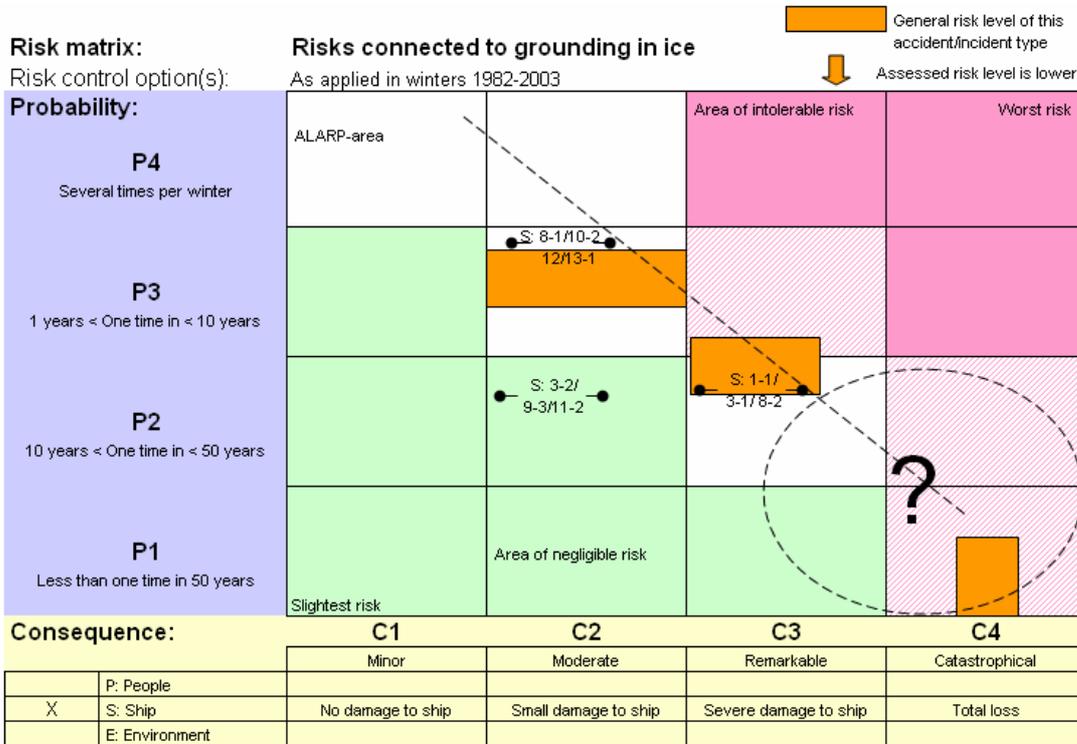
The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The acceptable risk level is characterized here by the light green area(s), in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). As there are no widely accepted risk criteria for structural damage or total loss of the ship (to the knowledge of the authors), the risk acceptance criteria presented here are based on the subjective views of the authors. Money that is paid on the insurance & repair costs can be used as a criteria, but a cost-benefit study is not included in this study.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the limits of the probability classes are as follows:
  P4: 1 time per year   - 10 times per year   ~ several times per year
  P3: 1 time per 10 years   - 1 time per year, **P2**: 1 time per 50 years   - 1 time per 10 years
  P1: 1 time per 250 years - 1 time per 50 years   ~ less than one time per 50 years

RISK MATRIX FOR WINTER NAVIGATION:
Grounding / Risk to ship

Risk matrix: Risks connected to grounding in ice
Risk control option(s): As applied in winters 1982-2003

General risk level of this accident/incident type
Assessed risk level is lower

| Scenario:	1-1	Powered grounding of a large oil tanker, related to ice conditions
	3-1	Powered grounding of a single bottom oil tanker
	3-2	Powered grounding of an oil tanker with single hull
	8-1	Drift grounding of a cargo ship (not due to ice) Small damage
	8-2	Drift grounding of a cargo ship (not due to ice) Severe damage
	9-3	Drift grounding of a cargo ship due to ice drift
	10-2	The ship operates independently in severe ice conditions. Grounding due to lacking icebreaker assistance
	11-2	Grounding due to misunderstandings in communication with IB or other ships
	12	Grounding due to avoiding of difficult ice conditions. (Navigational error)
	13-1	Grounding due to missing traffic separation scheme in winter

The risk assessed in this study is presented here in the same type of risk matrix that was used by Juva (2002), who assessed the risk level for some detailed scenarios described above. The risk assessed by Juva (2002) is expressed here by the location of the code of the corresponding scenario (e.g. P 9-1). The horizontal line segments connected to them represent the uncertainty of the consequences, which have been added by the authors of this risk analysis. The area marked with the question mark is the area of major uncertainty.

The result of this risk analysis is presented here by the location of the orange rectangle(s) the height and width of which represent or reflect the uncertainty of the corresponding risk assessment.

The acceptable risk level is characterized here by the light green area(s), in the lower left corner, and the area(s) of intolerable risk by the rose area, in the upper right corner (and right side). As there are no widely accepted risk criteria for structural damage or total loss of the ship (to the knowledge of the authors), the risk acceptance criteria presented here are based on the subjective views of the authors. Money that is paid on the insurance & repair costs can be used as a criteria, but a cost-benefit study is not included in this study.

Note! The scales of this risk matrix are unconventional, but they are similar to the ones used by Juva (2002). The vertical scale is logarithmic, but in a stepwise way, so that the scale for the upper part is different to the lower half.

RISK MODEL FOR ICE DAMAGE IN COMPRESSIVE ICE
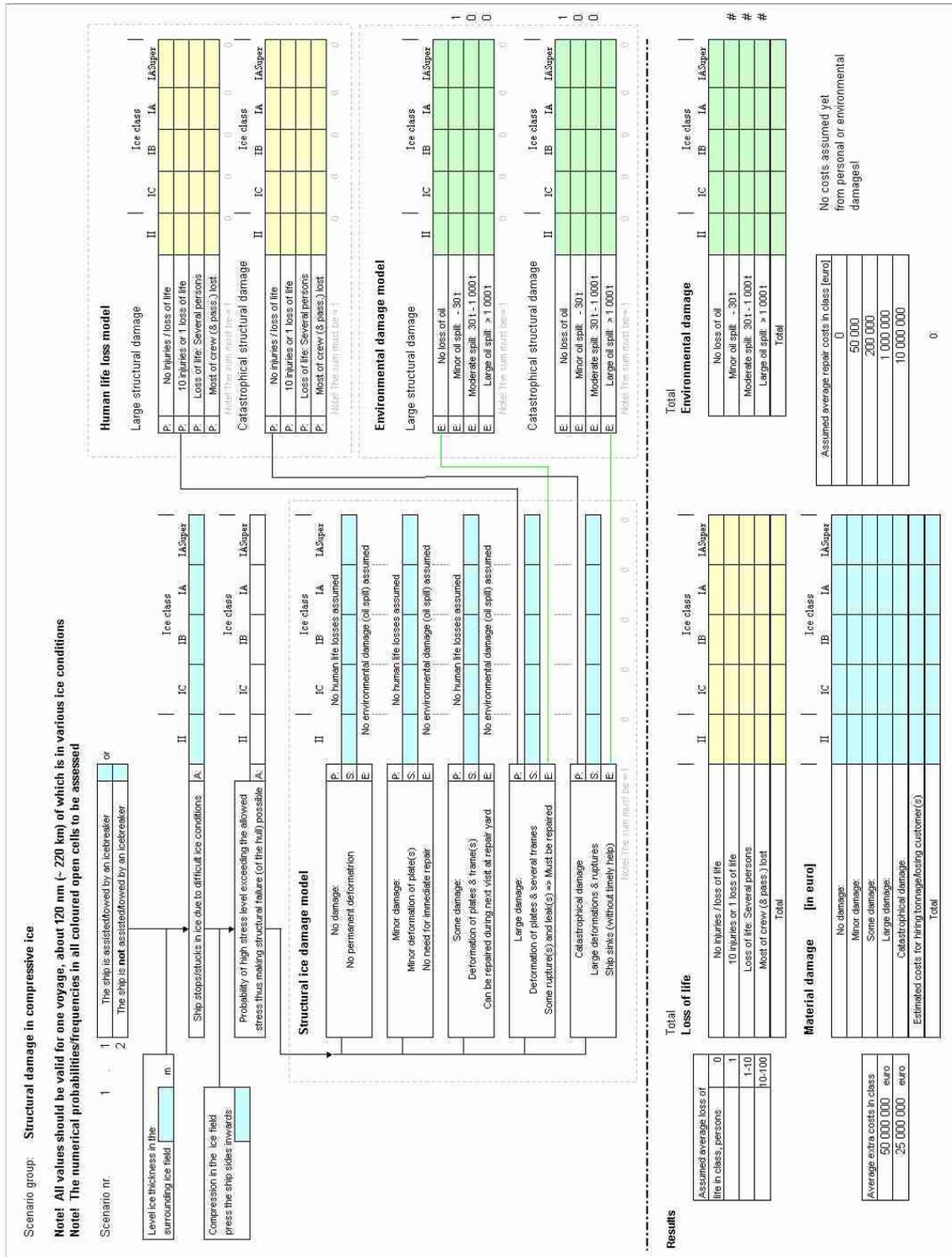
Note! This is not necessarily the final structure of the corresponding risk model. This model is presented here to act as a catalyst to a discussion enabling the development of a risk model with a broad acceptance. Estimates of the probabilities need to be assessed.