Åland Sea FSA study

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Baltic Sea Safety

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Summary

This FSA study has been carried out by VTT as commissioned by the Finnish Ministry of Transport and Communications and the Finnish Maritime Administration. The study is a part of the Nordic BaSSy -project (Baltic Sea Safety) which is partly funded by the Nordic Council of Ministers. During the study process, VTT has been cooperating with the Danish University of Technology in matters related to the BaSSy tool used in the risk analyses.

The aim of this FSA study was to assess the effectiveness of the proposed routeing measures supported with monitoring, reporting and navigational assistance systems as measures to improve maritime safety in the Åland Sea area by reducing the risk of casualties and increasing the protection of marine environment. The study was focused on collision and grounding risk. The risk impacts of four different risk control options (RCO) were of special concern in the study: RCO 1: traffic separation scheme and deep-water route; RCO 2: RCO 1 added with monitoring; RCO 3: RCO 2 added with reporting systems; RCO 4: RCO 3 added with VTS with navigational assistance service.

The risk modelling framework used in the present study was based on the BaSSy tool software, which estimates collision and grounding frequencies based on historical AIS traffic, and estimation of the situational awareness of the navigators in different situations, which affect their ability to avoid accidents in potentially hazardous situations. The estimation situational awareness was performed using the Bayesian networks.

The benefit of improved safety was measured in terms of expected reduced consequence cost. The cost-benefit performance of the RCOs was assessed in terms of the total return of the investment.

The outcome of the FSA study clearly indicates that the implementation of the proposed traffic separation schemes and deep-water route to the Åland Sea is highly recommendable. In addition, implementation of a Ship Reporting System, similar to the one in the Gulf of Finland, is also recommendable.

Confidentiality	Public

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Preface

For a long time, the Åland Sea has been recognised as one of the sea areas of increased ship accident risk in the Baltic Sea. The traffic flows bound to the Gulf of Bothnia coming from the Gulf of Finland and the Central Baltic are joining on the area and intersecting the dense passenger vessel traffic between Finland and Sweden. The traffic has been unorganised due to lack of traffic routeing and surveillance systems. Both the seafarers sailing in the area, people living on the coasts of Åland Sea as well as the Maritime Administrations of Finland and Sweden have been concerned about the risk level. Thus the Åland Sea was selected as the first case of the Formal Safety Assessment studies to be performed by VTT in the Baltic Sea Safety (BaSSy) –project.

The preliminary outlining of the FSA study was commenced already in October 2005 but the proper work started after the contract about the funding from the Nordic Council of Ministers for the BaSSy project was signed in December 2006. The work followed the development phases of the collision and grounding risk analysis software, BaSSy tool, performed by the Danish Technical University as one of the tasks in the BaSSy project. The collision module of the software was ready at the end of 2007 and the Åland Sea collision risk analysis was completed in March 2008. The grounding module of the software was available in the second half of 2008 and the grounding risk analysis was performed in February 2009. The Åland Sea FSA study was completed in June 2009.

The progress of the Åland Sea FSA study was annually reported to the BaSSy project advisory board and the reference group consisting of the Finnish, Swedish and Danish members appointed by the Nordic Council of Ministers and the other financiers.

The VTT´s research group will express its compliments to the advisory board and the reference group for their guidance of the work and to the BaSSy project group for the fruitful and competent cooperation. In addition, special thanks to the participants of the expert workshops for the expertise they gave to the project as well as to the municipalities around the Åland Sea in Finland and Sweden for their response to the questionnaire carried out in the beginning of the project.

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1 Introduction

In the Åland Sea the traffic flows which are coming from the Gulf of Finland and the Central Baltic Sea and which are bound north to the Swedish and Finnish ports in the Gulf of Bothnia join, see Figure 1. From time to time the traffic congests in the confined areas and the lack of clear procedures causes potential risk of accidents. In addition, there is frequent traffic between Finland and Sweden which intersects the northbound traffic vessel transits - consisting mainly of passenger car ferries and ro-ro vessels. The traffic in the Åland Sea is unorganized because there is no traffic separation schemes (TSSs) in the area. There is a recommended deep-water route in the area of Svenska Björn and Southern Quark but the major part of the vessels only follow their own routes without taking into account the deep-water route.

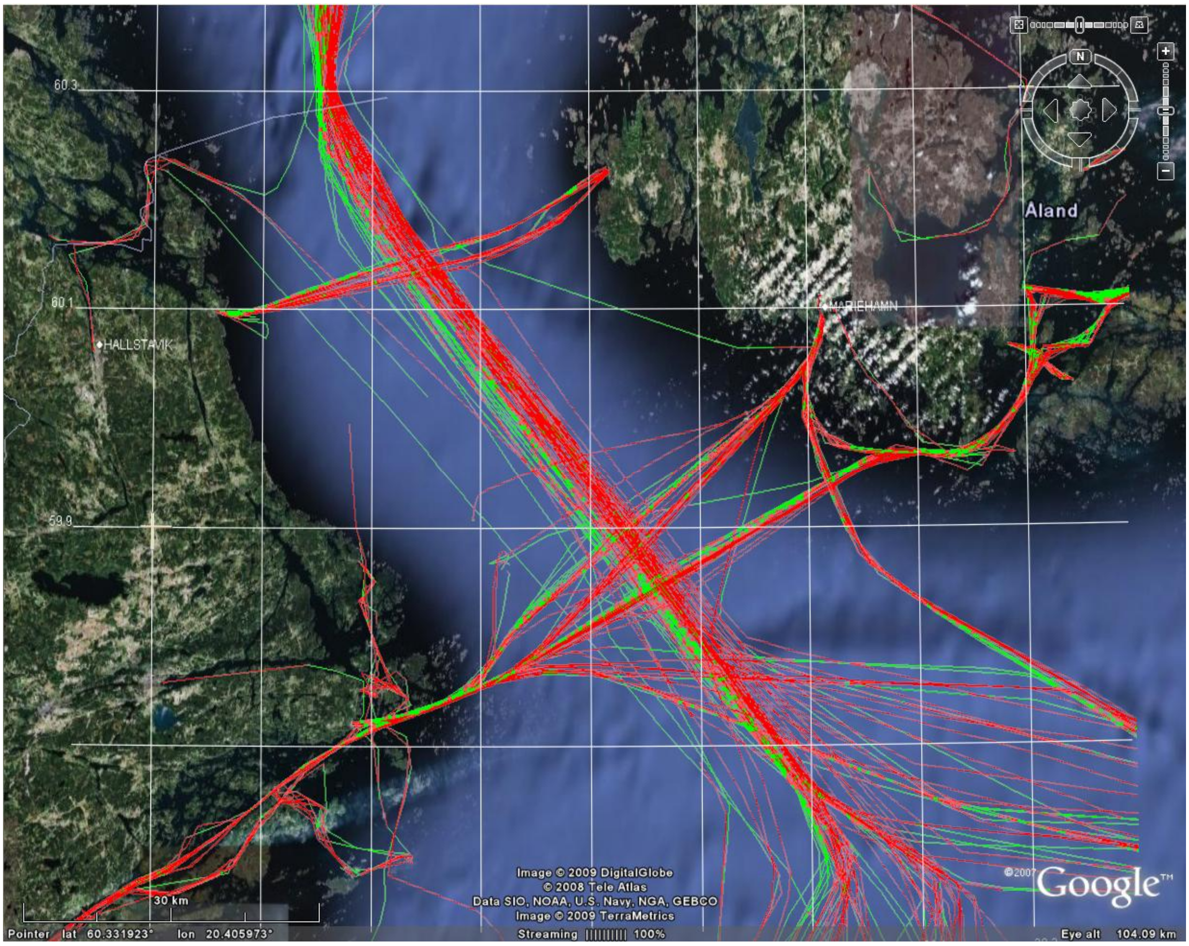


Figure 1 Ship tracks in the Åland Sea recorded 1.-3.7.2007 from Automatic Identification System (AIS). The tracks of the northbound vessels (heading in the range of 270°- 90°) are coloured in red and the tracks of the southbound vessels (heading in the range of 90° - 270°) are coloured in green.

The main concern that has been expressed is the risk of collision between different types of vessels and the environmental damage due to subsequent oil spills. In order to improve the navigational safety in the area the Maritime Administrations of Finland and Sweden have designed a set of traffic separation schemes and a new deep-water route to the Åland Sea. In addition, in the expert workshops arranged during the FSA process additional risk control measures were identified supporting the designed routeing measures and finally a set of four risk control options (RCO) were formed.

The objective of the present study was to systematically assess the effectiveness of the designed RCOs before the proposal for the implementation of the most cost effective solution is passed on to the IMO decision making process. For this purpose, this Formal Safety Assessment (FSA) study was commissioned by the Finnish Ministry of Traffic and Communications together with the Finnish Maritime Administration.

This study is a part of the Nordic BaSSy -project (Baltic Sea Safety). One of the objectives of the project is to develop harmonised principles for the FSA process to be applied in the Baltic Sea. The project is formed by the following organisations: SSPA Sweden AB (SSPA), MSI Design, Chalmers Shipping and Marine Technology (Chalmers) from Sweden, VTT Technical Research Centre of Finland (VTT) from Finland and Technical University of Denmark (DTU) and Gatehouse from Denmark. In addition to the national funding, the project is funded by the Nordic Council of Ministers. The BaSSy tool software, which is developed within the BaSSy project by DTU and Gatehouse, was used for calculation of the collision and grounding frequencies in this study. The used features of the BaSSy tool are also important elements in the ongoing development of the IWRAP Mk2 (IALA Waterway Risk Assessment Program) programme.

2 FSA method

The method used in the Åland Sea risk analysis is the Formal Safety Assessment (FSA) method which is described in [IMO 2007]:

- Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment.

- FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs.

- FSA is consistent with the current IMO decision-making process and provides a basis for making decisions in accordance with resolutions A.500(XII) "Objectives of the Organization in the 1980's", A.777(18) "Work Methods and Organization of Work in Committees and their Subsidiary Bodies" and A.900(21) “Objectives of the Organization in the 2000s”.

- The decision makers at IMO, through FSA, will be able to appreciate the effect of proposed regulatory changes in terms of benefits (e.g. expected reduction of lives lost or of pollution) and related costs incurred for the industry as a whole and for individual parties affected by the decision. FSA should facilitate the development of regulatory changes equitable to the various parties thus aiding the achievement of consensus.

– FSA should comprise the following steps (the process is illustrated in Figure 2):

1. Identification of hazards;
2. Risk analysis;
3. Risk control options;
4. Cost benefit assessment; and
5. Recommendations for decision-making.

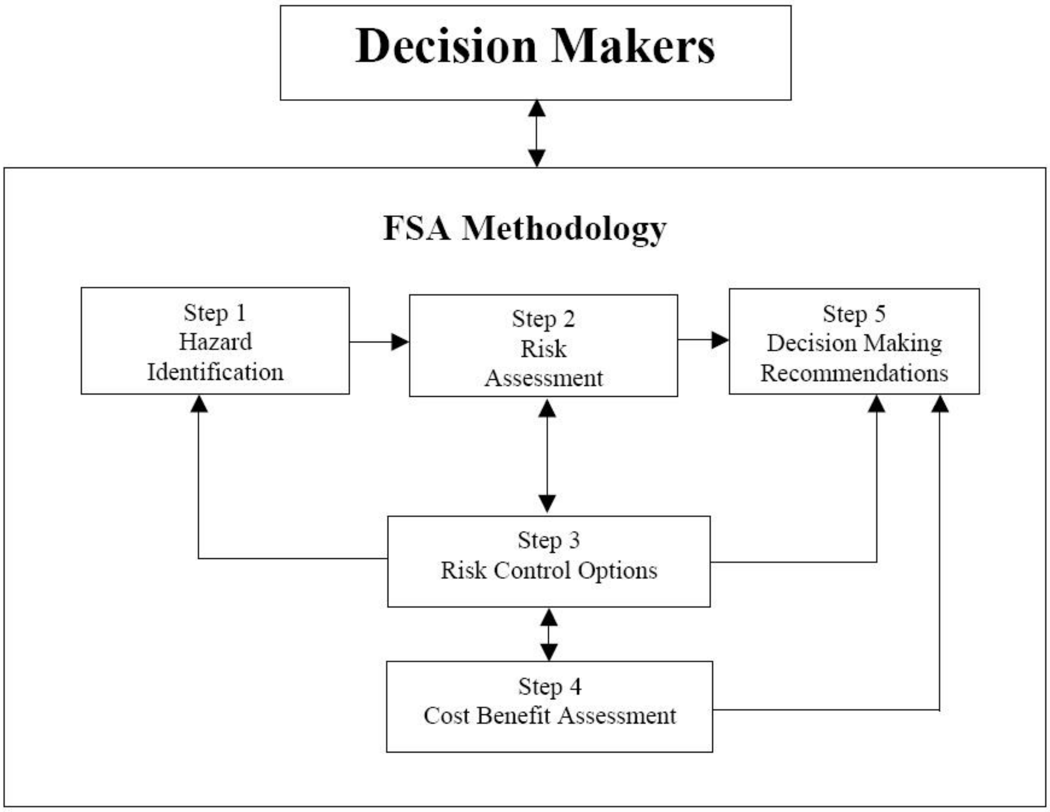


Figure 2 Flow chart of the FSA methodology [IMO 2007].

3 Description of the Åland Sea

3.1 General geography

The open sea area between Sweden and the coast of Åland is called the Åland Sea. The bedrock of central and western Åland consists of reddish rapakivi granites. In many areas the bedrock is exposed and shows traces of the last ice age. Ordovician limestone occurs in central Åland under Lumparn Bay. Clay and moraine deposits predominate whereas sandy deposits and sandy shores are rare. An important geological feature of the area is post-glacial land uplift, which is now 0.5-0.6 cm/year. As a result of the land uplift semi-enclosed brackish inlets gradually develop into freshwater lakes [Lindholm, T. and Rönnberg, O. 1985].

In the Stockholm´s archipelago and in Sweden´s mainland the coastline consists mainly of bare cliffs. Even clay, sand and gravel beaches can be found in some places of the coast. The beaches are also an example of border zones between different nature types. The beach zones have often richer flora and fauna than water or land zone. Water salinity gradient changes from south to north and from west to east. Water salinity changes also as a function of depth. Because of the nutrient inputs from mainland, sea water has become more turbid. Increased algae blooms have dimished the living space of many species. [Länsstyrelsen Stockholm 2007].

The northern part of the Åland Sea is 200 – 300 meters deep. The southern part of the sea area is somewhat shallower. A threshold formed by the continuation of the Salpausselkä end moraines separates the northern and southern parts of the sea protecings the Gulf of Bothnia. The salinity of the Åland Sea and the outer archipelago is near 7 promille. Because rivers are lacking, the salinity is as high as 5-6 promille even in many inshore waters. The salinity is lower in enclosed basins with occasional inflows of brackish water. A halocline is often present in deep or very sheltered basins. Thermal stratification is present from May to September and the ice cover usually lasts from December or January to April. The oxygen conditions are good in the outer archipelago but may be poor below the thermo cline in deep or sheltered inner archipelago waters. In shallow areas with poor circulation the water becomes anoxic under the ice. The transparency (Secchi depth) of the water is usually 5-8 m in the outer archipelago, 3-5 m in the transient zone and 2-3 m in the innermost bays. The Secchi depth values are lower in spring and in eutrophicated areas. The Åland Sea and Finnish Archipelago are the flow-through areas of Baltic Sea. Water currents flow counter clockwise in the Baltic Sea. Mass of water flows from Baltic Sea proper and Gulf of Finland through the Finnish Archipelago and the Åland Sea to the Gulf of Bothnia [Lindholm, T. and Rönnberg, O. 1985].

The Finnish Archipelago is a shallow sea area. The numerous islands and rocks make the area look rambling. The coastline is very long due to the number of islands. The medium depth of the Finnish Archipelago is only 23 metres, but in places there are basins, which are nearly hundred metres deep. Water depth in the coast is usually less than ten metres.

The landscape of the Finnish Archipelago can be divided into three zones. The land area exceeds the water area in the inner archipelago, and it consists of either wooded islands or small islets. The water areas are shallow and rambling. Typical features are bays that protrude deeply into the mainland. Water is changed slowly in these bays. The inner archipelago has good traffic connections to the mainland.

The land and water areas are almost equal in the middle part of the archipelago. Typical scenic features are forest covered islands. There is existing housing in the middle part of the archipelago. The traffic connections to the inner archipelago and mainland consist of ferries and ferryboats.

The outer archipelago is water dominated. Some islets and rocky islands can be seen in the open sea. Only few inhabitants live in the outer archipelago.

3.2 Meteorological and related conditions

3.2.1 Winds

The wind conditions in the Åland Sea were determined based on the statistics of two weather stations of the Finnish Meteorological Institute: the Korppoo-Utö and Lemland-Nyhamn weather stations. In the Åland Sea the annual prevailing wind direction is South-

West the average wind speeds varying in different directions from 5,6 m/s (East) to 8,0 m/s (South-West) (Figure 3).

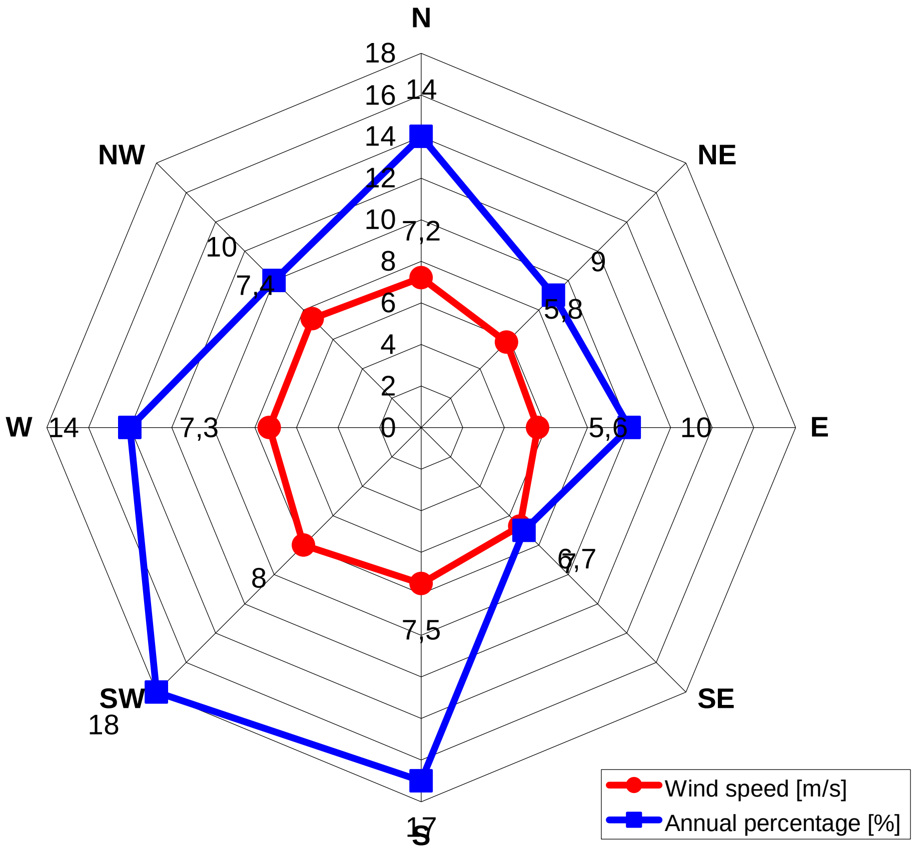


Figure 3 Annual average wind speed and percentage distributions in different directions based on the observations in the Lemland-Nyhamn weather station during years 1961-1990 (Source: Finnish Metrological Institute).

From the wind speed distribution in Figure 4 it can be seen that in all seasons the probability that the wind speed is in the range of 5 – 10 m/s is almost 50 %. The percentage of low wind speeds is increasing during spring and summer seasons and during autumn and winter seasons the percentage of high winds is higher. Wind speeds over 20 m/s have been measured only during winter season when their probability is only 0,2 %.

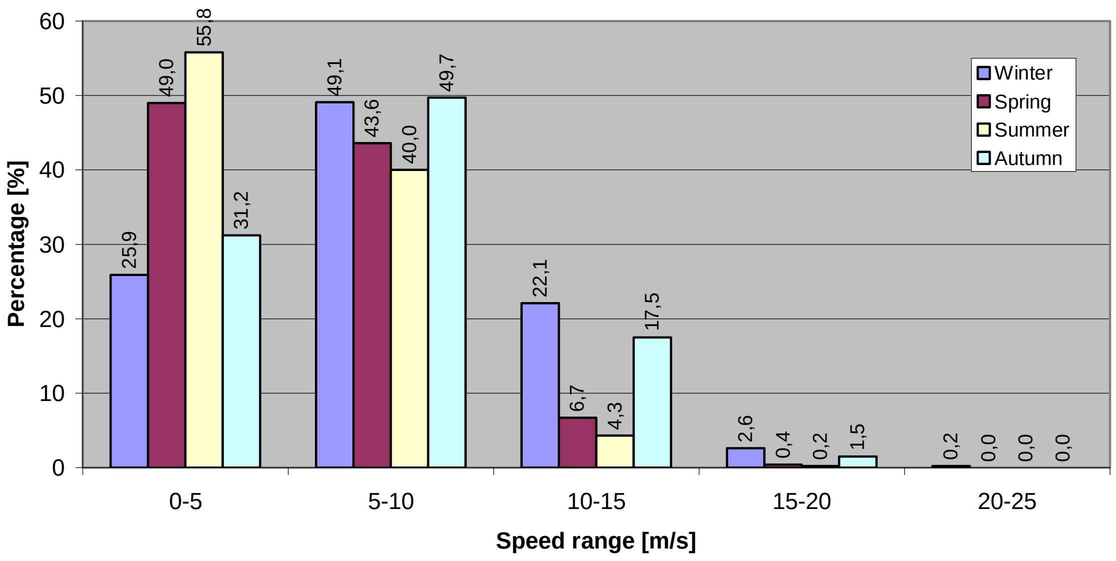


Figure 4 Seasonal wind speed percentage distribution into different speed ranges based on the observations in the Korppoo-Utö weather station during years 1971-2000 (Source: Finnish Metrological Institute).

3.2.2 Ice conditions

The average freezing time in the Åland Sea is in the middle of February and the break-up in the beginning of April (Figure 5). The average annual maximum ice thickness is 20 – 30 cm.

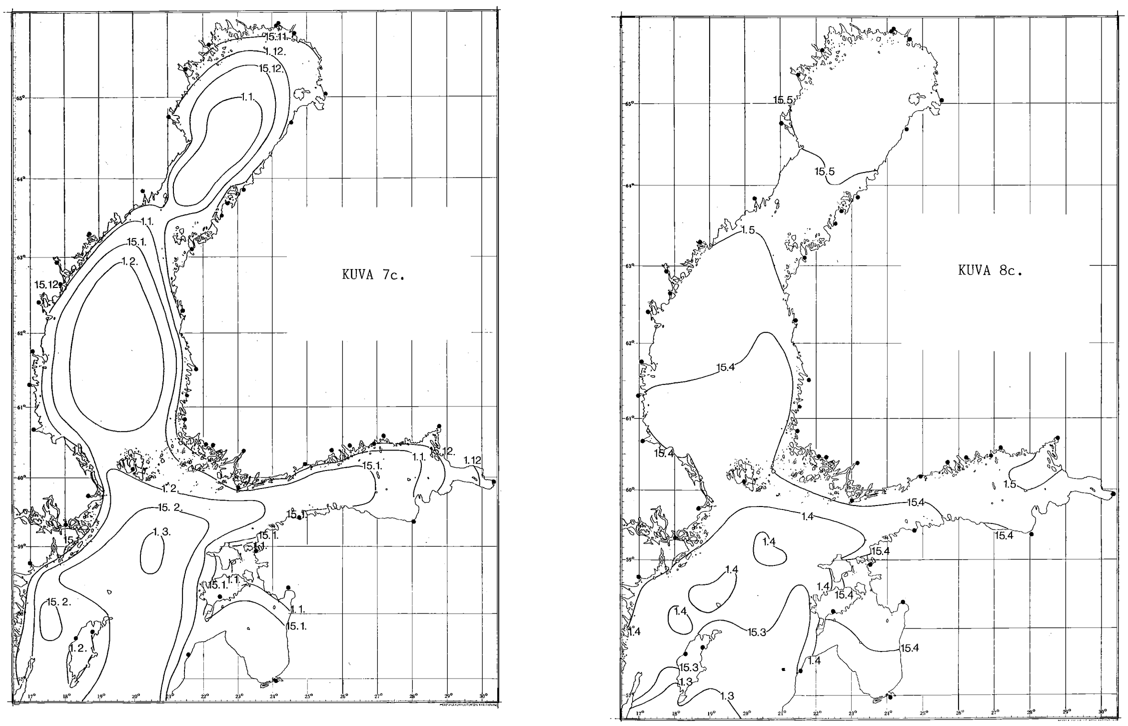
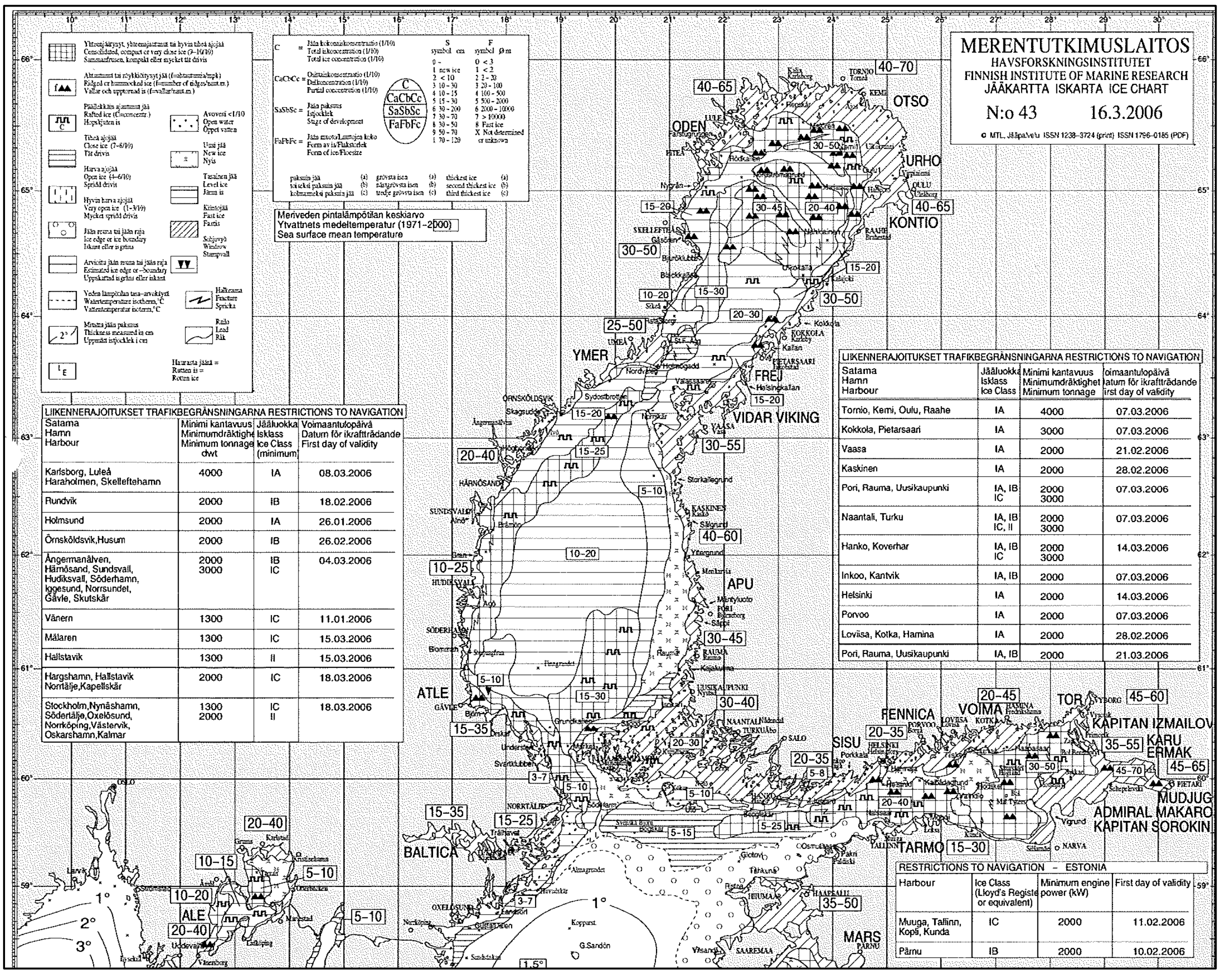


Figure 5 The average dates of the freezing and the break-up of the ice based on the statistics collected during 1963 – 1980. [Leppäranta et al. 1988]

The winter 2005 – 2006 can be classified as normal if the criterion is the extent of the ice cover. The maximum situation can be observed from the ice map in Figure 6.

According to the ice map (Figure 6), the ice cover is thicker on the west coast of the Åland Sea causing slight drop in the speed of the vessels on that area. This can be observed from Figure 7 where the temporary speeds of some vessels on the west coast are 60 – 70 % of the maximum speed.



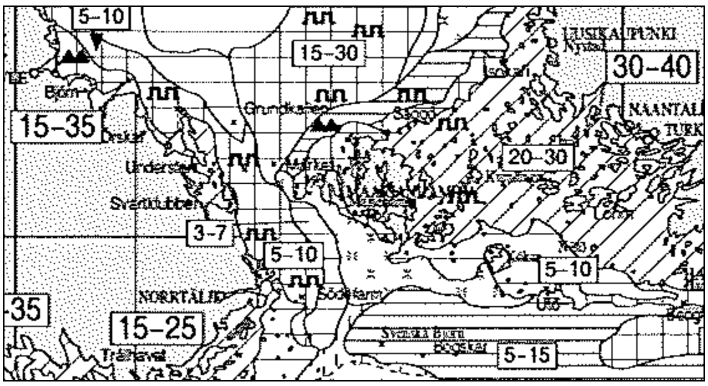


Figure 6 The ice map published in 16.3.2006 and enlargement of the Åland Sea area map [Source: Finnish Institute of Marine Research].

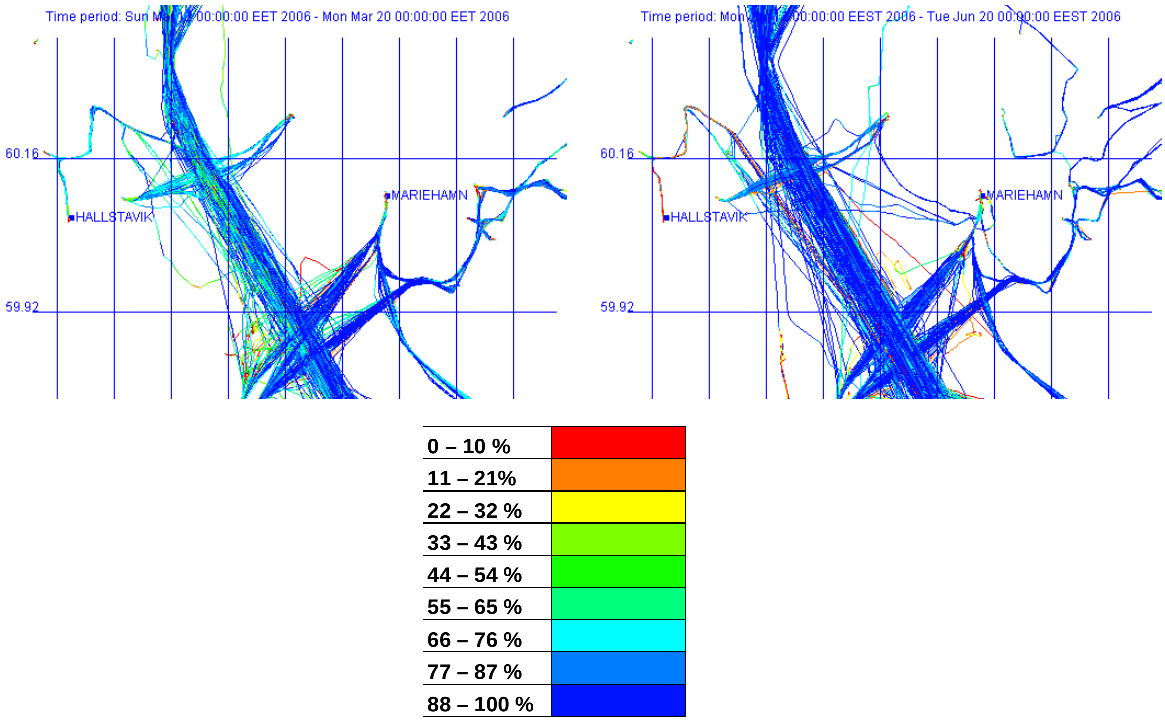


Figure 7 Winter time (left) and summer time (right) AIS tracks analyzed with the VTT´s tool. The colour indicates the difference of the temporary speed compared with the observed maximum speed of the vessel. The winter period is 12.-20.3.2006 and the summer period 12.-20.6.2006.

According to the expert opinions [Uusiaho 2007] and [Aro 2007] the ice season in the Åland Sea area which has some influence on the ship traffic lasts is no more than one month. The icebreaker assistance is needed less than during one winter in ten years – last time icebreaker assistance was needed in 1987. Some channel formation may exist but due to the south-north and east-west traffic as well as the currents the ice field is widely broken on the area. Due to the limited space the ships can not select their routes freely but if no icebreaker assistance is available the traffic is directed to the areas where the ice conditions are lighter.

As the winter navigation conditions on the Åland Sea are mostly relatively mild and do not have significant impact on the traffic patterns, winter conditions were not explicitly modelled.

3.3 Environmental sensitivity

The coastal areas of the Åland Sea have been evaluated according to the sensitivity of environment to oil spill from ship accidents (Figure 8). The determined sensitivities were between high and medium. In addition UNESCO Biosphere Reserves, and areas under the category of Baltic Sea Protected Areas e.g. Important bird areas and Ramsar sites, locate in the Åland Sea (Figure 9) [HELCOM 2007].

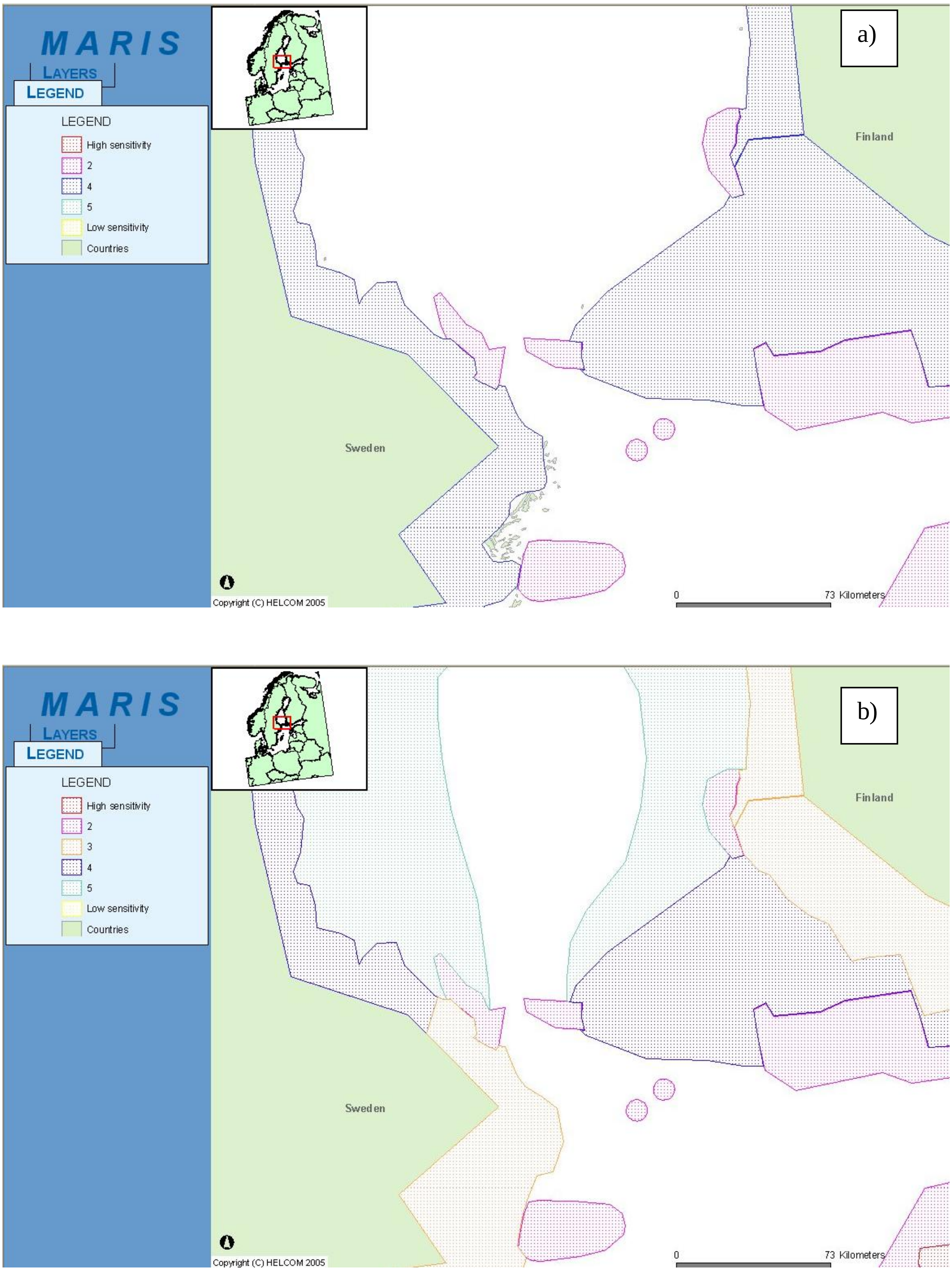


Figure 8 Shore sensitivity to oil spills in a) summer, b) winter [HELCOM 2007]

In December 2003, the Governments of Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden put forward a joint proposal to the 51st session of IMO´s Marine Environment Protection Committee (MEPC) to designate the Baltic Sea area with the exeption of Russian waters, as a PSSA. MEPC 51 agreed, in principle, to the designation of the Baltic Sea Area as a PSSA and noted that the countries concerned would submit detailed proposals for Associated Protective Measures (APMs) to the 51st session of the Sub-Committee on Safety of Navigation (NAV) in 2005, which would provide recommendations to MEPC 53.

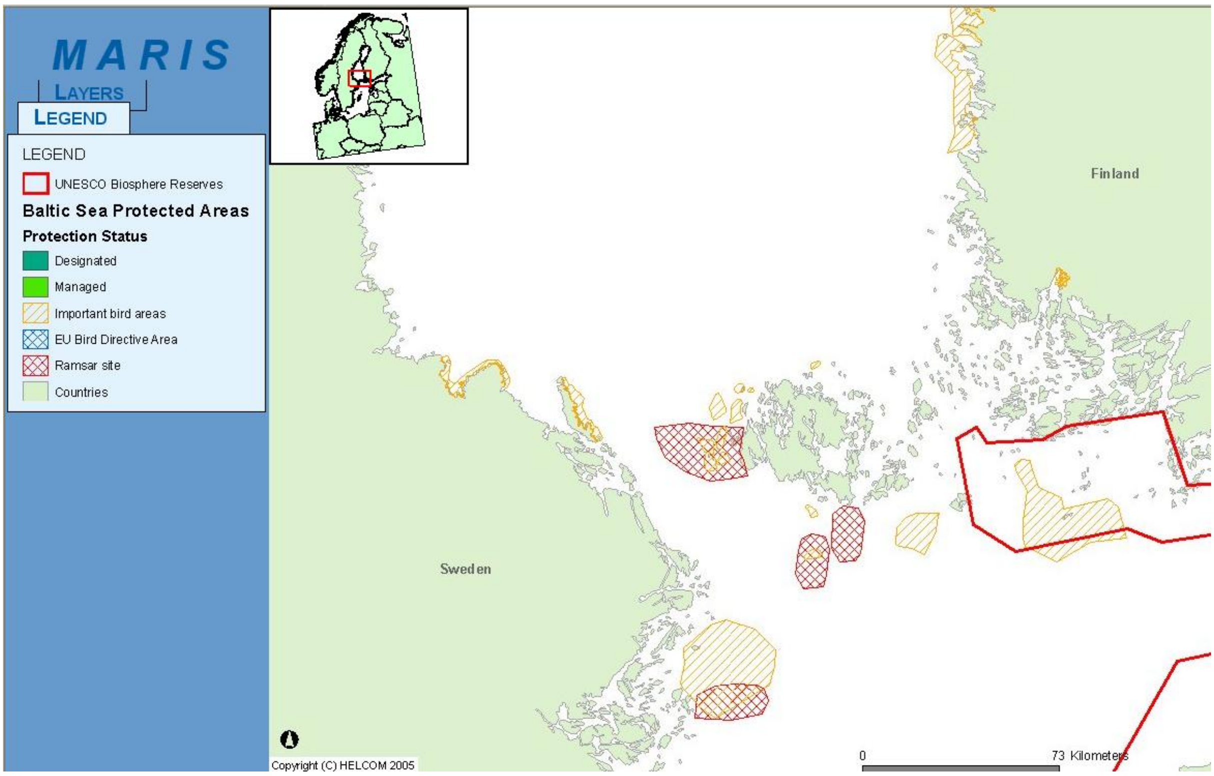


Figure 9 Baltic Sea protected areas and UNESCO Biosphere Reserves [HELCOM 2007].

3.3.1 Enquiry to the coastal municipalities in the Åland Sea area

In the beginning of the FSA study an enquiry regarding the objects which could be damaged as a consequence of possible accidental oil or chemical spill was sent to the coastal municipalities in the Åland Sea area both in Finland and Sweden. The items of the enquiry were as follows:

Does in your municipality exist:

1. Conservation areas (Natura 2000 –areas, national parks or other conservation areas)?
2. Rare or endangered species?
3. Environments which are essential for fish-, bird- and mammal populations in their different life cycles?
4. Outdoor, camping and recreation areas (e.g. popular boating routes, camping islands, beaches or areas for recreational fishing)?
5. Holiday cottages?
6. Areas or objects of special historic interest (e.g. humanized landscape)?
7. Fish farms?
8. Commercial fishers (How many?) and fishing waters?
9. Industry or source of livelihood using sea water?
10. Sources of livelihood exploiting sea environment?
11. Other recreational use of the sea environment?

12. Other information which should be taken into account in the assessment work?

The enquiry was sent to 56 municipalities and 22 responded. The locations of the municipalities can be found from the maps in Figure 10 and Figure 11. From the maps it can be concluded that most of the responded municipalities locate in the range of possible oil or chemical spill illustrated in Figure 38.

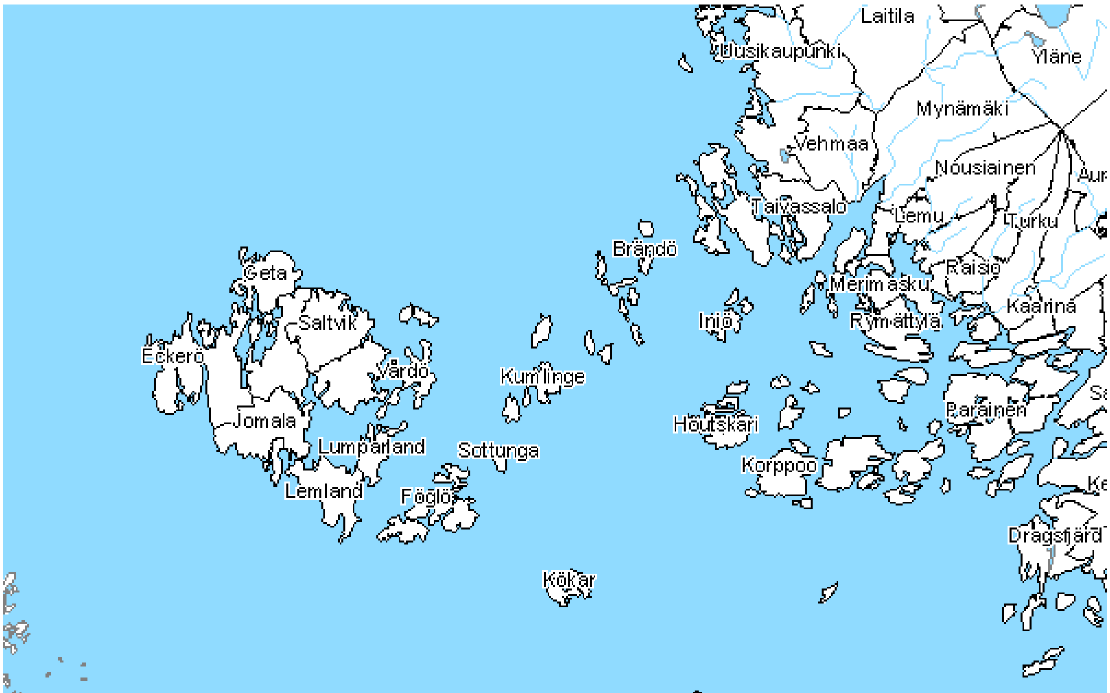


Figure 10 Municipal division in South-West Finland and Åland [Map Finland 2008]

Figure 11 Municipal division in the East coast of Sweden [Map Sweden 2008]

The general results seen in Table 1 clearly indicate that the whole area is dependent on the uncontaminated environment. According to the answers, each of the responded municipalities has some kinds of conservation areas, most of them are Natura 2000 areas (question 1). In 9 of the responded municipalities there are rare or endangered species (question 2) and in 10 there are areas which are essential for fish-, bird- and mammal populations in their different life cycles (question 3). Holiday cottages (question 5) exist in 18 of the 22 responded municipalities. Recreational use of sea and land area (question 11) is in 17 of the responded municipalities. Commercial fishers and fish farms (question 8) are in 10 of the responded municipalities. The answers of the municipalities are collected in Appendix 2.

Table 1 General results of the enquiry

	1	2	3	4	5	6	7	8	9	10	11	12
Finland												
Dragsfjärd				Y								Y
Västanfjärd	Y	Y	Y	Y	Y		Y	Y	Y		Y	Y
Perniö	Y											
Iniö	Y		Y	Y	Y	Y	Y			Y		
Kustavi Taivassalo Vehmaa	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Askainen ja Lemu	Y		Y	Y	Y	Y				Y	Y	
Kaarina	Y				Y	Y		Y			Y	
Masku	Y	Y		Y	Y						Y	
Åland												
Kökar	Y			Y	Y		Y	Y	Y	Y	Y	
Kumlinge	Y	Y		Y	Y		Y		Y	Y	Y	
Föglö	Y	Y		Y	Y	Y	Y		Y		Y	
Vårdö	Y		Y	Y	Y	Y	Y	Y		Y	Y	
Lumparland	Y				Y		Y				Y	
Lemland	Y			Y	Y	Y	Y	Y			Y	
Sweden												
Gävle	Y	Y			Y	Y		?		Y	Y	
Lidingö	Y			Y	Y	Y				Y	Y	
Norrtälje	Y	Y	Y	Y	Y	Y		?		Y	Y	
Tierp	Y		Y	Y		Y		Y				
Värmdö	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	
Älvkarleby	Y	Y	Y	Y	Y			Y	Y		Y	
Österåker	Y			Y	Y	Y				Y	Y	
Östhammar	Y		Y			Y		Y				
Summary	22	9	10	17	18	14	10	10	6	11	17	2

4 Current practices in the Åland Sea

4.1 General

The Åland Sea is divided into Finnish and Swedish territorial waters. Only part of the planned southernmost Traffic Separation Schemes is in International waters.

4.2 Vessel Traffic Service, VTS

The Åland Sea is not under the control of VTS but the fairways starting in the Åland Sea and ending at ports in Finland fall within the monitoring area of the Archipelago VTS, whereas fairways going to ports in Sweden are covered by the Stockholm VTS.

In the Archipelago VTS area, vessels of 24 metres in length overall or more are obliged to participate in the vessel traffic service by reporting to the VTS authority, listening to the VHF channels used in the VTS area and observing the provisions concerning traffic in the VTS area. Three types of services are provided by the Archipelago VTS: Information, Navigational assistance and Traffic organisation.

In the Stockholm VTS area, reporting is compulsory for vessels exceeding 300 GRT and all vessels, including tows, of over 45 metres in length. These vessels must report to the VTS when passing reporting points. The reason for the reports is to prevent meeting in narrow passages and to give the VTS and ships an overall view of the traffic situation. The service provided by the Stockholm VTS is information.

4.3 Deep-water pilotage

IMO recommends that ships wishing to avail themselves of deep-sea pilots in the area of the Baltic should only take those licensed by a pilotage authority of a Baltic coastal state, i.e. Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia or Sweden.

Deep-sea pilotage in the Baltic Sea area must only be performed by deep-sea pilots from the respective ports of departure of a Baltic coastal state, including the Kiel-Holtenau locks, the Sound and the Belts.

Due to an agreement between the Pilot Authorities in the Baltic concerning expertise and local knowledge in connection with deep-sea pilotage in the Gulf of Bothnia, pilotage has to be carried out by Swedish or Finnish pilots, with a pilot change at Sandhamn for destinations in Sweden and at Mariehamn for destinations in Finland.

4.4 Reporting during the ice season

Each winter the Gulf of Bothnia develops an ice cover. As the ice situation becomes more difficult, traffic restrictions are imposed. The restrictions pertain to the availability of icebreaker assistance. Some of the restrictions are safety restrictions independent of assistance standards; others are based on the availability of icebreaking services. Traffic restrictions are based on the Act on the Ice Classes of Ships and Icebreaker Assistance and on the requirements on the construction and engine output of vessels for winter navigation. They are also based on the ice class and deadweight of the vessel. The restrictions enter into force five days after their date of issue, except for relaxations, which enter into force immediately.

Traffic restrictions are imposed by the Winter Navigation Department of the Finnish Maritime Administration when ice conditions become more difficult. From then on icebreaker assistance is given only to vessels that meet the requirements set out in the restrictions. Some of the restrictions are imposed because of safety considerations; others relate to the need to improve the efficiency of vessel traffic.

Vessels bound for ports in the Gulf of Bothnia in which traffic restrictions apply must, when passing Svenska Björn, report their nationality, name, port of destination, ETA and speed to VTS Gävle using VHF . This report can also be given directly by phone. If required due to the ice conditions, the position for reporting can be transferred farther south.

4.5 Deep water route in the Åland Sea

In 1987 a deep-water route (depth 18.0 metres) in two parts was established in the Åland Sea for north-south transit traffic. The route was established after a hydrographical resurvey. It is supported by several aids to navigation. The route has not been the object of any decision by IMO but is simply shown on Finnish and Swedish charts [Swedish Maritime Safety Inspectorate 2007].

5 Ship traffic in the Åland Sea

5.1 General

In the Åland Sea join the traffic flows which are coming from the Gulf of Finland and the Central Baltic Sea and which are bound north for the Swedish and Finnish ports in the Gulf of Bothnia. From time to time the traffic congests in the confined areas and the lack of clear procedures causes potential risk of accidents. In addition, there is frequent traffic between Finland and Sweden which intersects the northbound traffic consisting mainly of passenger car ferries and ro-ro vessels. The traffic in the Åland Sea is unorganized because there is no traffic separation schemes (TSSs) in the area. There is a recommended deep-water route in the area of Svenska Björn and Southern Quark but the major part of the vessels only follow their own routes without taking into account the deep-water route.

Loaded tankers are part of the traffic. Accidental oil spill from a tanker loaded with heavy fuel oil is a big threat to the vulnerable environment of the Åland Sea. However a bigger threat than cargo spills are heavy oil spills from bunker tanks. Contrary to double hull tankers transporting heavy fuel oil as cargo, bunker tanks are not required to have a double hull structure as protection.

Traffic analyses in this study are based primarily on historical AIS data recorded in 2006. In addition, port statistics from the Gulf of Bothnia and the timetables of scheduled ferry traffic from Finland, Estonia and Russia to Sweden were used in the analysis. Oil tanker traffic to ports in the Gulf of Bothnia was analysed separately.

For the analysis of AIS data two software applications were developed partly in the framework of the BaSSy project – one by VTT in Finland and one by DTU and GateHouse in Denmark.

In the Finnish software the ship tracks can be visualised with different colours for different ship types or the rate of change in vessel’s speed or course. In addition with the software the exact number of vessels having AIS equipment crossing the predefined reference line can be calculated divided into four different ship types (tankers, passenger vessels, tugs and other ships).

The Danish software is a part of the BaSSy tool and is essentially linked with the collision and grounding risk analysis software in the BaSSy tool. The software is described in more detail in Chapter 9 Risk analysis.

5.2 Traffic analyses based on the AIS data

5.2.1 AIS data used in the analysis

5.2.1.1 Configuration description

AIS data is obtained from the Finnish AIS data server that acts as a proxy server for the Finnish AIS base station network, i.e. it acts as an interface to external clients (also to the central HELCOM AIS Server in Denmark). For a description of the AIS network, see ref [FMA 2008]. The AIS data may be filtered at this stage to provide data at a reduced rate for applications not needing full resolution data. The AIS data flow from the Finnish AIS data server to the BaSSy toolbox is presented in Figure 12.

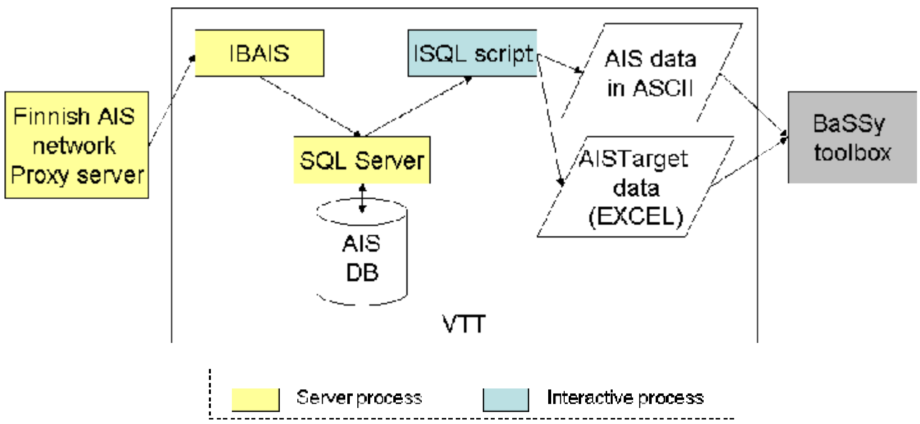


Figure 12 Flow of AIS data used in the Åland Sea case.

5.2.1.2 Contents and filtering of AIS data

The AIS data is further filtered when stored in a database. The storing functionality is implemented in a client application, IBAIS, and in database procedures used by the client. The filtering rules of IBAIS are implemented as follows: new position and speed data for an AIS target are stored only if at least one of the following conditions is met:

- Ship speed changes by 1 knot or more
- Ship is stopping (change to < 0.1 knots) or starting to move (change from zero to >0.3 knots)
- Distance to previous stored position > 5nM
- Status of speed information changes to Valid
- Course changes by over 10 degrees compared to last stored position

The parameters stored for each target are: MMSI, Latitude, Longitude, SOG (Speed Over Ground), Heading, COG (Course Over Ground) and ROT (Rate of Turn). In addition a timestamp (save time of data) is stored. Fixed data for the targets are also stored in a separate table. These parameters are MMSI, CallSign, IMO-number, Name, Draft (voyage specific), Length, Width and Ship type (a two-digit code according to IALA Guidelines on AIS [IALA 2002].

5.2.1.3 *Export of data*

Export of data from the database to other applications has been performed manually in two ways:

1) Using SQL queries to dump position data according to a specified format as an ASCII file, and
2) Import of data to an EXCEL table and then export of the table.

The second option can be used for the fixed AIS target data, as its volume is feasible for handling in EXCEL. The position data, however, easily amounts to a very high number of records (the number of records in a file covering the observations from the Gulf of Finland in 2006 was 17.9 million), and is therefore exported as an ASCII-file sorted according to the timestamp field. Import of the data to the BaSSy Toolbox is done using tailored conversion software.

5.2.2 Evaluation of the AIS-data

The AIS data may contain errors, as reported in the article published in The Journal of Navigation [Harati-Mokhtari 2007]. According to one of the studies reported in the article about 8% of 400 059 analysed AIS reports contained some errors. The study concentrated on errors in MMSI number, IMO number, position, course over ground (COG), and speed over ground (SOG).

In the current study it was not possible to analyse the contents of the AIS data in more detail. Only the number of vessels crossing the reference line drawn over the entrance fairway of the port was compared with the number of port calls obtained from the traffic statistics of the port. Altogether the traffic of eight Finnish ports in the Gulf of Bothnia in 2006 was analysed. In the analysis, the software developed at VTT was used.

The percentual monthly differences between the AIS traffic and the port statistics was calculated using the equation:

$$AIS_{\Delta} = \frac{(n_{AIS} - n_{stat}) \times 100}{n_{stat}} \ [\%]$$

where n_{AIS} is the number of vessels obtained from AIS data and n_{stat} obtained from port statistics. The results are presented in Figure 13.

The analysis showed that during the ice season (January – April) especially in the northern ports there was traffic having AIS but not included in the port statistics (tugs and icebreakers). During ice free conditions the amount of traffic outside the statistics was smaller.
However in some months, the number of AIS records did not cover the number of port calls obtained from statistics. When only these months are considered, AIS analysis gives on an average of 5% smaller figures than the statistics.

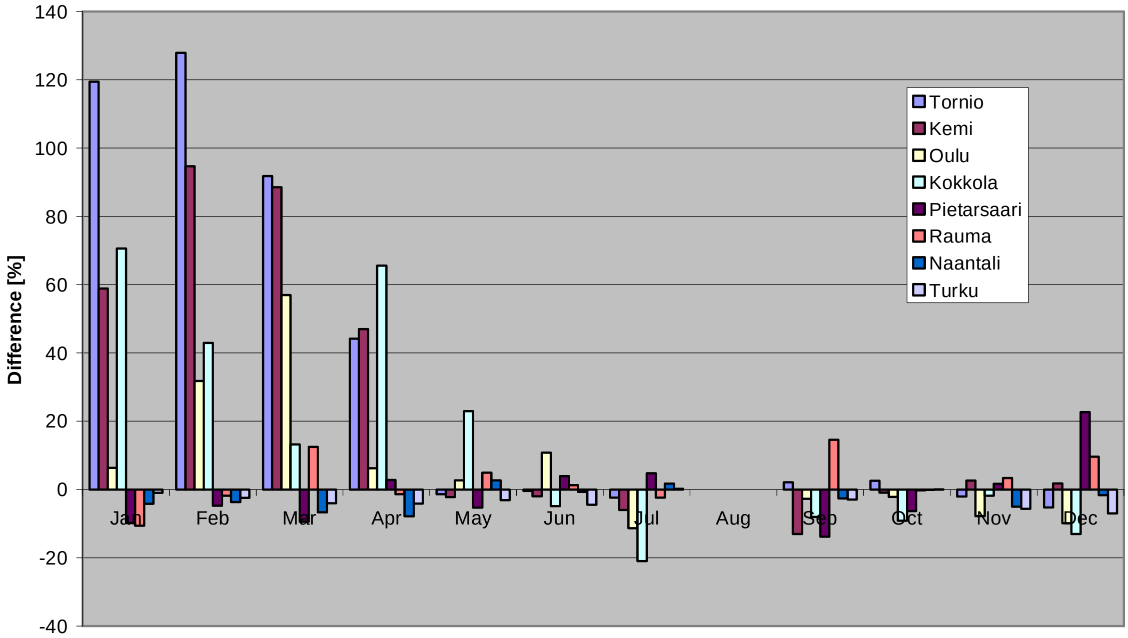


Figure 13 Difference between the number of vessels entering the ports obtained from AIS-data and the number of port calls obtained from port statistics.

5.2.3 Results of the AIS analysis

The traffic in the Åland Sea was analysed using the AIS data recorded in 2006 and with a program created by VTT. For the analysis in the Åland Sea area, ten reference lines were defined as shown in Figure 14. The number of monthly crossings over each reference line is shown as differently coloured columns in Figure 15. The figure above each group of columns is the annual number of crossings. The traffic, divided into four ship categories crossing the different reference lines, is presented in Figure 16.

The total traffic in the north-south direction through the Åland Sea crosses reference line 8. Of the total number of 16,370 vessels, 1,642 are tankers and 257 are passenger vessels. Other vessels are in the category “other ships”.

The main portion of vessel traffic between Finland and Stockholm crosses reference line 5. Of the total amount of 12,472 vessels 11,483 are passenger vessels, nine are tankers and 980 are “other ships”.

The crossings over reference line 9 (in total 2,557 vessels) consist mainly of car-passenger ferry traffic (1,514 vessels) between Eckerö and Grisslehamn, but the significant proportion of traffic is in the category “other ships” (930 vessels). The rest of the ships are tankers (114 transits).

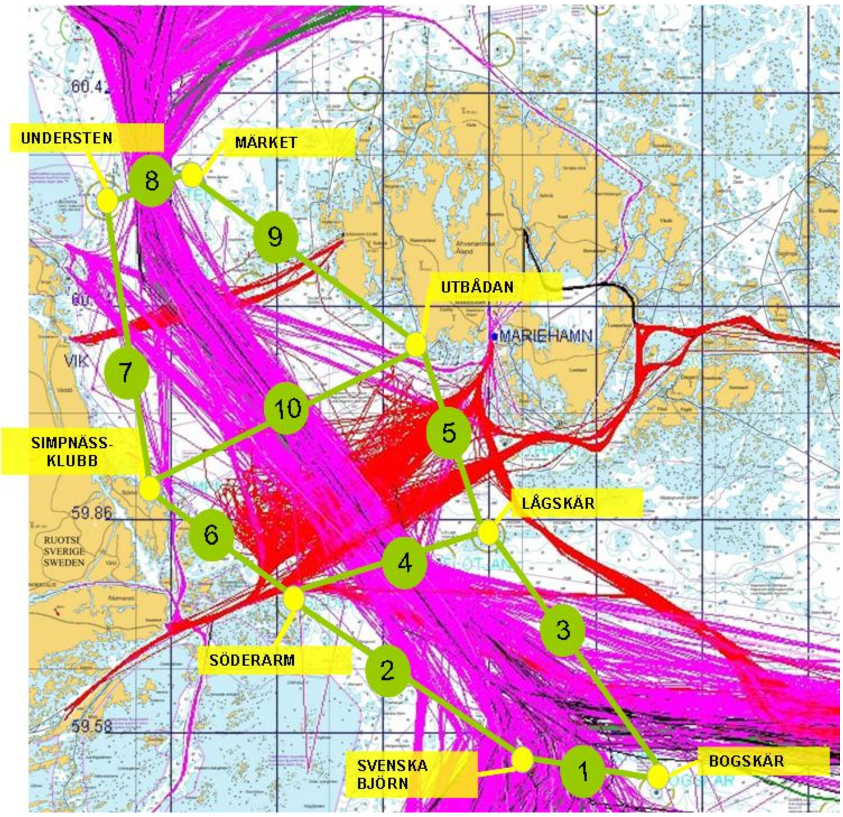


Figure 14 Reference lines and a sample of AIS tracks. The tracks are coloured as follows: red = passenger ships, black = tankers, green = tugs, pink = other ships. (© Merenkulkulaitos lupa nro 242/721/2006.)

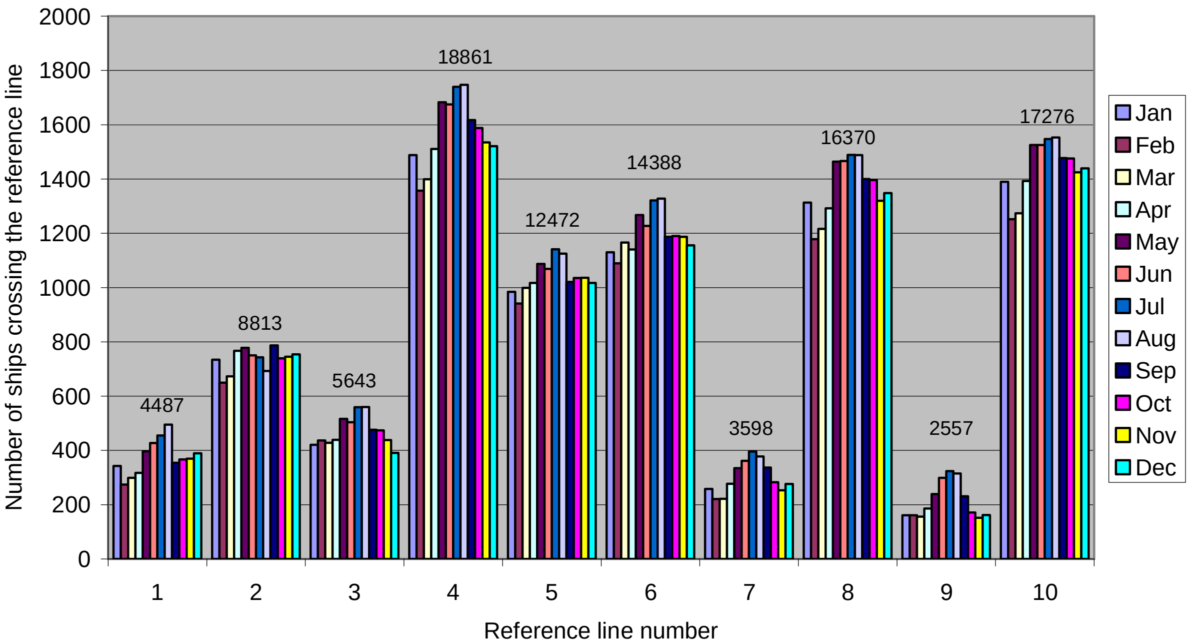


Figure 15 Number of ships crossing the reference lines. The figure above each column group is the annual number of crossings of each reference line.

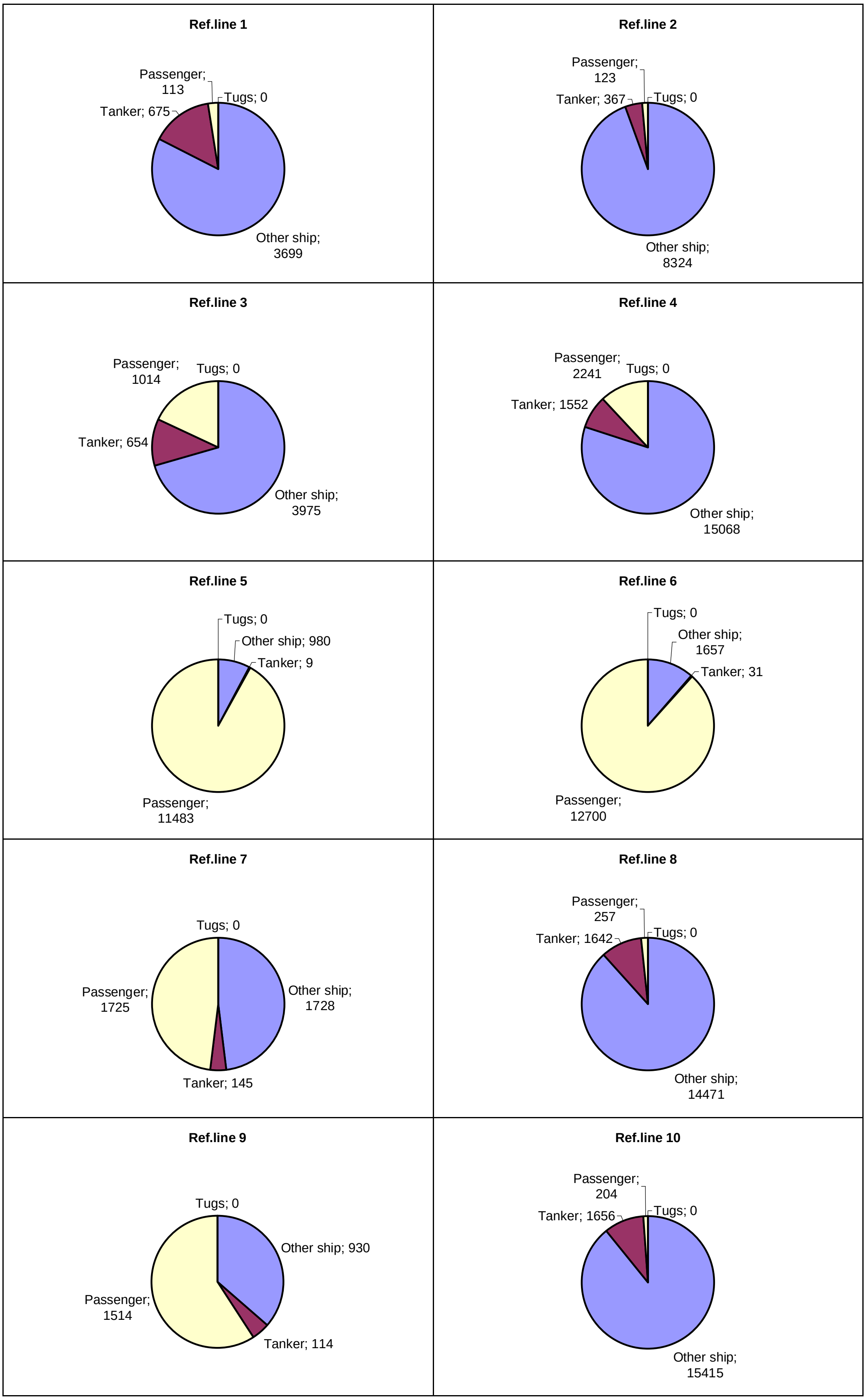


Figure 16 Number of different category vessels crossing the reference lines.

5.3 Analysis of port statistics in the Gulf of Bothnia

Analysis of traffic statistics for ports in the Gulf of Bothnia is based on data for the year 2005 obtained from the Finnish and Swedish Maritime Administrations. The total number of port calls is 13,557 vessels, meaning 27,114 vessel transits in the Gulf of Bothnia. The major number of vessel transits is in the category 'other dry cargo vessel' (Figure 17 and Table 2).

According to the AIS analysis (Figure 15), the number of ship transits in the narrow passage between Understeen and Märket (Figure 14) is 16,370 vessels and the number of ship transits based on the port statistics is 27,114 vessels. Thus some of the vessels visit more than one port in the Gulf of Bothnia and there is also internal traffic in the Gulf. In addition, some of the vessels bound towards or coming from ports on the Gulf of Bothnia use the eastern fairways through the archipelago and do not pass through the Åland Sea. Based on the AIS data analysis there were 867 vessel transits through the archipelago in 2006.

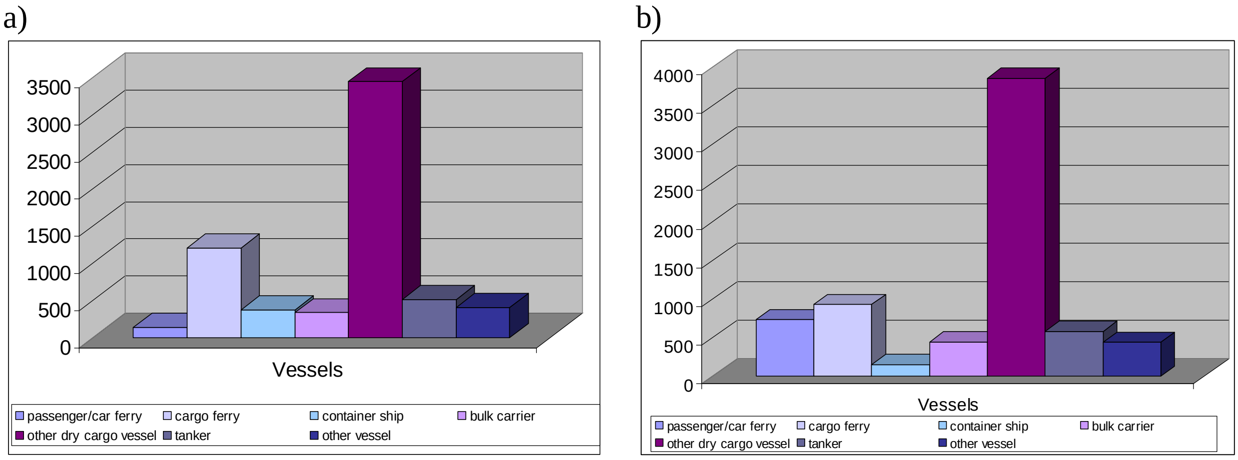


Figure 17 Number of port calls in the Gulf of Bothnia by ship category. a) Finnish ports, b) Swedish ports.

Table 2 Number of port calls in Finnish and Swedish ports of the Gulf of Bothnia by ship category.

Ship category	Finnish ports	Swedish ports
Passenger/car ferry	143	736
Cargo ferry	1207	930
Container ship	372	151
Bulk carrier	336	445
Other dry cargo vessel	3438	3858
Tanker	513	582
Other vessel	407	439
Total	**6416**	**7141**
Vessel transits (2 x port calls)	12832	14282

5.4 Oil transportation in the Åland Sea area

Oil transportation in the Åland Sea area is almost solely of oil products. The crude oil transportation route to the oil refinery in Naantali through the Utö fairway does not use the planned Åland Sea Traffic Separation Schemes (TSS), whereas traffic flow intersecting the tanker route may be reorganised due to the planned TSS. Thus Utö fairway traffic is included in the risk analysis.

Accidental oil spill from a tanker loaded with heavy fuel oil is a big threat to the vulnerable environment of the Åland Sea. The total amount of oil products transported to Finnish and Swedish ports of the Gulf of Bothnia is about 6 million tons, but the division into light and heavy fuel is not represented in the port statistics. According to an e-mail conversation with director Erkki Kotiranta of Neste Shipping [Kotiranta 2007] and a telephone questionnaire of the ports on the Gulf of Bothnia having oil traffic, the total amount of heavy fuel oil transported through the Åland Sea to the Gulf of Bothnia is about 30% of the total amount of transported oil products. The division of transportation volumes between the Finnish and Swedish ports is shown in Table 3 [FMA 2007] and Table 4 [SIKA 2007].

Taking into account the following information in the current study it is assumed that the tankers transporting heavy fuel have a double hull structure. Any tanker used for transportation of heavy oil products must have a double hull according to Regulation (EC) No 417/2002 and the amending acts: Regulation (EC) No 1726/2003, Regulation (EC) No 2172/2004 and Regulation (EC) No 457/2007 [SCADPlus 2007]. The transport of highly pollutant heavy fuel oil in single-hull tankers bound for or leaving ports in EU countries is prohibited. Large single-hull oil tankers like Erika and Prestige were taken out of operation in 2005. Smaller and newer single-hull vessels are allowed to operate in the Union's waters until the end of 2010.

As big a threat as cargo heavy oil spills are heavy oil spills from bunker tanks. According to the questionnaire performed by the Finnish Maritime Administration in 1995, roughly 90% of merchant vessels use heavy fuel oil as bunker fuel [Mäkelä et al. 2000]. Contrary to tankers transporting heavy fuel oil as cargo, bunker tanks are not required to have a double hull structure as protection.

Table 3 Transportation of oil products in the Gulf of Bothnia in 2006 - Finnish ports [FMA 2007]

Port	International transport		Domestic transport		In total
	Import [ton]	Export [ton]	Import [ton]	Export [ton]	[ton]
Maarianhamina	6 320				6 320
Eckerö		45			45
Other ports of Åland			9 361		9 361
Rauma	33 642	5 796			39 438
Pori	184 311		236 925	1 248	422 484
Vaasa	94 089		351 423		445 512
Pietarsaari	40 607				40 607
Kokkola	194 522		346 212		540 734
Raahe			306 015		306 015
Oulu	190 449		380 419		570 868
Kemi	36 272		369 206		405 478
Tornio	82 337				82 337
In total	**862 549**	**5 841**	**1 999 561**	**1 248**	**2 869 199**

Table 4 Transportation of oil products in the Gulf of Bothnia in 2006 - Swedish ports [SIKA 2007]

Port	International transport		Domestic transport		In total
	Import [ton]	Export [ton]	Import [ton]	Export [ton]	[ton]
Haparanda-Skellefteå	313 000	4 000	201 044	6 228	524 272
Umeå-Sundsvall	803 000	10 000	187 230	6 981	1 007 211
Hudiksvall-Gävle	950 000	38 000	589 565	0	1 577 565
In total	**2 066 000**	**52 000**	**977 839**	**13 209**	**3 109 048**

5.5 Scheduled traffic

Most of the traffic in the Åland Sea from Finland and Estonia to Sweden is scheduled traffic. This traffic intersects south-north traffic in the Åland Sea. Traffic flows consisting of passenger car ferries, ROPAX ferries and RO-RO ferries are estimated according to published schedules and listed in Table 5. Comparison of the results of the schedule analysis (Table 5) and the number of crossings of reference lines 5 and 9 (Figure 14 and Figure 15) shows that scheduled traffic accounts for roughly 81% of the total traffic flow between Finland and Sweden.

Table 5 Scheduled traffic in the Åland Sea from Finland and Estonia to Stockholm.

Route	Shipping companies	Reference line	Number of transits
Maarianhamina-Stockholm	Tallink Silja, Viking Line,	5 and 6	4389
Maarianhamina-Kapellskär	Viking Line, Tallink Silja	5 and 6	1411
Långnäs-Stockholm	Viking Line, Tallink Silja, Seawind Line,	5 and 6	2702
Långnäs-Kapellskär	Tallink Silja	5 and 6	133
Naantali-Kapellskär	Finnlines	5 and 6	2184
		Total	**10819**
Paldiski – Kapellskär	Tallink Silja	6	410
Paldiski – Kapellskär	Baltic Scandinavian Lines	6	360
St.Petersburg – Helsinki – Stockholm	Tallink Silja	6	620
		Total	**12209**
Eckerö-Grisslehamn	Eckerö Linjen	9	1380
		Total	**1380**

5.6 Leisure boat traffic

In the third BaSSy expert workshop, the hazard posed by leisure boats was ranked seventh on the prioritised list of hazards. These boats commonly use the same routes as merchant vessels and the seamanship of their crews was considered to be often inadequate, increasing the collision risk by misinterpreting the speed and manoeuvrability of large vessels.

The number of leisure boats crossing the Åland Sea has been estimated by the Finnish Coast Guard [Molarius et al. 2007] based on observations in the area. The results are shown in Table 6. Summing up the estimates of the daily traffic gives an annual traffic of 9600 – 13000 boat transits.

However, it is considered that the TSS and different service levels of the VTS and SRS as risk control measures do not have a significant effect on the collision risk of leisure boats with merchant vessels. Thus boat traffic is not included in the risk analysis.

Table 6 Number of leisure boats crossing the Åland Sea [Molarius et al. 2007].

	April May	June	July	August	September October
Number of crossings of the Åland Sea per day	10-12	40-50	150-200	80-100	10-20
Annually	9550 – 12752				

5.7 Earlier traffic analyses

Traffic flows in the Åland Sea area have been estimated before the current project, in 2000, based both on the statistics of the Finnish Coast Guard and on one week's monitoring by the local VTS centre (Table 7) [FMA 2000]. The estimations for north-south traffic (17,000 – 20,000 transits) and east-west traffic (11000 transits) are pretty much in line with the results of the current study in which north-south traffic across reference lines 8, 10 and 4 were 16,370, 17,276 and 18,861 transits respectively, and east-west traffic across the reference lines 5 and 6 were 12,472 and 14,388 transits respectively. The estimation for boat traffic was only about one third of the estimation presented by Molarius et al. [2007].

It was also estimated that around 20-50 vessels use the DW route between Svenska Björn and Södra Kvarken. The figure based on the 2006 AIS data is about 50 vessels.

Table 7 Traffic flows in the Åland Sea in 2000 based on statistics of the Finnish Coast Guard and observations of the VTS.

	Coast Guard	**VTS**
North-south	17 000 (54%)	20 000 (64%)
East-west	11 000 (35%)	11 000 (Eckerö traffic not included) (36%)
Leisure boats	3 500 (11%)	Not observed
Total	31 500	31 000

5.8 Accident and near miss statistics

5.8.1 Accident statistics

Accident statistics for the Sea of Åland were collected by combining information from HELCOM, SMA:s database (Sjöolyckssystemet, SOS), FMA:s database (DAMA), the Finnish accident investigation board and the press. The Swedish statistics cover reported accidents between 1985 and 2007, whereas the other sources cover the years 1989 – 2007. The full lists of collisions and groundings are found in Table 8 and Table 9 and presented in Figure 18 and Figure 19. In order to compare with the BaSSy tool analysis results, the statistics were further filtered to include only cases covered by the model. Only collisins or groundings fulfilling all of the following criteria were selected:

- The accident happened in the modelled area
- Both parties (in collisions) were non-leisure ships, that in current traffic would be equipped with AIS
- The accident was not clearly ice related (e.g. during icebreaker assistance)
- In groundings, only powered groundings are included.

Four collisions fulfil all selection criteria, namely collisions number 2, 3, 6 and 7. The inclusion of collisions 2 and 7 can however be discussed. Strictly speaking, one of the vessels in collision 2 is reported to be of 299 gross tonnage and would not be forced to carry AIS equipment according to SOLAS chapter V, Reg. 19 §2.4, which concerns ships of 300 gross tonnage and upwards. Further, the barge in collision 7 would not be equipped with AIS, but the tug towing the barge would probably be. In groundings, 17 accidents fulfil the selection criteria: grounding number 1, 4, 5, 10, 13, 14, 17, 18, 22, 26, 32, 34, 35, 37, 44, 47 and 53.

The collisions, groundings and near miss situations are categorised according the collision and grounding types used by BaSSy tool using the accident descriptions and information on port of departure and arrival when possible. It is however hard to distinguish between crossing and merging situations and bend and head-on situations.

Table 8 Collisions 1985 - 2007.

Number on map	Date	Vessel type	Latitude (deg.min)	Longitude (deg.min)	Gross	Length	Port of departure	Port of arrival	Collision type	AIS ship
1	22.2.1985	Icebreaker	60.2	19.07	6908	96			IB assistance	Yes
	22.2.1985	Dry cargo	60.2	19.07	1596	82			IB assistance	Yes
	22.2.1985	Dry cargo	60.2	19.07	3184	97			IB assistance	Yes
2	**21.6.1985**	**Dry cargo**	**60.16**	**18.57**	**499**	**69**	**Örnsköldsvik**	**Rendburg/Bremen**	**Head-on or bend**	**Yes**
	21.6.1985	**Dry cargo**	**60.16**	**18.57**	**299**	**60**	**Denmark**	**Vasa**	**Head-on or bend**	**Yes?**
3	**24.4.1991**	**Bulk**	**60.25**	**18.58**	**1598**	**80**	**Norrköping**	**Gävle**	**Head-on or bend**	**Yes**
	24.4.1991	**Bulk**	**60.25**	**18.58**	**1323**	**82**	**Uleåborg**	**Antwerpen**	**Head-on or bend**	**Yes**
4	25.7.1995	Passenger ship	60.06	19.57	35492	171	Åbo	Mariehamn	Port area	Yes
	25.7.1995	Other	60.06	19.57			Mariehamn		Port area	?
5	30.4.1996	Working vessel	59.42	19.04		12	Kapellskär	Kapellskär	Pilot boarding	No?
	30.4.1996	Dry cargo	59.42	19.04	2575	88	Västerås	Mäntyluoto	Pilot boarding	Yes
6	**1.1.1997**	**Ro/ro**	**60.09**	**19.09**	**22193**	**169**	**Luebeck**	**Holmsund**	**Overtaking**	**Yes**
	1.1.1997	**Tanker for chemicals and oil products**	**60.09**	**19.09**	**6544**	**117**	**Antwerpen**	**Jakobstad**	**Overtaking**	**Yes**
7	**8.8.1998**	**Dry cargo**	**60.07**	**19.18**	**2457**	**114**	**St Petersburg**	**Husum**	**Overtaking**	**Yes**
	8.8.1998	**Barge**	**60.07**	**19.18**	**1367**		**Mersrags**	**Husum**	**Overtaking**	**Yes? (barge + tug)**
8	23.6.2001	Passenger ship	59.40	18.56	218	35	Blidö	Norröra	Port area	Yes
9	23.6.2005	Dry cargo	59.55	19.30	4483	106	Domsjö	Hull	Crossing	Yes
		Leisure yacht				13	Westbound		Crossing	No
10	2006		Position	from	MARIS				?	?

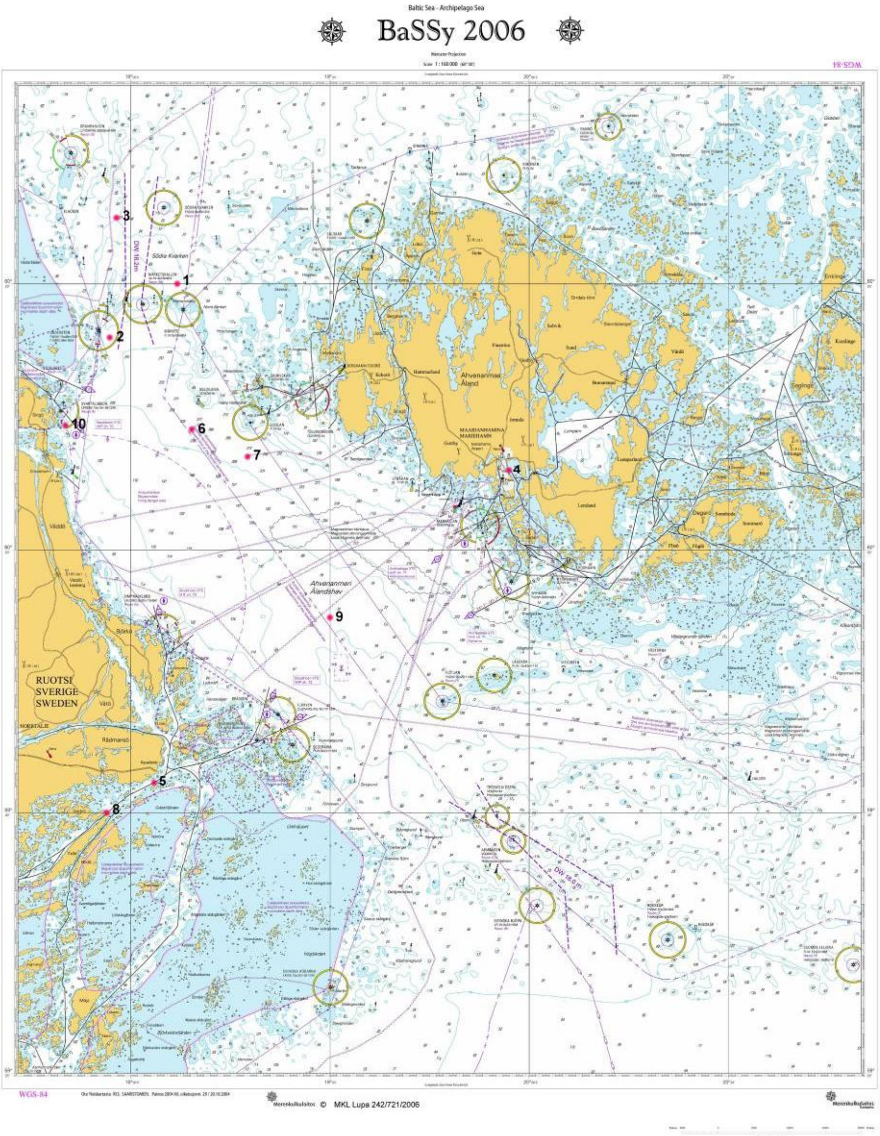


Figure 18 Collisions 1985 – 2007 (map © MKL Lupa 242/721/2006).

Table 9 Groundings 1985 - 2007

Number on map	Date	Vessel type	Latitude (deg,min)	Longitude (deg,min)	Gross	Length	Port of departure	Port of arrival	Collision type	AIS ship
1	**1985-09-12**	**Tanker for veg. Oil**	**60.2**	**19.02**	**11290**	**164.4**	**SKÖLDVIK(BORGÅ)**	**KEMI**	**powered**	**Yes**
2	1985-12-18	Tug	59.5	19.05	271	33.0	ÖREGRUND	FINNBODA VARV	powered	No
3	1986-04-07	Dry cargo	59.5	19.05	499	79.2	STOCKHOLM	GÄVLE	powered	Yes
4	**1986-06-19**	**Dry cargo**	**59.5**	**19.1**	**499**	**80.0**			**powered**	**Yes**
5	**1986-07-22**	**Dry cargo**	**59.5**	**20.15**			**TORREVIEJA**	**RAUMO**	**powered**	**Yes?**
6	1986-12-12	Dry cargo	59.43	19.12	424	52.7	JAKOBSTAD	HADERSLEV	powered	Yes
7	1987-08-16	Dry cargo	59.43	19.09	499	67.0	MÄNTYLOUTO	ÅRHUS	powered	Yes
8	1988-02-12	Passenger ship	59.2	18.55		10.0	STAVSNÄS	HARÖ	powered	Yes

9	1988-11-30	Oil tanker	59.5	19.05	2673	99.0	HUSUM	STOCKHOLM	powered	Yes
10	**1989-02-05**	**Passenger ship**	**59.4**	**19.13**	**11537**	**137.0**	**MARIEHAMN**	**KAPELLSKÄR**	**powered**	**Yes**
11	1989-10-01	Passenger ship	59.41	18.56	186	32.0	STOCKHOLM	GRISSLEHAMN	powered	No
12	1989-10-19	Dry cargo	59.5	19.05	499	66.0	VÄSTERÅS	RAJHA	powered	Yes
13	**9.5.1990**	**Other**	**59°49.7 N**	**19°55.4E**						**Yes**
14	**1990-09-11**	**Dry cargo**	**59.4**	**19.14**	**499**	**56.0**				**Yes**
15	1990-12-09	Passenger ship	59.25	18.56	93	31.0	STAVSNÄS	LÅNGVIK	powered	No
16	6.2.1991	Ro/ro	60°02.0 N	20°00.0E						Yes
17	**1991-02-06**	**Ro/ro**	**60.1**	**18.55**	**6299**	**137.0**	**HARGSHAMN**	**NYSTAD**		**Yes**
18	**1991.03.21**	**Dry cargo**	**near Marhällan**							**Yes**
19	1991-04-27	Passenger ship	59.42	19.06	49	22.0	STAFSNÄS	KAPELLSKÄR	powered	No
20	1992-04-28	Working vessel	59.43	19.04	220	29.0			drift?	No
21	1992-10-21	Dry cargo	59.46	19.01	299	49.0	STOCKHOLM	NORRTÄLJE	powered	No
22	**1993-11-23**	**Dry cargo**	**59.4**	**19.11**	**497**	**71.0**		**MÄNTYLUOTO**		**Yes**
23	1994.03.29	Fishing	Borgö							?
24	1994.12.01	Ferry	59°57.32 N	20°11.27E					drift	?
25	1995-01-13	Passenger ship	59.41	18.59	59912	172.0	Mariehamn	Stockholm	powered?	Yes
26	**1995.03.13**	**Other**	**59°50.7 N**	**19°56.0E**						**Yes**
27	1995-07-06	Passenger ship	59.26	18.55	174	27.5	Långvik Möja	Finnhamn	powered	No
28	1995-09-08	Passenger ship	59.36	19.05	209	38.3	Svartlöga	Rödlöga	powered	No
29	1996-10-29	Working vessel	59.35	19.07		7.5	Gräddö	Söderarm	powered	?
30	1996-12-24	Barge	59.53	19.03		37.0	Tallinn	Gävle	powered	?
31	1997-04-16	Tug	59.39	19.09	237	31.7	Ventspils	Iggesund	powered	No
32	**1997-04-18**	**Other**	**59.4**	**19.29**	**2140**	**73.1**	**Norrtälje**	**Söderarm**	**powered**	**Yes**
33	1997-07-31	Working vessel	59.42	19.04	13	11.7	Kapellskär	Köpmanholm	powered	No
34	**1997-10-05**	**Reefer ship**	**59.4**	**19.38**	**1662**	**77.0**	**Vasa**	**Heröya**	**powered**	**Yes**
35	**1997.12.12**	**Cruise ship**	**near**	**Marhällan**					**powered?**	**Yes**
36	1998-04-26	Passenger ship	59.31	19.1	49	21.9	Fejan	Stockholm	powered?	No
37	**1998.07.19**	**Cargo ship**	**60°25.6 N**	**19°14.5E**					**powered**	**Yes**
38	1998-08-20	Passenger ship	59.46	19	50	19.1	Norrtälje	Krokholmen	powered	No
39	1998-09-10	Fishing	59.59	19.07	95	22.0	fiskevatten	Ankarudden	powered	No
40	1998-11-24	Passenger ship	59.51	19.08	50	19.1	Arholma	Arholma	powered	No
41	1999-02-24	Dry cargo	59.52	19.04	2780	89.3	Husum	Norrtälje	powered	Yes
42	1999-06-03	Cargo ship	59.25	19.01	44	18.1	Stockholm	Nassa skärgård	powered	No
43	1999-08-26	Passenger ship	59.26	18.55	387	35.5000	Möja/Långvik	Stockholm	powered	Yes
44	**1999-11-02**	**Dry cargo**	**59.4**	**19.22**	**919**	**59.3**	**Gävle**	**Bergen**	**powered**	**Yes**
45	2001-05-26	Passenger ship	59.29	19.02	53	21.8	Stockholm	Stockholm	powered?	No
46	2001-09-27	Other	59.25	18.58	33	20.1	Stavsnäs	Stavsnäs	powered?	No
47	**2002.04.14**	**Dry cargo**	**59°48.N**	**20°30.6E**						**Yes**
48	2003-11-21	Passenger ship	59.51	19.06	50	19.1	Simpnäs	Arholma	powered	No
49	2004-01-20	Passenger ship	59.43	19.04	29841	188.0	Kapellskär	Rostock	powered	Yes

50	2005-09-27	Passenger ship	59.44	19.14	18345	145.2	Stockholm	Tallinn	drift?	Yes
51	2005.09.30	Cargo ship	60°18.3 N	19°32.5E					powered?	Yes
52	2006-11-25	Working vessel	59.25	18.56	0	7.7	Saltsjö-Boo	Möja	powered	No
53	**2007.10.23**	**ferry**	**Near**	**Marhällan**					**powered?**	**Yes**

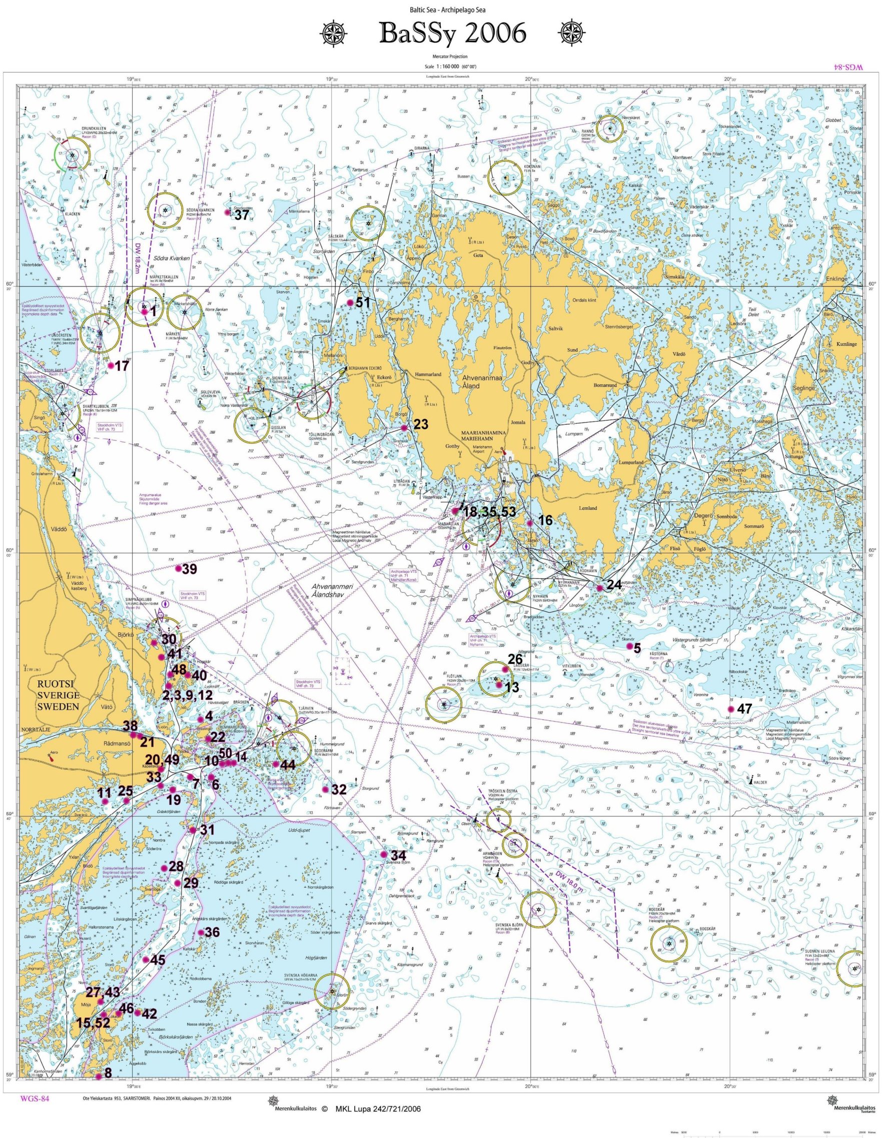


Figure 19 Groundings 1985 – 2007 (map © MKL Lupa 242/721/2006).

One significant group of the accidents are the collisions with the aids to navigation. Eight times a ship has collided to a fixed edge mark: four times to the Tröskeln Västra and four times to the Tröskeln Östra. In most of these collisions the main cause was navigational error. However, these are not reported here since collisions with edge marks are not modelled in the analysis.

5.8.2 Near miss statistics

Near miss statistics for the Sea of Åland were received from SMA:s database (Sjöolyckssystemet, SOS), covering the years 1985 – 2007. Clearly, the records shown in

Table 10 and Figure 20 are far from comprehensive, but nevertheless they provide some additional information on the risk level.

Table 10 Near miss collision statistics from SMA covering 1985 - 2007.

Number on map	Date	Vessel type	Latitude (deg,min)	Longitude (deg,min)	Gross	Length	Port of departure	Port of arrival	Collision type
1	1.7.1997	Passenger ship	59.53	19.35	34414	168.0000	Åbo	Stockholm	crossing
		Tanker					Southbound		
2	9.1.1998	Passenger ship	59.52	19.33	3564	86.3400	Mariehamn	Stockholm	crossing
		General cargo ship					Northbound		
3	12.4.1998	Passenger ship	60	19.55	21484	141.0300	Mariehamn	Stockholm	crossing
		Unknown							
4	16.9.1998	Passenger ship	60	19.45	3564	86.3400	Mariehamn	Stockholm	crossing
		Cargo ship					Northbound		
5	6.10.1998	Dry cargo	60.2	19.05	2280	78.5700	Raumo	unknown (Northbound)	head on
		Unknown					Southbound		
6	21.1.2000	Passenger ship	59.5	19.25	3564	86.3400	Mariehamn	Stockholm	crossing?
		Wooden barque							
7	20.1.2000	Passenger ship	59.46	19.23	29841	188.3000	Kapellskär	unknown	head on
		Passenger ship							
8	21.2.2000	Passenger ship	59.45	19.2	7564	110.1400	Kapellskär	unknown	head on
		Passenger ship							
9	14.4.2000	Passenger ship	59.52	19.34	58377	202.8700	Stockholm	Mariehamn	crossing
		Unknown					Northbound		
10	24.7.2000	Passenger ship	59.44	19.12	58376	202.0300	Stockholm	Mariehamn	leisure
		Leisure craft							
11	5.3.2001	Passenger ship	60	19.4	6172	104.6000	Mariehamn	Kapellskär	crossing
		Unknown							
12	30.5.2000	Passenger ship	59.53	19.33	6172	104.6	Kapellskär	Mariehamn	crossing?
		Unknown							
13	25.5.2002	Passenger ship	59.53	19.34	6336	105.23	Mariehamn	Kapellskär	crossing
		Unknown							
14	30.11.2002	Passenger ship	59.52	19.4	34414	170.73	Åbo	Stockholm	crossing
		General cargo ship							
15	29.6.2003	Passenger ship	59.52	19.4	29841	188.3	unknown	unknown	crossing?
		General cargo ship							
16	9.5.2004	Passenger ship	60	19.4	6336	105.23	Mariehamn	Kapellskär	?
		Unknown							
17	24.1.2005	Dry cargo	59.53	19.38	4081	104.4	Riga	Haraholmen	crossing

		Passenger ship					Mariehamn	Stockholm	
18	28.6.2006	Passenger ship	59.53	19.39	6336	105.23	Kapellskär	Mariehamn	head on
		General cargo ship					SW-bound		
19	23.7.2006	Passenger ship	59.39	18.56	34414	170.73	Åbo	Stockholm	head on
		Sailing yacht							
20	9.3.2007	Ro/ro-fartyg	59.52	19.34	9708	134.4	Braviken	Hallstavik	blackout
		Passenger ship							
21	1.4.2007	Passenger ship	59.52	19.42	15879	154.4	Långnäs	Stockholm	crossing
		General cargo ship					Riga	Husum	
22	23.5.2007	Ro/ro-fartyg	60.18	19	22193	169	Luebeck	Holmsund	head on
		Unknown							

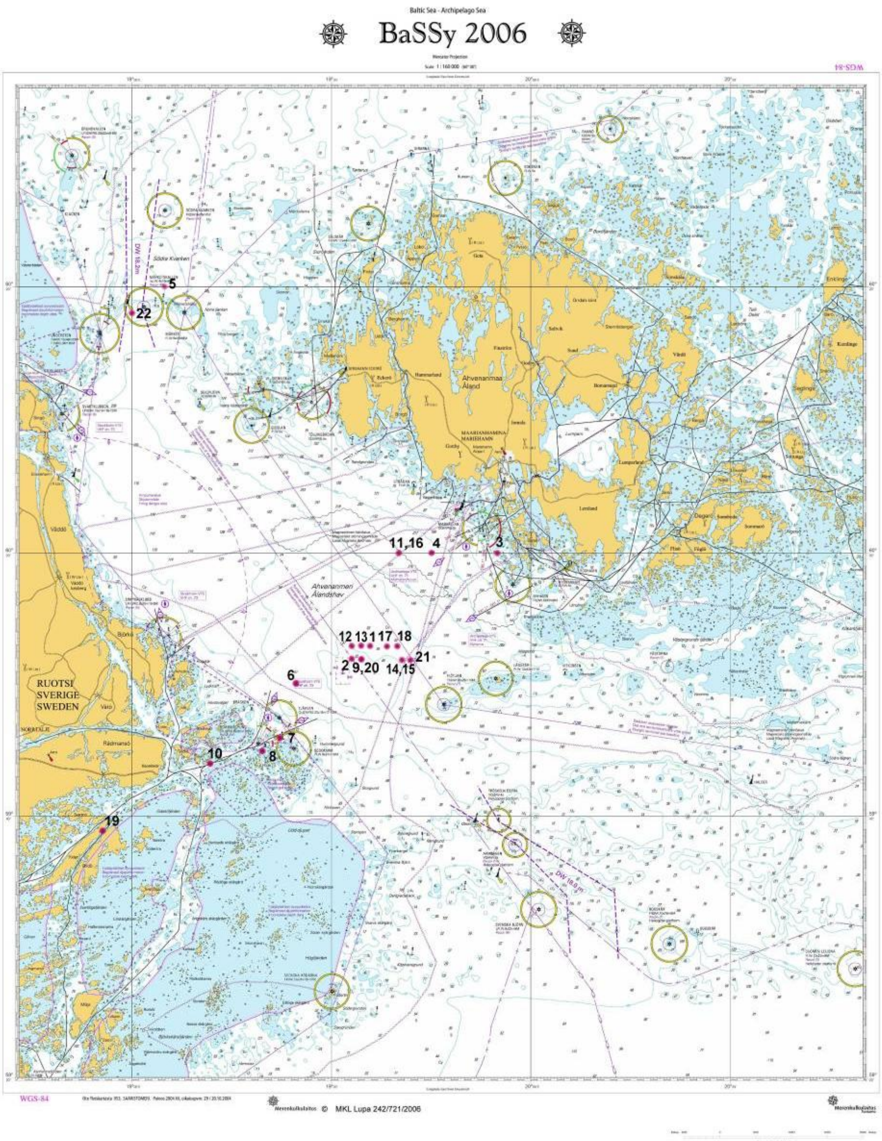


Figure 20 Near miss collision statistics from SMA covering 1985 – 2007 (map © MKL Lupa 242/721/2006).

6 Limitations

The risk analysis is limited to ship-to-ship collisions between and powered groundings of ships of 300 gross tonnage or more. Although there is considerable leisure traffic in the area in summertime, it was excluded from the analysis because the assessed risk control measures were not seen to have any major effect on risks concerning leisure traffic. As the winter navigation conditions on the Åland Sea are mostly relatively mild and do not have significant impact on the traffic patterns, winter conditions were not explicitly modelled.

In the calculation of the consequence costs of the ship-to-ship collisions only the consequences of the struck ship were taken into account, discarding the consequences of the striking ship. This limitation underestimates the benefits of the Risk Control Options.

The consequence cost calculations were performed for the average sized ship in each ship type as well as the size of the possible oil spill was assumed to be a fixed portion of the cargo or bunker capacity of the ship.

7 Method of work

This FSA study has been carried out by VTT as commissioned by the Finnish Ministry of Transport and Communications and the Finnish Maritime Administration. During the study process, VTT has been co-operating with DTU in matters related to the utilisation of the BaSSy tool in the analysis of the AIS data and the risk of ship collisions and groundings.

The study was performed by a project team consisting of eight experts from VTT. The core project team has a good knowledge and several years of experience relevant to the present FSA study. In particular, the members of the team have a wide-ranging knowledge on ship technology, shipping, FSA methodology and risk assessment.

Expert interviews and expert workshops have been utilised in the study, when appropriate, to complement the knowledge and experience of the core project team. In particular, the practical and operational aspects of sea transportation have been the focus of these sessions. During the FSA process, a set of expert workshops were organised; one for the hazard identification step and two for the step of defining risk control options and one for assessing the effects of the risk control options on causation factors. Eleven experts from Finland and Sweden attended the first session called together to consider hazards of the sea traffic in the Åland Sea. To the second expert group session six experts from Finland were invited to identify what kind of Risk Control Measures could reduce the hazards identified in the first session. The work was continued in the third expert workshop where sixteen experts from Finland and Sweden specified in more detail the risk control measures identified in the second session and grouped them into sensible risk control options. These three sessions were computer assisted workshops utilizing the Group Systems ThinkTank software. In addition, one specialist meeting with six experts was arranged to estimate the effect of the different risk control options to the situational awareness of the bridge officers. The results of this session were used as input data for the BaSSy tool when the collision and grounding risk analyses for the Åland Sea were performed.

The skill base used in the Åland Sea FSA –study is presented in Appendix 1 where the FSA study core project team as well as the participants of the expert workshops are introduced.

The preliminary outlining of the FSA study was commenced already in October 2005 but the actual work started after the contract about the funding from the Nordic Council of Ministers was signed in December 2006. The Åland Sea FSA study concerning collisions was completed in March 2008.

The Åland Sea FSA was complemented by performing the grounding risk analysis after the grounding frequency calculation module of the BaSSy tool was available. This part of the work was completed in the end of March 2009.

8 Identification of hasards

Hazards of the vessel traffic in the Åland Sea were identified in the first expert workshop on 16th February 2006 referred to in Chapter 7. Eleven experts representing maritime and environment authorities as well as shipping companies participated in the workshop, see Appendices 1 and 3. A risk scenario involves an initiating event which may evolve into an accident which, in turn, may cause environmental, economic and health consequences. The prevailing circumstances affect how often the initiating events occur, lead to accidents and how serious consequences the accidents result in. In the workshop, the experts were asked to generate hazards, or risk factors, which contribute to the risk level on the Åland Sea in different stages of a risk scenario. Some increase the number of hazardous initiating events while others affect their possibilities to evolve into accidents or worsen the consequences.

The experts identified a total of 45 hazards which can be categorised into human factors, external (environmental) factors, winter navigation factors, technical factors and others. The hazards were later prioritised in the third expert workshop (Appendix 4). The 14 experts (see Appendix 1) in the third workshop were asked to select 10 risk factors they found to be the most significant on the Åland Sea. The experts voted “Yes” on the hazards they found to be most significant and “No” on the others. Table 11 and Figure 21 show all identified hazards in prioritised order according to the votes. Risks with at least 4 “Yes” votes (bolded in the table) were considered to be the most significant ones and were taken into account in the following expert assessments on risk control measures.

Table 11 Prioritised list of hazards.

		Vote Distribution			
#	Hazard	**N**	**Y**	**Avg**	**Votes**
4.	Fatigue: Officer of the watch and crew are tired (e.g. due to long journey in rough weather)	2	12	0.9	14
33.	Blackout	4	10	0.7	14
8.	Navigators rely too much on the modern navigation equipment	5	9	0.6	14
22.	Poor visibility due to fog or darkness making navigation and observation of pleasure crafts difficult	5	9	0.6	14
42.	Unpredictable traffic picture because there is no traffic separation	5	9	0.6	14

	scheme (TSS) in the area. The situation is especially bad in the southern part of the area.				
10.	Ship violates COLREGs	6	8	0.6	14
3.	Leisure boats disturb safe navigation during summer time	7	7	0.5	14
27.	Crew is not competent to navigate in ice	7	7	0.5	14
18.	Multinational crew navigating at this sea area for the first time	8	6	0.4	14
34.	Failures in the navigation systems	8	6	0.4	14
2.	Collision between a passenger vessel and a vessel carrying dangerous cargo	9	5	0.4	14
15.	Collision in crossing traffic area Nyhamn - Söderarm	9	5	0.4	14
32.	Dangerous meeting and overtaking situations in narrow ice channels	9	5	0.4	14
6.	Communication problems between vessels in VHF radio communication due to insufficient language skills	10	4	0.3	14
7.	Misunderstanding while agreeing on actions to be taken over VHF radio causing e.g. collision	10	4	0.3	14
19.	Rough sea and high winds concentrate traffic to a small sea area	10	4	0.3	14
26.	Icing with high seas	10	4	0.3	14
9.	Ship takes a shortcut outside the route e.g. close to shallow water to save time	11	3	0.2	14
11.	Carelessness / nonchalance of the officer of the watch - neglecting radio watch	11	3	0.2	14
14.	Collision in crossing traffic area Marhällan - Söderarm	11	3	0.2	14
39.	Poor / confusing radar targets (especially on heavy seas) i.e. aids to navigation are not easily noticed from the radar picture	11	3	0.2	14
41.	Time schedules are so tight that in order to stay in schedule ships are forced to take additional risks (e.g. taking shortcuts and neglecting good seamanship in give-way situations)	11	3	0.2	14
45.	Fire on passenger ferry (especially in wintertime)	11	3	0.2	14
1.	Officer of the watch is drunk	12	2	0.1	14
5.	Collision between a vessel and a navigational aid	12	2	0.1	14
12.	Bridge culture i.e. significant hierarchy difference between bridge personnel (e.g. OOW versus pilot, OOW versus master) causing bridge resource management to fail	12	2	0.1	14
25.	Ship is stuck in the ice and drifts to shallow water or is damaged due to heavy ice pressure	12	2	0.1	14
35.	Radio-equipment is not working properly	12	2	0.1	14
36.	Ship’s AIS is out of order	12	2	0.1	14
37.	Navigational aids are not working properly	12	2	0.1	14
13.	Collision in crossing traffic area Eckerö - Grisslehamn	13	1	0.1	14
16.	Out-of-date navigation charts are used for navigation	13	1	0.1	14
17.	Poor design of ship	13	1	0.1	14
24.	Cargo is detached – vessel loses its stability and capsizes	13	1	0.1	14
28.	The ship is not suitable for winter navigation	13	1	0.1	14
44.	Dangerous cargo, generating dangerous situation e.g. after a collision or grounding	13	1	0.1	14
20.	Unexpected and strong currents	14	-	0.0	14

21.	Poor or inconsistent weather forecasts (Swedish/Finnish forecasts)	14	-	0.0	14
23.	Ship hits a floating item e.g. a drifting container	14	-	0.0	14
29.	Visibility of navigational aids is poor or they may be missing	14	-	0.0	14
30.	Ship has an exemption to winter traffic restrictions	14	-	0.0	14
31.	Incorrect ice information	14	-	0.0	14
38.	Hydrographical data is missing or incorrect leading to grounding	14	-	0.0	14
40.	Dangerous cargo + fire onboard	14	-	0.0	14
43.	Terror attack on passenger ferry	14	-	0.0	14

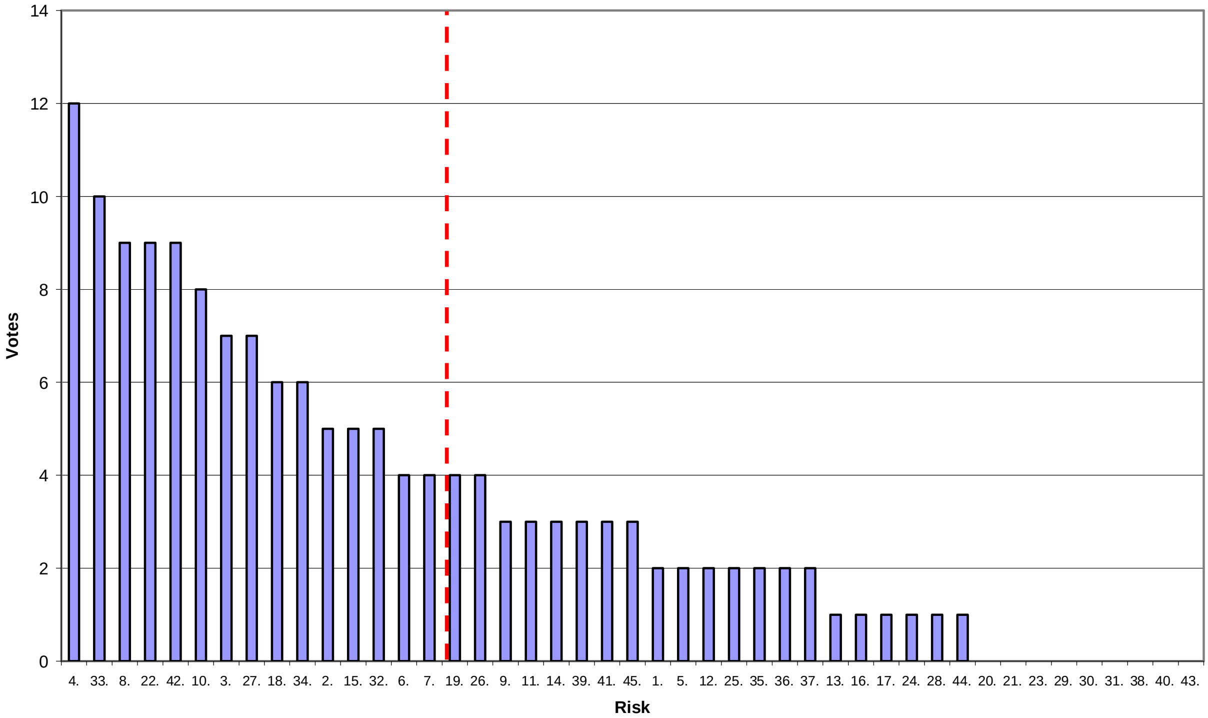


Figure 21 Results of the hazard prioritisation voting.

9 Risk analysis

The objective of the risk analysis was to assess the effect of the proposed traffic separation scheme (TSS) and deep-water route as well as different levels of surveillance and vessel traffic services on maritime accident risk on the Åland Sea. The risk assessment was focused on ship-to-ship collision and powered grounding risk. Although there is considerable leisure traffic in the area in summertime, it was excluded from the analysis because the assessed risk control measures were not seen to have any major effect on risks concerning leisure traffic. As the winter navigation conditions on the Åland Sea are mostly relatively mild and do not have significant impact on the traffic patterns, winter conditions were not explicitly modelled. The collision and grounding risk was estimated with respect to five decision options: baseline (= do nothing), RCO 1, RCO 2, RCO 3 and RCO 4, as described in section 10.2.

The risk-modelling framework applied in the present study is based on models established by Fujii [Fujii 1983] and further developed by Pedersen and Friis-Hansen [Pedersen 1995; Friis-Hansen et al. 2009]. In addition, Bayesian networks and expert judgement elicitations were used.

With respect to ship-to-ship collision situations, five different collision types were examined:

1. *Overtaking collision*, in which two vessels moving in the same direction collide on a straight leg of a fairway as a result of one overtaking the other
2. *Head-on collision*, in which two vessels collide on a straight leg of a fairway as a result of two-way traffic on the fairway
3. *Crossing collision*, in which two vessels using different fairways collide at the fairway crossing
4. *Merging collision*, in which two vessels using different fairways collide at the merging of the fairways
5. *Bend collision*, in which two vessels moving in opposite directions on the same fairway collide on a turn of the fairway as a result of one of the vessels neglecting or missing the turn (error of omission) and thus coming into contact with the other vessel

When estimating expected collision frequencies, the latent collision frequency is first calculated given the traffic data. The latent frequency represents the amount of theoretically possible collision situations per unit time assuming blind navigation. The *expected* frequency of a collision type is then obtained by multiplying the latent collision frequency with the expected value of the causation factor, representing the capability of the officer on the watch to avoid a potential accident, related to the collision type. The expected frequency of a collision type is the measure of collision risk used in the present study.

The causation factor is defined as the fraction of potential accidents that finally end up in an actual accident. It represents the capability of the vessels to notice the presence of the dangerous encounter situation in time and to react by carrying out sufficient actions to avoid collision or grounding. The causation factor depends on several functions related to traffic perception, communication and avoidance actions. It also depends on external factors such as the vessel types involved in the collision, weather conditions, physical manoeuvre options, etc. The smaller the causation factor is, the better is the capability of the navigators to avoid potential accidents.

Two types of powered groundings were examined:

1. *Ships following the ordinary direct route at normal speed.* Accidents in this category are mainly due to human error, but may include ships subject to unexpected problems with the propulsion/steering system that occur in the vicinity of the fixed marine structure or ground.
2. *Ships that failed to change course* at a given turning point near the obstacle.

Grounding frequencies are estimated in similar manner as the collisions: first, the latent grounding frequencies are derived, i.e. number of ships on grounding course, which are then multiplied with the corresponding causation factor. For grounding type 1, the causation factor represents the fraction of the grounding candidates which fail to avoid the obstacle, whereas for type 2 the causation factor represents the fraction failing to change course at the given point. In type 2, the vessel can still avoid grounding after failing to make a turn if it is able to detect the error in time. The officer of the watch is assumed to check the position of the ship randomly following a Poisson process. The checking frequency is determined by a modelling parameter called the *average time between checks*. The collision and grounding analysis methodology is further described in [Friis-Hansen et al. 2009].

The actual calculations to estimate the collision and grounding risks were performed using a beta version of the BaSSy tool software (work name GRISK v1.0.8 for collisions and v1.0.19 for groundings). The BaSSy tool was developed by DTU and Gatehouse within the BaSSy project. The software is a successor of the GRACAT software (Grounding and Collision Analysis Toolbox), which has been validated in case studies by the developers. Development of the BaSSy tool has subsequently continued under the name IWRAP Mk2 (IALA Waterway Risk Assessment Program) programme.

The BaSSy tool takes into account different characteristics of ships such as length, width, speed etc. by categorising ships according to ship type and length. The ship types used are: Crude oil tanker, Oil products tanker, Chemical tanker, Gas tanker, Container ship, General cargo ship, Bulk carrier, Ro-Ro cargo ship, Passenger ship, Fast ferry, Support ship, Fishing ship, Pleasure boat and Other ship.

Calculation of the collision and grounding frequencies is based on careful specification of the operational environment of the ship traffic considered. The ship routes relevant for the present study were specified for the risk calculations as shown in Figure 23 and Figure 24. The routes consist of legs that are defined as straight lines between given waypoints. The routes for the baseline study were defined based on a density plot of the 2006 AIS data covering the examined sea area (Figure 22). The proposed new traffic separation scheme and deep-water route were taken into account in the route specifications for risk control options 1 – 4. As a result of the TSS, the traffic from the Gulf of Bothnia bound to the Gulf of Finland cannot use the current main route, which will be reserved for traffic in the opposite direction, but will have to choose between the northern TSS route or turning east only after going through the main southbound TSS. The latter option creates a new eastbound route, which can be seen in Figure 24. The deep-water route is situated between the southbound and northbound lanes of the southern TSS. It is assumed that only ships with a draught of 12m or more will use the deep-water route. Based on 2006 AIS data, there are 45 ships with the specified draught moving in each direction per year, about one ship per week in each direction. Because of the small traffic intensity, the deep-water route is not modelled in the analysis.

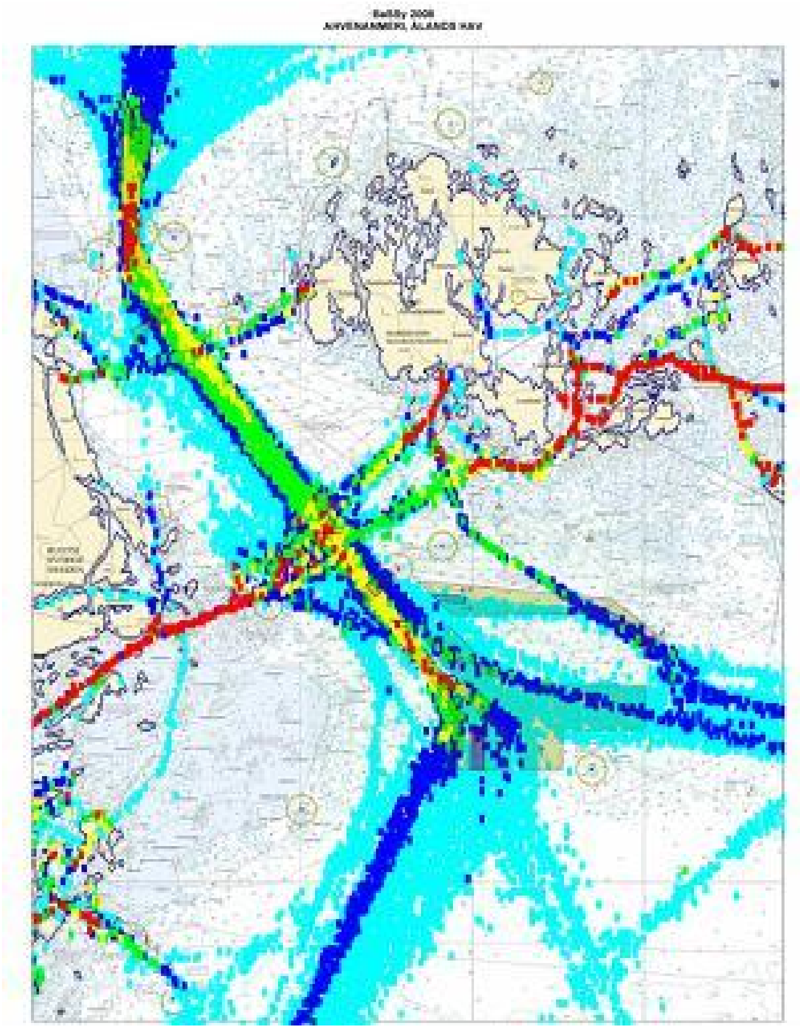


Figure 22 Traffic density plot based on the AIS data of the year 2006.

Water depth information was needed in the grounding risk analysis module in the BaSSy tool. For this analysis, electronic nautical chart material including coastlines and water depth curves was received from the Finnish Maritime Administration. The chart material was converted from ESRI Shapefile (.shp) format into BaSSy tool XML in order to be used in the BaSSy tool. The conversion process is described in Appendix 7.

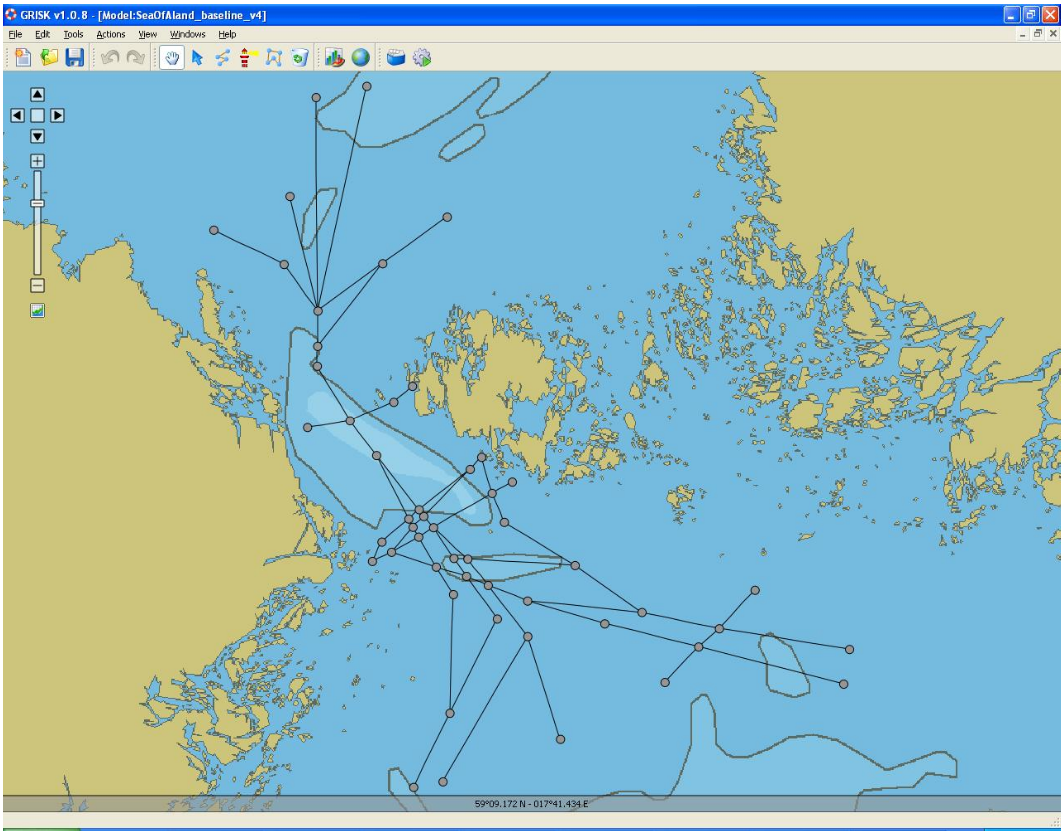


Figure 23 Traffic model for the baseline study.

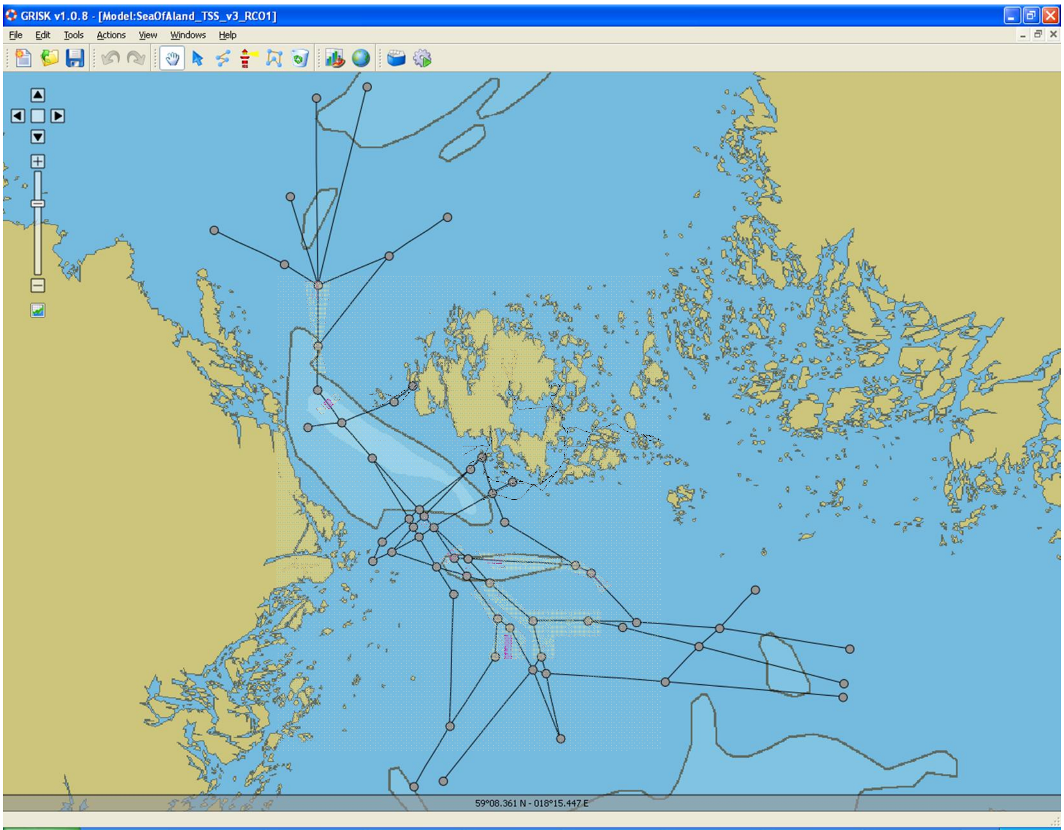


Figure 24 Traffic model for RCO 1 – 4 reflecting the changes in routes due to the traffic separation scheme.

The 2006 AIS traffic data was used for estimating the annual numbers of vessels of different types and lengths on the various routes in the baseline situation (Appendix 8). This is considered to be a good approximation of the future traffic, because no significant changes in traffic volumes are anticipated in the Åland Sea. The AIS signals were allocated to the route net by defining reference lines to each traffic leg. All ships that cross a reference line with less than angle of 20° to the leg are associated with that leg. A relatively small proportion of the traffic does not fulfil the given conditions and is therefore discarded from the analysis. However, this is judged not to have any significant effect on the analysis. The ship types were received by using the Lloyd's database.

The same traffic volumes as in the baseline were used in the analysis of RCO 1 – 4. The changes in the traffic pattern were taken into account by moving some of the traffic from one route to another, keeping the total traffic volume constant. It was assumed that all ships from the Gulf of Bothnia bound to the Gulf of Finland with a draught of less than 7m will take the northern route option in the South Åland Sea TSS and the larger ships will take the route through the main southbound TSS. Because the BaSSy tool categorises ships by ship type and length only, it was approximated that tankers with a length of less than 100m, passenger ships under 225m and all other ships under 125m have a draught less than 7m. It was also assumed that southbound ships in the Southern Quark coming from the eastern part of the Gulf of Bothnia cannot take the currently used short cut because of the COLREGS associated with traffic separations. Only northbound traffic is assumed to take the shortcut if the TSS is implemented. For details on the assumed traffic volumes on each leg for RCO 1 – 4, see Appendix 9.

In the baseline situation, the lateral distribution of the traffic on each route leg was specified based on AIS data. Histograms of the traffic crossing the reference line of each leg was processed from the AIS data, see example in Figure 25. Theoretical distributions consisting of a mixture of either a normal distribution and a uniform distribution or two normal distributions were then fitted to the histograms (Figure 26).

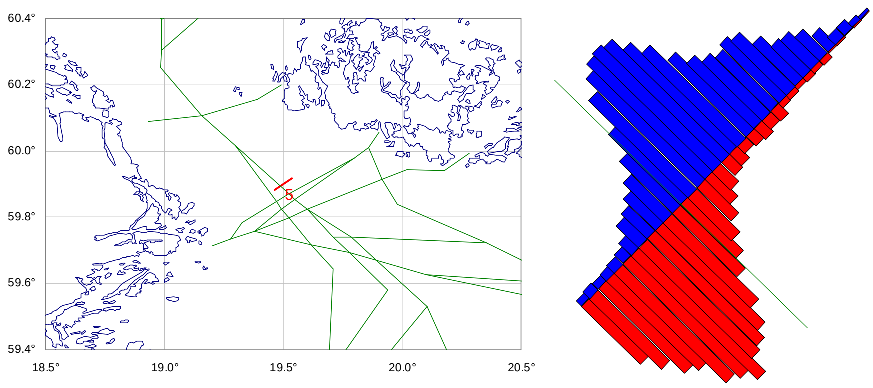


Figure 25 Example of a histogram showing the observed lateral distribution of the traffic on a leg.

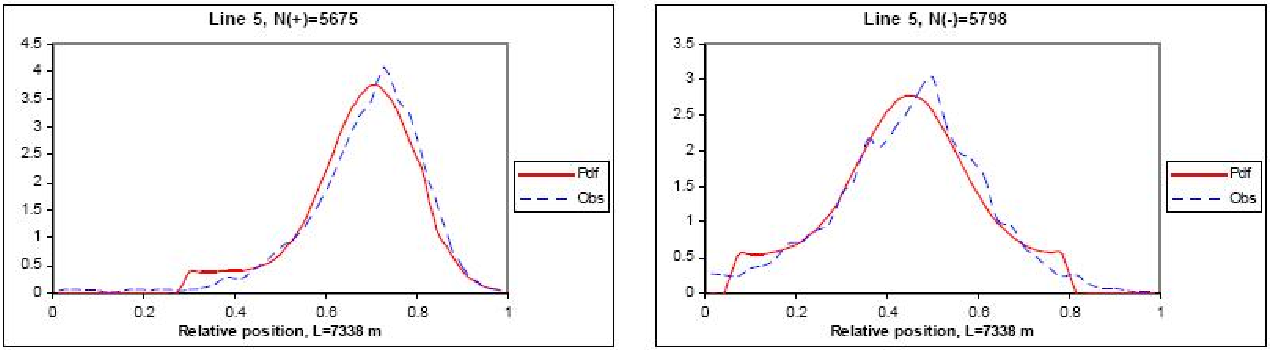


Figure 26 Example of a theoretical distribution (solid red line) fitted to the observed traffic (dashed blue line). Southbound traffic to the left and northbound to the right.

In the Gulf of Finland the TSS is followed well and the traffic is clearly divided in an eastbound and a westbound lane (Figure 27). In RCOs 2 - 4 the traffic in the Åland Sea TSS was assumed to behave in a similar manner. For the Gulf of Finland traffic, it was observed, that the standard deviation of the lateral traffic distribution is approximately 1/5 of the width of the one-way lane of the nearest TSS segment. This observation was used as a guideline for setting the lateral distributions in the Åland Sea TSS, see example in Figure 28. The north- and southbound traffic is assumed to overlap slightly more in RCO 1 than in the other RCOs because of no surveillance of the traffic.

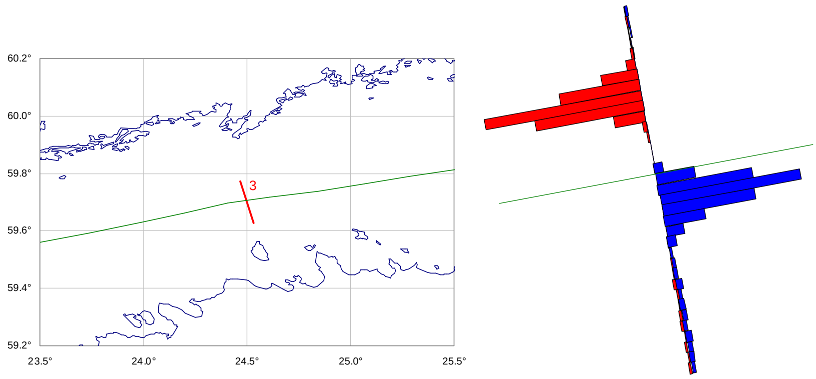


Figure 27 Example of the traffic in the TSS area of the Gulf of Finland.

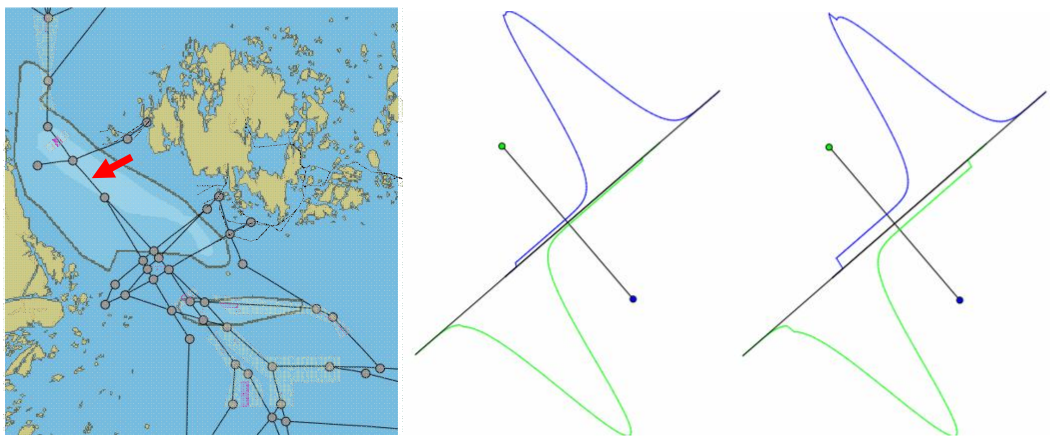


Figure 28 Example of the assumed lateral distribution of the traffic after implementation of a TSS. The traffic in RCO 1 (right) is slightly more overlapping than in RCOs 2 - 4 (middle), due to lack of surveillance of the traffic.

The BaSSy tool enables the use of different causation factor values for groundings and each collision type. The collision causation factor value $3.0 \cdot 10^{-4}$, obtained from an analysis of oil and chemical spills in Danish waters made by COWI in 2006 – 2007 [Friis-Hansen et al. 2009], was used for all collision types in the analysis for the baseline situation. This was also the default value of the collision causation factor in the development version of the BaSSy tool software (GRISK v1.0.8), which was used for calculating the collision frequencies. For powered groundings in the baseline situation, the causation factor $1.6 \cdot 10^{-4}$ and time between checks 180 seconds were used. These values were the default settings[1] of BaSSy tool v1.0.19 and mainly rooted in observations of Fujii and Mizuki, see [Friis-Hansen et al. 2009].

In order to obtain the values for the causation factors for the considered risk control options, reduction coefficients for the causation factors were modelled with Bayesian networks. The new causation factor values were obtained by multiplying the baseline causation factors with the reduction coefficients. The reduction coefficients of the causation factors were assessed by a group of six experienced mariners, all operating on the Åland Sea (see Appendix 1), in a fourth expert workshop. The Bayesian network used to estimate the expected value of the coefficient for collisions due to implementing of one of the RCOs is shown in Figure 29. The experts were first asked to assess the change in the awareness, excluding the other traffic, of the officer of the watch (OOW) onboard an average ship due to one of the RCOs ("Own ship awareness"). This includes e.g. status of the own ship, dangers to navigation, environmental factors, safe position, speed and course and safe and efficient route. Then they were asked to assess the effect of the RCOs on the OOWs awareness concerning the surrounding traffic ("Other ships awareness"). This includes e.g. knowledge of the locations, speed, courses and intentions of other ships. In the final step, the experts assessed how different combinations of "Own ship awareness" and "Other ships awareness" affect the causation factor. All assessments were made relative to the current state. The reduction coefficients for groundings were assessed directly for each RCO without any decomposition since there is only one ship involved in a grounding scenario.

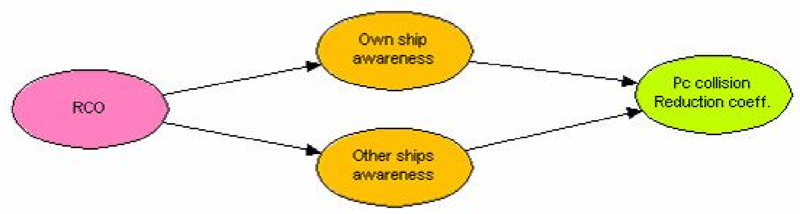


Figure 29 Bayesian network used to estimate the effect of the RCOs on the collision causation factor.

The experts gave their assessments as probability distributions, which facilitated the consideration of uncertainty factors such as environmental conditions and different bridge equipment levels. For detailed results, see Appendices 5 and 6. The mean values of the aggregate results are shown in Table 12 and Table 13. The opinion of the experts was that already a TSS without any surveillance (RCO 1) improves the OOWs ability to avoid collisions significantly by making the traffic flow more predicable and defining crossing areas. However, without surveillance one cannot be totally sure that all other ships follow the TSS. Therefore RCO 2 was seen to improve collision safety further. RCOs 3 and 4 have the same positive effect of RCO 2, but in addition include the effect of a GOFREP-style Ship Reporting System (RCO 3) or a Vessel Traffic Service with navigational assistance (RCO 4).

[1] In the default settings of BaSSy tool GRISK v1.0.19 there is a reduction factor for certain ship types. In this study, the reduction factor was not used.

RCOs 3 and 4 were judged to be practically equally effective with respect to collision risk. With respect to groundings, all RCOs were found to reduce the causation factor. The more expensive RCOs were seen to have more significant effect than the less expensive ones.

Table 12 Results of the collision causation factor assessments.

Inside TSS effect area						*Outside TSS effect area*	
	RCO 1	***RCO 2***	***RCO 3***	***RCO 4***		***RCO 3***	***RCO 4***
Reduction coefficient	0.69475	0.49167	0.41655	0.40517		0.84722	0.82408
Baseline causation factor	0.0003						
New causation factor	0.00021	0.00015	0.00012	0.00012		0.00025	0.00025

Table 13 Results of the grounding causation factor assessments.

Inside TSS effect area						*Outside TSS effect area*	
	RCO 1	***RCO 2***	***RCO 3***	***RCO 4***		***RCO 3***	***RCO 4***
Reduction coefficient	0.66425	0.58425	0.49275	0.39275		0.84339	0.67223
Baseline causation factor	0.00016						
New causation factor	0.000106	0.000093	0.000079	0.000063		0.00013	0.00011

The obtained new causation factors were applied in the analyses to traffic legs that are either directly affected by the TSS or cross routes that are affected. In RCOs 1 and 2, the causation factors on the legs far from the TSS were left with the baseline value of the factor. The SRS and VTS effect of RCOs 3 and 4 outside the TSS effect area was not assessed in the expert workshop. To estimate this, it was assumed that the effects of TSS with surveillance and the added effect of SRS or VTS are independent. Under this assumption, the reduction coefficient without TSS effect can be calculated using following equation:

$$\text{reduction coefficient without TSS effect} = \frac{\text{reduction coefficient with TSS effect}}{\text{reduction coefficient for RCO 2}}$$

The results are shown to the right in Table 12 and Table 13.

9.1 Estimated collision and grounding frequencies

The results of the collision and grounding risk calculations performed for the baseline situation and the RCOs are presented in Table 14…Table 16 and Figure 30…Figure 32 . The results represent the estimates of the expected yearly frequencies of collisions and groundings.

Table 14 The expected collision frequencies per year of baseline and the RCOs divided by type of struck vessel.

Struck vessel type	Baseline	RCO 1	RCO 2	RCO 3 and 4
Bulk carrier	6.07E-03	2.04E-03	1.19E-03	9.54E-04
Chemical tanker	2.83E-03	1.24E-03	8.40E-04	6.75E-04
Container ship	3.38E-02	1.89E-02	1.37E-02	1.10E-02
Crude oil tanker	8.07E-05	3.26E-05	2.15E-05	1.72E-05
Gas tanker	6.11E-04	2.89E-04	1.97E-04	1.58E-04
General cargo ship	9.76E-02	4.03E-02	2.61E-02	2.10E-02
Oil products tanker	2.04E-02	9.17E-03	6.18E-03	4.97E-03
Other ship	1.40E-03	5.41E-04	3.37E-04	2.72E-04
Passenger ship	8.35E-02	7.68E-02	6.95E-02	5.74E-02
Ro-Ro cargo ship	6.05E-04	3.44E-04	2.60E-04	2.11E-04
Support ship	1.73E-03	6.40E-04	3.93E-04	3.17E-04
SUM	**0.249**	**0.150**	**0.119**	**0.0971**

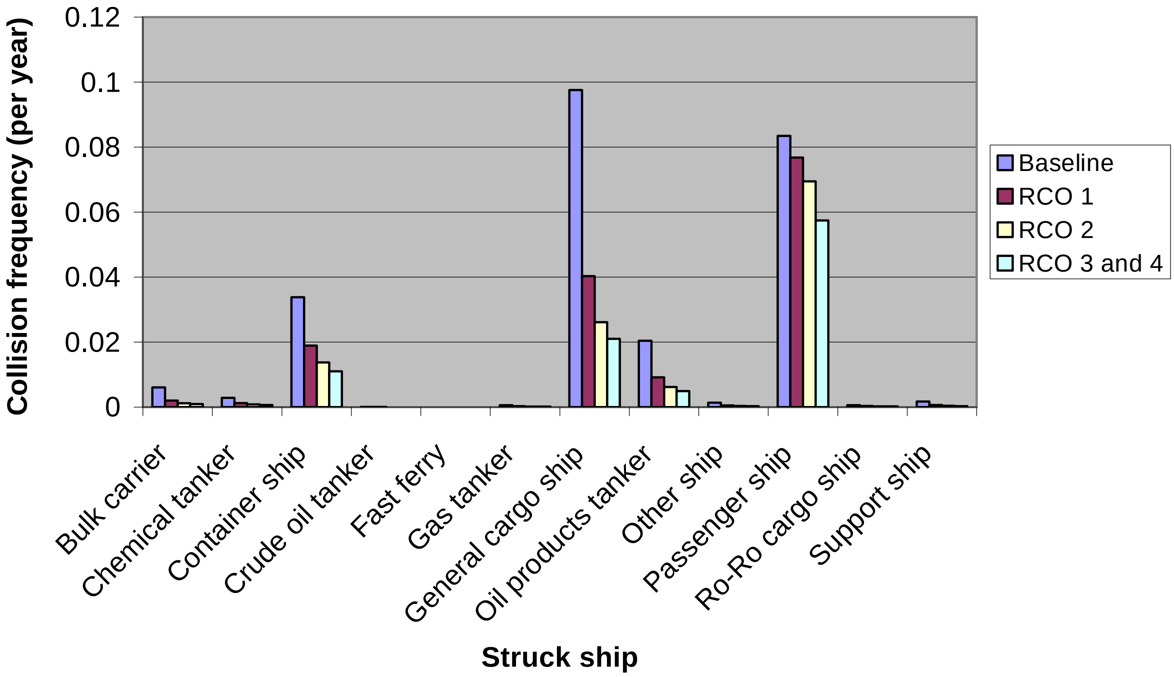


Figure 30 The expected collision frequencies per year of baseline and the RCOs divided by type of struck vessel.

Table 15 The expected collision frequencies per year of baseline and the RCOs divided by type of collision.

Struck vessel type	Baseline	RCO 1	RCO 2	RCO 3 and 4
Overtaking	0.0239	0.0267	0.0220	0.0177
HeadOn	0.1793	0.0867	0.0691	0.0569
Crossing	0.0053	0.0058	0.0046	0.0038
Merging	0.0014	0.0044	0.0032	0.0026
Bend	0.0387	0.0267	0.0199	0.0161
SUM	**0.2486**	**0.1503**	**0.1187**	**0.0971**

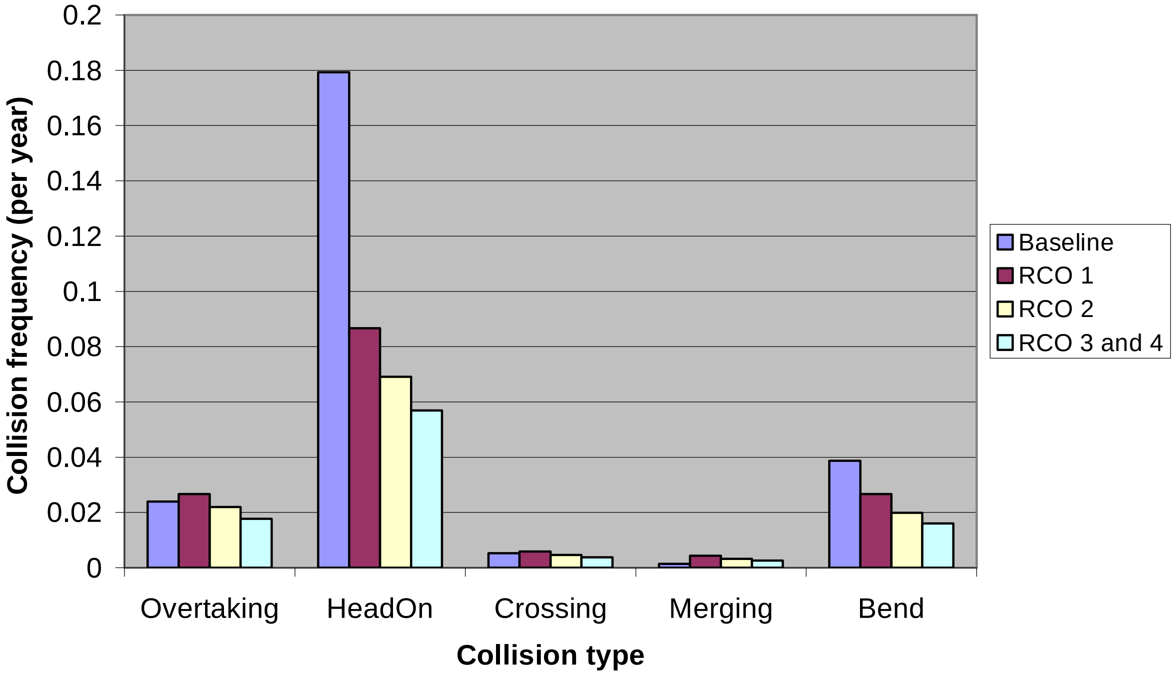


Figure 31 The expected collision frequencies per year of baseline and the RCOs divided by type of collision.

The estimated collision frequency for the baseline situation is 0.25 collisions per year, which can be compared to the observed frequency of 0.174 based on accident statistics for years 1985 – 2007 for the sea area. Because the accident statistics contains only four collisions during that time period, the observed frequency is rather imprecise and the analysis result can be seen to fit the observations with reasonable accuracy. However, the lack of a more thorough validation of the baseline causation factor constitutes an uncertainty in the model.

Table 16 The expected grounding frequencies per year of baseline and the RCOs divided by type of vessel.

Vessel type	***Baseline***	***RCO 1***	***RCO 2***	***RCO 3***	***RCO 4***
Bulk carrier	1.20E-03	4.59E-04	4.18E-04	3.92E-04	3.13E-04
Chemical tanker	2.60E-05	1.72E-05	1.65E-05	1.36E-05	1.09E-05
Container ship	1.35E-02	4.37E-03	3.84E-03	3.75E-03	2.99E-03
Crude oil tanker	1.52E-06	1.86E-06	1.63E-06	1.75E-06	1.39E-06
Gas tanker	7.29E-05	3.47E-05	3.04E-05	2.84E-05	2.26E-05
General cargo ship	3.34E-03	2.09E-03	2.00E-03	1.75E-03	1.40E-03
Oil products tanker	7.58E-04	2.63E-04	2.46E-04	2.22E-04	1.77E-04
Other ship	1.16E-04	1.24E-04	1.19E-04	9.27E-05	7.39E-05
Passenger ship	7.73E-01	7.45E-01	7.45E-01	6.35E-01	5.06E-01
Ro-Ro cargo ship	1.85E-05	1.51E-05	1.50E-05	1.24E-05	9.86E-06
Support ship	1.90E-04	1.92E-04	1.92E-04	1.61E-04	1.28E-04
SUM	**0.792**	**0.753**	**0.751**	**0.642**	**0.511**

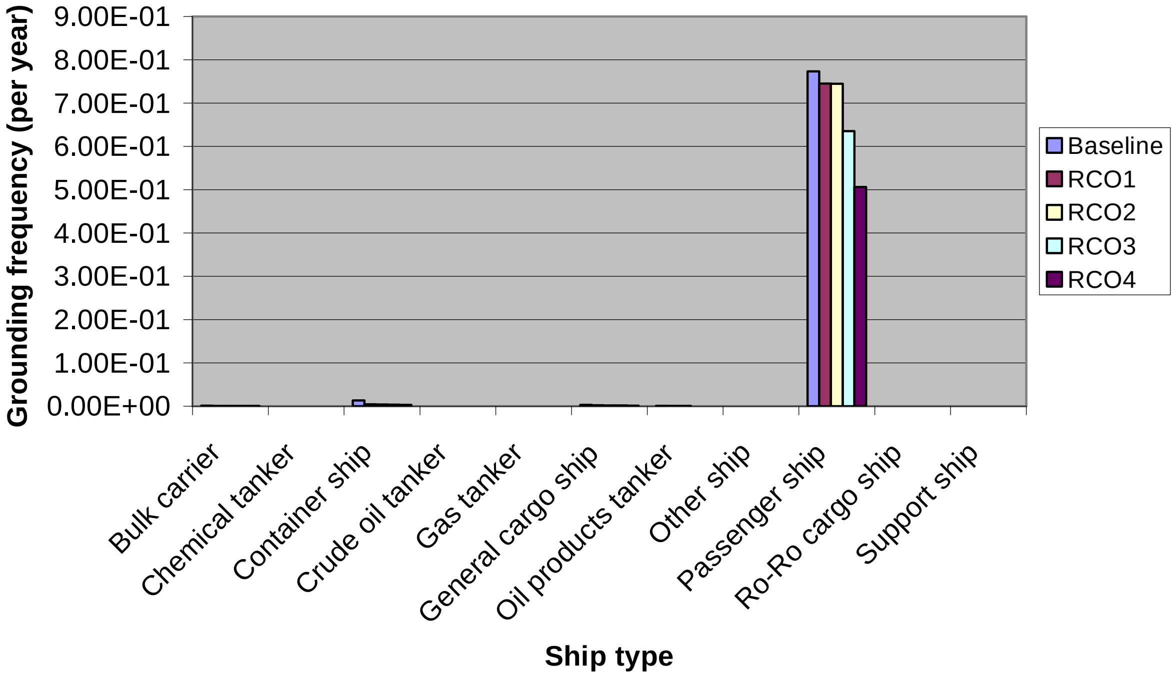


Figure 32 The expected grounding frequencies per year of baseline and the RCOs divided by type of vessel.

The estimated grounding frequency for baseline is 0.79 collisions per year, which can be compared to the observed frequency of 0.74 based on accident statistics for years 1985 – 2007 for the sea area. Thus, the overall analysis result can be seen to fit the observations with good accuracy. However, passenger ships seem to be overrepresented in the analysis results.

The results show that all considered RCOs have a mitigating effect on both collision and grounding risk. The effect on collisions comes both from separating the north- and southbound traffic from each other and making the traffic picture more predictable. Monitoring of the traffic, resulting in fewer violations to the COLREGs, causes the difference between RCOs 1 and 2. RCOs 3 and 4 further decrease the collision risk with the service offered by SRS or VTS. However, according to the results, RCOs 3 and 4 have the same effect on collision risk. The reason for this is that the experts in workshop 4 did not find the VTS with navigational assistance almost at all more efficient than the GOFREP-style SRS in assisting the mariner in avoiding potential collisions. The more expensive RCOs decrease grounding risk more than the less expensive ones.

10 Risk control options

10.1 Background

As a consequence of several collisions to the aids to navigation in the Åland Sea the Finnish and Swedish Maritime Administrations (FMA and SMA) considered some risk control measures (RCM) to improve the maritime safety in the area. The first version of the Åland

Sea Traffic Separation Scheme (TSS) was outlined by the Administrations in 1999 and updated in 2000. In order to support the functioning of the TSS, the idea of Åland Sea Vessel Traffic Service (VTS) was drafted by FMA in cooperation with the Coast Guard and the shipping companies in Finland. The Swedish party had also similar system under discussion. In addition, improving the fairway markings in the Åland Sea as one RCM was under discussion.

The planning was continued in 2005 in a meeting organised in Stockholm by the SMA. From Finland FMA and VTT participated in the meeting. It was agreed that VTT should perform a FSA study regarding the Åland Sea as a part of the BaSSy project in order to find suitable RCMs to the Åland Sea area.

10.2 Formulation of RCMs and grouping into RCOs

Expert opinion was utilised in the identification, formulation and assessment of the risk control measures in three workshops arranged during the FSA process (BaSSy Åland Sea Expert Workshop sessions 2 – 4). The participants of the expert workshops are presented in Appendix 1. In session 2 the experts identified and prioritised RCMs which as comprehensively as possible could cover the hazards of the Åland Sea identified during the hazard identification step (BaSSy Åland Sea Expert Workshop session 1) (Appendix 3). As a result of the session twelve RCMs were identified as follows:

1. Traffic separation scheme (TSS)
2. Vessel traffic services (VTS)
3. Ship reporting system (SRS)
4. Emergency towing (in case of incident, e.g. blackout)
5. Escort towing (preventive measure)
6. Air patrolling (amendment to the implementation of VTS, SRS or TSS)
7. Compulsory piloting
8. Reporting of route plans (route information) to authorities
9. Recommended blackout notification (report) to authorities
10. New fairways for leisure boats
11. Improved aids to navigation
12. Improved weather services (icing)

In session 3 the functionalities of the RCMs were defined in more detail and the RCM list was augmented with three new RCMs (Appendix 4):

13. Advance report with deficiencies
14. Mandatory ECDIS
15. Enhanced use of AIS

In the next phase the participants of the workshop were asked to rate each RCM according to their feasibility on the scale “Low” (= 1), “Medium” (= 2), “High” (= 3). The results of the voting are presented in Figure 33. As a result of voting, it was agreed in the workshop to merge emergency and escort towing into one RCM and separate VTS into two RCMs VTS Information service (RCM 2a) and VTS Navigational assistance (RCM 2b). In addition based on the results, following RCMs were cut out from the following discussion:

12. Improved weather services (icing)
10. New fairways for leisure boats

6. Air patrolling (amendment to the implementation of VTS, SRS or TSS)
7. Compulsory piloting

The final prioritised list of the most feasible risk control measures is in Table 17. In addition, to keep the workload of the FSA process reasonable the RCMs were preliminary grouped into realistic RCOs.

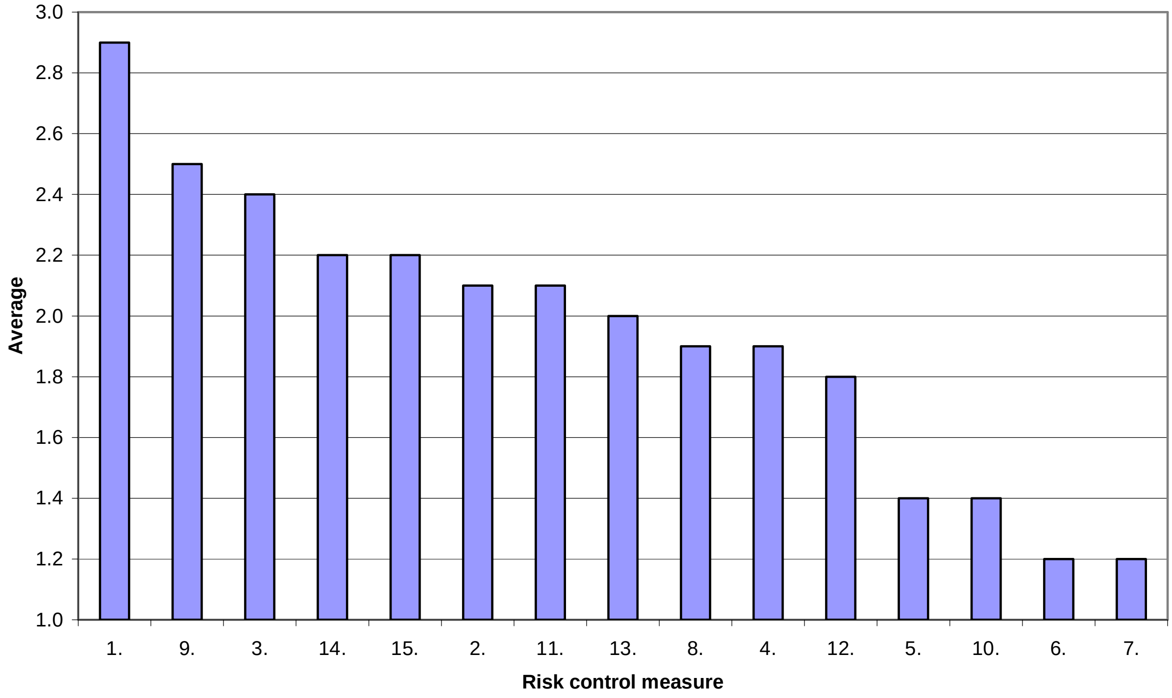


Figure 33 Prioritisation of RCMs according to their feasibility

Table 17 Prioritised list of RCMs identified in the expert workshops and preliminary grouping of the RCMs into RCOs.

RCM	RCO A	RCO B	RCO C	RCO D	RCO E
RCM 1. Traffic separation scheme (TSS)	X	X	X	X	
RCM 9. Recommended blackout notification (report) to authorities	X		X	X	X
RCM 3. Ship reporting system (SRS)		X			
RCM 14. Mandatory ECDIS	X	X			
RCM 15. Enhanced use of AIS	X	X	X	X	
RCM 2a. Vessel traffic services (VTS) Information service			X		
RCM 2b. Vessel traffic services (VTS) Navigational assistance				X	
RCM 11. Improved aids to navigation		X			
RCM 13. Advance report with deficiencies		X	X	X	
RCM 8. Reporting of route plans (route information) to authorities	X	X	X	X	
RCM 4&5. Emergency and escort towing					X

The RCOs were further regrouped for expert workshop 4 where the effectiveness of the RCOs was estimated by experienced captains operating regularly in the Åland Sea area. The idea in the regrouping was that each new RCO is including, in addition of new RCMs, all of the RCMs of the previous RCOs as illustrated in Figure 34. The final RCOs assessed in this study are described below.

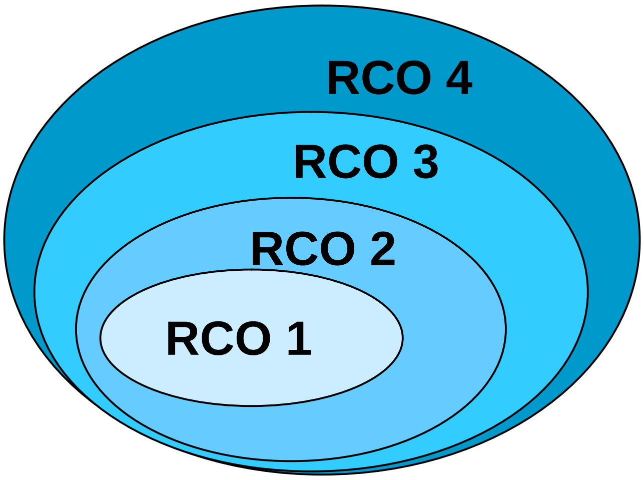
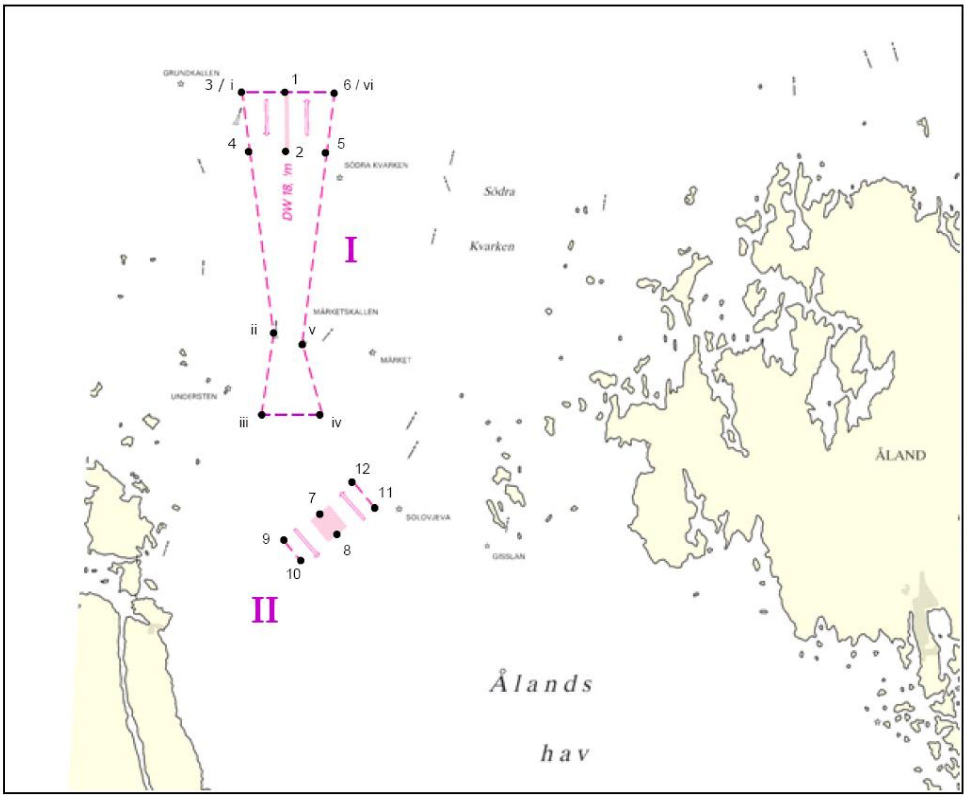


Figure 34 The principle of the different RCOs.

RCO 1 (TSS + deep-water route):

The traffic separation schemes (RCM 1 in the prioritised list of RCMs) have proved to be very effective in organising the traffic in the Baltic Sea. Examples of this are the TSSs in the Gulf of Finland and in the Bornholm area. RCO 1 consists merely of the TSSs and the new deep-water route designed in cooperation between the Finnish and Swedish Maritime Administrations. The TSS makes traffic flows more predictable separating the opposite traffic flows from each other. It also reduces the number of areas where the traffic flows intersect and it also makes the crossings more recognisable in advance. The deep-water route offers a separate and safe route for the vessels having large draught and it is supposed that the other traffic does not disturb their safe passage there. Maps of the TSSs and the deep-water routes are presented in Figure 35.

a)



b)

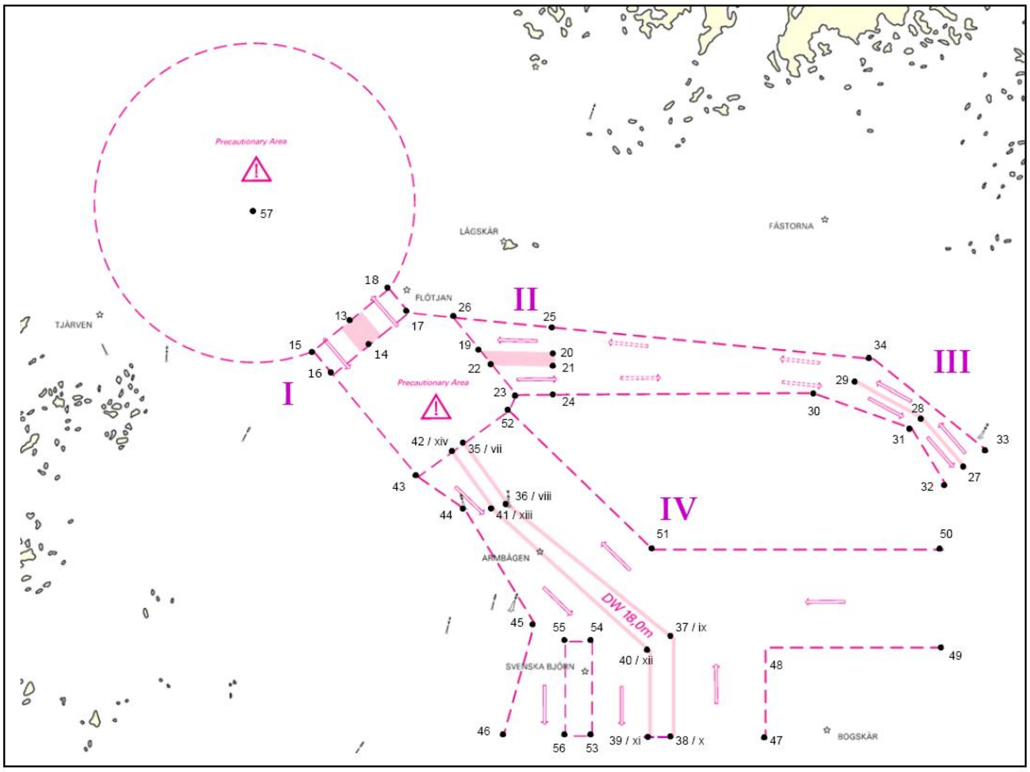


Figure 35 TSSs and deep water routes designed for the Northern Åland Sea a) and The Southern Åland Sea b).

RCO 2 (RCO 1 + monitoring):
RCO 2 was obtained by adding to RCO 1 monitoring of compliance with the rules regarding the navigation in TSSs and deep-water route. The experiences from the Gulf of Finland have showed that the effect of the TSS can be improved by monitoring. The monitoring is performed utilising the AIS system.

RCO 3 (RCO2 + reporting systems):
One of the elements of safe navigation is accurate and real time information about the traffic and other conditions in the sea area in question available in time for on-board navigational decision-making. This is ensured in RCO 3 by adding to RCO 2 a ship reporting system (RCM 3) similar to the one in use in the Gulf of Finland. The function of this is in practice quite similar to a VTS Information service (RCM 2a). This RCO includes in addition other RCMs related to reporting that can be arranged through the SRS: reporting of route plans (automated by some means, not by VHF) (RCM 8), notifying about blackout situations (RCM 9) and advance reporting about deficiencies (RCM 13).

RCO 4 (RCO 3 + VTS navigational assistance):
There is an increasing number of ships entering the Åland Sea whose officers do not have experience in the local conditions. The shallow and shoaly waters increase the risk of grounding especially if the navigational equipment of the vessel is insufficient. In order to improve the situation the VTS Navigational assistance service (RCM 2b) is included into the RCO 4 in addition to the RCMs of RCO 3. The VTS Navigational assistance service is a service to assist on-board navigational decision making and to monitor its effects.

Three of the proposed RCMs, Mandatory ECDIS (RCM 14), Enhanced use of AIS (RCM 15) and Improved aids to navigation (RCM 11) were left out of the risk analysis in order to keep the number of RCOs to be considered realistic. Another reason to exclude ECDIS and AIS from the analysis is that they are bridge equipment, whose carriage and functional requirements are governed by IMO. It is not likely that Finland and Sweden could restrict ships from entering the area based on the level of bridge equipment as long as the equipment fulfils the minimum requirements set by IMO.

11 Cost-benefit assessment of the risk control options

11.1 General

The economic feasibility of implementing any of the RCOs introduced earlier was the prime assessment problem in this FSA study. To perform a cost-benefit assessment of the RCOs, both costs and benefits were expressed in monetary values. The costs consist of implementation and maintenance costs of the RCOs and the benefits of reduced societal costs due to averted accidents.

11.2 Ship-to-ship collision and grounding damage costs

11.2.1 General

The BaSSy tool calculates the accident risk for different ship types separately. Thus the amount of spilled oil in an accident was estimated separately for an average sized ship of each ship type. The average ship length of each ship type was determined from the AIS data by calculating the weighted average ship length by taking into account the total distance which each ship had moved in the Åland Sea area during the reference year 2006. The average ship lengths used in the analysis are presented in Table 18 as well as the average oil spill sizes determined based on the vessel size.

The collision risk was calculated for the struck vessel which usually is experiencing the biggest losses. The damages of the other colliding party, the striking ship, are disregarded from the analysis.

Table 18 The average ship length and estimates of the oil spill sizes of different ship types.

Vessel type	Vessel length [m]	Bunker spill size in collisions [ton]	Cargo spill size in collisions [ton]	Bunker spill size in groundings [ton]	Cargo spill size in groundings [ton]
Crude oil tanker	144,7	416	73	208	112
Oil products tanker	125,5	322	47	161	72
Chemical tanker	106,3	240	-	120	
Gas tanker	140,4	394	-	197	
Container ship	146,0	423	-	211	
General cargo ship	104,5	233	-	116	
Bulk carrier	149,0	439	-	219	
Ro-Ro cargo ship	91,0	183	-	92	
Passenger ship	170,1	559	-	279	
Support ship	39,7	54	-	27	
Fishing ship	37,5	46	-	191	
Other ship	138,0	382	-	208	

In collision and grounding accidents the possibility of oil outflow is significant. Depending on the ship type the spilled oil may be bunker or cargo oil. In addition the spilled oil may be crude oil or heavy or light distillates. The size of the oil spill depends on the ship size and structure and damage mechanics. The scatter in the reported damage costs obtained from ship accidents having oil spill is huge. Especially the evaluation of the costs of the environmental damages is difficult. There is mutual understanding that the following technical factors have an essential influence on the cost of oil spills [White and Molloy 2005]:

- Type of oil,
- Physical, biological and economical characteristics of the spill location,
- Weather and sea conditions,
- Amount spilled and rate of spillage, and
- Time of the year, and effectiveness of clean-up.

The interactions between factors explained in the following chapters are complex, which make cost predictions based on simple parameters very unreliable (Figure 36).

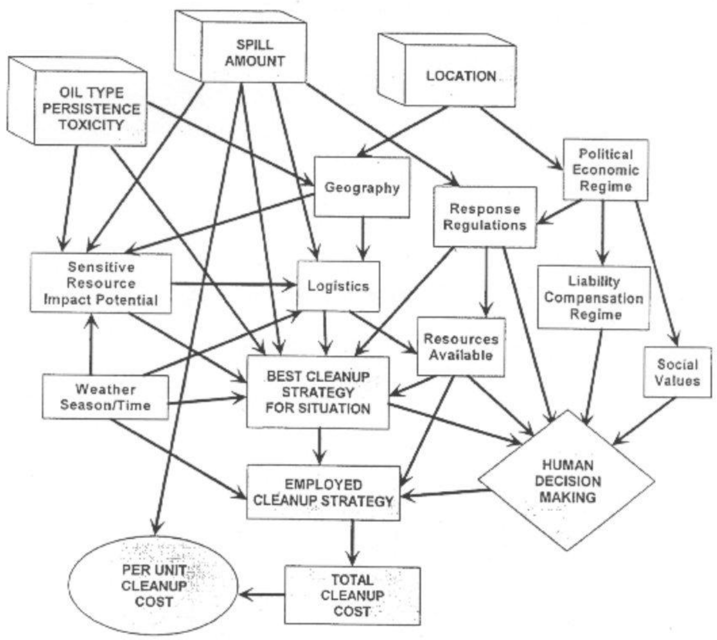


Figure 36 Factors determining per unit oil spill clean-up costs [Etkin 1999].

The most important factors determining a per-unit amount cost are location and oil type, and possibly total spill amount.

The amount of oil spilled is clearly an important factor when determining costs. Thus, given no variation in other factors, a 100,000 tonne spill will result in far wider contamination, will require a far more extensive clean-up response, cause greater damage and result in substantially higher costs than for example 10,000 tonne spill. However, the relationship is not linear. The clean-up costs on a per tonne basis decrease significantly with increasing amounts of oil spilled. Thus, the relative cost of cleaning up smaller spills is much higher than for large spills (Figure 37).

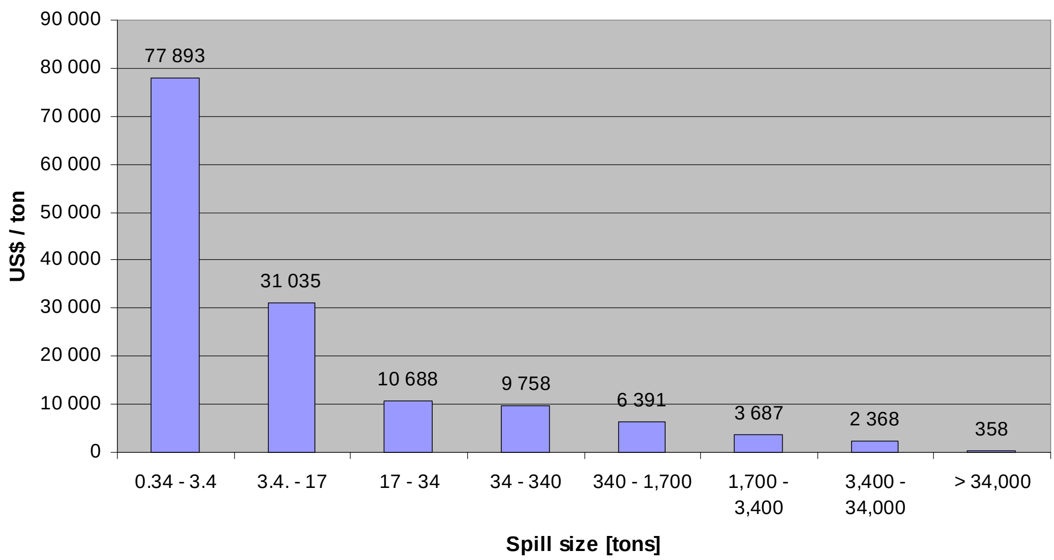


Figure 37 Per-unit marine oil spill clean-up costs by spill size for non-US Spill, in 1999 US$, according to [Etkin 2000].

After the collision and grounding frequencies were calculated the process to determine the consequence costs of an oil spill included the following estimations:

- oil spill probability in accident
- size and type of oil spill
- effectiveness of oil combating operations at sea (amount of oil collected at sea and amount of oil drifting ashore)
- oil spreading and width of the contaminated coast area
- costs of repair of damaged vessels
- costs of oil combating operations at sea and shore cleanup costs
- costs of damage caused to sea-dependent means of livelihood; tourism, fishing and fish farming.

The estimation methods are described in the following chapters.

11.2.2 Probability of oil spill in accident

In a detailed study performed by Safetec UK Ltd [Safetec UK 1999] the average probabilities of cargo and bunker spills in different casualty types were estimated based on wide historical spill data from the following sources:
- Lloyds's Casualties
- ITOPF (International Tanker Owners Pollution Federation)
- Worldwide Tanker Spill Database

The probabilities of bunker and cargo spills in ship-to-ship collisions and groundings are listed in Table 19.

Table 19 Cargo and bunker spill probability [Safetec UK 1999].

Spill type	**Spill probability (Spills per casualty)**	
	Collisions	**Groundings**
Cargo spill	0.39	0.30
Bunker spill	0.128	0.12

11.2.3 Estimation of spill type and size

Crude oil is not transported to the Gulf of Bothnia, but according to a questionnaire conducted among the ports of the Gulf of Bothnia, about 30% of cargo carried by tankers going to the Gulf of Bothnia is heavy fuel oil. As regards to bunker oil according to the questionnaire conducted by the Finnish Maritime Administration in 1995 some 90% of merchant vessels use heavy fuel oil as bunker fuel [Mäkelä et al. 2000].

In case of an accident of such severity that it results in outflow of cargo, a number of cargo tanks will leak. A portion of the tank content will then escape into the sea, the amount depending on the type of damage, the vessel's loading condition and the properties of the cargo and whether the vessel is a single or double hull ship. According to a study published by HELCOM [HELCOM 1990] the estimate of the size of cargo spill in ship-to-ship collisions is 1/200 of the total cargo, assuming that the tanker has a double hull and that the cargo is lighter than water and insoluble. In groundings, the estimate of the cargo spill is 1/130 of the total cargo.

Regulation 13F of MARPOL 73/78 requires all new tankers above 5000 DWT to have a double hull, a mid-deck, or an alternative arrangement approved by IMO. However, the regulations apply only to cargo oil tanks. The fuel oil tanks usually locate in the engine room where a double hull arrangement is not required. In the case of bunker spill, all oil is assumed to outflow from tanks penetrated in collisions and 50% in groundings assuming that the bunker tanks were 98% full [Michel and Winslow 1999]. In the current study it is assumed that in an accident, collision or grounding, one of the bunker tanks is penetrated.

In the current study the bunker fuel is assumed to be stored in two tanks of equal size. Based on the analysis of built ships the bunker capacity of one tank is roughly dependent on the vessel size as follows:

$$V_{bunker}[ton] = 0{,}0161 \times L^2 + 0{,}5457 \times L .$$

11.2.4 Effectiveness of oil combating

Many factors determine the success of oil combating operations: e.g. the location of the oil spill, water depth in the spill area, season, weather conditions, number of available oil combating vessels, type of oil etc.

The effectiveness of oil combating operations depends on the type of oil. The equipment in oil combating vessels in the Baltic Sea is designed for crude oil or heavy fuel oil spills. Diesel oil and light fuel oil spills usually evaporate over time without causing long-lasting damage to the environment.

According to Finnish oil combating specialists [Jolma and Lampela 2007] the costs/ton of shore cleaning operations are ten times more expensive than collecting the oil at sea and hundred times more expensive than pumping the oil from the damaged vessel.

Current oil combating vessels are capable of operating in sea conditions with significant wave heights of 1 – 1.5 metres. In the Gulf of Finland, the probability of suitable conditions is 80%, in the Northern Baltic 60% [SYKE 2007]. The maximum collecting capacity of oil combating vessels operating in the Åland Sea area is shown in Table 20. In the current study it is estimated that on average 50% of spilled oil can be collected before the oil reaches the shoreline.

A rough estimation of the oil combating costs for the following scenario presented by [Jolma and Lampela 2007]:

- 50 tons of oil is pumped from the tanks of the damaged vessel
    - time needed for the operation is 2 days
    - one oil combating vessel
    - costs 40 000 €
- 100 tons of oil is collected at sea
    - time needed for the operation is 2 days
    - three oil combating vessels needed
    - costs 120 000 €

Taking into account that in bigger oil spills more vessels are needed and adding to the costs some authority costs the value used in the current study for the costs related to the oil combating at sea was 1670 €/ton.

The oil spreading calculations were performed by the Finnish Environment Institute using the model developed by Dr. Ovsienko. The model is based on long-term statistics of current and wind information. Figure 38 shows an example of the oil spreading calculations for an oil spill of 108 tons during spring in the Åland Sea. The prevailing wind direction in the Åland Sea is southwest; therefore the rough estimate of probability that oil will reach the coast of Åland is greater (70%) than that of oil reaching the Swedish coast (30%).

It has been estimated [Rytkönen and Sukselainen 1994] that one ton of oil can foul from 60 to 600 metres of shoreline. In the current study, taking into account the oil type (heavy fuel oil) and the fragmented shoreline of the Åland Sea area, a value of 300 metres was used.

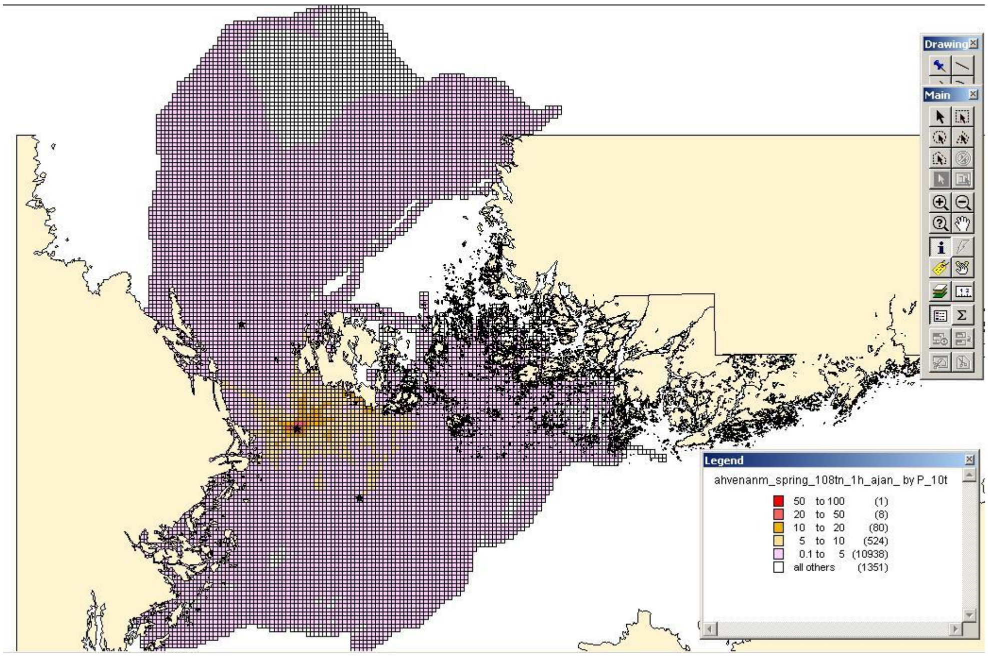


Figure 38 Oil spreading calculations performed by the Finnish Environment Institute using the Ovsienko model. The spill size used in the calculations is 108 tons and the spill position (black dot) is in the middle of the Åland Sea. The colours from red to yellow indicate that the probability of oil occurrence is from 100 to 10%.

Table 20 Collecting capacities of oil combating vessels operating in the Åland Sea area [SYKE 2007].

Vessel	Capacity [m³/day]
Sektori	216 (2 × tank capacity 108 m³)
Oili II	160
Oili III	160
Halli	1400
Uisko	200
Tursas	200
Svärtan	156 (3 × tank capacity 52 m³)

11.2.5 Oil combating costs on shore

The interactions between factors affecting to the costs of oil combating are complex, making cost predictions based on simple parameters very unreliable. One method that takes at least some of the factors into account is the formulae and methodology presented by Etkin [Etkin 2000]. However according to Finnish oil combating experts [Jolma and Lampela 2007] this methodology underestimates the costs if the average European value for regional unit costs is used. In the current study the Norwegian value of 24828 €/ton (expressed in euros of the year 2006) is used which is the highest in Europe. The estimation is based on the following formulae:

$C_{ei} = C_{ui} \times A_i$ = estimated total response cost for scenario *i*,
$C_{ui} = C_{li} \times t_i \times o_i \times m_i \times s_i$ = response cost per unit for scenario *i*;
$C_{li} = r_i \times l_i \times C_n$ = cost per unit spilled for scenario *i*,

Symbol	Explanation	Used value
C_n	General cost per unit spilled in nation, *n,*	24828 €/ton
t_i	Oil type modifier factor for scenario *i*,	0.71 (No 6 bunker fuel)
o_i	Shoreline oiling modifier factor for scenario *i*	$o_i = -0.000007 \times l_{oi}^2 + 0.0058 \times l_{oi} + 0.4658$
m_i	Cleanup methodology modifier factor for scenario *i*	1.89 (mainly manual collection)
s_i	Spill size modifier factor for scenario *i*,	$s_i = 9.6518 \times A_i^{-0,5288}$
r_i	Regional location modifier for scenario *i*,	1.0
l_i	Local location modifier for scenario *i*,	1.46 (nearshore accident)
A_i	Special spill amount for scenario *i*,	[ton]
l_{oi}	Length of oiled shoreline	$l_{oi} = 250 \times A_i$

11.2.6 Reparation costs

The estimation of reparation costs is based on the H&M claims published by the Swedish Club [Swedish Club 2005], which reports the reparation costs of 130 collisions and 133 groundings. The average costs are 837 900 € for collisions and 366 060 € for groundings (expressed in euros of the year 2006).

11.2.7 Costs of damage caused by oil spill on sea-dependent means of livelihood

11.2.7.1 General

In the coastal area of the Åland Sea, tourism, fishing and fish-related industries are the most important means of livelihood. SSPA carried out a study in Sweden in which the damage costs of an oil spill for these businesses were estimated [SSPA 2005]. The results of the study for the Swedish coastal area are exploited in this study and the method is also applied for the coastal areas of Åland.

11.2.7.2 Costs to tourism

Both in Sweden and in Finland, tourism accounts for a significant part of the gross national product (GNP). According to the statistics for 2002, the relative proportion of the GNP was 2.63% in Sweden and 2,4% in Finland. In Åland, when comparing the regional proportion of the GNP with the number of inhabitants, tourism is the most important means of livelihood.

In the SSPA study [SSPA 2005], the damage costs were estimated based on the Tourism Satellite Account system. This is a statistical system that depicts the financial importance and economic effects of tourism in an extensive and versatile manner. It is based on internationally given standards and norms, which makes it comparable between countries. The Tourism Satellite Account system is also used in Finland [Konttinen J-P 2005].

In the SSPA study [SSPA 2005] the damage costs to tourism were determined using the formula:

$$Damage_{tourism}[€] = Coastdamage[m] \times Sensitivity_{tourism}[€/m] \times Damagerate[\%]/100$$

where:

– $Damage_{tourism}$ is damage costs of an oil spill to tourism in €,
– *Coastdamage* is the length of polluted coastline in metres,
– $Sensitivity_{tourism}$ is the socioeconomic sensitivity index of tourism in €/metre
– *Damagerate* is the pollution rate of the coastline

The socioeconomic sensitivity index can be determined by dividing the increase in value of all tourism-related branches by the length of the coastline [SCB].

The pollution rate can have values between 0 and 100% depending on the time of year when the oil spill happened, the thoroughness of shore cleaning operations, and to what extent tourism is dependent on sea-related activities. In this study the value of 100% was used.

In the SSPA study [SSPA 2005], socioeconomic sensitivity index values were determined for different coastal provinces in Sweden. The relevant provinces having a coastline in the Åland Sea area are the provinces of Uppsala and Stockholm. Their socioeconomic sensitivity indexes were 46.8 €/m and 95.7 €/m respectively for the year 2002. When calculating the weighted average for the socioeconomic sensitivity index, taking into account the coastline lengths of the provinces, a value of 85.6 €/m is obtained. The coastline length was obtained from the SCB web site [SCB] (values expressed in euros of the year 2006).

For Åland the increase in value of all tourism-related branches for 2002 was 197 million € (expressed in euros of the year 2006) [Konttinen J-P 2005] and the coastline length is 6156 km. The coastline length was obtained from the INTERMIN web site [INTERMIN]. The socioeconomic sensitivity index for tourism in Åland is then 32.1 €/m.

11.2.7.3 Costs to fishing

Commercial fishing

Although the number of registered commercial fishers has dropped in recent years, commercial fishing is still an important source of livelihood in the Åland Sea area.

The socioeconomic sensitivity index can be determined for commercial fishing in a similar manner to that for tourism. However, the relationship between the polluted length of coastline and the costs of the damage to commercial fishing is not as clear as for tourism, because the fishing waters are often far from the home port. SSPA [SSPA 2005] lists the different ways in which an oil spill can damage commercial fishing:

– Possibilities for fishing can be limited:
  • Some fishing ports might be closed to prevent oil spreading
  • Fishing vessels might be needed in oil cleaning operations
  • Fishing might be restricted in normal fishing waters due to oil cleaning operations
– The catches may become smaller:

  - Fish retreat from the polluted areas
  - Fishing tackle becomes useless when covered in oil
  - The area of fishing waters diminishes
- The demand for fish will decrease:
  - Consumers associate fish with news of the oil spill and cut their consumption of fish.

However, despite the more complex situation in commercial fishing a similar formula as for tourism can be used to get a rough estimate of damage costs:

$$Damage_{comm.\ fishing}[€] = Coastdamage[m] \times Sensitivity_{comm.\ fishing}[€/m] \times Damagerate[\%]/100$$

In the SSPA report [SSPA 2005], the socioeconomic sensitivity index was determined for the east coast of Sweden to be 0.20 €/m (expressed in euros of the year 2006).

In Finland, the statistics for commercial fishing are published by the Finnish Game and Fisheries Research Institute [RKTL 2007a]. Based on these, the catches of Finnish commercial fishers for different sea areas in the Baltic Sea are presented here for 2006. The division into regions used in the statistics is shown in Figure 39. The most relevant area for the current study is area 29, in which the total catch of Finnish commercial fishers in 2006 was 14 040 tons with a value of 3.2 million €. The most important fish species based on the amount and value of the catches are Baltic herring (6500 tons, 0.8 million €), sprat (6800 tons, 0.7 million €), pikeperch (200 tons, 0.7 million €), European whitefish (100 tons, 0.4 million €) and perch (300 tons, 0.3 million €).

The Finnish socioeconomic sensitivity index of commercial fishing can be calculated based on the value of the total catch and the length of the Finnish coastline in area 29. The coastline length of Åland and the southwest coast of Finland including the Archipelago area is 16 367 km.

The Finnish socioeconomic sensitivity index of commercial fishing is 0.20 €/m.

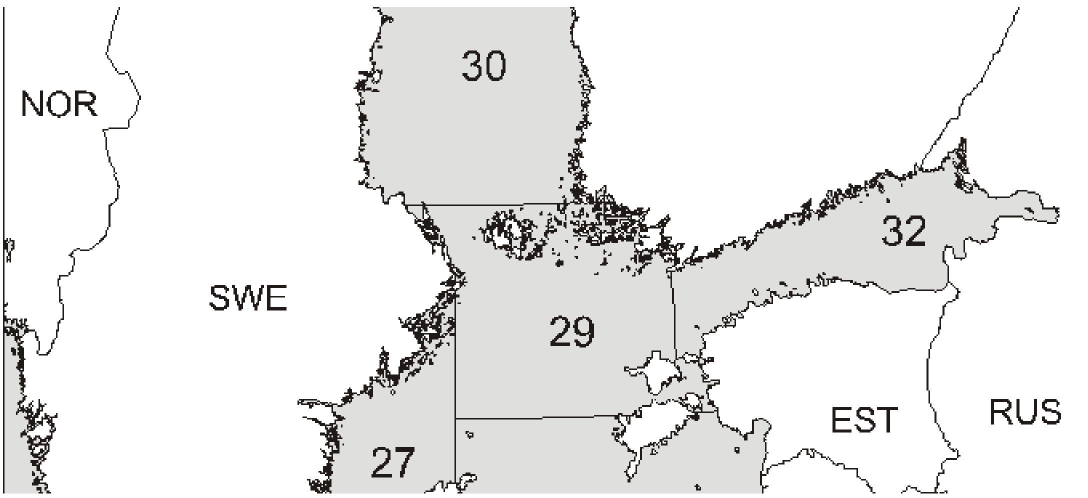


Figure 39 Regional division used in commercial marine fishery statistics [RKTL 2007a].

Fish farming

Like tourism and commercial fishing, fish farming in the Åland Sea area is strongly dependent on the sea, and it is hugely sensitive to contaminants in seawater. Along the east coast of Sweden in 2003 there were 30 fish farms with a total production of 828 tons of fish and a value of 2.17 million € [SSPA 2005] (expressed in euros of the year 2006). The most important fish species is rainbow trout.

In Åland in 2006 there were 36 fish farms with a total production of 5200 tons of food fish and a value of 8.9 million €. Also in Åland, the most important fish species was rainbow trout [RKTL 2007b].

$$Damage_{fishfarm}[€] = Coastdamage[m] \times Sensitivity_{fishfarm}[€/m] \times Damagerate[\%]/100$$

The socioeconomic sensitivity index given in the SSPA report [SSPA 2005] regarding Swedish fish farming in the Åland Sea area is 0.038 €/m. For Åland, based on the above figures the sensitivity index of fish farming is 1.45 €/m.

11.3 Implementation and maintenance costs of RCOs

The assumed implementation and maintenance of the RCOs are based on cost figures obtained from the Finnish Maritime Administration. The costs of RCO 1 include only the planning, informing and implementation of the TSS and deep-water route. RCO 2 includes in addition costs of ensuring VHF coverage on the sea area, which requires three new VHF base stations, duplex channel relay and maintenance costs of the new base stations. RCO 3 would require new software to the VTS-equipment, but the SRS activities could be managed with current VTS personnel. RCO 4 would still require four new radars and their maintenance as well as employing and training of seven new VTS operators. The costs are summarised in Table 21.

Table 21 Implementation and maintenance costs of the RCOs.

Cost breakdown	Costs (k€)	RCO 1	RCO 2	RCO 3	RCO 4
TSS implementation	20	x	x	x	x
Ensuring VHF coverage:			x	x	x
3 new base stations	300		x	x	x
Duplex channel relay	100		x	x	x
Maintenance of 3 new VHF base stations	20 per year		x	x	x
Additional VTS equipment software	100			x	x
Employing 7 new VTS operators	445 per year				x
Training of new VTS operators	14				x
4 new radars	1000				x
Maintenance of 4 new radars	50 per year				x
Total implementation costs (k€)		20	420	520	1979
Total maintenance costs per year (k€)		0	20	20	515

11.4 Cost-benefit

As the costs and benefits of the RCOs are expressed in monetary values, the cost-benefit assessment may be formulated in terms of an investment problem: Which investment option, i.e., RCO, has the largest total return, where *total return = amount received/amount invested*? As the standard deviations related to the investment options are of the same magnitude, it suffices to compare the RCOs in terms of expected total return (ETR) only (refer to mean-variance portfolio analysis in, e.g., [Luenberger 1998]). The return is calculated over an assumed lifecycle of the RCOs of 10 years. All costs and benefits during the 10 year lifecycle are discounted to their net present value (NPV) using a 5% real interest rate.

Table 22 shows the NPV of the life-cycle costs (LCC) of the respective RCO incurred over the expected lifecycle of 10 years for the RCOs (for calculation details, see Appendix 11).

Table 22 The NPV of the lifecycle cost (LCC) of the RCOs.

RCO	**LCC [k€]**
RCO 1	20
RCO 2	562.2
RCO 3	662.2
RCO 4	5640.0

The benefit, i.e. expected reduced consequence cost (ERCC) is computed as the difference between the lifecycle cost associated with accidents in the baseline situation, i.e., the cost without implementing any new risk control measures, and the lifecycle cost calculated for implemented RCO. The annual accident consequent costs for all examined scenarios are found in Appendix 10. Table 23 shows the NPV of the ERCCs for the RCOs. Because the RCOs are designed in a way that the former is always included in the latter, e.g. RCO 1 is a part of RCO 2, the increment in reduced costs when moving from one RCO to the next one can also be studied. This is shown in the rightmost column in Table 23.

Table 23 The NPV of the expected reduced consequence cost after implementation of a RCO and the increment in reduced costs when moving from one RCO to the next one.

RCO	**NPV Expected reduced consequence cost [k€]**	**Increment in NPV Expected reduced consequence cost [k€]**
RCO 1	1668.0	
RCO 2	2218.0	549.9
RCO 3	3494.8	1276.8
RCO 4	4606.9	1112.1

The expected total return of the RCOs can now be calculated as

$$ETR_{RCO\,i} = \frac{ECRR_{RCO\,i}}{LCC_{RCO\,i}}.$$

Table 24 shows the ETRs of the RCOs (for calculations, see Appendix 11). For RCOs with the ETR value larger than 1 the economic benefits are expected to exceed the costs of the risk control option implementation and operation. Based on the results shown in Table 24, RCOs 1 – 3 can be found justifiable from a commercial point of view, but RCO 4 is too expensive compared with the reduced risk. RCO 1 is highly cost-effective and RCOs 2 and 3 give also about four to five times higher benefits than the incurred implementation and operation costs.

Table 24 The expected total returns (ETR) of the RCOs.

RCO	**ETR**
RCO 1	83.40
RCO 2	3.95
RCO 3	5.28
RCO 4	0.82

Because the RCOs are building on top of each other, so that the latter always includes the former one, also the increment benefits and costs can be assessed. This gives e.g. answer to the question whether it would be beneficial to implement RCO 2 or 3 if RCO 1 had already been implemented in an earlier stage. The expected total returns when increasing the risk control from one level to another are shown in Table 25. These calculations show, in fact, that the increased risk mitigating costs when adding monitoring to the TSS (RCO 1 -> RCO 2) are about equally high compared to the reduced accident consequence costs. However, if the SRS would also be implemented (RCO 1 -> RCO 3), the reduced accident consequence costs would be greater than the risk mitigating costs. The detailed cost-benefit calculations are shown in Appendix 11.

Table 25 Expected total return when increasing the risk control from one level to another.

	ETR
RCO 1 -> RCO 2	1.01
RCO 1 -> RCO 3	2.84
RCO 1 -> RCO 4	0.52
RCO 2 -> RCO 3	12.77
RCO 2 -> RCO 4	0.47
RCO 3 -> RCO 4	0.22

12 Recommendations for decision making

The conclusions presented in this section are based on the results of the conducted FSA study only. As the consequences of collisions and groundings have been measured in monetary terms only, absolute risk criteria, such as the ALARP-principle (Melchers, 2001), have not been feasible here in judging the relative merits of the decision options. In addition, the evaluation of the acceptability of the absolute level of risk represented by the baseline option is unfeasible in this sense.

All RCOs assessed in this study were found to decrease the risk of ship-to-ship collisions and groundings, and thus to be capable to improve the safety of shipping and protection of the marine environment on the Åland Sea. The more expensive RCOs decrease the accident risk more than the less expensive.

From an economic point of view, the investment in RCO 1 can be highly recommended based on the cost-benefit analysis. The investment in RCO 3, which would decrease the accident risk further, can also be economically justified. Investing in RCO 2 does not give full value for the money, as a relatively small additional amount of money required for implementing also RCO 3 would yield a considerable improvement of safety. Therefore, if investing in RCO 2 is considered, it is recommendable to invest in RCO 3 at the same time. Based on this study, RCO 4 cannot be recommended from an economic point of view.

The reduced consequence costs because of improved safety applied in this study are calculated based on groundings and ship-to-ship collisions. In collisions, only the consequences of the struck ship are taken into account, discarding the consequences of the striking ship, thus underestimating the benefits of the RCOs.

A consistent uncertainty/sensitivity analysis has not been conducted to reveal the most critical model parameters. It is, however, the belief of the analysts that one of the main uncertainties in the present study pertains to the selection of the causation factor values for the baseline situation. A thorough validation of the causation factors would require extensive analyses of traffic and accident statistics from larger areas with a higher number of collisions and groundings, but still similar characteristics as the Åland Sea.

13 Final recommendations for decision making

This FSA study has concentrated on the direct impact of the proposed risk control options for reducing the risk of collision and grounding. It views the effect of the options from an economic point of view, based on the cost-benefit analysis.

The outcome of the FSA study clearly indicates that the implementation of the proposed traffic separation schemes and deep-water route to the Åland Sea is highly recommendable. In addition, implementation of a Ship Reporting System, similar to the one in the Gulf of Finland, is also recommendable.

Appendices

1. Skill base used in the Åland Sea FSA study
2. Results of the questionnaire sent to the municipalities in the Åland Sea area
3. Report of expert workshops 1 – 2
4. Report of expert workshop 3
5. Results of expert workshop 4
6. Calculation of causation factors for RCOs 1 – 4 based on workshop 4 results
7. Electronic chart data conversion from shapefile format to xml format
8. Traffic volumes on legs, Baseline situation
9. Traffic volumes on legs, RCO 1 – 4
10. Collision and grounding damage cost calculations
11. Cost – benefit -calculations

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