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Research Report No 111

Ilkka Perälä and Maria Tikanmäki

Study on the Current Winter Navigation Challenges Related to EEDI regulations at the Bay of Bothnia

Finnish Transport and Communications Agency
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FOREWORD

In this report no 111, the Winter Navigation Research Board presents the results of the study on current and future challenges of the winter navigation in the Baltic Sea and especially in the Bay of Bothnia. The study completed a survey for icebreaker crews and pilotage services. Furthermore, an analysis based on ice conditions, icebreaker assistance data, ship data and AIS data was made.

Based on the surveys the current winter navigation system was found working quite well. There was also concern that ice-going performance of new ships and the experience of crews on ice conditions is getting worse. On the other hand, the data-analysis indicated that there is no clear trend that new ships (fulfilling EEDI) need more assistance that older ships.

The Winter Navigation Research Board warmly thanks Mr. Ilkka Perälä and Mrs. Maria Tikanmäki for this report.

Helsinki and Norrköping

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Study on the Current Winter Navigation Challenges Related to EEDI regulations at the Bay of Bothnia

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Summary

Current and future challenges of the winter navigation in the Baltic Sea was investigated. The focus was in the Bay of Bothnia where the ice conditions are most severe. Part of the study was a survey for icebreaker crews and pilotage services. Another part of the study was analysis based on ice conditions, icebreaker assistance data, ship data and AIS data.

Based on the surveys the general opinion is that the winter navigation system is at the moment working quite well. On the other hand there was concern that ice-going performance of new ships and also that the experience of crews on ice conditions is getting worse. Other problems that were pointed out were: Towing of new ships is harder, ships are getting wider and might require two assisting icebreakers and more unpredictable weather conditions. From the survey answers a list of possible improvements to the winter navigation system was gathered.

The data analysis performed gives some insight to the issues listed above. According to FMI, winters are getting milder and severe winters are becoming rare. However, ice ridges might be more prominent in the future as ice thickness decreases. According to AIS data, amount of ships and traffic is increasing in the Baltic Sea and Bay of Bothnia. Also, amount of wider ships (Breadth > 24 m) are increasing more rapidly than ships overall. Based on analysis of ships that have visited Bay of Bothnia in winter of 2019, new ships have lower P / DWT ratio and this has been linked to decreased ice-going performance. There is clear correlation that ships with P / DWT ratio over 0.7 need less icebreaker assistance. However, these ships are small minority and there was no clear trend that new ships (fulfilling EEDI) need more assistance than old ships.

When the EEDI for the current General Cargo ships was estimated, it was noted that most of the current ships seem the fulfil the EEDI phase 3 requirements.

Espoo 21.2.2020

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Contents

1. Background and objectives

In this chapter, the background and objective for the project are viewed. The earlier research is looked to identify the relevant topics.

1.1 Introduction

Winter navigation in the Baltic Sea is based on the efficient use of assisting icebreakers and ice classed merchant vessels. The winter navigation system is mainly balanced between two main issues, merchant vessels performance to sail in ice conditions and the number and performance of assisting icebreakers. The better the ice-going performance of the merchant vessels, the less icebreaker assistance is needed (lowering the costs of the system for tax payers). However, the good ice-going performance of the merchant vessels comes at a cost for the vessel owners in way that the vessels are more expensive, heavier, need more power and can carry less cargo. In addition, it should be considered that the ice strengthened merchant vessels sail most of the year in open waters. The above mentioned factors make them less economical in open water than ships that are no ice classed. Thus, very high ice class requirements are economically inefficient, costly and in the end can actually create more emissions.

The ice-going performance of merchant vessels is controlled by the Finnish-Swedish Ice Class Rules (FSICR), which give minimum requirements for hull strengthening and engine power. The rules have four ice class categories (IA Super, IA, IB and IC), IA Super being the highest ice class. Most of the merchant vessels are in the category IA. During the winter, the authorities give restrictions based on the ice conditions. These restrict lower ice class vessels for entering certain areas where the conditions are too harsh for their ice class. In this way, only the vessels with high ice class can operate in the Baltic Sea without restrictions, forcing the vessel owners to have ice classed ships. For these ships, the icebreaker assistance is free of charge. It should also be noted that the intension of the rules is also to ensure safety when operating in ice conditions.

Finally, the question becomes, that how many and what kind of icebreakers are needed for assisting, to ensure that the winter navigation is fluent and merchant vessels are not stuck in ice for long periods. This is an ongoing discussion as old icebreakers are replaced and modernized. Naturally, more icebreakers have positive effect on the fluency of the winter navigation, but they also increase the cost of the system. In addition, during the summer the unused icebreakers will have maintenance costs. For these decisions, it is valuable to have insight on how the winter navigation in the Baltic Sea is developing during the next 10 or 20 years. There are many aspects that affect, but some of the important ones are; amount of merchant vessel traffic during winter, ice-going performance of merchant vessels, development of ice conditions in the future due to climate change and overall technical development.

A new aspect for the discussion is the increasing restrictions on emissions imposed by IMO to move towards more clean shipping industry. This is achieved with the Energy Efficiency Design Index (EEDI), which is a way to force the design of more efficient vessels. In essence, this puts pressure on lowering the engine power of the ships, using fuels with less emissions and developing more efficient hull forms. These are welcoming changes when considering the emission in the open water conditions, but they might make the ice-going performance of the vessels worse.

In this study EEDI-related issues, and other challenges in winter navigation, are looked upon based on earlier research, data analysis and surveys.

1.2 Earlier studies

The ice-going performance of merchant vessels at the Baltic Sea has been studied in earlier Winter Navigation Research Board (WNRB) projects. Here, some notes on these projects are presented.

In 2010, the VoyStat project (Berglund et al., 2010), Report No 68, studied the vessel speeds and amount of icebreaker assistances in ice conditions and compared these to the vessel technical data. There was a quite clear relation of weak engine power to longer assisting times. Also, a rough estimate of effect of ice thickness to vessel speed was established.

In 2011, the OBSERV project (Leisti et al., 2011), Report No 76, looked at the ice-going performance of certain ships that had been designed and built based on ice model tests (direct method) rather than using FSICR simple formulae. Also, the factors behind good, and poor, ice-going performance was studied. It was found that the ships designed with direct methods performed as well as other ships in ice conditions. Again, it was seen in the results that the ships with more power performed better in ice conditions than ships with less power. The quality index used in the study was the ratio of actual ship power to required min power (given in the rules at the time). However, with larger ships (DWT > 10 000 ton) the relation was not so clear anymore, and many poorly performing ships had relatively good quality index.

Another study conducted during 2011 (Eronen et al., 2011) looked at the possibilities to decrease the attained EEDI of the Finnish merchant ships (Report No 78). This was the first time the effect of Energy Efficiency Design Index (EEDI) on ice-classed ships was studied. It was identified that changes in the hull, improved propulsion, improved machinery efficiency and LNG fuel would be the main parameters to attain the EEDI in the future. It was concluded that especially bulk carriers and tankers would have most problems at fulfilling the EEDI in the future. Wide use of LNG was seen necessary. It should be noted that the correction factors for ice-classed ships have been updated after this study.

In 2014, in a study of EEDI and Finnish-Swedish Ice Class Rules (Westerberg, 2014), Report No 88, the main focus was to look at the then current ships operating at the Bay of Bothnia and the Bothian Sea and analyse their performance in ice conditions. This was then looked from the viewpoint of the future EEDI regulations. It was concluded that fulfilling EEDI regulations will decrease the performance of the winter navigation system in the Baltic Sea. It was also noted that some of the then current ships had lot of excess power when compared to minimum requirements by FSICR and that this would not be possible anymore in the future due to EEDI.

2018 a study by Aker Arctic (Heinonen, 2019) looked at the how the EEDI compliant ships performed against non-EEDI ships. In this study, a ship was categorized as EEDI compliant if it fulfilled the EEDI phase 1 requirement. It was noted that 20-30% EEDI compliant ships required icebreaker assistance while only 5-10% of non-EEDI ships needed help. In the report it was suggested that ships installed power divided by ships deadweight (P / DWT) is a good indicator of ships ice-going performance. It was noted that ships with P / DWT ratio below 0.6 kW/ton will most likely need icebreaker assistance in ice.

2. Current challenges at winter navigation - survey

To better understand the current challenges in the winter navigation, a web-based survey was carried out. People for this survey included ice breaker crews, pilotage services and ship owners.

2.1 Survey questions

There was some variations in the questions depending on the target group but most of the questions were the same. See Appendix 1 for the questions.

Part of the questions were questions were the answer had to be given on a scale from 1 to 5 and part were with open answer field. With open answer fields it is harder to compare the answers and to plot graphs, but they give possibility to rise topics that have not been identified by the researcher beforehand. In this case, there were many interesting topics that rose from these open answer fields.

2.2 Survey results and identified challenges

Below in Figure 1 - Figure 4 are the main results from the survey questions. Icebreaker crews and pilots were active in answering, but unfortunately the answers from ship owners were very few and thus they are not included here.

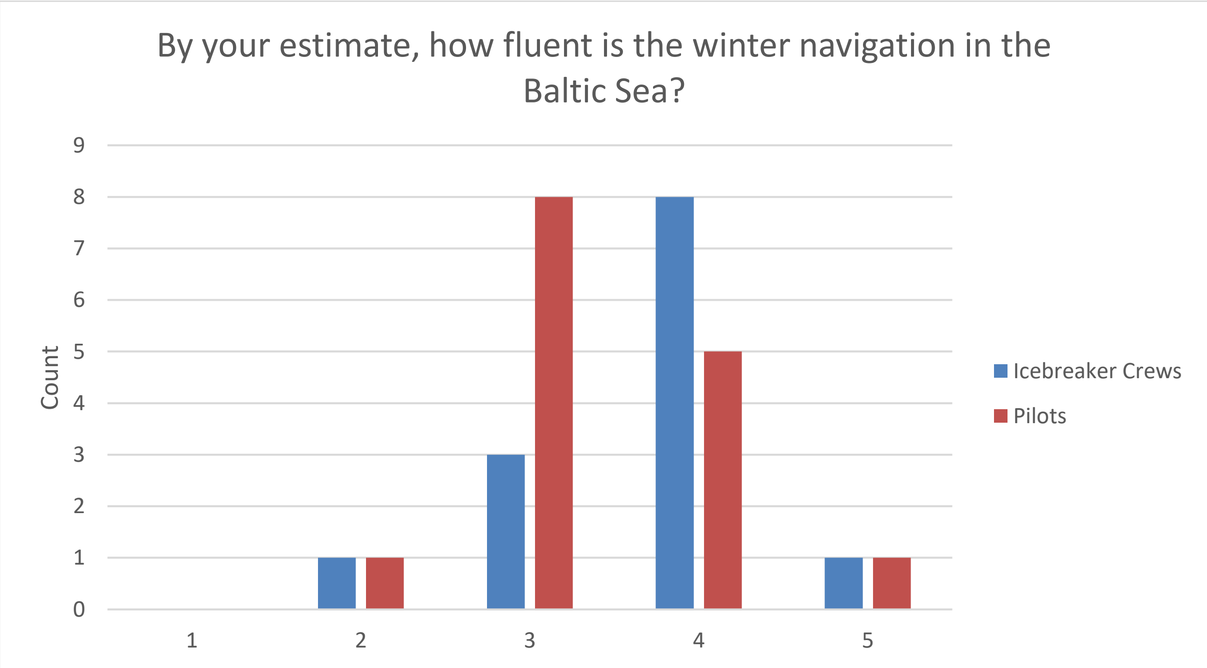

Figure 1. Results from survey to icebreaker crews and pilots. 1 = not fluent at all, 5 = very fluent.

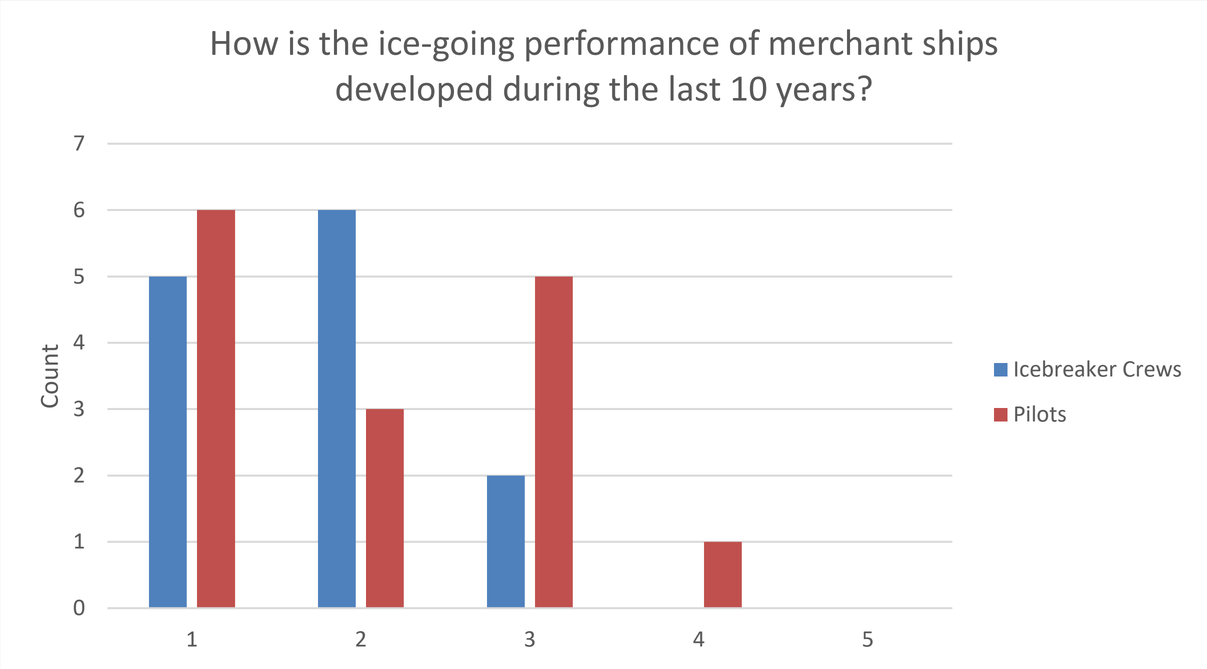

Figure 2. Results from survey to icebreaker crews and pilots. 1 = got worse, 5 = got better

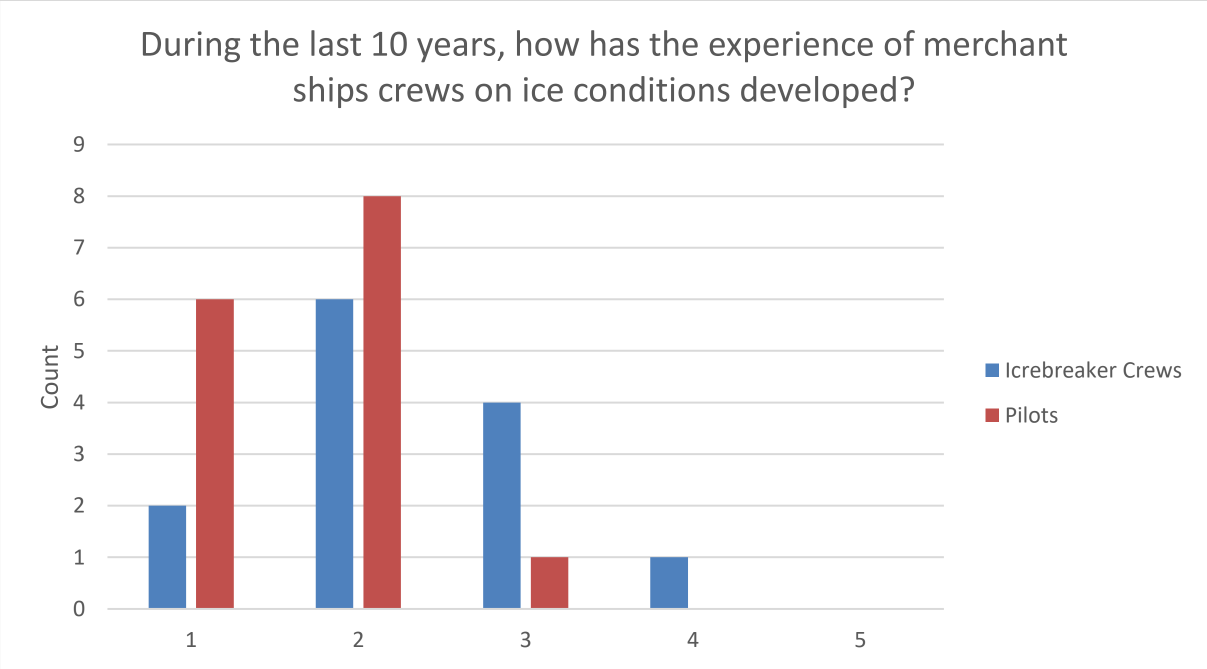

Figure 3. Results from survey to icebreaker crews and pilots. 1 = decreased, 5 = increased

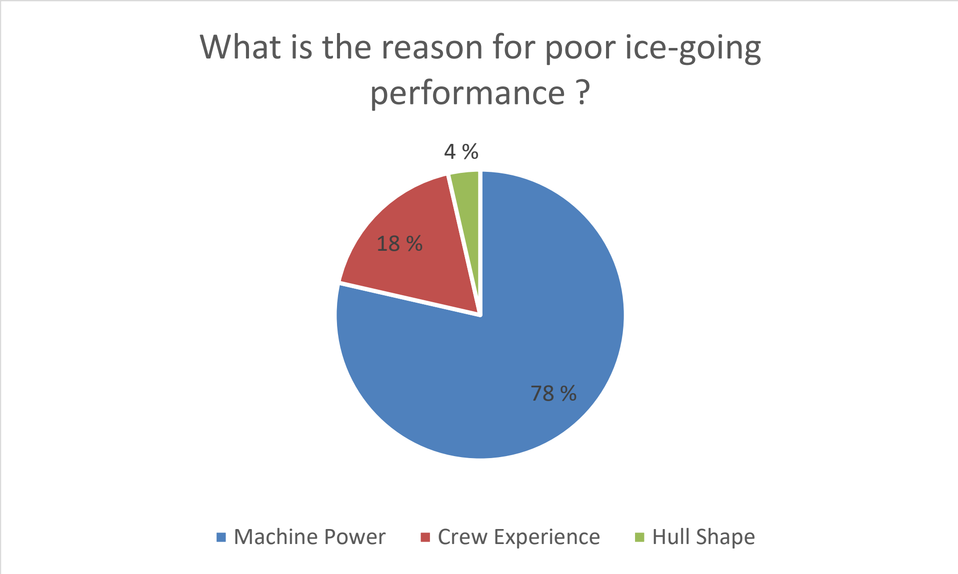

Figure 4. Results from survey to icebreaker crews and pilots.

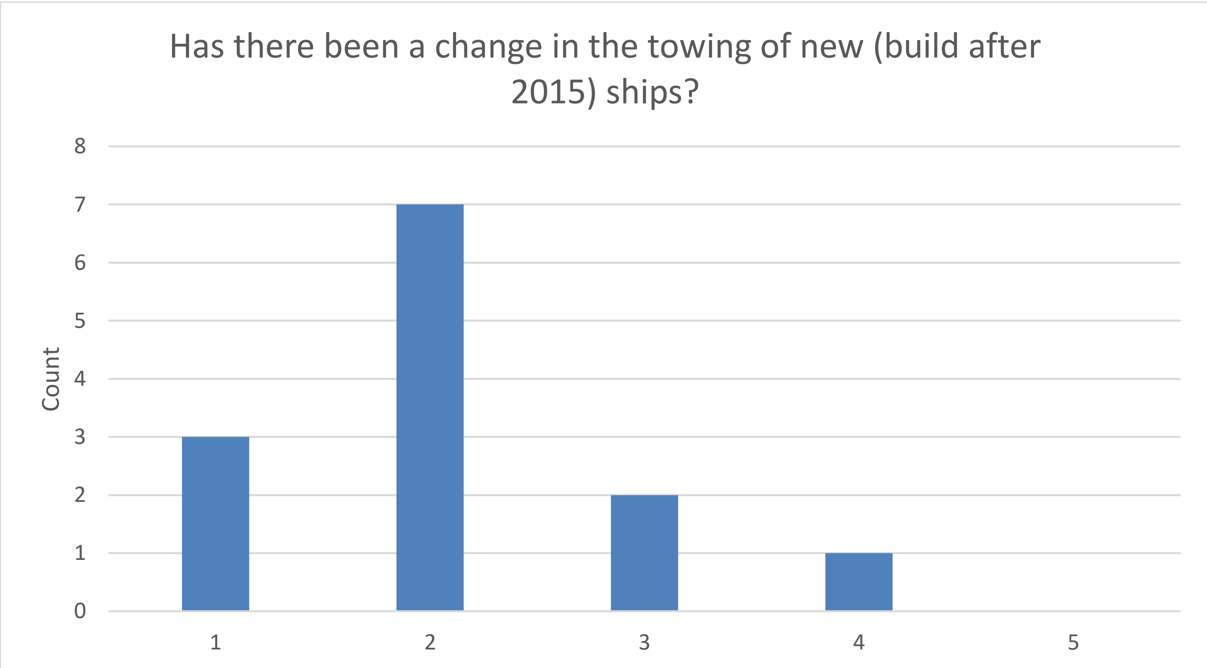

Figure 5. Results from survey to icebreaker crews. 1 = got worse, 5 = got better

In general it seems that both icebreaker crews and pilots feel that the winter navigation system is working relatively well at the moment. It should be noted that the past winters have been average or mild and these answers probably reflect situation in winters like these. However, when considering the ice-going performance and the experience of merchant ship crews in ice conditions, it seems that both icebreaker crews and pilots feel that these factors have got worse. Finally, Machine power is regarded the main reason for poor ice-going performance. There are some differences when comparing the answers from icebreaker crews and pilots but in general they give similar picture.

Next are listed the most frequent and interesting topics that icebreaker crews and pilots raised in the open answer fields:

Overall, the view was that the new ships are performing worse than the older ships. There were various reason listed for this. However, the main reason was the reduced engine power.

In addition, it was noted in many answers that in many cases the power that is available in ice conditions is less than what has been listed as installed power. For example, it was listed that in some cases cooling and mechanical problems limit the maximum power. Also, it seems that in some cases the ship crews are reluctant to use maximum power. On a positive note, the increase of new “booster” equipment, which means a shaft motor/generator, was seen as a positive thing. However, in some answers it was also noted that the boosters did not work as intended and did not give the listed extra power or the duration of their use was limited.

One of the ways to counter the challenges coming from EEDI regulations is to equip the ship with a nozzle on the propeller. This increases the thrust at low speed. However, it was noted in several answers that in bad ice conditions the nozzles are blocked by ice rubble.

Using LNG as fuel is currently one of the main ways to cut emissions. However, in the answers it was noted that use of LNG can cause problems in ice-going ships as the increase of engine power is slower with LNG fueled engines.

In regard to the question about the towing of new ships, the common answer was that the new ships are harder to tow because bow forms are not suitable for towing (x-bow etc.). These bow forms are at least partly developed to increase the open water efficiency. In addition, problem is that some of the towing equipment (for example bollards) are not located in favorable place, and this requires more risky towing arrangements. Another challenge in the towing was the lack of experience of the towed ships crew. In addition, it was noted that also icebreakers have differences in towing capabilities and are not all suited for all ships.

Regarding the number and performance of current icebreakers, it was mostly noted that in mild and average winters the current number is enough. However, in case of severe winters the number and performance would not be adequate. Judging from the answers, it would seem that pilots were more satisfied with the current number of icebreakers than icebreaker crews. In many answers the width of current icebreakers was seen as a problem, as larger (for example Panamax class, B = 32 m) ships will require two icebreakers to escort them. It was noted that the merchant ships are growing in size and in the future this will be a problem. In many answers it was proposed that the future there should be at least two different sizes of icebreakers, large (larger than current) to escort the large ships and smaller ones to operate more flexibly.

The weather conditions and forecasts of weather were seen as a challenge in the future. It was noted that the weather is changing quicker and it makes the conditions more unpredictable. Quick changes in the wind conditions can pack the ice and make conditions considerably worse very fast.

One particular fear was that there might be lack of experience in the future regarding the severe ice conditions, as this kind of conditions happen very seldom nowadays. For example, the last severe winter was 2011 and some of the people involved in the winter navigation system might have never experienced this kind of conditions.

Regarding the possibilities and challenges in the future, many interesting ideas and views were raised. Autonomous vessels (which have been discussed a lot recently and are under intense development) were not seen as suitable for winter navigation. It was noted that it will take considerably more effort to have autonomous vessels in ice conditions than in open water.

Technological development in the future was seen as a possibility and below are listed some of the ideas which were seen as increasing the efficiency of the winter navigation system.

- Better communication possibilities with the merchant ships. Especially an easy way to send them waypoints to navigate trough the ice.

- Better coordination with land based coordination center. This would help icebreakers to focus on the assistance work. Merchant ships could be helped and guided depending on the ice conditions. However, it was noted that this kind of center would need skilled people with hands on experience on winter navigation.

- Better and faster understanding of the ice conditions with help of radars and drones. Use of coastal radars was seen very efficient way to get quick understanding of the situation. This would then help to coordinate the ships trough the ice field. Drones equipped with cameras and other instruments could also patrol the ice conditions. Large fixed wing drones with long operational range could be operated from the shore. In addition, more advanced ice buoys could be developed and used onboard icebreakers.

3. Used data sources and methods

Below are listed the sources for the data used in the analysis.

3.1 Ice data

The navigational ice charts of the Finnish Meteorological Institute (FMI) where used to get an overlook of the ice conditions from the winter 2018/19. Assistance restrictions were received from Finnish Transport Infrastructure Agency (FTIA).

3.2 Icebreaker assisting and towing data

The data about the icebreaker assistance and towing was acquired from FTIA. This data is based on the IBnet system.

3.3 Ship data

Ship data was gathered from IBnet system as well as from IHS vessel database. Some missing data was gathered manually from ship owners websites.

VTT has long history in using AIS data and has access to FTIA AIS database.

4. Ice data analysis and forecast for the future

4.1 Ice conditions in the winter 2018/19 in the Bay of Bothnia

In the following, the development of the ice winter in the Bay of Bothnia is shortly summarized based on the Finnish Meteorological Institutes ice charts (2019). Here, the term drift ice zone relates to the areas in the middle of the Bay of Bothnia where ice is moving driven by mainly winds. The term fast ice zone relates to the coastal areas where ice is not moving.

In the beginning of January, only the very coastal areas of the Bay of Bothnia were frozen. The freezing continued so that in the beginning of the February, the whole Bay of Bothnia had frozen over. The ice thickness was up to 20 cm in the drift ice zone and up to 40 cm in the fast ice zone. The concentration of ice at the 1st of February was around 90% meaning that the ice cover is compact and there are not much open water to ease the winter navigation.

During February, there were day-to-day changes in ice cover. Sometimes the winds compacted ice to some areas and created open water and new ice to other areas. Nevertheless, the thickness of ice continued to increase and was up to 30 cm in the drift ice zone and up to 50 cm in the coastal areas at the end of the month.

In March, the ice cover was mostly compact and the thickness was up to 40 cm in the drift ice zone and up to 50 cm in the coastal areas. In April, there were still thick fast ice in the coastal regions but the concentration of ice in the drift ice region in the middle of the Baltic Sea was low.

Figure 6 shows the assistance restrictions issued by FTIA. It can be seen that from the beginning of February until the end of April there were ice class IA restrictions in all ports of the Bay of Bothia (Tornio, Kemi, Oulu, Raahe, Kalajoki, Kokkola, Pietarsaari).

Based on this analysis, it is believed that the ice conditions during February and March were the hardest for the winter navigation. In January and April, there has been often possibility to sail in open water so these months are not taken into account in some of the later icebreaker assistance analysis.

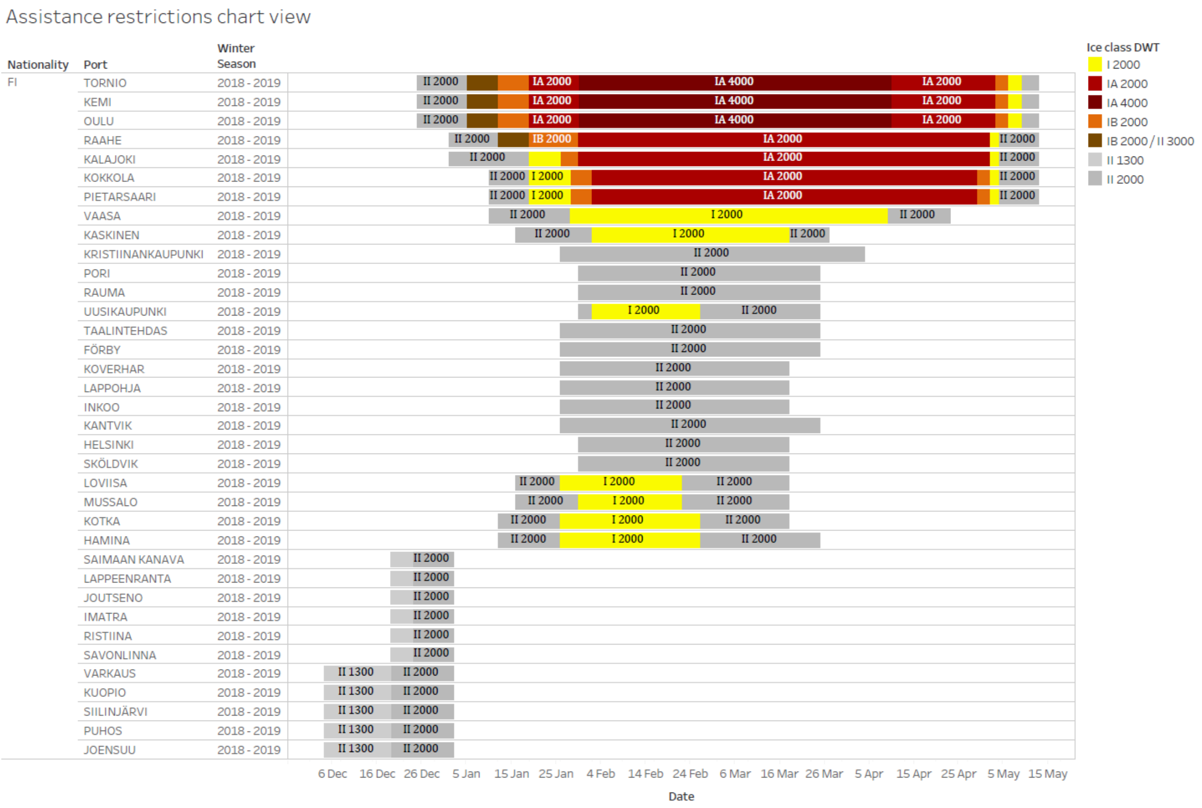

Figure 6. Winter 2018 - 2019 assistance restrictions issued by FTIA.

4.2 Future ice conditions

The ice conditions in the Baltic Sea have large interannual variability but a change towards milder winters have been noticed over the past 100 years (Haapala et al., 2015). The ice season has become shorter and the maximum ice extent (MIB) has decreased about 2% per decade.

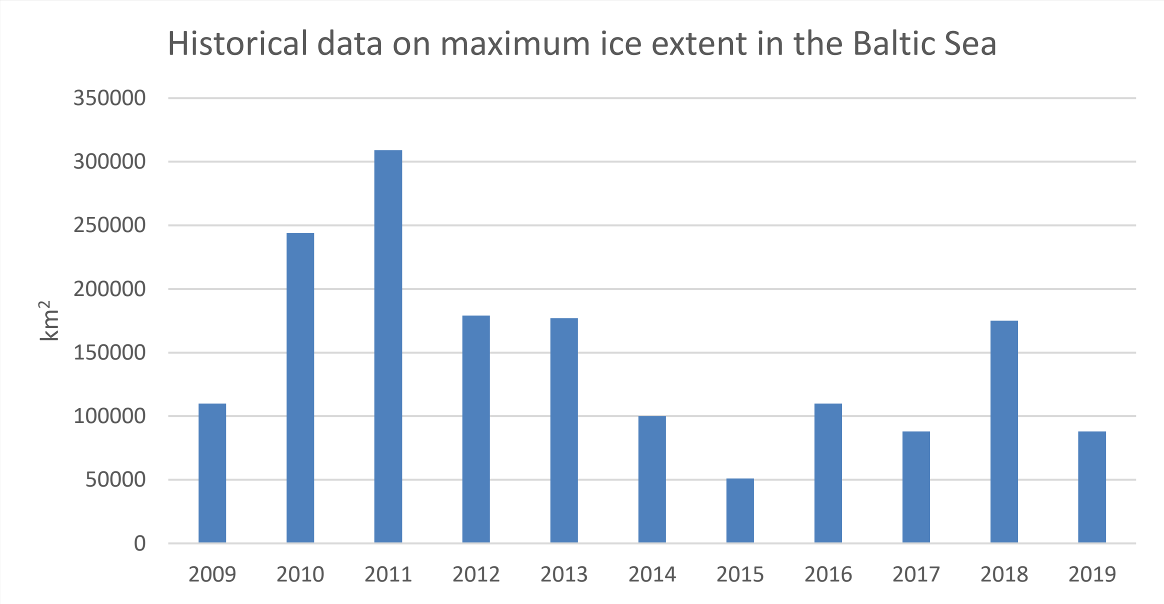

Figure 7. Maximum ice extent in the Baltic Sea (FMI)

The decreasing trend of the MIB is estimated to accelerate in the future by Luomaranta et al. (2014). They state that from 2060 the MIB is below 60 000 - 80 000 km^2. They also estimate that for cold winters the change in the maximum ice extent is even faster than for a typical winter. Already in 2041-50, they estimate that a median winter would be mild in the current classification and the 95th percentile is classified as average. It means that severe ice winters would be extremely rare in that decade. The current classification of severity of ice winters in the Baltic Sea is given in Table 1.

Table 1. The classification of the severity of ice winters in the Baltic Sea based on the maximum ice extent (Luomaranta et al., 2014).

Maximum ice extent (km^2)	**Severity of ice winter**
MIB < 49×10^3	unprecedentedly mild
49×10^3 < MIB < 115×10^3	mild
115×10^3 < MIB < 230×10^3	average
230×10^3 < MIB < 345×10^3	severe
345×10^3 < MIB	extremely severe

Luomaranta et al. (2014) also estimated that the thickness of ice will decrease significantly during the next decades. They estimated that the ice thickness in Kemi at the northern Bay of Bothnia will decrease about 25-32% on average depending on the emission scenario in the period of 2041-2050 compared to the observations from 1971-2000. For the period of 2081-2090, the decrease was be estimated to be 37-63%. Nevertheless, they state that the Baltic Sea is unlikely to become totally ice-free during this century.

Declining trends in ice season length and the maximum ice extent mean that the period and the area where icebreaker assistance is needed have been declining. The total duration of the icebreaker assistance in a winter as a function of the maximum ice extent is shown in Figure

8. The line is a second degree polynomial fit to the same data. From this data, it can be seen that the total sum of hours of icebreaker assistance declines as the maximum ice extent declines.

Even though the maximum ice extent, the length of ice season and the thickness of ice are declining, ice-going ships will continue to have a need for icebreaker assistance especially in the Bay of Bothnia. Ice is drafted and ice ridges are formed when ice thickness is around 15-20 cm. By this way, the decrease in ice thickness can lead to situations that are more severe for the winter navigation than one would expect.

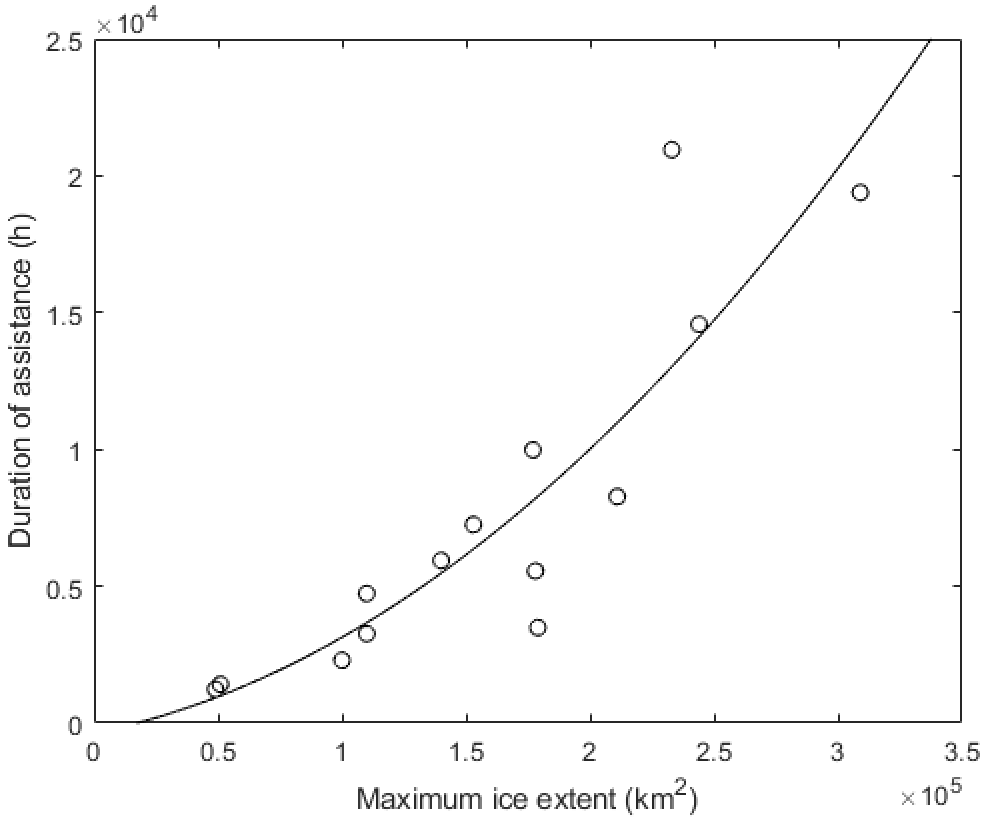

Figure 8. The circles present the total duration of icebreaker assistance as a function of the maximum ice extent of the same year from the period of 2003-2016. The line is a second degree polynomial fit to the same data..

5. EEDI and FSICR minimum power requirement

Energy Efficiency Design Index (EEDI) is plays a crucial role in how the future ships are build. This chapter gives a brief introduction to EEDI and how it can be calculated.

It should be noted that to calculate EEDI accurately for each ship, a lot of information is needed. Gathering that information for large amount of ships would be impractical. Thus, here a simplified way of calculating EEDI is used with information that can be realtively easily acquired.

After the EEDI is calculated for a ship it is compared to the reference value which is based on the DWT and ship type. The lower the EEDI the more efficient the ship is. The baseline reference (EEDI phase 0) values are based on average EEDI indexes of large amounts of ships built between 2000 - 2010. The EEDI phase 1 to 3 give more and more strict reductions which are calculated from the phase 0 value. For example in phase 1 a ship must, in general, have 10 % better (smaller) EEDI than the reference value. Phase 2 and phase 3 have a reduction requirement of 20% and 30%, respectively. Different phases are coming to effect in the future. EEDI phase 1 came to effect in 2015 and phase 2 and 3 are coming to effect in 2020 and 2022, respectively.

5.1 Simplified calculation of EEDI

In depth guide to calculate EEDI for a ship is given in IMO guidelines [IMO 2018]. The simplified equation for estimating ships EEDI in this study is:

$$EEDI = \frac{f_j * Power * C_F * SFC}{f_i * DWT * V_{ref}}$$

- f_j and f_i are correction factors for ice classed ships
  - f_j is power correction factor and is calculated according to table 1 in [IMO 2018]. It depends on DWT and ice class. The max value is 1.
  - f_i is capacity correction factor and is calculated as $f_i = f_{i(ice\ class)} \times f_{iCb}$. Term $f_{i(ice\ class)}$ is defined in table 2 in [IMO 2018]. However, to calculate f_{iCb} correctly the block coefficient of the ship should be known. This is not easily found information and thus the term f_{iCb} is taken as 1. This will add some error in the calculation.
- The ship power is calculated by taking 0,75 x P_{MCR} (MCR = maximum continuous rating). To account for auxiliary engines the terms below are added to the power:
  - Ships with main engine power > 10 000 kW: 0,025 x P_{MCR} + 250
  - Ships with main engine power < 10 000 kW: 0,05 x P_{MCR}
- C_F is the carbon correction factor
  - For LNG fueled ships: C_F = 2,75
  - Other ships are expected to use Heavy Fuel Oil (HFO): C_F = 3,114
  - Only some new ships have LNG as fuel
- SCF, specific fuel consumption. This engine specific but as this information is hard to find only two different values are used here
  - For LNG fueled ships: 162 g/kWh
  - Other ships: 190 g/kWh
  - The LNG value 162 is taken as 15% lower to the base value 190. This is according to [Gilbert et al., 2018]
- Dead Weight DWT and ship speed V_{ref} are taken from databases

Features that are NOT accounted for in the EEDI calculation in this study include:

- Power take off and Power Take In (PTO/PTI, “booster”) devices
- Innovative mechanical energy efficient technology for main and auxiliary engines

- Factors: $f_{jRORO,}$ f_j for GC ships, f_w, f_{iCSR}, f_c, f_l

The required EEDI value is calculated according to [IMO 2018] which gives out the reference lines for different ship types.

5.2 FSICR minimum power requirement

To ensure the ice-going performance of ice classed merchant ships FSICR set minimum power requirements that must be fulfilled. The requirement is based on a performance that the ships should be able to travel with a speed of 5 kn in a brash ice channel. Rules give a calculation method for minimum power requirement based on the dimensions and geometry of the ship. However, it is also possible to fulfill the requirement with ice model tests or other applicable methods.

Because it is generally thought that the EEDI regulations will lead to reduced power in the ships, it is interesting to look how well the current ships fulfill the minimum power requirements of FSICR.

Calculation of exact minimum required power for a ship requires detailed information on the hull dimensions. These are not usually available and it would be a very labourous to try to go trough all the ships. Thus, here a more general approach is used to estimate the required minimum power. In general, group of ships, with correctly calculated power requirement, are used as example and then the results from these are used to estimate the minimum power requirement for other ships. First, data for example ships is gathered from IBnet and HIS databases. Next data for couple of newer ships is gathered and the minimum power requirement calculated. Finally, a linear fit is made to match minimum power and parameter *Length x Breadth* of ship. In Figure 9. this fit is shown. Length and Breadth is chosen because these are key parameters used in the rule requirement. The fit is taken as a liner fit which takes into account only the minimum values, thus this should not over estimate the power requirement. Only ice class IA ships are considered here. The fit is used later in the analysis to estimate the ships minimum power requirement. It should be emphasized that this is a rough estimation.

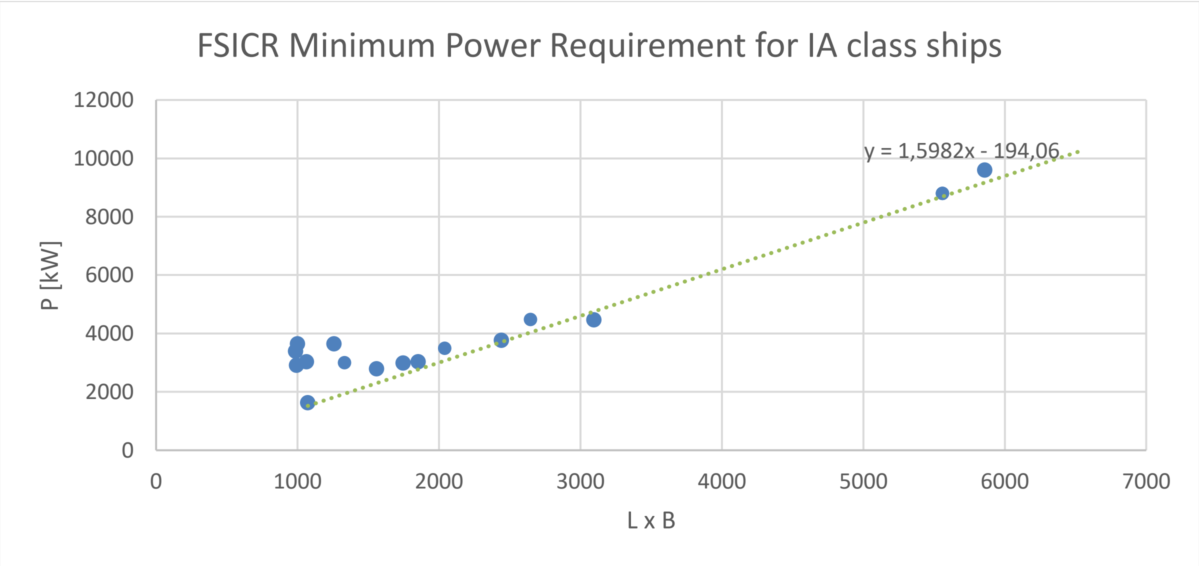

Figure 9. Simple fit to find FSICR minimum power requirement by using ships length and breadth. Points represent example ships that have minimum power requirement calculated according to rule equation.

6. Analysis and observations

If not otherwise said, all the data analyzed in this data-analysis is gathered from winter 2019 (from the beginning of January to the end of April) and focuses on the Bay of Bothnia. This limitation is because at the Bay of Bothia the ice conditions are the hardest in the Baltic Sea and thus the challenges in the winter navigation there are the greatest. Even in average and mild winters, there are IA ice class restrictions (issued by Finnish Transport Infrastructure Agency) at least in February and March. Thus, for this study it is assumed that the ice conditions at the Bay of Bothia represent harsh conditions for the merchant ships. The Bay of Bothia is here defined as the area north of 63.5 latitude. It should then be possible to see which kind of ships are experiencing problems by looking at the needed assistance. It should be noted that in this study the local ice conditions are not taken into account (local ice thickness, ice channel conditions and ridges where the ship is sailing). It is assumed that by looking at a large number of ships, the effect of these condition average out. This assumption will affect the results to some extent. Error or bias caused by this assumption is further tried to minimize by looking at the results on different periods during the winter.

One parameter that will be used in this study is called *ship hour.* This is calculated from the AIS data. The definition here is that a ship hour is counted when a ship has been in the Bay of Bothia and moved with speed of over 5 kn. Thus, if a ship has constinuously travelled, with speed of over 5kn, from 12:15 till 15:20, it would have accumulated 4 ship hours. Alternatively, if the ship would have stopped for 20 minutes between 13:10 and 13:30, it would have still accumulated 4 hours. Thus this is a rough estimate of ships traveling time. It would be possible to increase the accuracy, but this would make it increasingly heavy to analyse. It is assumed that merchant ships, when not stuck in ice, are traveling without stops, and thus the error caused by the definition here is reasonable. In a similar way a *ship day* can be counted. This is also used in some of the analysis in this report.

One of the focus in this analysis is to look at the topics and challenges that were raised in the survey and to try to find answers to those from the data. The main topic to be discussed is the the ice-going performance of the new ships.

6.1 Ship types and sizes

First, for understanding the large picture of the winter navigation in the Bay of Bothia it is good to look a the distributions of different types of ships ans sizes of ships.

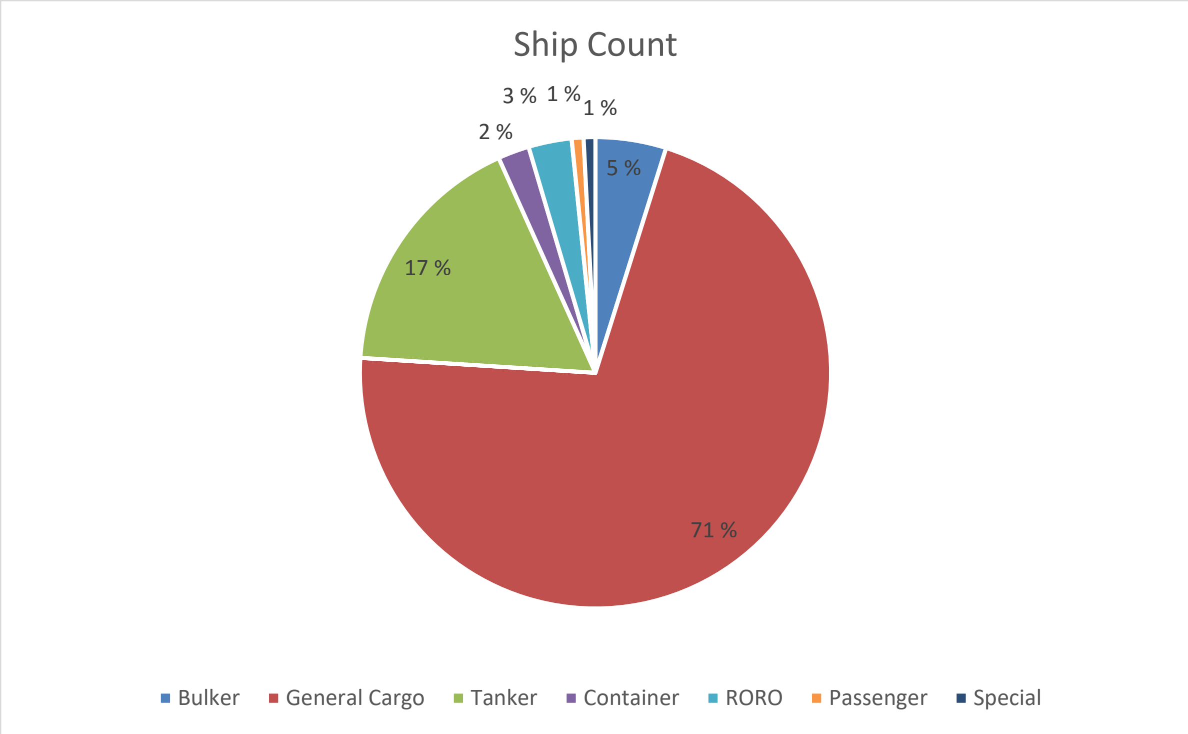

Figure 10. Ships that have visited in the Bay of Bothia in winter 2019, categorized by type, count

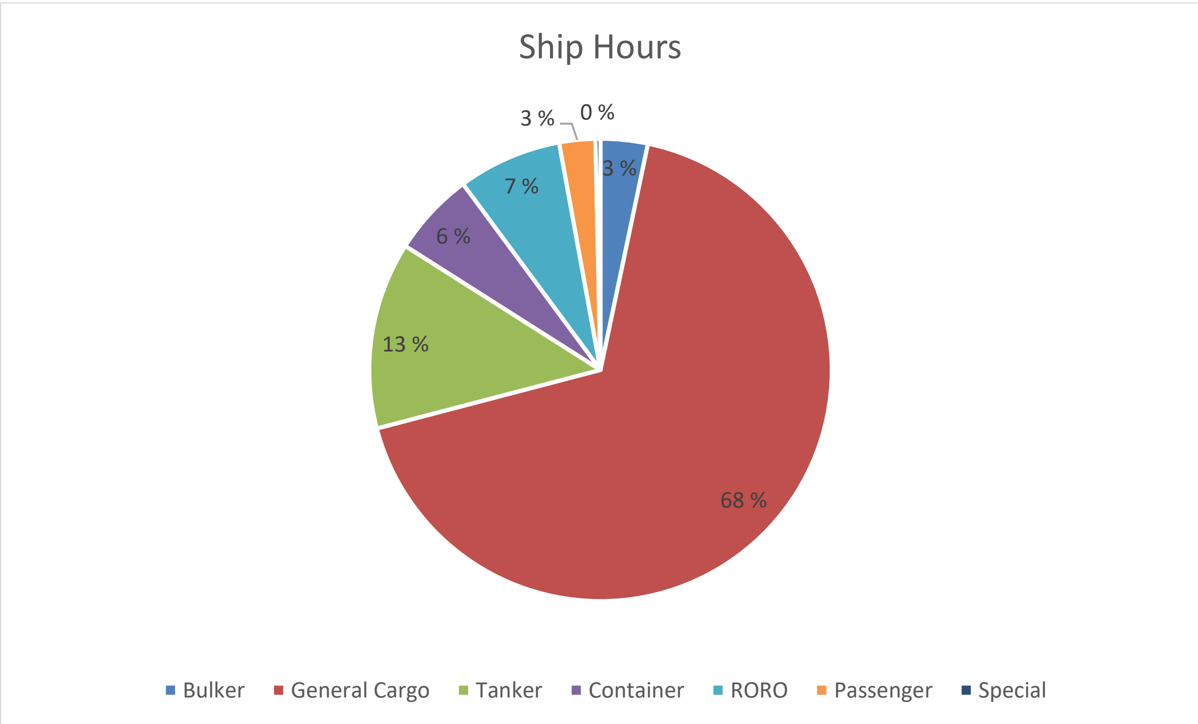

Figure 11. Ships that have visited in the Bay of Bothia in winter 2019, categorized by type, ship hours

From Figure 10 and Figure 11, it is evident that General Cargo ships and Tankers form the majority of the ships.

Next, in Figure 12, the ships are categorized by ice class. It is evident that great majority of ships have ice class IA.

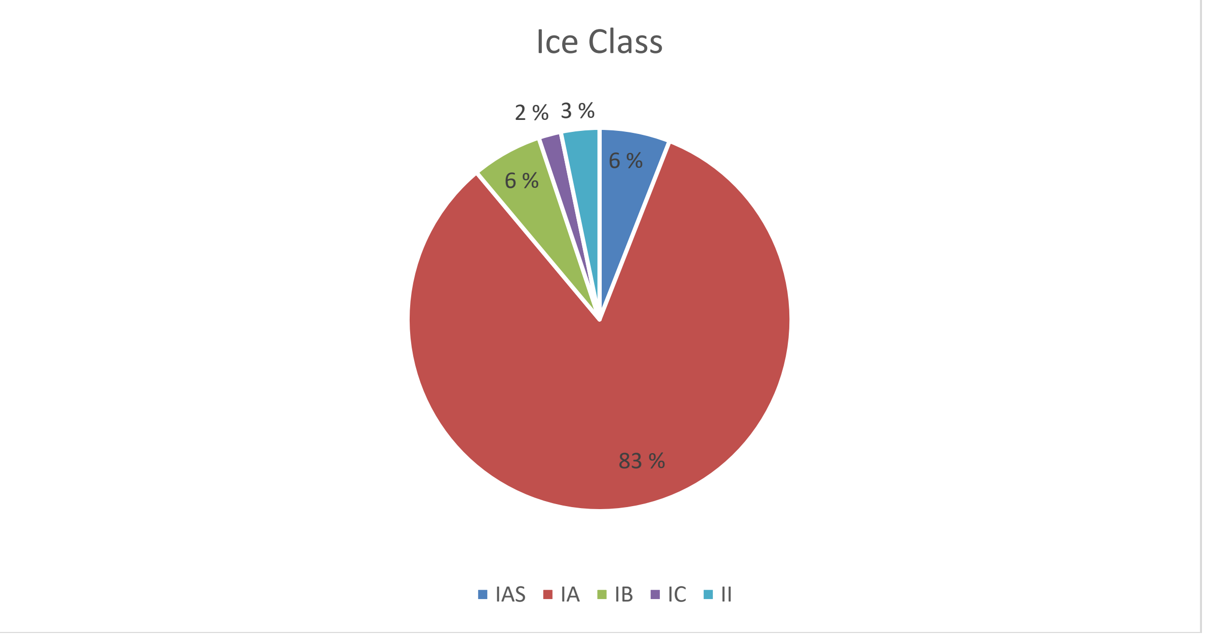

Figure 12. Ships that have visited in the Bay of Bothia in winter 2019, categorized by ice class

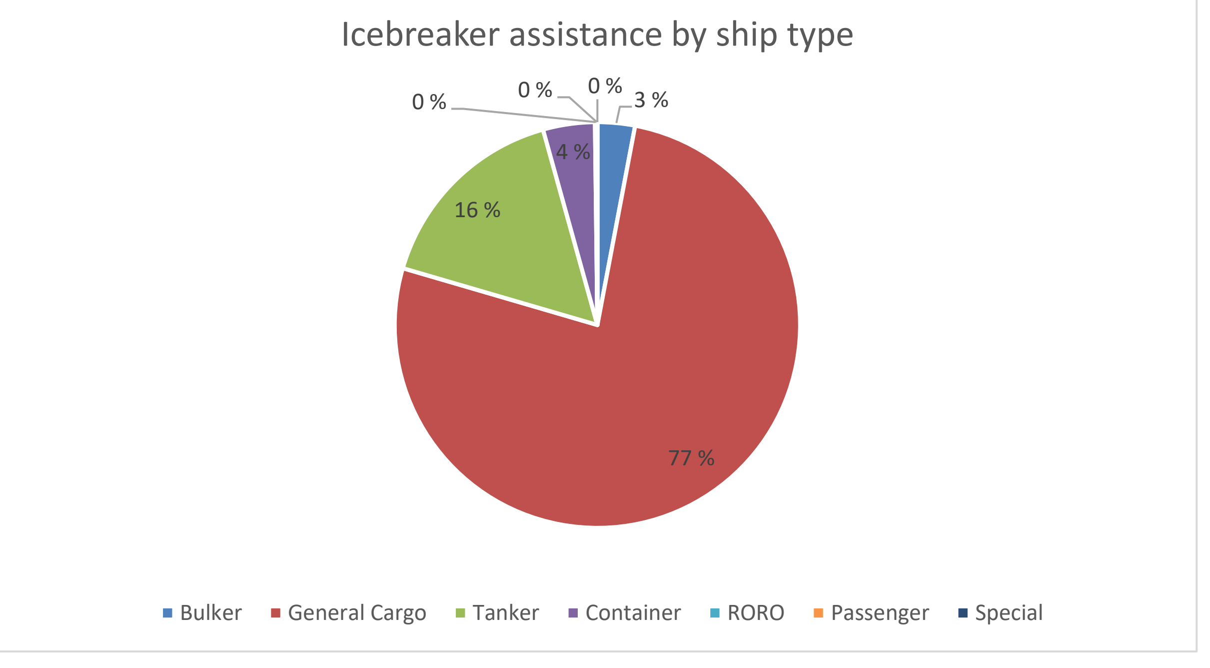

Figure 13. Ships that have visited in the Bay of Bothia in winter 2019, Icebreaker assistance

Figure 13, shows how the icebreaker assistance hours are divided by different ship types. Again, it is mostly the general cargo and tankers that need assistance. By comparing Figure 11 and Figure 13, it can be seen that the share of icebreaker assistance is larger than the share of ship hours for tankers and general cargo ships. It means that the large share of their icebreaker assistance is not only due to their amount but there are also other reasons. For example, container ships, passenger ships and roro ships usually have good power reserve because they travel faster than the other ships. Because of good power reserve these ships usually have less problems in ice condions. This can be seen also by comparing Figure 11 and Figure 13.

In Table 2. the total icebreaker assistance and towing hours and ship hours are presented for ice class IA General Cargo and Tanker ships. It can be seen that assistance and towing numbers are highest in February and March, as would be expected when considering the ice conditions. During these two months, on average, ships have needed assistance during 20 - 22 % of their travel time. In comparison, during the same period, ships have needed towing during 2 - 3 % of their travel time.

Table 2. Icebreaker assistance and towing compared to ship hours, winter 2019, General Cargo and Tanker ships, ice class IA

	January	February	March	April
Assistance [h]	340	1003	1114	326
Tow [h]	26	120	110	51
total ship hours [h]	4439	4831	5594	5094
Assistance / ship hours	0,077	0,208	0,199	0,064
Tow / ship hours	0,006	0,025	0,020	0,010

Based on the above, this study will focus on the general cargo and tanker ships. Afterall, the idea is to look at the ships that cause most of the assistances. Also, the number of ships in these categories is sufficiently large to look at the average performance in ice conditions.

As a background information for the further analysis it is good to also take a look at the age and size of ships visiting in the Bay of Bothia. Below in Figure 14 the cumulative number of ships by build year is presented. Here, also container ships and bulkers are included. It can be seen that 85% of the ships are build in the past 20 years. Thus, it coud be said that roughly in 20 years the fleet is mostly renewed. Also, it can be seen that about 8 % of the ships have been built after 2014. These are the ships that, in general, must fulfill the EEDI level 1 requirement.

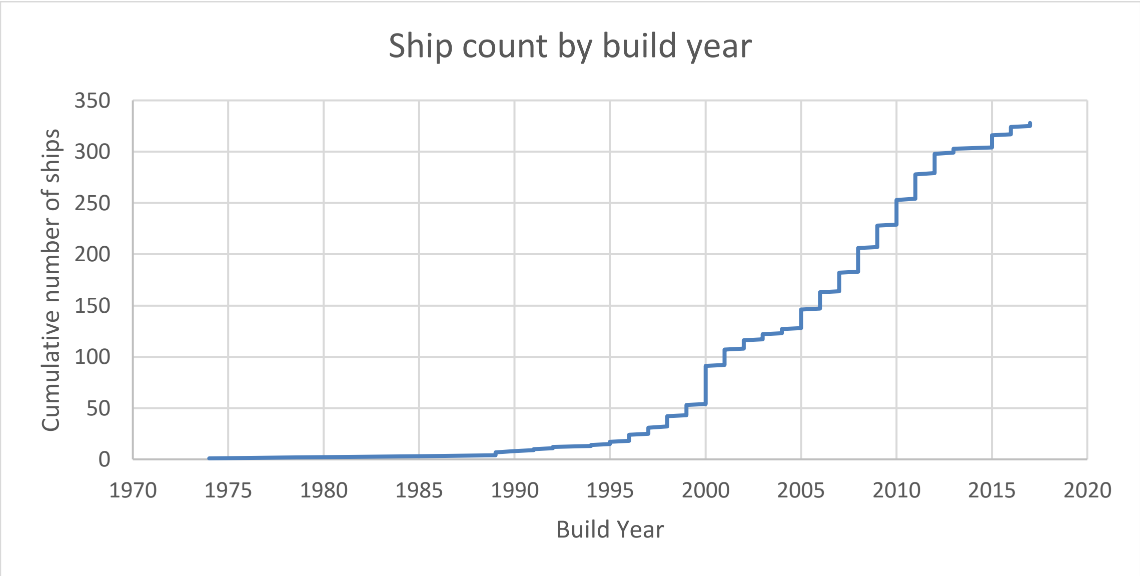

Figure 14. Ships that have visited Bay of Bothia in winter 2019 by build year

One specific issue that was raised in the survey as a problem was the increase of ships breadth in the Baltic Sea. Ships with large breadth pose a problem for the icebreakers because the channel made by the icebreaker might not be wide enough. In worst case two icebreakers are needed.

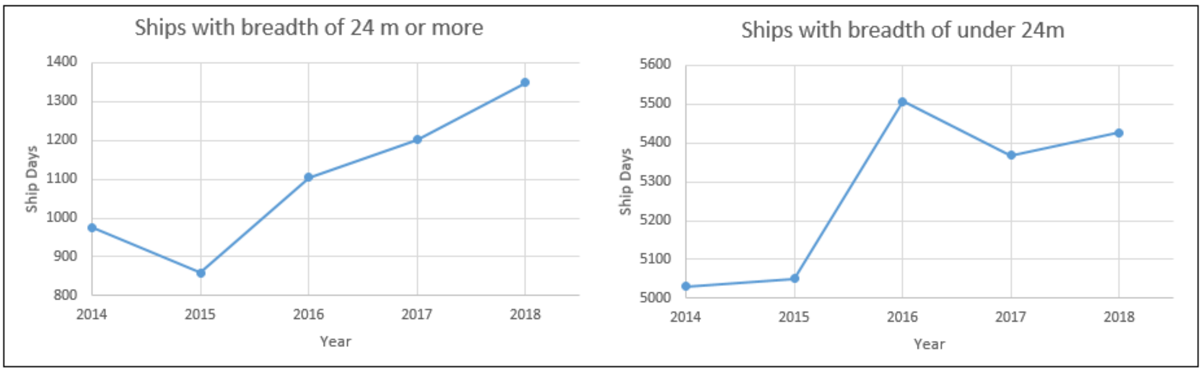

Figure 15. Development of ships breadth in the Bay of Bothnia during 2014 - 2018, All ships. Measured in ship days

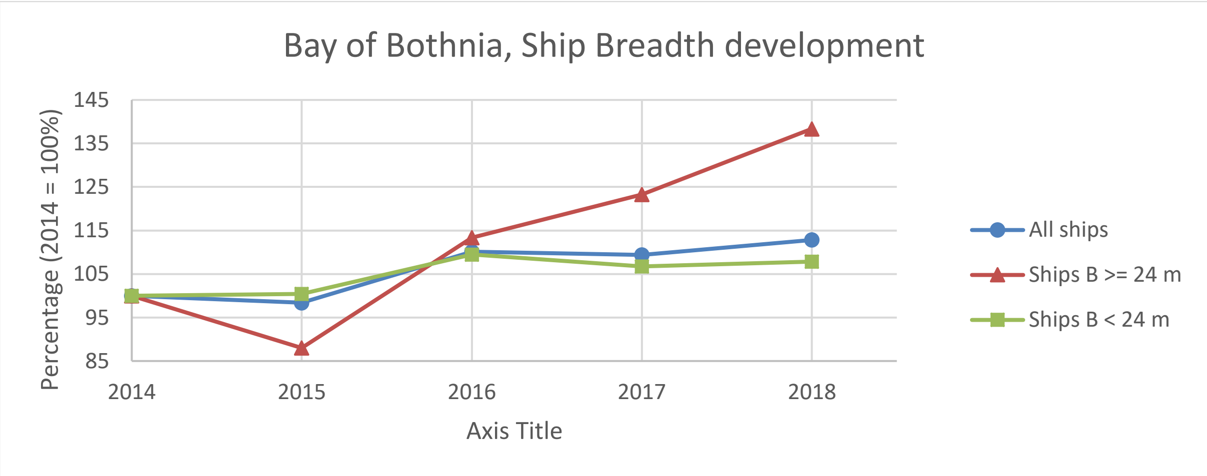

Figure 16. Development of ships breadth in the Bay of Bothnia during 2014 - 2018, All ships. Measured in percentage of ship days. 2014 = 100%

Figure 15. and Figure 16. show how the breadth has developed during 2014 - 2018. Numbers are taken from AIS data and include all ships that have spent ship days in the Bay of Bothnia. The breadth of 24 m is chosen because most of the icebreakers have this breadth. Thus, ships with larger breadth than 24 m might cause problems. Of course, this is not a strict limit and ships can probably manage even if the ice channel is slightly narrower than the breadth of the ship. In any case, the data shows that the overall ship hours have increased almost every year, but the increase is higher with ships that have breadth of 24 m or more. Thus, there seems to be evidence that the wider ships are becoming more common also in the Bay of Bothnia.

6.2 Power to deadweight ratio and need of icebreaker assistance

In earlier studies, ice-going performance of ships has been linked to parameters like Power / Beam and Power / DWT. It has been shown that both of these give a reasonable correlation to ice-going performance [Berglung et al. 2010, Heinonen 2019]. Obviously, with a larger ratio the ice-going performance is better. In this study the Power / DWT is used.

First, its interesting to look at how the P / DWT ratio has developed in the last 20 year. Below, in Figure 17, the P / DWT ratio is shown by ship ship build year. The average is calculated for 5 year periods. It can be seen that the P / DWT ratio has been in decline already for a long time. When considering the EEDI regulations, there is no visible sharp decline in the past 5 years. It would appear that even before the EEDI regulations there has been trend to lower the P / DWT ratio. The natural explanation for this would be ship owners will to lower the fuel comsumption and operating costs. However, there might be oher reasons as well.

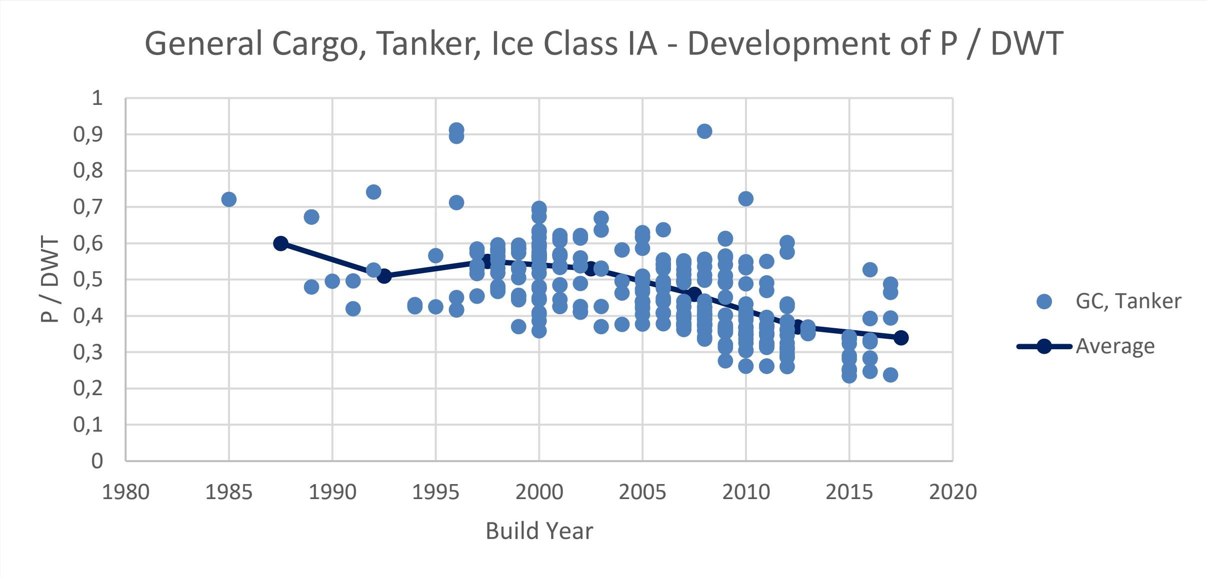

Figure 17. Ships that have visited Bay of Bothia in winter 2019, development of P / DWT ratio

Next, it is time to look at the correlation between the P / DWT ratio and icebreaker assistance. This can be done by plotting the P / DWT ratio against assistance hours / ship hours ratio. The ship hours are used here to normalize the assistance hours. In general this ratio, called here the *assistance ratio*, is a percentange of assistance hours. In this way, the ships with different ship hours can be compared.

Further, to make the dataset more realiable it is limited with two factors. Firstly, only ships that have visited the Bay of Botnia during February and March are taken into account. Secondly only ships that have 60 ship hours or more are used. The reason for using only February and March is that this way the ice conditions are more even. Most of the assitances are also recorded in February and March as seen in Table 2. Because in this study the local ice conditions are not taken into account, it might be that ships that have traveled during early January have not seen much ice. When considering the ice conditions explained in paragraph 4, it can be noted that between February and March the Bay of Bothia has been covered mostly with ice. Other problem is that even if the ice conditions are somewhat similar, it might be that the ship in question has been traveling trough an open ice channel made by other ships. When ships with considerable amount of ships hours are used (in this case over 60h), the data should be more comparable.

It should be noted that if the above mentioned limitations are too tight, there will not be enough ships to have meaningfull results. Thus, it is a compromise what criteria is used when selecting the ships for the analysis.

Finally, Figure 18. shows the results for this limited set of ships. It can be seen that there is trend that ships with very high P / DWT (over 0.7) have significantly lower assistance ratio, about 0.05 - 0.1. However, when the P / DWT is between 0.2 and 0.6 kW/ton there is no significant increase in assistance ratio. This is somewhat surprising as the ice going-performance, and thus the need for icebreaker assistance, should grow with low P / DWT. The average assistance ratio for these ships is between 0.2 - 0.25, meaning that in average the ships have needed assistance during 20 - 25 % of their travel time. Also highlighted in the graph are the ships build between 2015 and 2019. These are ships that should, in general, fulfill at least the EEDI 1 requirement. It is noticeable that these ships have low P / DWT ratio, but on the other hand they do not stand out with higher assistance ratio than the older ships.

The average assistance ratio of ships with P / DWT less than 0.7 is similar to what was seen in the Table 2 for the all general cargo and tanker ships in February and March.

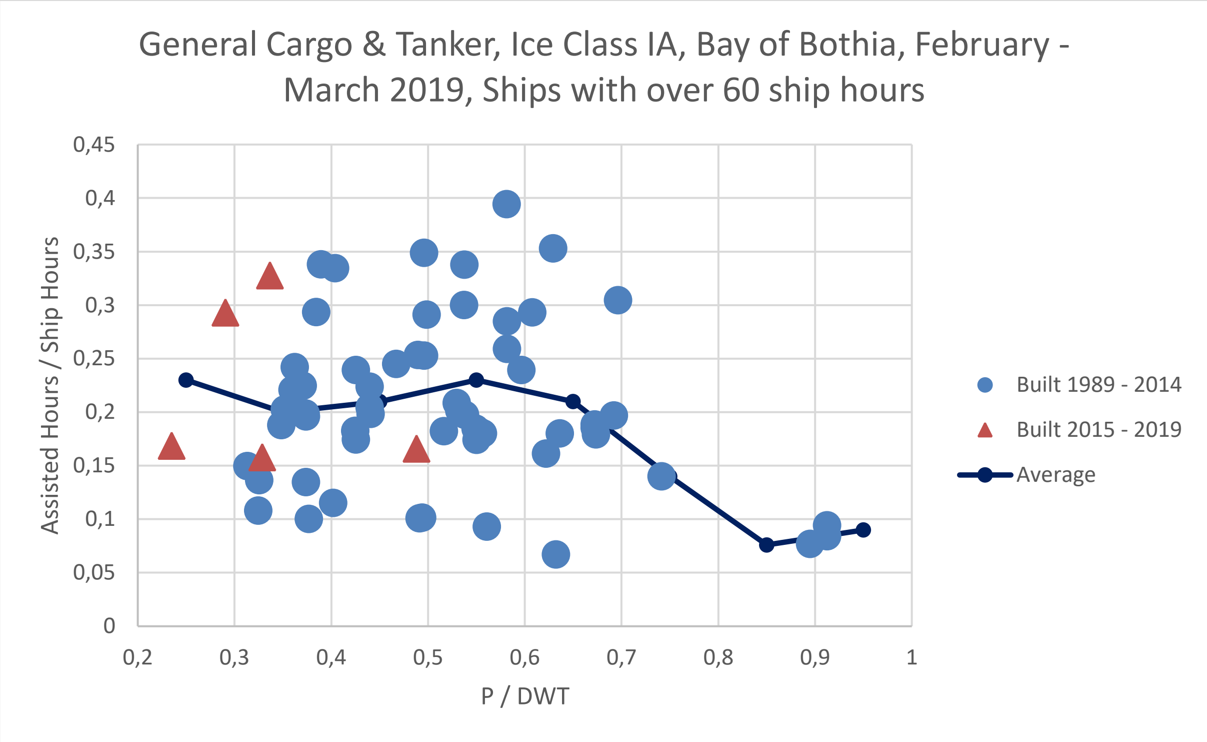

Figure 18. Reduced set of ships that have visited Bay of Bothia in winter 2019, assistance ratio and P / DWT ratio.

Already, in Figure 18. there are only 14 of 63 ships that have P / DWT ratio over 0.6. By looking at Figure 17, which shows IA class General Cargo and Tanker ships in Bay of Bothnia, it is evident that ships with P / DWT over 0.6 represent a small minority in the Bay of Bothia. They represent currently about 10% of general cargo and tanker ships.

6.3 FSICR minimum power requirements and assistance

At this point it is interesting to look at the FSICR minimum power requirements for the current ships. In this analysis the simplified fit shown in paragraph 5.2 is used.

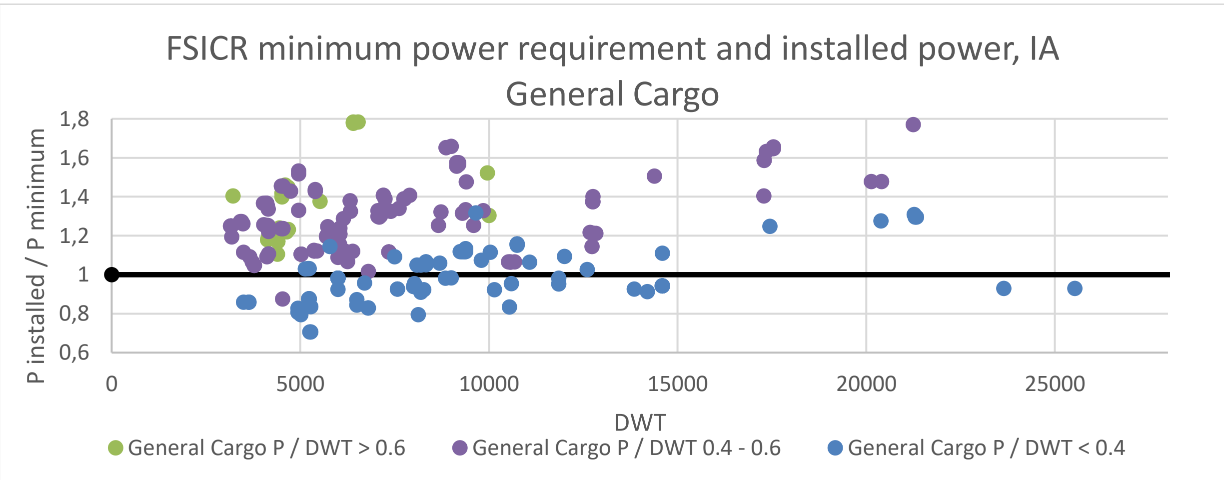

Figure 19. General Cargo ships that have visited Bay of Bothia in winter 2019, estimated FSICR minimum power requirement and installed power

From Figure 19. it seems that there are quite many ships in General Cargo that do not fulfill the FSICR minimum power requirement. Mostly these seem to be ships that have power / DWT ratio under 0.4 and DWT under 15 000. As noted earlier this is not accurate calculation of the minimum required power, but an estimate. However, it seems that at least with smaller ships there is no excess power reserve (when compared to minimum requirement) when the P / DWT ratio is under 0.4. The reason for smaller than required power is not completely clear and should be investigated more. One reason is that in these cases the minimum power might have been defined with model ice tests. Another reason might be that the thrust in bollard pull conditions is defined more accurately with tests. For example, a ship with a ducted propeller can have more thrust than what the rule equation gives. Also, the old ships (built before 2002) have lower minimum power requirement.

6.4 General Cargo ships, current EEDI categories

In Figure 20. the EEDI is estimated for General Cargo ships and the difference to EEDI phase 0 reference value is shown. The value here represents how much lower, in percentage, the ships EEDI is when compared to EEDI phase 0. Lines in the graph represent the different phases of EEDI regulation for General Cargo ships. For example EEDI 1 requirement states that the ship must have 10% reduction in EEDI when compared to reference value (phase 0). It is maybe surprising that almost all of the current General Cargo ships seem to fulfill even the EEDI phase 3 regulation. It can be noted that most of the ships are so small that they benefit from the linear reduction of the requirement, which takes place for ships under 15 000 DWT.

As the EEDI phase 3 is coming into effect in 2022 it would appear that for the next couple of years similar ships than nowadays can be built. However, tightening of regulations in the future will put pressure on the current type of ships, especially if regulations are tightened for smaller vessels too.

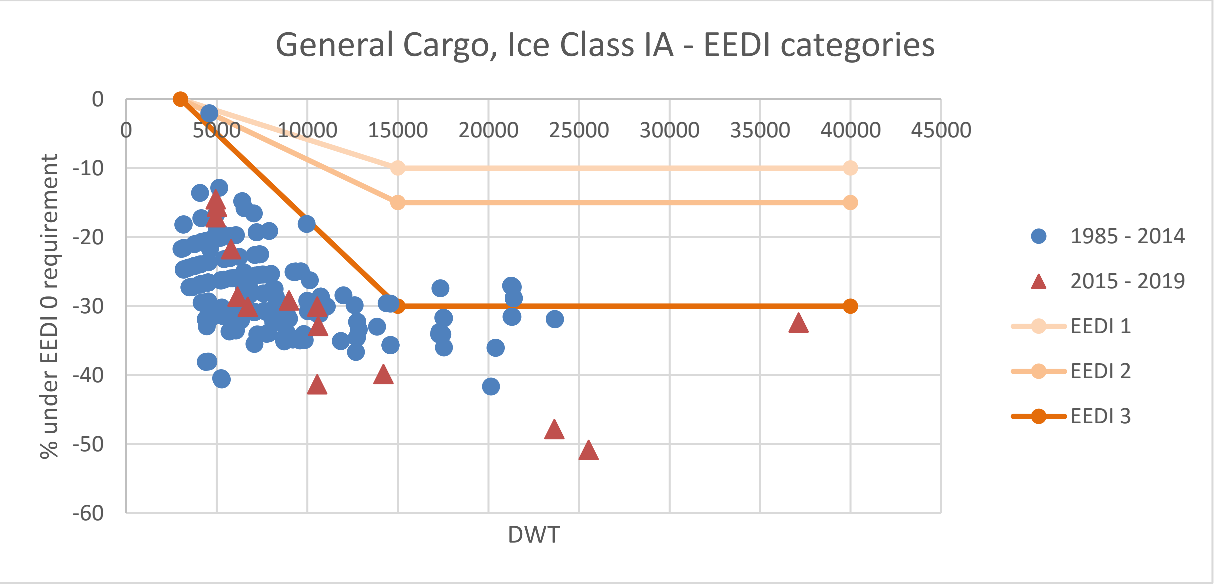

Figure 20. General cargo ships that have visited Bay of Bothia in winter 2019. Y-axis represents the difference of calculated EEDI and phase 0 EEDI in percentage. Lines show the EEDI phase 1 - 3 requirements. New ships built after 2014 are highlighted.

7. Discussion and future trends

Based on the survey answers it seems that currently, with winters like 2019, the winter navigation system is working quite well. However, there are several key issues that can change this, these are listed below:

- Ice conditions
  - Directly effects the need for icebreaker assistance
  - Large variations in severity of winters
  - Due to climate change ice coverage is shrinking and severe winters are becoming rare
- Amount of traffic in the Baltic Sea
  - Traffic is increasing
  - More ships means more assistance
- Ice-going performance of merchant ships
  - Lower performance increases the need for icebreaker assistance
  - Power levels, or more accurately P / DWT ratio, of ships are decreasing which in general decreases the ice-going performance
  - EEDI regulations put pressure on lowering the P / DWT ratio
- Size of merchant ships
  - Wider ships might need two icebreakers for assistance
  - Wider ships are more frequent also in the Bay of Bothnia
- Advances in ice condition monitoring and coordination
  - Can reduce the need for assistance and increase the efficiency of the winter navigation system

It is hard to estimate exactly how severe ice winters will be in the future in the Bay of Bothnia. As discussed in chapter 4, the overall trend is that ice coverage is shrinking and winters are getting milder. When looking at the next 20 years severe winters are still possible, even if rare. Based on the survey answers and observations of ice-going performance of ships, severe winter will probably cause delays in assisting which will effects the delivery times of goods and cargo. Other aspect of the future ice conditions is that with smaller ice thickness the ice ridges might be formed more easily due to winds and currents. These ice ridges can cause difficult ice conditions locally, and in this case it would be very valuable to have more accurate picture of the prevailing ice conditions. These difficult conditions might then be possible to avoid if they are very local.

According to HELCOM statistics traffic in the Baltic Sea has been increasing. Also in Figure 16 it can be seen that in Bay of Bothnia the calculated ship hours have increased about 13 % in 4 years. Amount of traffic in the Bay of Bothia is largely dependent on economics of Finland and Sweden. For example pulb and paper industry, steel production and mining industry are major contributors to the amount of ships needed to transport the products. Thus, to estimate the amount of traffic in the Bay of Bothnia in the future would require also estimate of how the industry will develop in the North of Finland and Sweden.

One of the main goals of this study was to look at the ice-going performace of the merchant ships and how it might change in the future. A reasonable indicator, found in earlier research, for ice-going performance is the ratio of power to deadweight (P / DWT). With lower P / DWT ratio the ship has, in general, worse ice-going performance. In chapter 6 it was found that the P / DWT ratio of ships has been decreasing for at least 20 years. Ships considered are only the ships that have visited Bay of Bothina in winter of 2019. It should be noted that larger ships have, in general, lower P / DWT ratio so when new ships are built larger this can partly explain the trend. When compared to the assistance ratio, there was a clear trend that ships with high P / DWT (above 0.7) have less need for assistance. However, there are only a few of these ships and on average the new ships have a P / DWT around 0.4. This ratio is probably still decreasing in the future as more efficient ships being designed due to EEDI regulation. However, it would appear that most of the current ships, with ice class corrections, fulfil the EEDI phase 3 regulation. At the moment there is no schedule nor regulations for EEDI beyond phase 3, but it is believed that phase 4 will come in the future. It is safe to say that at least until 2025 it is sufficient for the new ships to fulfil EEDI 3 regulations. Thus, for the next 5 years there should be no significant pressure to achieve lower EEDI (and consequently lower P / DWT) than what the current ships have.

Beyond the ratio P / DWT there are other smaller details that are affected by EEDI and modern ship design in general. Firstly, it should be remembered that most of the ships operating in the Baltic Sea are designed for open water conditions. Ice conditions are encountered only during 3 - 4 months each year. For example many modern ships have vertical bows to increase performance in open water conditions. This sort of bow can perform badly in ice conditions. Although, a recent study [Heinonen, 2019] showed that vertical bows can actually work quite well in ice channels but less so in level ice.

There is evidence that the ships are getting larger and the breadth of ships is increasing. This was mentioned many times in the survey and the trend can be seen in Figure 16. Even a small number of large ships with breadth larger than what one icebreaker can handle, can cause problems to the winter navigation system. In worst scenario these ships require two assisting icebreakers. If these ships become frequent in areas where ice conditions are worst and assisting is needed, then this should be taken into account when planning the future icebreaker fleet. Larger icebreakers are of course an obvious solution. A very large icebreaker with breadth of 100m was studied by Johansson [2004].

In many answers of the survey it was mentioned that the better knowledge of the ice conditions, increased coordination of icebreakers as well as directing merchant ships to avoid difficult ice conditions can make the winter navigation system more efficient. This should be considered from the point of view that these means can be cost effective if, for example, compared to operating of one extra icebreaker. Use of radars, drones, satellite imagery and other innovative concepts could give a more detailed picture of the ice conditions. With a detailed and up to date information the merchant ships could be directed to the route which would avoid the difficult ice conditions. This sort of directing would need an easy to use communications system to relay the information to the ships. Lastly, a land based coordination center for Finnish and Swedish icebreakers operated by experienced crew could make the icebreaker coordination more efficient.

8. Conclusion and future work

Current and future challenges of the winter navigation in the Baltic Sea was investigated. The focus was in the Bay of Bothnia where the ice conditions are most severe. Part of the study was a survey for icebreaker crews and pilotage services. Another part of the study was analysis based on ice conditions, icebreaker assistance data, ship data and AIS data.

Based on the surveys the general opinion is that the winter navigation system is at the moment working quite well. When asked if the winter navigation was fluent, the average answer was 3.5 when the scale was from 1 (not fluent at all) to 5 (very fluent). On the other hand there was concern that ice-going performance of new ships and also the experience of crews on ice conditions is getting worse. Other problems that were pointed out were:

- Towing of new ships was considered harder
- Ships are getting wider and might need two icebreakers for assistance
- More unpredictable weather conditions

Improvements that were suggested in the survey were:

- Better ways to instruct merchant ships on best route trough ice field
- New ways to gather information on ice conditions (drones, radars)
- New wider icebreakers

The data analysis performed gives some insight to the issues listed above.

- Winters are getting milder and severe winters are becoming rare
- Ice ridges might be more prominent in the future as ice thickness decreases
- Amount of ships and traffic is increasing in the Baltic Sea
- Wider ships (Breadth > 24 m) are increasing more rapidly than ships overall
- New ships have lower P / DWT ratio which has been linked to decreased ice-going performance
- There was clear correlation that ships with P / DWT ratio over 0.7 need less icebreaker assistance
- There was no clear trend that new ships need more assistance than old ships

When the EEDI for the current General Cargo ships was estimated, it was noted that most of the current ships seem the fulfil the EEDI phase 3 requirements.

The data analysis performed in this report has shortcomings which could be improved in future analysis. For example when analysing the ice-going performance the local ice conditions are not taken into account here. With more sophisticated analysis this could be possible. To have a more definitive answer on the question that how many and which kind of icebreakers are needed in the future, a more thorough analysis should be performed. In the past, simulation tools to simulate the whole winter navigation system have been developed. These could be updated/improved with the information on weather conditions, traffic predictions and predictions on which kind of ships are sailing in the Baltic Sea in the future. In the meantime the winter navigation system should be further developed from the point of view of better coordination, better communication and better ice condition monitoring.

Acknowledgements

The author wants to thank Finnish Transport Safety Agency (Traficom) and Finnish Transport Infrastructure Agency (FTIA) for the data kindly provided for this analysis.

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APPENDIX 1 – Survey Questions

1. By your estimate, how fluent is the winter navigation in the Baltic Sea?

(1 = not fluent at all, 5 = very fluent)

2. How is the need for icebreaker assistance in the Bay of Bothia changed in the last 10 years?

(1 = increased, 5 = decreased)

3. How is the ice-going performance of assisted ships developed during the last 10 years?

(1 = got worse, 5 = got better)

4. During the last 10 years, how has the experience of assisted merchant ships crews on ice conditions developed?

(1 = decreased, 5 = increased)

5. Which of the following affects most to merchant ships poor performance in ice conditions?

(1 = Engine power, 2 = Hull shape, 3 = Crew experience)

6. Has there been a change in the towing of new (build after 2015) ships?

(1 = Harder to tow, 5 = Easier to tow)

7. What are the reasons (in towing) behind the change?

(open answer field)

8. By your estimate, is there a difference in ice-going performance of new (build after 2015) EEDI compatible ships when compared to older ships?

(open answer field)

9. Do you feel that the current number and performance of ice breakers in the Baltic is suitable for fluent winter navigation?

(open answer field)

10. In you opinion, how the winter navigation services and ice breaker fleet should be developed in the future?

(open answer field)

11. What kind of challenges and possibilities do you see in the winter navigation in the future (Considering change in climate, change in weather forecasts, change in technology and increase of intelligent and autonomous systems)?

(open answer field)

12. Other comments considering winter navigations?

(open answer field)