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Marine traffic, accidents, and underreporting in the Baltic Sea

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Key words: Marine traffic, risk, accidents, underreporting, ship collisions, groundings

Abstract

This paper presents an overview of ship traffic volume and accidents in the Baltic Sea with a special focus on the Gulf of Finland. The most common accidents are groundings and collisions, usually reported to be caused by human error. The annual number of Baltic Sea accidents reported to HELCOM varied from 34–54 for collisions and 30–60 for groundings. The number of yearly port calls varied from 468–505 thousand with a peak in 2008. Exact port call data could not be found for all ports and hence had to be estimated. The number of line crossingings in HELCOM AIS data was found to be a good, rough surrogate measure for the total number of port calls and could be used if more precise port call data was not available. By analyzing two separate accident databases, an estimate for accident underreporting was calculated. Different statistical methods yielded an underreporting rate in the range of 40–50%. Lastly, the true number of accidents was estimated, based on the estimated underreporting percentage for the Baltic Sea. Based on these results, the true number of true accidents should be first estimated if accident statistics are used in building or validating maritime risk models. When using such models or accidents statistics in decision-making, the underlying uncertainty in the accident statistics should be taken into account as the underreporting frequency estimates are only approximations of the real number of accidents.

Introduction

The Baltic Sea is among the most heavily trafficked Sea areas in the world with a 15% share of the world's maritime transportation (HELCOM, 2009). It is relatively shallow, has narrow shipping routes, and its northern areas have yearly ice cover (HELCOM, 2009). Parts of the Baltic Sea, such as the Gulf of Finland (GoF), have treacherous, rocky archipelagos and the Baltic Sea has been classified as a particularly sensitive Sea area (PSSA) by the IMO, due to the shallowness and the slow water circulation (Uggla, 2007). Also due to these factors, of special concern is tanker traffic that is on the rise despite a brief drop during the financial crisis that began in 2008 (HELCOM, 2012). So far, there have been no catastrophic oil spills of the order of magnitude of Exxon Valdez or the Prestige; the largest spill was from the collision between Baltic Carrier and Tern in 2001, resulting in 2700 tons of oil spilled (HELCOM, 2013). Due to the risk, measures to reduce the possibility and mitigate the consequences of oil and chemical spills have been studied and taken (Lecklin, Ryömä & Kuikka, 2011; Hänninen et al., 2011; Häkkinen & Posti, 2013; Häkkinen et al., 2013; Montewka, Weckström & Kujala, 2013; Hänninen et al., 2014; Sormunen et al., 2015)

In order to either prevent tanker spills or mitigate their consequences, knowledge of the most commonly occurring ship accidents is important. This information can be used in risk mitigation frameworks such as the Formal Safety Assessment

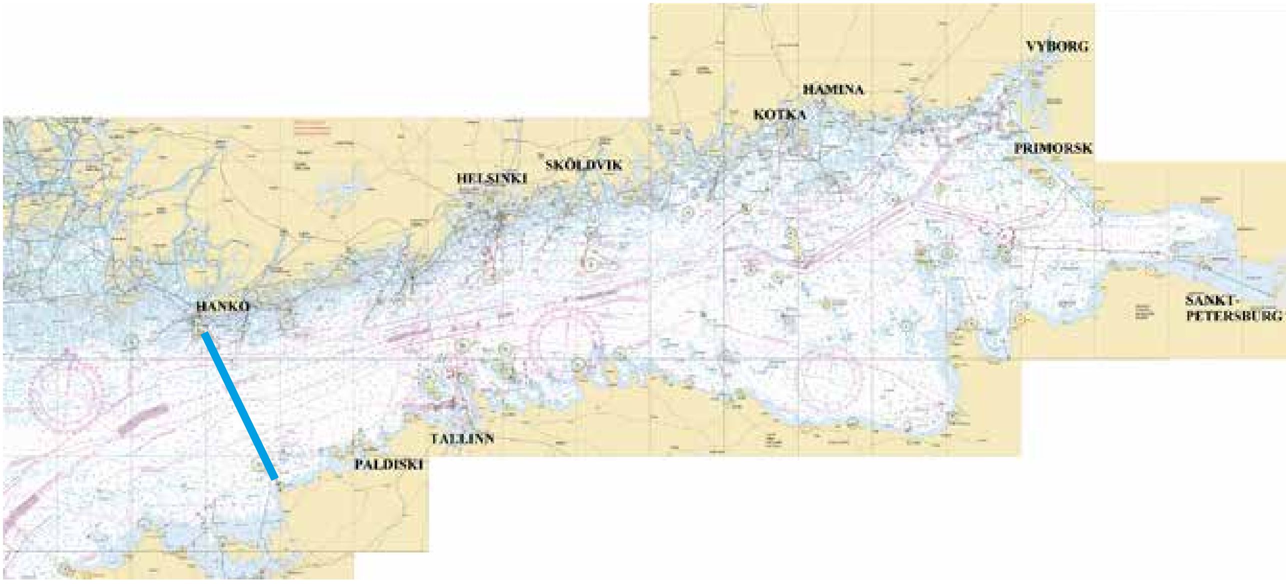


Figure 1. The Gulf of Finland with the HELCOM crossing line illustrated. Map © Finnish Transport Agency license No. 1803/1024/2010

(IMO, 2002). Furthermore, reliable accident statistics facilitate risk analysis and risk model validation. Comprehensive accident reports and statistics allow the circumstances of accidents to be thoroughly analyzed and others to learn lessons from them. All in all, good reporting improves knowledge for undertaking risk mitigation measures, which is why the reliability of accident reporting is paramount. If the reporting is sloppy, accident statistics become unreliable and risk analysis and validation based on these reports more uncertain. This might lead to a biased or underestimated view on the risk, which in turn can lead to taking inappropriate or suboptimal countermeasures; see Mazaheri et al. (Mazaheri, Montewka & Kujala, 2014). This particularly affects risk-analysis methods that use accident statistics as input or as a validation tool; for further discussion see e.g. Sormunen et al. (Sormunen et al., 2015). Therefore, it is important to evaluate to what extent accidents are underreported.

Hassel et al. (Hassel, Asbjørnslett & Hole, 2011) estimated that the authorities of Denmark, Norway, and Sweden as flag states receive reports of anywhere between 13–94% of the estimated true number of maritime accidents. Accident data of tankers registered in Norway covering 1997–2008 was used by Psorros, Skjong, and Eide (Psorros, Skjong & Eide, 2010); the reporting performance had an upper bound of 41% for Norwegian Maritime Directorate and 30% for Lloyd's Register FairPlay. Thomas and Skong (Thomas & Skong, 2009) estimate that only around 30% of fire and explosion accidents in tankers are reported in the same databases. For the Gulf of Finland, Hänninen et al. (Hänninen et al., 2013) and Ladan and Hänninen (Ladan & Hänninen, 2012) have previously shown that the accidents reported to the previously used Finnish accident database DAMA and the data collected by HELCOM do not always match; some accidents are missing from either database. However, based on our literature review, an exact underreporting rate assessment has not yet been conducted in the GoF.

Aim and structure

This paper presents an overview of accidents and ship traffic volume in the Baltic Sea with a special focus on the Gulf of Finland. Such information is useful in a variety of functions, e.g., quantitative risk analysis and risk mitigation. Multiple sources and ways of measuring ship traffic are compared. The underlying trends and the accident-to-ship traffic ratio were analyzed along with the ship type distribution and the causes of accidents. The trustworthiness of the data was analyzed by estimating the accident-underreporting percentage in order to know what the "true" number of accidents was along with the 95% confidence interval for this estimate.

The last comprehensive analysis of accident statistics in the GoF was based on data from 1997–1999 and 2001–2006 (Kujala et al., 2009). This paper begins by presenting an updated view by augmenting and comparing those previous accident statistics with more recent cases from the HELCOM accident database. For a summary of the HELCOM data, see HELCOM (HELCOM, 2013). In addition, available

HELCOM ship-traffic data was compared to actual Baltic Sea port visits. The port visit data was collected from multiple sources and estimates were used for the harbors that had no available port call data. Traffic volume data was compared to the number of accidents to calculate the relative accident frequency and to investigate whether any kind of trend exists. As not all accidents are reported, the accident underreporting percentage was evaluated in order to estimate the true number of accidents.

The rest of the paper is organized as follows. Section *Ship traffic and accidents* presents the ship traffic and accident statistics from the Baltic Sea. Section *Underreporting and reliability of accident statistics* describes the data and methods applied in the accident underreporting assessment and shows the results. Finally, the conclusions are drawn in Section *Underreporting Conclusions*.

Ship traffic and accidents

Baltic Sea line crossings

Automatic Identification System (AIS) data provide a means for establishing ship traffic composition in a certain area, which in this case is the Baltic Sea. AIS data is automatically sent by the ships themselves via VHF-channel to a land station, including static data about ship particulars and dynamic data about ship movements. AIS transponder is mandatory in international traffic for all ships over 300 GT (500 GT for non-international cargo ships) and passenger ships irrespective of size (HELCOM, 2008). Based on AIS data, HELCOM has counted the ships entering and exiting the Baltic Sea and GoF since 2006. The total annual number of ships that have crossed the GoF Line (see Figure 1) are presented in Table 1. In addition, harshness of the ice winter for the Baltic Sea in general is shown (Itämeriportaali, 2013). Table 2 shows the numbers for all crossings in the Baltic Sea.

From the tables it can be seen how ship-traffic volume grew from 2006–2008 and then dropped by over 19% from 2008–2009. However, since 2010, the traffic volume has been increasing again. The composition of ships entering and exiting has remained roughly the same: 10–14% passenger vessels, around 50% cargo vessels, and somewhere around 17–18% tankers, with the exception of the 2008 year. It should be noted that in the Baltic Sea, information from one ship can be counted several times during one voyage as the figures represent the number of total crossings of ships through several crossing lines in the Baltic Sea; see HELCOM (HELCOM, 2012) for the line definitions.

HELCOM registers vessel crossings into and out of the Gulf of Finland (see line in Figure 1). This means that it does not measure the actual number of port visits as there is some traffic that is inside GoF only (e.g. Helsinki-Tallinn) as well as GoF into lake Saimaa or Ladoga. Note that each ship coming from the outside of GoF crosses the line twice: once on the way in, once on the way out.

GoF port visits

To calculate the true number of port visits, data from Baltic Port List (BPL, 2014), Eurostat

Table 1. The Gulf of Finland traffic volumes expressed as the number of ships entering and exiting the GoF for different ship types (HELCOM 2012) and ice winter classification from Itämeriportaali (Itämeriportaali, 2013)

Year	Total	Annual change	Passenger	Cargo	Tanker	Other	Unknown	Ice
2011	43 112	18.0%	5613	23 338	7416	3956	2789	Harsh
2010	36 541	–4.8%	4607	19 398	6574	3346	2483	Average
2009	38 396	–19.3%	5349	19 749	7031	4115	2152	Mild
2008	47 584	19.4%	4585	23 237	6053	10 986	2723	Very mild
2007	39 866	7.6%	5507	23 323	6796	3472	767	Mild
2006	37 036	–	5098	23 107	6850	1981		Average

Table 2. Annual Baltic Sea HELCOM AIS – line crossings for different ship types

Year	Baltic crosssings total	Change	Passenger	Cargo	Tanker	Other	Unknown
2011	411 440	13.3%	39 943	210 030	65 605	69 353	26 509
2010	363 293	–7.8%	32 779	184 166	60 200	58 684	26 383
2009	394 026	–13.2%	42 408	200 595	69 021	73 906	8096
2008	453 698	9.6%	49 355	210 021	61 996	122 029	10 297
2007	413 774	9.9%	43 215	237 342	69 335	56 981	6901
2006	376 671		42 731	226 855	67 458	39 627	

(Eurostat, 2014), Finnish Transport Agency (Finnish Transport Agency, 2014), administration of the port of Saint Petersburg (Administration of Port of Saint Petersburg, 2014), and ESIMO (ESIMO, 2014) were used. Complete data for the Finnish GoF could be found in 3 different sources: Eurostat, BPL, and Finnish Transport Agency. These numbers are compared in Figure 2.

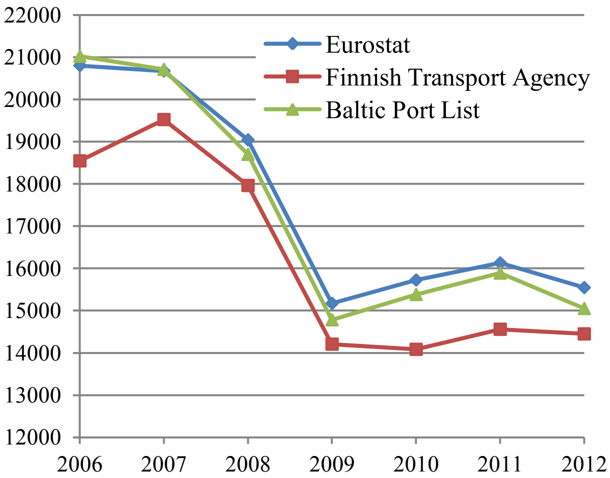


Figure 2. Port visits in Finnish GoF harbors according to different sources

The Finnish port visits show a downward trend even before the financial crisis of 2008 had started. The numbers between the databases are similar but there is a noticeable deviation of up to 13% in 2006 when comparing the Finnish Transport Agency data to BPL and Eurostat. This might have to do with this specific Finnish Transport Agency data not including domestic traffic. For further calculations, BPL data is used.

There was no single, complete source for Russian port visits for all of years 2006–2011, so data from several sources were combined: Port of Saint Petersburg (Administration of Port of Saint Petersburg, 2014), ESIMO (ESIMO, 2014), and BPL (BPL, 2014) (Table 3).

For Estonia, complete data for all the years could be found in Baltic Port List. The combined GoF port-visit numbers are presented in Table 4. As can be seen in Figure 3, the numbers are of the same order of magnitude: the GoF port visits are approximately the same as the GoF line crossings in the HELCOM data. The numbers from BPL deviate noticeably only in 2011, unless the Russian visit estimates are also included, in which case the difference becomes smaller; see Figure 3.

Table 4. GoF line crossings compared to GoF port visits using BPL data only and BPL data combined with estimates for the missing Russian entries

Year	HELCOM GoF crossings	GoF port visits, BPL + Russian estimates	GoF port visits, BPL only
2011	43 112	38 120	24 931
2010	36 541	36 297	33 428
2009	38 396	36 831	34 929
2008	47 584	46 733	45 390
2007	39 866	50 025	49 496
2006	37 036	49 221	48 132

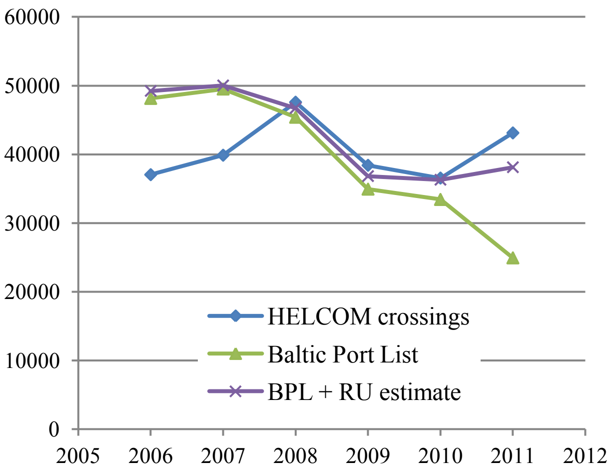


Figure 3. Comparison of port visits to GoF line crossings using BPL data only and BPL data combined with other sources and estimates for Russian port entries

Table 3. Number of Russian GoF port ship entries

Best estimate	2006	2007	2008	2009	2010	2011	2012
St. Petersburg	**12 593**	*14 633*	*14 789*	*10 786*	*9309*	9861	**9750**
Primorsk	**658**	*740*	*804*	*935*	*970*	1109	**1350**
Ust-Luga	213	**555**	*451*	*517*	*705*	1222	**2290**
Vyborg	422	**250**	438	*302*	*547*	431	**470**
Vysotsk	453	529	551	611	565	566	643
Sum:	**14 340**	**16 707**	**17 033**	**13 151**	**12 096**	**13 189**	**14 503**

In Table 3, numbers in **bold** come from BPL, numbers in *italics* from pasp.ru (Administration of Port of Saint Petersburg, 2014). The underlined values are estimates based on cargo volume and the estimated volume per ship; see appendix 1. In case of several sources, the one with the highest number of port visits was chosen.

Table 5. Port calls by country, Baltic harbors only

Baltic port calls	2006	2007	2008	2009	2010	2011	2012
Denmark	276 848	278 107	295 172	287 311	272 119	271 567	267 336
Estonia	10 265	9 689	8 470	6 733	25 370	28 483	28 474
Latvia	2 343	2 750	2 455	2 202	6 872	6 998	7 404
Lithuania	2 747	2 886	2 934	2 503	4 526	4 766	4 857
Poland	14 454	16208	17 059	15 315	16 316	15 748	15 300
Finland	40 583	40 431	39 721	33 331	34 682	34 784	33 818
Germany	36 213	37 287	35 930	33 776	33 046	32 726	32 639
Sweden	75 686	83 806	84 339	74 551	61 546	65 385	62 423
Russia	16 180	18 603	19 098	14 447	13 757	14 662	15 797
Total	475 319	489 767	505 178	470 169	468 234	475 119	468 048

Total Baltic Sea port visits

To obtain the total number of Baltic Sea port visits, data from Eurostat was combined with the best estimates for Russian port visits, this time including an estimate for Kaliningrad as well; see Appendix 1 and Table 5.

Comparing the total port visits to Baltic Sea line crossings, we again see that they roughly correspond to each other; see Figure 4. However, the number of port visits shows less change from year to year than the crossings. The HELCOM line crossings are 11–29% less than the actual port visits, depending on the year. Within the selected time period, there have been recorded 20% fewer crossings than actual port visits on average.

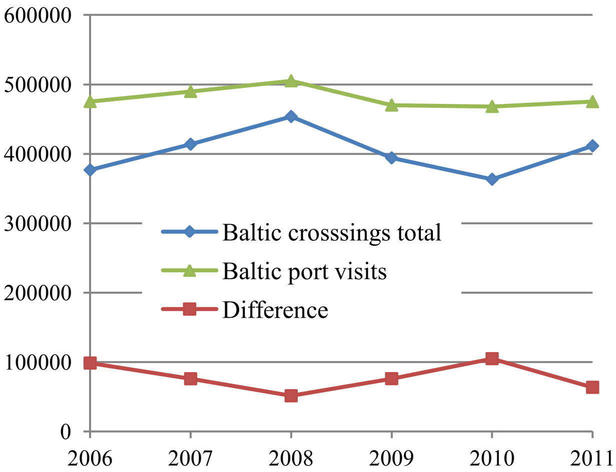


Figure 4. HELCOM line crossings compared to the best estimate for Baltic Sea port visits

In conclusion, all traffic volume metrics for the GoF, as well as for the Baltic Sea, show a dip in volume after 2008 as well as a slight recovery towards 2011. The number of line crossings corresponds roughly to the actual number of port visits and can, as such, be a rough estimate for the number of port visits in case of a lack of more detailed information (and vice versa).

Accident types

All accidents involving a ship of over 400 GT or a tanker of over 150 GT are required to be reported to HELCOM by the Baltic Sea flag states. For the Gulf of Finland, according to the HELCOM and DAMA accident databases, groundings were the most common type of accident from 1997–1999 and 2001–June 2006 with 100 reported cases (Kujala et al., 2009); see Table 6 and Figure 5. Groundings were followed by collisions with 73 reported cases, 42 of them being ship-ship collisions. According to more recent HELCOM data, as can be seen in Table 7 and Figure 8, groundings have still been the most common accident type in the GoF but also in the whole Baltic Sea (36% of all Baltic Sea cases), followed by collisions with objects or vessels (34% of all cases). The HELCOM data include 24 groundings and 21 collisions in the GoF for 2007–2011. If the numbers in Tables 3 and 4 are combined, the GoF had had approximately 9 groundings and 7 collisions with objects or vessels within one year, on average.

The reporting format changed in 2004, thus 2002–2003 data is not directly comparable to data from 2004 onwards. HELCOM (HELCOM, 2008)

Table 6. Accidents in the GoF according to DAMA – and HELCOM databases 1997–1999 and 2001–June 2006 (Kujala et al., 2009)

Accident type	Cases
Grounding	100
Ship-ship collisions	42
Coll. w. an object	33
Fire, explosion	10
Machinery damage	9
Sinkings	3
Capsizings, severe tiltings	2
Storm damage	2
Leak	1
Environmental damage	0
Other / unkown	8
Total cases:	210

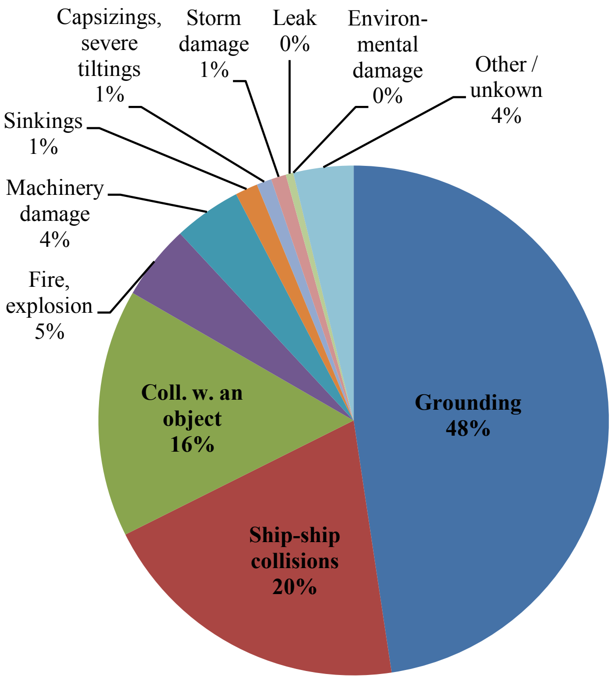


Figure 5. Accidents in the GoF according to DAMA and HELCOM databases 1997–1999 and 2001–June 2006 (Kujala et al., 2009)

Table 7. Accidents in the Gulf of Finland and the whole Baltic Sea between July 2006 and the end of 2011 according to HELCOM data

Accident type	GoF	Baltic Sea
Grounding	24	236
Ship-ship collisions	13	92
Coll. w. an object or unreported target	8	122
Fire	7	54
Machinery damage	4	41
Pollution	20	34
Technical failure	0	1
Other	6	69
Total cases:	82	653

themselves suspect that the change in reporting had led to a higher number of accidents being reported, starting in 2004.

Annual number of groundings and collisions

Figure 7 presets the annual number of collisions and groundings in the whole Baltic Sea from 2004–2011. It can be seen that both collisions and groundings increased when comparing the data from 2002–2003 to data from 2004–2011. There also seemed to be a slight drop in groundings after 2008. Furthermore, after 2009, collisions were more frequent than groundings.

Focusing on the collisions in the Baltic Sea, the annual number of different types of collisions

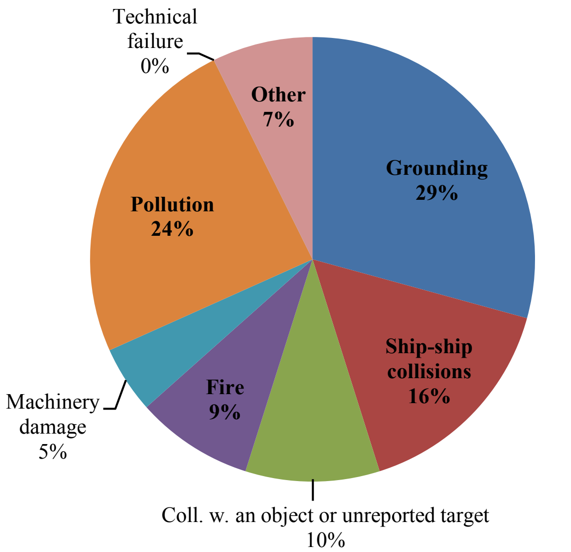


Figure 6. Accidents in the GoF between July 2002 and the end of 2011, according to HELCOM (HELCOM, 2013)

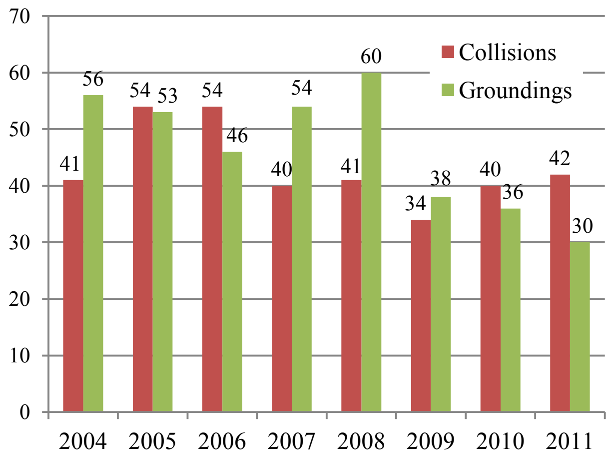


Figure 7. The annual number of groundings and collisions in the Baltic Sea in 2004–2011, according the HELCOM data

Table 8. Numbers of different types of collisions in the Baltic Sea according to the HELCOM data

	Collision with			
Year	object	vessel	both	unknown
2011	16	21	5	0
2010	19	20	1	0
2009	25	6	0	3
2008	22	16	1	1
2007	25	15	0	0
2006	26	28	0	0
2005	23	30	2	0
2004	10	13	0	13
Total:	166	149	9	17

reported to HELCOM from 2004–2011 is summarized in Table 8. Contrary to the trend in the Gulf of Finland (Tables 3 and 4), on average it had been more common that the ship had collided with an object (a peer, navigation sign, etc.) rather than with another ship.

In the Gulf of Finland, the annual number of groundings and collisions varied between 1 and 15 for the years 2004–2011 (Figure 8). The numbers seem to drop sharply after 2005.

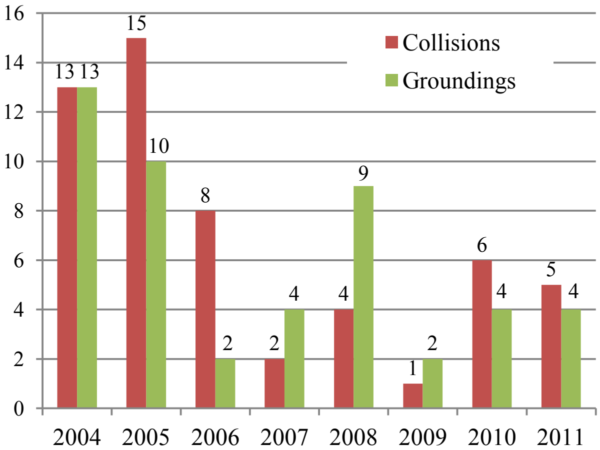


Figure 8. The annual number of groundings and collisions in the Gulf of Finland from 2004–2011, according to the HELCOM data

Accidents compared to ship traffic

Knowing the accident frequency as well as the ship traffic volume, it is possible to calculate the number of accidents relative to the traffic volume. Having data over several years also allows for any potential trends in this relationship to be seen.

Table 9 and Figure 9 show a possible decreasing trend for accidents per 1000 port visits or line crossings for the Baltic Sea as a whole. The average number of groundings (collisions) is 0.109 (0.105) per 1000 crossings and 0.091 (0.087) for 1000 port visits. When it comes to the Gulf of Finland only, the numbers are presented in Table 10. For the Gulf of Finland, the trend is more erratic, cycling up and down from year to year with a slightly increasing trend. The average number of groundings (collisions)

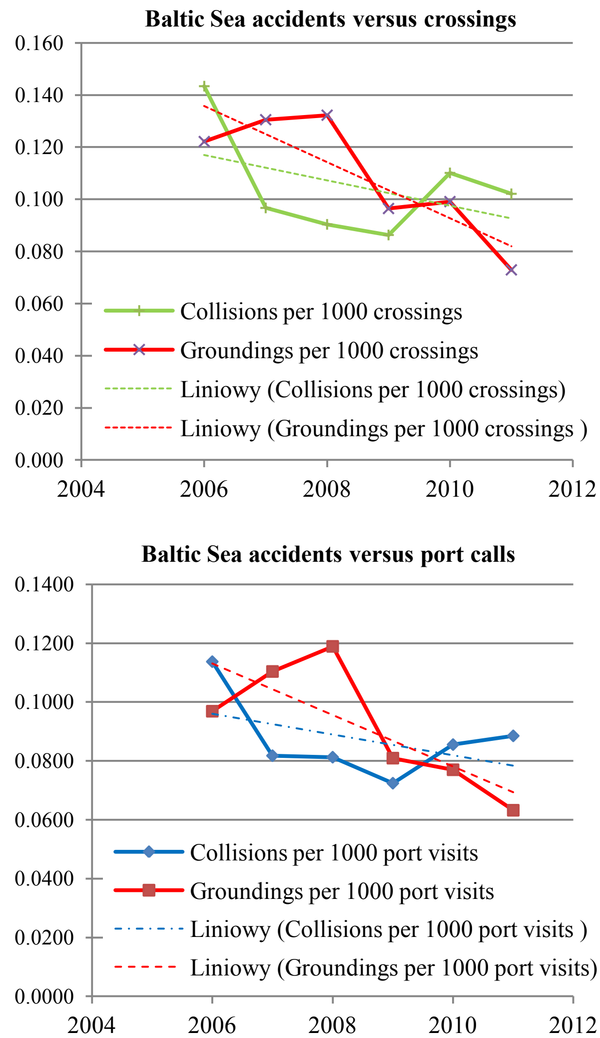


Figure 9. Accidents per 1000 port visits or line crossings in the Baltic Sea along with linear trend lines

is 0.1 (0.109) per 1000 crossings and 0.098 (0.103) for 1000 port visits.

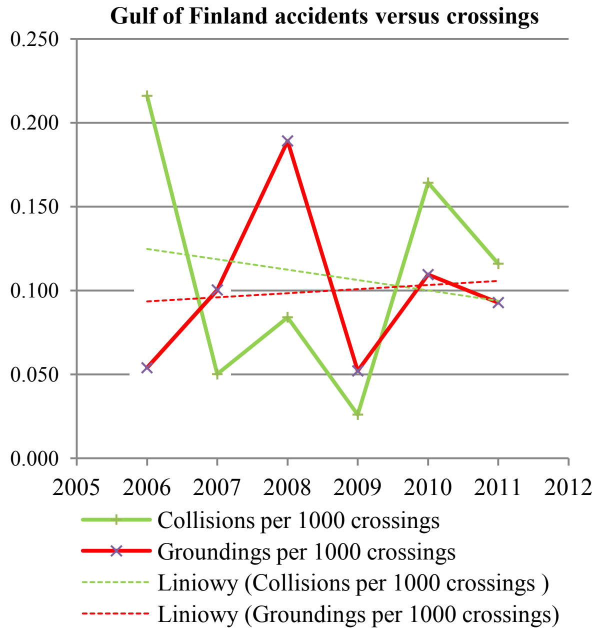
Besides this, there are other risk metrics such as accident rate (number of accidents per 1000 vessel movements; see TSB (TSB, 2011)) or ship year (accidents per year per ships in a given fleet; see, e.g., OGP (OGP, 2010)). For Finland, DAMA data from 2005 show that there were 19 accidents and 642

Table 9. Accidents per 1000 Baltic Sea port visits or HELCOM line crossings

Accidents per 1000	crossings		port visits	
Year	collisions	groundings	collisions	groundings
2011	0.102	0.073	0.0884	0.0631
2010	0.110	0.099	0.0854	0.0769
2009	0.086	0.096	0.0723	0.0808
2008	0.090	0.132	0.0812	0.1188
2007	0.097	0.131	0.0817	0.1103
2006	0.143	0.122	0.1136	0.0968

Table 10. Accidents per 1000 port visits or HELCOM line crossings in the Gulf of Finland

Accidents per 1000	crossings		port visits	
Year	collisions	groundings	collisions	groundings
2011	0.116	0.093	0.1312	0.1049
2010	0.164	0.109	0.1653	0.1102
2009	0.026	0.052	0.0272	0.0543
2008	0.084	0.189	0.0856	0.1926
2007	0.050	0.100	0.0400	0.0800
2006	0.216	0.054	0.1625	0.0406



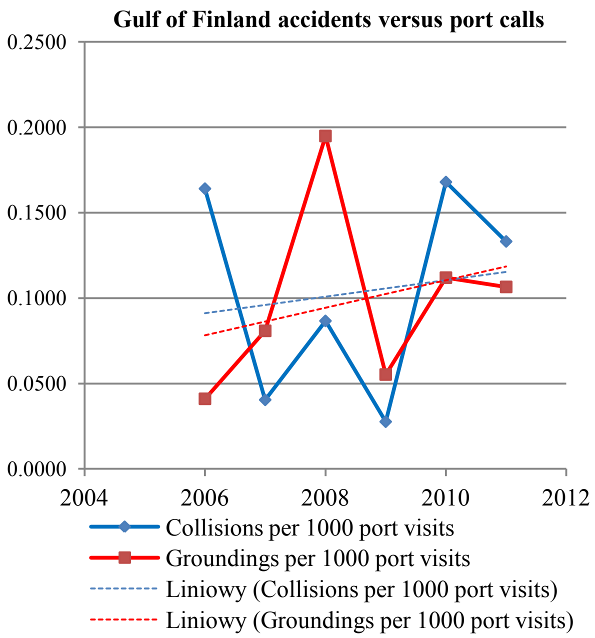


Figure 10. Accidents per 1000 port visits or line crossings in the Gulf of Finland with linear trend lines

vessels (at least 15 m long) in the Finnish merchant fleet (Trafi, 2010). Dividing the number of accidents by the number of ships for that year, we obtain we obtain 0.03 accidents per ship-year. The number of groundings and collisions were both 6, yielding 0.0093 collisions/groundings per ship-year.

OGP (OGP, 2010) calculate that globally for a serious casualty the ship-year is 0.0093 among all merchant vessels over 100 GT. For total loss, the ship-year is 0.003. For the data, Lloyd's Register's annual World Casualty Statistics were used as a source. Compared to the OGP serious casualty ship year, the Finnish numbers are quite high even though the numbers are not directly comparable due to different definitions.

In this paper, the risk is mainly thought of as a quantitative metric consisting of a set of negative events and their frequency (as well as their epistemic and aleatory uncertainty). Since in this case we are interested in accidents within a particular geographical area, the number of accidents per 1000 port arrivals or crossings is more informative than, e.g., accidents per ship-year. Even more informative would be, e.g., a map over where the accidents are concentrated; for example, an estimate of the relative collision risk in the different parts of the Gulf of Finland have been shown in Sormunen et al. (Sormunen et al., 2015) and in Goerlandt and Kujala (Goerlandt & Kujala, 2011).

Ship type distributions

Table 11 shows the ship type distributions in the 2006–2011 HELCOM database for accidents and traffic statistics for the Baltic Sea and the Gulf of Finland. It can be seen that the distributions are roughly similar. However, the passenger vessel shares differ. For the Baltic Sea, passenger vessels are overrepresented in the accident statistics compared to the traffic share. On the other hand, if only the GoF is considered, their share in accidents is noticeably smaller than the one in the traffic statistics. Since HELCOM has recorded traffic information as ships crossing certain lines in the Baltic Sea, not all passenger vessels are necessarily recorded, such as the ships operating between Helsinki and Tallinn. This makes the difference in the passenger vessel share even more distinct, and implies that the passenger vessels navigating in the GoF are less prone to accidents than vessels navigating in the Baltic Sea in general.

Table 11. Ship type shares in % in the 2006–2011 accidents and their %-share in traffic statistics

Ship type	Baltic Sea		Gulf of Finland	
	Traffic	Accidents	Traffic	Accidents
Cargo ship	54.38%	49.38%	57.09%	42.05%
Tanker	16.87%	13.18%	17.59%	20.45%
Passenger vessel	10.73%	22.61%	13.29%	3.41%
Other	18.02%	14.84%	12.03%	34.09%

Reported causes of accidents

In Kujala et al. (Kujala et al., 2009), human factors were reported as the most common primary cause group of the Gulf of Finland accidents during

1997–1999 and 2001 – June 2006 (Table 12). As Table 13 shows, this is also true for the HELCOM Baltic Sea data with human factors being the cause in approximately half of the accidents.

Table 12. Causes of the GoF accidents reported to DAMA and HELCOM during 1997–1999 and 2001 – June 2006 (Kujala et al., 2009)

Human failure	External	Technical	Other[1]	Unknown[2]
38.57%	15.24%	11.90%	3.8	30.48%

[1] Other here includes all categories with less than 2% share see Kujala et al. (Kujala et al., 2009) for a full description.
[2] Cause was not registered in the HELCOM-data between 1997 and 2003, hence "Unknown" group's relatively large proportion.

Table 13. Causes of the Baltic Sea accidents as reported to HELCOM

Year	Human factor	Technical	External	Other	No information
2011	50%	22%	17%	5%	6%
2010	30%	20%	9%	5%	36%
2009	52%	20%	15%	8%	5%
2008	47%	13%	18%	7%	15%
2007	32%	20%	12%	4%	32%
2006	36%	15%	9%	5%	35%
2005	42%	23%	5%	23%*	7%
2004	45%	21%	5%	10%	19%

* includes cases where multiple factors were the cause.

According to the HELCOM accident data, a pilot had been reported to be on board for 37% of the collisions, 20% of the groundings, and 24% of all accidents within the Baltic Sea from 2004–2011 (Table 14). In 3–8% of cases, the ship had had a pilot-exemption certificate. In most cases, however, no pilot had been on board. Rather often it had not been reported whether or not a pilot had been on board. Thus, if only the cases with reported pilot information are considered, the proportion of accidents without a pilot onboard is even higher; 49%, 72%, and 64% for collisions, groundings, and all accidents, respectively.

Table 14. Pilot presence on board during 2004–2011 Baltic Sea accidents, according to the HELCOM data

	Collisions	Groundings	All accidents
Present	37%	20%	24%
Absent	43%	59%	55%
Pilot exemption certificate	8%	3%	7%
Unknown	12%	17%	14%

Summary of the accident and traffic statistics

During the financial crisis of 2008, the Baltic Sea traffic volume experienced a drop. Nevertheless, in 2011 the volumes had reached approximately the same level as the pre-crisis year 2007; in the Baltic Sea, a total of 411,000 ship crossings had taken place in 2011 versus 414,000 in 2007. The total number of Baltic Sea port visits were estimated to be 489,239 for 2007 and 467,406 for 2011.

In the Gulf of Finland, there were more HELCOM line crossing in 2011 than in 2007 (43,112 versus 39,866) but the number of port visits were much higher in 2007 than in 2011 (37,555 versus 49,496). As can be seen in Figures 3 and 4, the crossings can be used as a rough metric for the actual number of port calls in case the latter data are unavailable.

The most common accident type was groundings. From 2004–2011, 346 groundings were reported in the Baltic Sea overall, of which 48 had occurred in the GoF. In the GoF, there was a large, statistically-significant drop in the annual number of accidents happening after 2005. On the other hand, the accident numbers in the Baltic Sea in general had not dropped so radically, although the trend seems to be decreasing as of 2008. Human factors have been the most commonly reported cause of accidents in both more recent HELCOM (47–56% of the cases with a reported cause) as well as the older DAMA and HELCOM (55%) data. Having a pilot on board does, by no means, make the ship "unsinkable"; in the HELCOM data, a pilot was on board during an accident in almost one-third of the cases with reported pilot presence. However, it should be noted that the pilot is typically onboard only when the ship is navigating in a demanding or unfamiliar waterway.

For every 1000 port visits or HELCOM line crossings, there are, on average, 0.1 (± ~0.01) collisions and groundings in the Baltic Sea or the Gulf of Finland. The trend seems to be decreasing for the Baltic Sea as a whole whereas for the GoF it seems to be slightly increasing, though with big deviations from year to year as can be seen in Figure 10. Knowing the traffic volume and the number of accidents allows for a simple accident-probability estimation by dividing the number of accidents by the traffic volume. However, in order for this to be reliable, certain conditions have to be met. One of them is that all accidents are actually reported to the input database. To estimate this, the underreporting frequency in the Gulf of Finland is calculated in the following section.

Underreporting and reliability of accident statistics

Data

To estimate the degree of underreporting of maritime accidents in Finland, accidents between January 2004 and June 2006 reported to the DAMA-accident database are compared with those found in the HELCOM database. The DAMA-database contains accidents in Finnish territorial waters as well as the cases where a vessel with Finland as flag state was involved. The HELCOM-database accidents where the country was reported as Finland were selected for this analysis; both contain Finnish vessels that had an accident outside of Finnish territory. Both databases cover all accidents, not just groundings and collisions. From the DAMA-database, the cases where ship size was smaller than 400 tons or was missing were filtered out, leaving the following number of accidents: Common accidents in both databases ($C_{D,H}$) = 23, Total accidents reported to HELCOM (T_H) = 28, Accidents reported to HELCOM only (O_H) = 5, Total accidents reported to DAMA (T_D) = 47, Accidents reported to DAMA only (O_D) = 24, and Total reported individual accidents ($T_{D,H}$) = 52.

Methods

Capture-recapture methods are used to estimate the number of missing accidents from both databases ($X_{D,H}$) and the true number of real accidents (N) as well as their confidence intervals (CI). These methods are more commonly used in estimating wildlife populations based on capturing and marking animals, then coming back to the same area to re-capture animals. The true population size is estimated by comparing the number of captures in the first and second capture as well as the re-captured, tagged animals in the second sample. When applied to accident databases, the captures are replaced and instead data from database 1 and database 2 are compared. See e.g. Brittain and Böhning (Brittain & Böhning, 2009) for a more comprehensive description and discussion on capture-recapture methods. The number of recaptures becomes the number of accidents found in more than one database. The used estimators are:

Lincoln-Petersen estimation:

$$X_{D,H}^{L-P} = \frac{O_H O_D}{C_{D,H}} \tag{1}$$

$$N^{L-P} = \frac{T_H T_D}{C_{D,H}} \tag{2}$$

The Chapman-estimator:

$$X_{D,H}^{C} = \frac{O_H O_D}{C_{D,H}+1} \tag{3}$$

$$N^{C} = \frac{(T_H+1)(T_D+1)}{C_{D,H}+1} - 1 \tag{4}$$

$$Var\left(N^{C}\right) = \frac{(T_H+1)(T_D+1)\,O_H O_D}{(C_{D,H}+1)^2(C_{D,H}+2)} - 1 \tag{5}$$

$$CI_{95\%}\left(N^{C}\right) = N^{C} \pm z_{\alpha}\sqrt{Var\left(N^{C}\right)} \tag{6}$$

Chao's lower bound estimate:

$$X_{D,H}^{CLB} = \frac{(O_H+O_D)^2}{4C_{D,H}} \tag{7}$$

$$N^{CLB} = O_H + O_D + X_{D,H}^{CLB} + C_{D,H} \tag{8}$$

$$Var\left(N^{CLB}\right) = X_{D,H}^{CLB}\left(\frac{O_H+O_D}{2C_{D,H}}+1\right)^2 \tag{9}$$

$$CI_{95\%}\left(N^{CLB}\right) = N^{CLB} \pm z_{\alpha}\sqrt{Var\left(N^{CLB}\right)} \tag{10}$$

The methods are the same as in Hassel et al. (Hassel, Asbjørnslett & Hole, 2011) so that the results might be compared better.

Results

Underreporting percentages

The results of the different accident underreporting estimation methods are summarized in Table 15.

Using the 3 different methods' expected value as the total number of accidents (N), it is obtained that 45.8–49.1% of all estimated accidents are reported to HELCOM and 76.9–82.5% to DAMA. Combining the databases, it is estimated that 85.1–91.2% of accidents are reported to at least one of the databases. Overall, the reporting rate range is approximately 40–55% for HELCOM, 68–93% for DAMA, and 75–100% for both combined.

When looking at the confidence intervals' (CI) lower (LB) and upper (UB) bounds, for the most optimistic case it can be seen that all accidents are reported to either database (102.8% reporting rate with Chapman LB) and in the most pessimistic case only 75.4% are reported (Chao's UB). The results are quite good in comparison with the results from

Table 15. DAMA and HELCOM reporting frequency estimates

	Lincoln-Peterson	Chapman	Chapman LB	Chapman UB	Chao's	Chao's LB	Chao's UB
N	57.22	57	50.6	64.3	61.14	53.32	68.95
X	5.22	5	–1.4	12.3	9.14	1.32	16.95
HELCOM reporting rate	48.9%	49.1%	**55.3%**	43.5%	45.8%	52.5%	**40.6%**
DAMA reporting rate	82.1%	82.5%	**92.9%**	73.1%	76.9%	88.1%	**68.2%**
Combined reporting rate	90.9%	91.2%	**102.8%**	80.9%	85.1%	97.5%	**75.4%**

Table 16. Hassel et al. (Hassel, Asbjørnslett & Hole, 2011) flag state reporting frequencies

Method / Flag state	Norway (NOR/NIS)	Sweden	Denmark (DK/DIS)	UK	USA	Canada	Netherlands
Lincoln-Petersen	38%	79%	24%	57%	21%	75%	23%
Chapman 95%CI	35–42%	73–86%	20–31%	53–62%	19–25%	73–77%	20–29%
Chao's LB 95%CI	37–40%	55–63%	21–27%	37–41%	13–15%	73–75%	19–23%

Hassel et al. (2011), whose results for the flag state reporting frequency are summarized in Table 16.

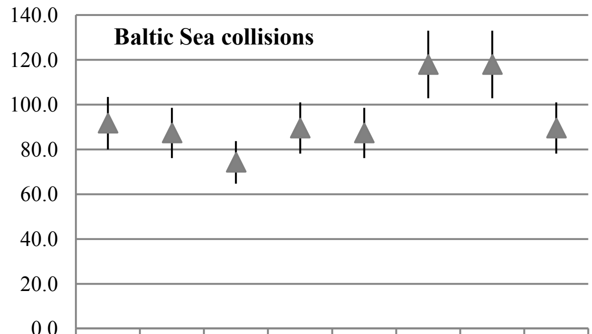
Note that both Lincoln-Peterson's and Chapman's estimates are sensitive to any dependency between the 2 databases, giving a downward biased estimate – that is, they tend to underestimate the real number of accidents in this case (Hassel, Asbjørnslett & Hole, 2011). A dependency exists here as the Finnish authorities are responsible for both reporting to DAMA as well as to HELCOM. Chao's lower bound estimate relaxes the assumption of independence of the 2 sources, and thus seems to be the most reliable method. Chao's estimate gives a 45.8% reporting rate to HELCOM, 76.9% to DAMA, and 85.1% combined. Due to the relatively small sample size, the reporting frequency for different accident types is not estimated. DAMA is no longer maintained as of 2011; instead, Trafi reports to the EMCIP-database (Ladan & Hänninen, 2012; Trafi, 2011).

The true number of accidents in the Baltic Sea

The Chao estimated reporting frequency for HELCOM is 40.6–52.5%, meaning that the true estimated number of accidents is 1.9–2.5 times the number reported to HELCOM. Thus, to estimate the real number of accidents one should multiply the number of HELCOM accidents with at least a factor of 2. The same applies, of course, to the other statistics that are based upon the number of accidents.

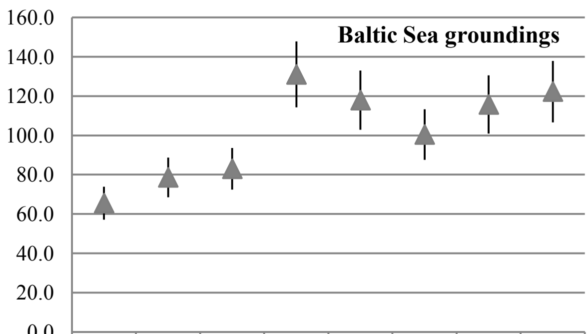
In the following Figures 11–14, the number of groundings and collisions reported to HELCOM (from Figures 7 and 8) are multiplied with Chao's reporting frequency estimates: LB = lower bound, reporting % = 52.5%, multiplier = 1.90; M = Chao's "mean", reporting % = 45.8%, multiplier = 2.18; and UB = upper bound, reporting % = 40.6%, multiplier = 2.46.

The diamond indicates the number of accidents reported to HELCOM multiplied with the "M" multiplier (2.18), the black line is the 95% confidence interval with lower bound determined by "LB" and the upper by "UB".



	2011	2010	2009	2008	2007	2006	2005	2004
UB	103.4	98.5	83.7	101.0	98.5	133.0	133.0	101.0
LB	80.0	76.2	64.8	78.1	76.2	102.9	102.9	78.1
▲M	91.7	87.3	74.2	89.5	87.3	117.9	117.9	89.5

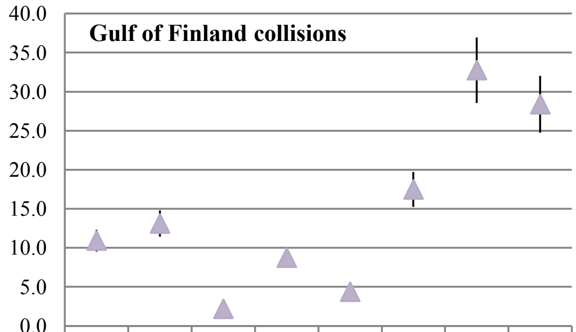
Figure 11. Estimate for true number of Baltic Sea collisions



	2011	2010	2009	2008	2007	2006	2005	2004
UB	73.9	88.7	93.6	147.8	133.0	113.3	130.5	137.9
LB	57.1	68.6	72.4	114.3	102.9	87.6	101.0	106.7
▲M	65.5	78.6	83.0	131.0	117.9	100.4	115.7	122.3

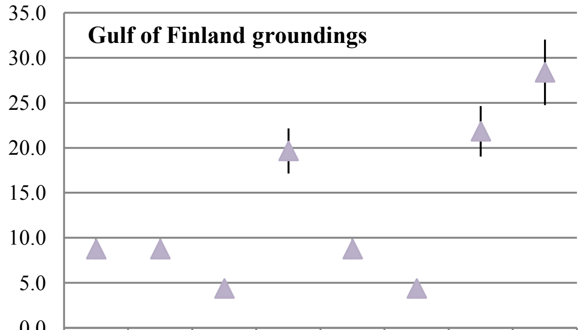
Figure 12. Estimate for true number of Baltic Sea groundings

As can be seen in Figure 12, the absolute value of the interval LB–UB grows in years with many accidents (such as 2008 and 2004) while the 95% CI is quite small in absolute value during years with fewer accidents. The same goes for GoF, where the big CIs are during the 2004–2005 years for collisions, for which the figures are as follows in Figures 13 and 14.



	2011	2010	2009	2008	2007	2006	2005	2004
UB	12.3	14.8	2.5	9.9	4.9	19.7	36.9	32.0
LB	9.5	11.4	1.9	7.6	3.8	15.2	28.6	24.8
▲M	10.9	13.1	2.2	8.7	4.4	17.5	32.8	28.4

Figure 13. Estimate for true number of Gulf of Finland collisions



	2011	2010	2009	2008	2007	2006	2005	2004
UB	9.9	9.9	4.9	22.2	9.9	4.9	24.6	32.0
LB	7.6	7.6	3.8	17.1	7.6	3.8	19.0	24.8
▲M	8.7	8.7	4.4	19.7	8.7	4.4	21.8	28.4

Figure 14. Estimate for true number of Gulf of Finland groundings

Underreporting Conclusions

Based on the estimated HELCOM reporting frequency, the true number of accidents is at least double of what is reported. This conclusion regarding the true number of accidents must be taken with slight reservations as the analysis is based on Finnish authorities only. However, the results are of the same order of magnitude as in other studies found in the literature for other countries – a multiplier of at least 2 is supported by results of other maritime accident reporting frequency studies (Hassel, Asbjørnslett & Hole, 2011; Thomas & Skjong, 2009; Psarros, Skjong & Eide, 2010) done for other (mostly European) countries. Using this estimate, the true number of accidents in the Baltic Sea for 2004–2011 is in the order of magnitude of ~750 groundings (373 reported) were in the Baltic Sea overall, of which ~100 were in the GoF (48 reported). The same numbers for collisions would be ~700 (346 reported), of which ~110 (54 reported) were in the GoF. This number might be even greater as the results here and in Hassel et al. (Hassel, Asbjørnslett & Hole, 2011) indicate that flag states get a better reporting frequency than other sources; in this case, the other source is HELCOM.

The high number of possibly unreported accidents raises questions on whether the reported cases form a representative sample of all accidents, or whether the unreported cases are somehow different from the reported ones. Most importantly, we wonder if severe accidents are more likely reported than less severe ones – though Psarros et al. (Psarros, Skjong & Eide, 2010) find that the severity of the (tanker) accident did not play a significant role in the tanker accident underreporting. Further research with multiple databases from all Baltic Sea states should be conducted to obtain a more reliable estimate of the underreporting frequency of HELCOM. With enough data, the underreporting estimation should be done for different ship and accident types, etc., as well.

Consequences of underreporting

Having accidents going unreported has obvious drawbacks – among other things, lessons from other mariner's mistakes go unlearned and authorities and other relevant agents such as insurance companies might get a false sense of security. The estimated true number of accidents in this study, as well as the previous studies, deviates so much from the ones reported that this has major implications to quantitative maritime risk analysis – when one is interested in estimating accident frequency or severity from historical data, the underreporting should be assessed first in order to obtain an estimate of the true number of accidents. Otherwise, in this case, if one would straightforwardly conclude that the number of accidents in the Baltic Sea is the same as the number of accidents reported to HELCOM, one would severely underestimate the true number of accidents. The same would be true if one would estimate the risk expressed as the number of accidents per year. If one would try to validate results of a maritime risk against the accident statistics, we might end up in a paradoxical situation where the risk model might actually be right but shown to be invalid when testing the validity against the statistics. This is a real problem since in risk analysis, in general, accident statistics are used for either model building or validation. Only when the true number of accidents is estimated can the data be used in quantitative risk analysis to validate or build models for maritime risk analysis.

Due to the significant underreporting, quantitative risk analysis / risk-analysis validation based on accident statistics not only becomes necessary but also introduces a new level of uncertainty: instead of having access to complete data, one must interpolate incomplete data to estimate the true number of accidents, which adds a layer of uncertainty in the analysis – the uncertainty related to the interpolation. Using formalized uncertainty assessment analysis methods, such as the ones presented by Sormunen et al. (Sormunen et al., 2015) or Milazzo and Aven (Milazzo & Aven, 2012), one can argue that the epistemic uncertainty for any quantitative risk analysis using accident data becomes a significant factor.

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Appendix 1: Russian port visit estimates

Table 17 describes ship port entries into Russian GoF harbors. As mentioned earlier, **numbers in bold come from BPL (2014),** *numbers in italics from administration of port of Saint Petersburg (2014).* Underlined numbers are estimates based on cargo volume and the estimated volume per ship. In case of several sources, the one with the highest number of port visits was chosen.

The numbers that were estimated were obtained based on the cargo volumes and the average cargo per ship (Table 18).

Numbers in red are from ESIMO (2014). The other numbers are from the administration of the port of Saint Petersburg (2014). The average cargo per ship was calculated for the missing years based on the average of the closest two years with data. These estimated numbers are underlined in Table 19.

Finally, the missing values from the number of ships entries are estimated by dividing the cargo volume by the average cargo per ship for the given year and harbor, see Table 19.

To estimate number of port calls to Vysotsk, the cargo volume from ESIMO was divided by the annual average of cargo per ship for all other Russian ports. For Kaliningrad it was based on the average for all ports except Primorsk, as not to distort the results due to the large tankers calling in to Primorsk.

Table 17. Number of Russian GoF port ship entries

Best estimate:	2006	2007	2008	2009	2010	2011	2012
St. Petersburg	**12 593**	*14 633*	*14 789*	*10 786*	*9309*	9 861	**9 750**
Primorsk	**658**	*740*	*804*	*935*	*970*	1 109	**1 350**
Ust-Luga	213	**555**	*451*	*517*	*705*	1 222	**2 290**
Vyborg	422	**250**	438	*302*	*547*	431	**470**
Vysotsk	453	529	551	611	565	566	643
Sum:	14 340	16 707	17 033	13 151	12 096	13 189	14 503

Table 18. Cargo volumes in Russian GoF harbors

Cargo [kT]	2006	2007	2008	2009	2010	2011	2012
St. Petersburg	54 839	59 628	59 856.9	50 408.4	58 059.9	59 989.3	57 814.4
Primorsk	66 078.1	74 226.9	75 581.9	79 157.2	77640.3	75 124.9	74 768.7
Ust-Luga	3766	7142.7	6906.9	10 357.7	11 775.6	22 693	46 786.1
Vyborg	1252.8	1110.9	1299.9	1184.4	1100.4	1103.6	1462.4
Sum:	125 935.9	142 108.5	143 645.6	141 107.7	148 576.2	158 910.8	180 831.6

Table 19. Average cargo [kT] per visiting ship

Cargo/ship	2006	2007	2008	2009	2010	2011	2012
St. Petersburg	4.06	4.07	4.05	4.67	6.24	6.08	5.93
Primorsk	97.16	100.31	94.01	84.66	80.04	67.71	55.38
Ust-Luga	17.67	17.67	15.31	20.03	16.70	18.57	20.43
Vyborg	2.97	2.97	2.97	3.92	2.01	2.56	3.11

Table 20. Cargo volumes in Russian Baltic Sea harbors

Cargo [kT]	2006	2007	2008	2009	2010	2011	2012
Kaliningrad	15 150.1	15 624.8	15 369.1	12 363	13 808.8	13 357.1	12 719.6
Kaliningrad estimated ship calls	1840	1897	2065	1295	1660	1473	1295
Russia total	16 180	18 603	19 098	14 447	13 757	14 662	15 797