Consequences of ship collisions in Swedish waters: A Coastal State risk management perspective

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Abstract

Ship collisions remain a persistent safety concern in high-density and geographically constrained maritime regions such as the Baltic Sea. This study examines collision risk in Swedish waters using multiple sources, integrating accident data from Transportstyrelsen with the operational activity data that the Swedish National Road and Transport Research Institute VTI calculated based on HELCOM's AIS-data and supplementary environmental and economic datasets. A total of 525 collision occurrences (2011–2023) were analysed, with a harmonised subset of 429 collisions subjected to exposure-normalised assessment. Collision frequencies were normalised against three measures of activity which include distance sailed, operational time and number of unique ships to provide strong interpretation of risk beyond absolute accident counts. The results show that collision occurrence is primarily driven by operational exposure and navigational context, with passenger ships exhibiting the highest collision rates due to intensive operations in confined and high traffic density environments. Dry cargo ships display more stable and proportional risk patterns, while tanker collisions are characterised by low frequency but high variability, limiting trend-based interpretation. Scenario analysis identifies three dominant risk structures such as high-frequency, low-severity operational collisions, interaction driven collisions with higher severity potential and low-frequency, high consequence events, especially involving tankers. Although most collisions result in minor consequences, the study highlights that overall risk is shaped by rare but high-consequence events, especially in environmentally sensitive areas of Baltic Sea. The findings demonstrate the importance of integrating exposure, consequence severity and operational context in maritime risk assessment and support the refinement of risk-based safety management and policy development in Swedish waters.

Keywords

Collision; maritime accident analysis; risk management; risk analysis; risk assessment; maritime safety; exposure-normalised risk; consequence assessment; Baltic Sea

JEL Codes

R41

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Ship collisions remain a persistent safety concern in high-density and geographically constrained maritime regions such as the Baltic Sea. This study examines collision risk in Swedish waters using multiple sources, integrating accident data from Transportstyrelsen with the operational activity data that the Swedish National Road and Transport Research Institute VTI calculated based on HELCOM's AIS-data and supplementary environmental and economic datasets. A total of 525 collision occurrences (2011–2023) were analysed, with a harmonised subset of 429 collisions subjected to exposure-normalised assessment. Collision frequencies were normalised against three measures of activity which include distance sailed, operational time and number of unique ships to provide strong interpretation of risk beyond absolute accident counts. The results show that collision occurrence is primarily driven by operational exposure and navigational context, with passenger ships exhibiting the highest collision rates due to intensive operations in confined and high traffic density environments. Dry cargo ships display more stable and proportional risk patterns, while tanker collisions are characterised by low frequency but high variability, limiting trend-based interpretation. Scenario analysis identifies three dominant risk structures such as high-frequency, low-severity operational collisions, interaction driven collisions with higher severity potential and low-frequency, high consequence events, especially involving tankers. Although most collisions result in minor consequences, the study highlights that overall risk is shaped by rare but high-consequence events, especially in environmentally sensitive areas of Baltic Sea. The findings demonstrate the importance of integrating exposure, consequence severity and operational context in maritime risk assessment and support the refinement of risk-based safety management and policy development in Swedish waters.

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1 Introduction

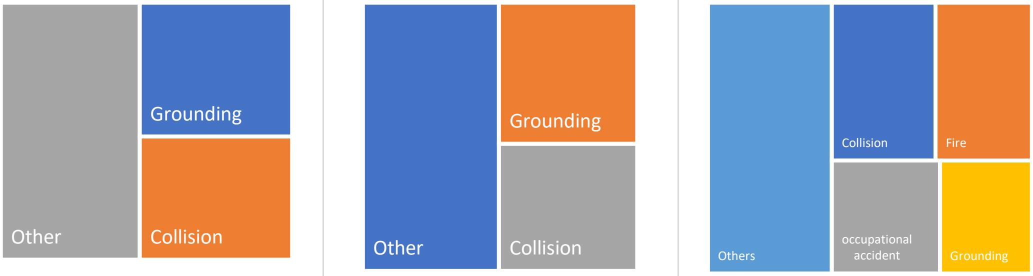
1.1 Background

Baltic Sea witnesses among the most intense traffic in semi-enclosed seas worldwide which is characterised by narrow straits, constrained fairways and complex archipelagic passages that heighten navigational difficulty (Grimvall & Larsson, 2014; HELCOM, n.d.). AIS-based traffic density patterns (Figure 1) show ship concentration around Gothenburg, Stockholm archipelago and Gulf of Bothnia, areas where constrained geometry and mixed-traffic operations increase the exposure to collision risk. These conditions position Sweden as a vulnerable maritime state for collisions within the broader Baltic region.

Figure 1: Traffic intensity in the Baltic Sea along pre-defined crossing lines

Source: https://maps.helcom.fi/website/mapservice/index.html

Ship collisions remain among the most frequent maritime incident types globally and regionally in the Baltic, often generating consequences to human, environment and ship (Antão et al., 2023; Eliopoulou et al., 2023; Li et al., 2024). HELCOM statistics indicate that collisions have consistently been among the top three accident categories in the Baltic Sea between 2004 and 2024 (Figure 2). Similar findings have been reported in European datasets and in analyses of casualties involving container ships and passenger ships (EMSA, 2024; IMO, 2024; Liu et al., 2022; Ugurlu & Cicek, 2022). Despite regulatory measures under SOLAS, COLREGs and technological advances such as VTS, ECDIS and AIS, collisions continue to occur (Hebbar et al., 2024; Park & Kim, 2017; Uğurlu, 2024) and human-factors persist as a dominant causal element (Chauvin, 2011; Chauvin et al., 2013; Ugurlu & Cicek, 2022). Beyond human error, research applying maritime adaptations of Human Factors Analysis and Classification System (HFACS) has demonstrated that organisational and supervisory deficiencies are underrepresented in official accident investigation reports despite their relevance for accident causation (Schröder-Hinrichs et al., 2011). Therefore, collision risk sits in a complex socio-technical system rather than as an isolated navigational failure.



(a) Top 3 accident types in Baltic Sea: 2004 - 2024 (N = 3021)

Source: HELCOM

(b) Top 3 accident types in Swedish waters: 2004 - 2024 (N = 932)

Source: HELCOM

(c) Top 5 accident types involving passenger ship globally: 2011 - 2022 (N = 574)

Source: IMO III 11/INF.2

Figure 2: Collision as proportion of top accident types

Historically, research on ship collisions has been dominated by studies focusing on likelihood estimation, predictive modelling and navigational failure typologies (Hänninen, 2014; Kretschmann, 2020; R. W. Liu et al., 2022; Mazaheri et al., 2014; Rasmussen, 1997). Probabilistic and simulation-based models have provided insights into collision probability under varying traffic, environmental and operational conditions (Lan et al., 2023; Liu et al., 2022; Park & Kim, 2017; Xiao et al., 2022). Expanded approaches have incorporated human and oil-spill consequence modelling (Chai et al., 2017). However, these models largely prioritise likelihood over consequence severity, often treating consequences as binary or categorical variables, limiting their value for real-world safety planning (Goerlandt & Kujala, 2011; Mazaheri et al., 2014). Attempts to integrate both likelihood and consequences, such as risk matrix frameworks remain mostly theoretical and rarely applied to national datasets (Wang et al., 2020).

Alongside the likelihood-focused studies, a substantial body of literature examines the economic loss of maritime accidents (Zhang et al., 2025). Valuation approaches increasingly draw on Value of Statistical Life (VSL) and the Cost of Averting a Fatality (CAF), which have become influential tools in safety policy and cost-effectiveness evaluation (Boardman et al., 2018; Hultkrantz & Svensson, 2012; IMO, 2018; Persson et al., 2001; Viscusi & Gentry, 2015; Wolff, 2007). However, concerns persist regarding transferring land-based VSL values to maritime operations, where casualty management and risk exposure differ markedly (Browne et al., 2022). Oil spill consequences have similarly been quantified through models estimating clean-up and restoration costs (Etkin, 2000, 2001; Grey, 1999; Harper et al., 1995; Kontovas et al., 2010; Liu & Wirtz, 2006; Moller et al., 1987; Vanem et al., 2008). However, scholars argue that global averages are not suited for the Baltic Sea's low salinity, slow flushing, ice cover and sensitive ecosystems (Mullai & Paulsson, 2011).

The literature reveals a structural disconnect where predictive studies emphasise collision probability while consequence research highlights economic and environmental consequences but few studies integrate both dimensions. The gap creates national level safety governance challenge, where decisions must account for both likelihood and severity of collision events.

Sweden presents a compelling case. Its archipelagic geography, dense seasonal passenger and cargo traffic and environmentally sensitive coastal waters simultaneously increase collision risk and amplify consequence severity (Grimvall & Larsson, 2014; Stevens & Ekermo, 2003). Despite this, analyses of collision consequences remain limited and existing risk frameworks don't quantify and integrate these consequences into policy.

The study responds to these gaps by adopting a consequence-focused approach to ship collisions in Swedish waters. It assesses the scale and typology of consequences to human, ship and environment; examines spatial and temporal patterns influencing severity; and evaluates economic costs associated with collision events. Through this integrated assessment, the study provides evidence to support more effective, consequence-informed maritime safety governance in high-density and geographically constrained waters of Sweden.

The remainder of the paper is structured as follows: section 2 describes data sources and methodological approach; section 3 presents results and discusses key findings; section 4 presents representative accident scenarios; and, section 5 provides conclusions and implications of the study.

2 Materials and methods

2.1 Materials

The study adopts a multi – source and exposure-based analytical framework to examine collision risk in Swedish waters. The primary dataset consists of 525 collisions recorded between 2011 and 2023, obtained from Transportstyrelsen database and distribution of ship types is as shown in Figure 3. The dataset includes collisions in Swedish waters involving both, Swedish and foreign-flagged ships and served as the core basis for analysing collision frequency, consequences and representative collision scenarios. Representative collision scenarios were identified by integrating collision frequency, exposure-normalised risk metrics and consequence characteristics. The approach ensures that both high-frequency operational risks and low-frequency, high-consequence events are captured. All records were translated from Swedish into English prior to analysis to ensure consistency in classification and interpretation.

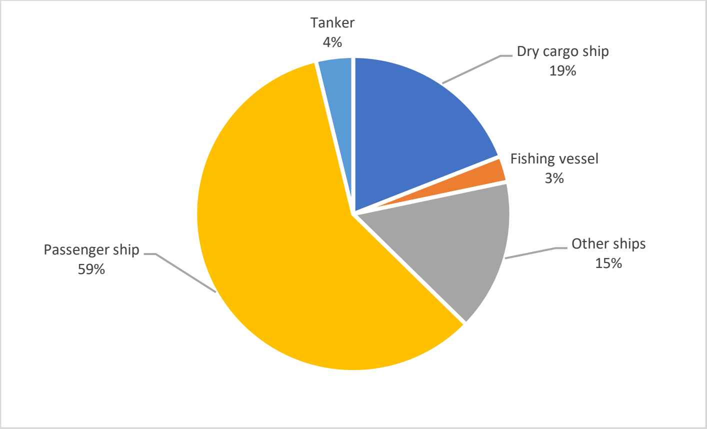


Figure 3: Distribution of Collision Incidents by Ship Type: 2011–2023 (N = 525)

Source: Transportstyrelsen

For the remainder of the study, a harmonised subset of 429 collisions covering the period 2011–2023 was constructed to align with the availability of operational activity data. The analysis focuses on two most dominant ship types which include passenger ships and dry cargo ships while tankers are also included due to their higher potential to cause severe oil spill consequences in the event of a collision.

To account for variations in maritime activity, VTI's operational exposure data were calculated by the Swedish National Road and Transport Research Institute VTI based on HELCOM's AIS-data (see Vierth, Johansson & Lind (2025) for details), which provides annual estimates of ship-kilometres sailed, ship-hours in operation and number of unique ships in Swedish waters. These data were integrated with the collision dataset for the overlapping period 2011–2023 and serve as the denominator in the exposure-normalised framework, allowing collision frequencies to be interpreted relative to traffic intensity rather than absolute counts. The inclusion of these data is essential to avoid bias arising from differences in fleet size and operational activity.

For comparative and contextual analysis at European level, 1,264 collision cases from the same period 2011 - 2023 were obtained from the European Maritime Safety Agency's EMCIP database.

To characterise environmental consequences, pollution incident records were obtained from HELCOM and oil-spill statistics were sourced from ITOPF. Economic assessments were supported by aggregated marine insurance claims from NoMIS and Swedish Club. EMCIP database enables benchmarking of Swedish collision patterns against broader European trends which supports external validity. HELCOM and ITOPF datasets provide independent information on environmental consequences which allows assessment of pollution-related consequences beyond what is captured in Swedish waters. Insurance data from NoMIS and Swedish Club contribute economic consequence estimates which supports evaluation of financial consequences associated with collisions. Together, the supplementary datasets extend the analysis beyond accident frequency to include environmental and economic dimensions of collision risk.

In addition to quantitative analysis, the study also involved identification of representative ship collision scenarios for Swedish waters, derived from distribution of collision types, ship types and operational contexts. The scenarios include the most likely collision scenario, the second most likely collision scenario and additional representative scenarios capturing less frequent but operationally relevant collision types. Scenario identification integrates collision frequency, exposure-normalised risk and consequence characteristics. The scenario-based approach complements the statistical analysis by providing contextualised representations of collision mechanisms, thereby supporting interpretation of risk patterns and linkage to consequence and mitigation analyses.

2.2 Methodological framework

Figure 4 presents the data integration framework which illustrates how each data source contributes to the analytical components of the study. Transportstyrelsen database provides the core dataset of collisions, forming the basis for collision frequency, consequences to human and serving as the numerator for exposure normalisation. VTI's operational exposure data calculated based on HELCOM's AIS-data supply measures of navigational activity namely ship-km sailed, ship-hours in operation and number of unique ships which are used to normalise collision frequencies and derive exposure-adjusted rates. EMCIP data is incorporated to enable comparative analysis at European level by providing additional information on consequences to human. Environmental consequence data from HELCOM along with oil spill statistics from ITOPF and IOPC Funds, inform the assessment of consequences to environment. Economic consequence evaluation is supported by aggregated insurance data from NoMIS and the Swedish Club, while Allianz provides information on total loss of ship.

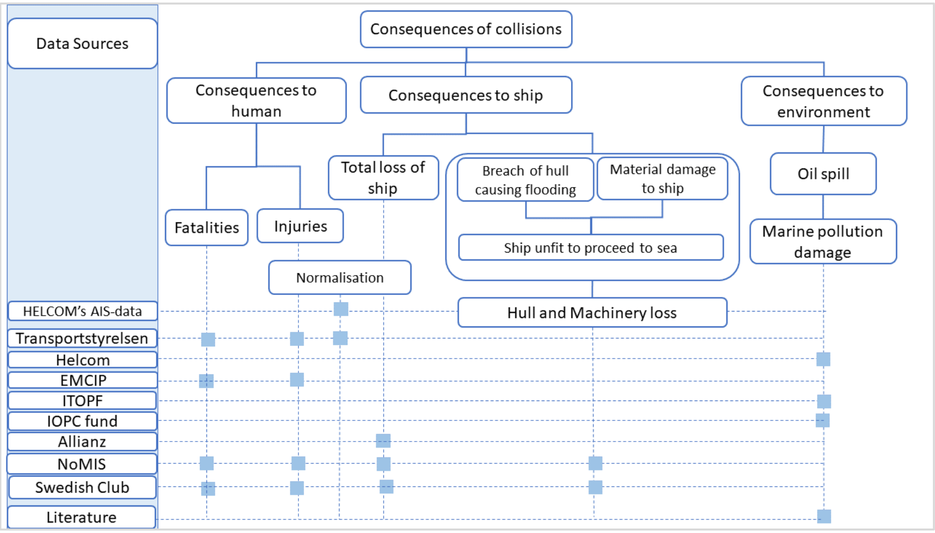


Figure 4: Conceptual framework for collision consequence classification and respective data sources for consequence analysis.

2.2.1 Inclusion and exclusion criteria

To ensure methodological consistency and relevance, the following inclusion and exclusion criteria was used. Only collision accidents involving physical contact were included which comprise collisions between ships, collisions with recreational ships, collision with quay, bridge, etc and collisions with floating objects (not ships). This inclusion reflects the operational realities of fairway navigation, where interactions with infrastructure and non-ship objects are critical components of risk. The analysis focuses on passenger ships, dry cargo ships and tankers which were selected due to their dominant representation in the dataset. Other ship types were retained in the dataset but excluded from detailed analysis. Near-miss incidents were excluded. Additionally, records with missing or incomplete key variables, such as ship type or collision classification, were excluded where reliable categorisation was not feasible. To ensure consistency between accident and exposure data, ship classifications were harmonised across datasets. Ship categories not consistently represented in both Transportstyrelsen and VTI's operational data based HELCOM's AIS-data (see Vierth, Johansson & Lind (2025) for details) were excluded from the exposure-normalised analysis.

2.3 *Exposure-normalised collision rates*

To enable exposure-normalised analysis, datasets from Transportstyrelsen (absolute collision data) and VTI's operational activity data based HELCOM's AIS-data were harmonised through a structured aggregation process. VTI's data provide annual records disaggregated by ship type and includes measures of ship activity such as distance sailed, hours of operation and number of unique ships. However, differences in ship classification schemes between the two datasets required alignment prior to integration.

Ship categories in VTI's operational activity data were therefore aggregated to match the classification used in the Transportstyrelsen dataset. Specifically, tanker categories were directly aligned, while passenger ship categories were grouped to include passenger ships, passenger/general cargo ships, passenger/Ro-Ro cargo ships and passenger (cruise) ships. Similarly, dry cargo ships were aggregated to include general cargo, other dry cargo, container ships, bulk carriers, Ro-Ro cargo ships and refrigerated cargo ships. This harmonisation ensured consistency between the exposure data (denominator) and accident data (numerator).

Following classification alignment, collision counts from Transportstyrelsen were aggregated by ship type and year. For each year, the total number of collisions involving dry cargo ships, passenger ships and tankers was computed. Correspondingly, exposure variables from VTI's operational data that has been calculated based on HELCOM's AIS-data were aggregated to the same ship groups and temporal resolution.

The harmonised datasets were then merged based on common dimensions of year and ship type, ensuring structural consistency between accident frequencies and exposure measures. Subsequently, exposure-normalised collision rates were calculated by applying the defined normalisation formulas, using collision counts as the numerator and the corresponding activity measures as denominators.

To account for variations in traffic intensity, collision frequencies were normalised against collisions per 1,000 unique ships, collisions per 1 million hours in operation and collisions per 1 million kilometres sailed (Bye & Almklov, 2019).

Each exposure metric captures a different dimension of activity. Distance-based measures reflect spatial exposure, time-based measures capture operational duration, and fleet-based measures represent participation in the traffic system. No single metric fully captures exposure; therefore, multiple measures are employed.

2.3.1 Limitations

AIS-based activity measures may be affected by transmission gaps, coverage limitations and differences in ship compliance. Furthermore, ship types are not directly comparable risk units. Differences in operational patterns, navigational environments and regulatory frameworks may influence observed collision rates independently of safety performance. Accordingly, exposure normalised rates should be interpreted as relative indicators of risk rather than absolute measures of collision probability. The assumption of proportionality between exposure and accident occurrence may not hold in all cases and normalised rates should therefore be interpreted with caution.

3 Results and discussion

3.1 *Collision distribution and characteristics*

Figure 5 presents the spatial distribution of collision occurrences between 2011 and 2024 involving ships insured by Swedish Club. The pattern shows a clear concentration of collisions in the southern and central Baltic Sea, especially along major commercial routes such as approaches to Gothenburg and Malmö and the corridor leading toward the Gulf of Finland. A secondary cluster is visible in the Stockholm archipelago, reflecting the combined influence of high ship density and constrained navigational channels. In contrast, significantly fewer collisions are witnessed in the northern Baltic Basin, where ship density is comparatively lower. These spatial trends highlight the dominant role of traffic intensity and geographical complexity in shaping collision risk across the Baltic region.

Figure 5: Spatial distribution of collisions in the Baltic Sea of ships entered with the Swedish Club (2011 - 2024)

Source: Swedish Club

The heat-map (Figure 6) of the spatial distribution of collisions recorded in EMCIP reveals several prominent spatial clusters across European waters, indicating that collision risk is not uniform but strongly shaped by traffic density, port proximity and navigational constraints.

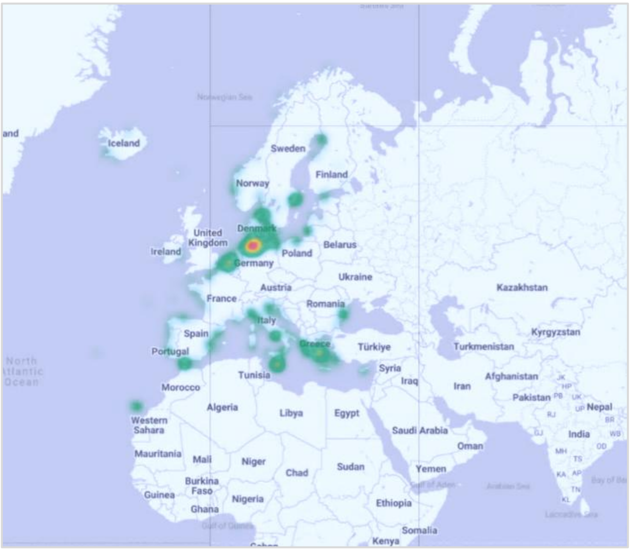


Figure 6: Heat map of ship collisions in EU waters: 2011 - 2024 (N=1315)

Source: EMCIP

Worldwide, 2,875 collisions were reported between 2015 and 2024 which shows that collision risk is persistent (Allianz, 2025). At European level, EMCIP database contains 1,264 collision cases from 2011 to 2023 (Figure 7), while HELCOM documents 851 collisions within the Baltic Sea between 2000 and 2019, confirming the navigational challenges inherent to the Baltic Sea region.

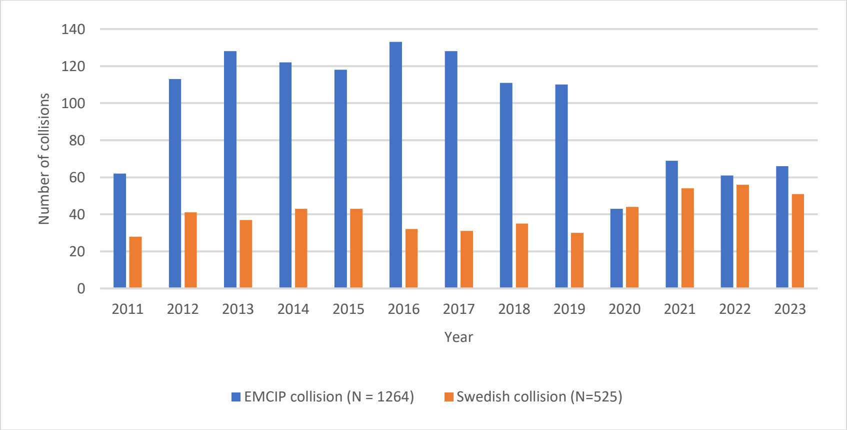


Figure 7: EMCIP v. Swedish collisions (2011-2023)

Source: Transportstyrelsen; EMCIP

Collisions in Swedish waters are dominated by passenger ships accounting for 59% of collisions, followed by dry cargo ships (19%) and tankers (4%) (Figure 3). In terms of severity, minor accidents dominate (94%), with serious accidents accounting for only 6% (Figure 8).

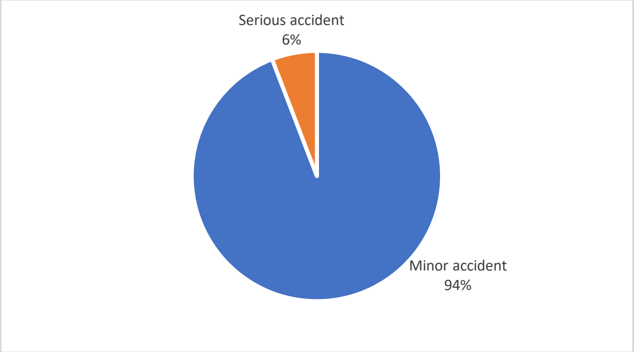
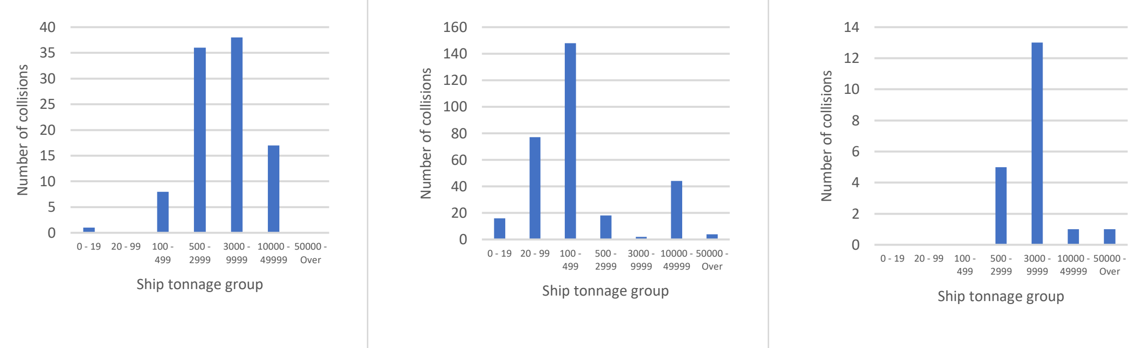


Figure 8: Distribution of Collision Accidents by Severity: 2011 - 2023 (N = 429)

Source: Transportstyrelsen

The distribution of collisions by ship tonnage group shows distinct patterns across passenger ships, dry cargo ships and tankers, indicating that collision is strongly associated with ship size and operational profile. For passenger ships, collisions are highly concentrated in 100-499 GT range (Figure 9b). Passenger ships which are over 10,000 GT account for a few incidents. The distribution indicates that passenger ships below 500GT dominate collision occurrences, reflecting their intensive operation in short-distance routes, frequent port calls and/or navigation in confined or congested waters. For dry cargo ships, collisions are primarily concentrated in 3,000-9,999 GT and 500-2,999 GT ranges (Figure 9a). The pattern suggests that collision risk for dry cargo ships is associated with medium-sized ships. For tankers, collisions are limited (Figure 9c).



(a) Dry cargo ship distribution by ship tonnage group (N=100)

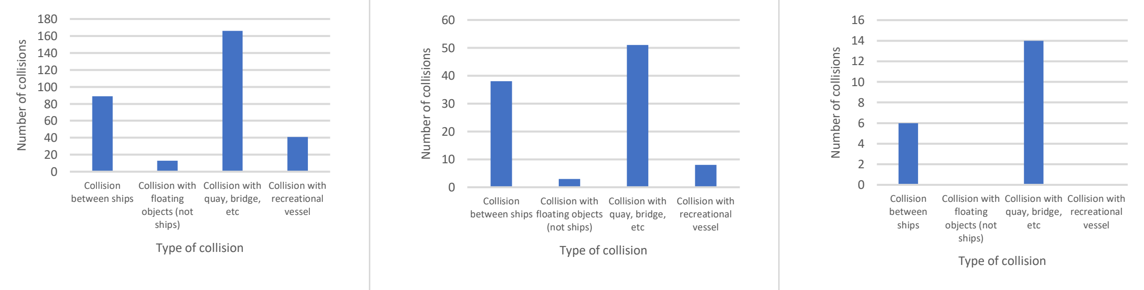
(b) Passenger ship distribution by ship tonnage group (N=309)

(c) Tank ship distribution by ship tonnage group (N=20)

Figure 9: Characteristics of ships involved in collisions in Swedish waters: 2011 -2023 (N = 429)

Source: Transportstyrelsen

On collision types distribution, collision with quay, bridge, etc dominate across the three ship types, indicating that manoeuvring phases constitute the primary collision-prone conditions (Figure 10). Collision between ships form the second largest category, especially for passenger ships, suggesting that interaction risk increases in high-density traffic environments where ship encounters are frequent. In contrast, tanker collisions are limited in number but are also primarily associated with collision with quay, bridge, etc, indicating that their risk exposure is operationally concentrated in port and terminal environments rather than during open-sea navigation.



(a) Collision involving passenger ships (N = 309)

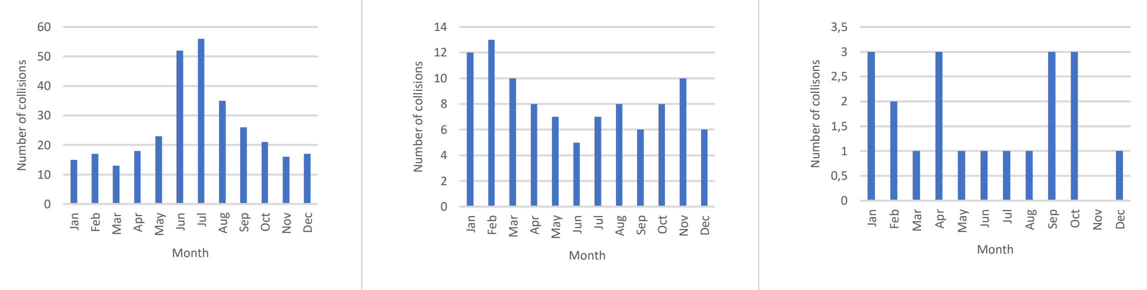
(b) Collisions involving dry cargo ships (N = 100)

(c) Collisions involving tankers (N = 20)

Figure 10: Collision types in Swedish waters per ship types: 2011 -2023 (N =429)

Source: Transportstyrelsen

Seasonal distribution of collisions indicates that collision risk in Swedish waters is strongly influenced by temporal variations in maritime activity rather than environmental severity alone. Passenger ship collisions show peak during the summer months, especially in June and July (Figure 11a), reflecting increased traffic density associated with seasonal passenger demand and recreational maritime activity. This suggests that collision risk for passenger ships is exposure-driven, where higher traffic volumes and intensified ship interactions elevate the likelihood of incidents. In contrast, dry cargo ship collisions (Figure 11b) are more evenly distributed throughout the year, with moderate increases during winter and early spring, indicating that their risk profile is less seasonal and more closely tied to continuous commercial operations. Tanker collisions (Figure 11c), although limited in number, do not exhibit a clear seasonal pattern, suggesting that their occurrence is operationally constrained and not significantly influenced by seasonal traffic fluctuations. Notably, the absence of a clear increase in collisions during periods typically associated with severe environmental conditions indicates that collision occurrence is more strongly linked to traffic intensity and operational complexity than to adverse weather or ice conditions.



(a) Passenger ship collisions (N = 309)

(b) Dry cargo ship collisions (N = 100)

(c) Tanker collisions (N = 20)

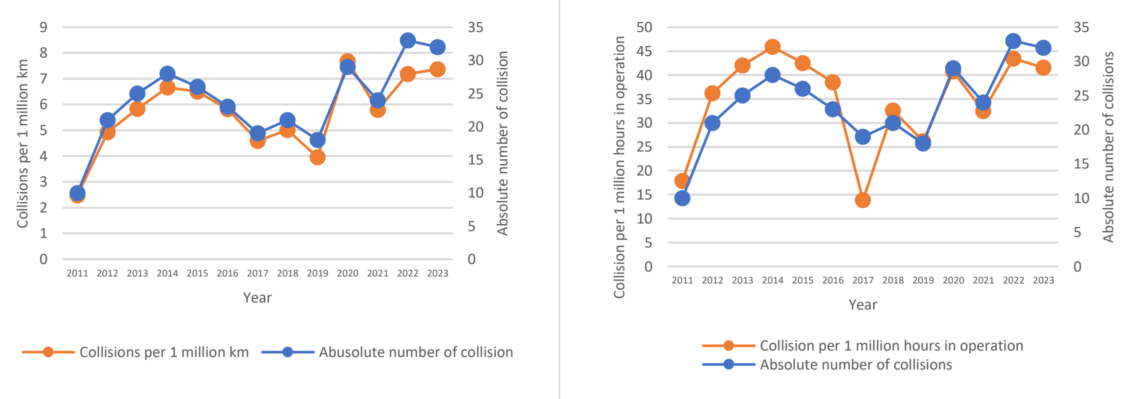
Figure 11: Seasonal distribution of ship collisions in Swedish waters: 2011-2023 (N = 429)

Source: Transportstyrelsen

3.2 Collision trends

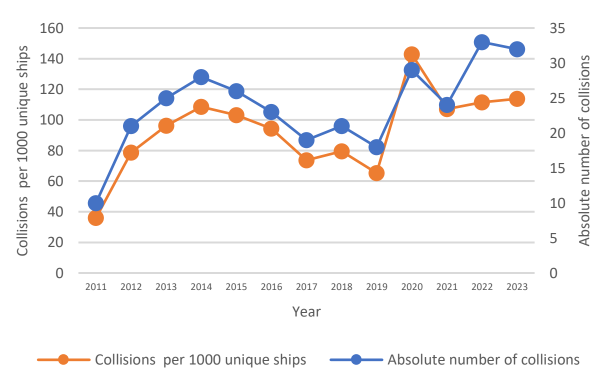
3.2.1 Collision trends among passenger ships

Trends in passenger ship collisions (Figure 12) indicate that absolute collision frequency and exposure-normalised rates follow broadly similar trajectories, suggesting that variations in collision occurrence are largely driven by changes in operational activity. The increase observed between 2011 and 2014, followed by a decline towards 2017–2019, is consistently reflected across distance -, time-and fleet-normalised metrics, indicating that collision risk per unit of activity remained relatively stable during this period. The sharp increase in 2020, followed by fluctuations in subsequent years, is evident across all normalisation approaches, suggesting a system-wide shift in operational conditions rather than a denominator-specific artefact. Importantly, the close alignment between absolute and normalised trends implies that exposure (traffic intensity, operational hours and fleet size) is the primary driver of collision frequency. However, minor divergences between the three-normalisation metrics highlight that different exposure dimensions capture distinct aspects of risk, with time-based rates showing greater variability, reflecting sensitivity to operational intensity during active navigation phases.



(a) Distance-normalised collision rates

(b) Time-normalised collision rates



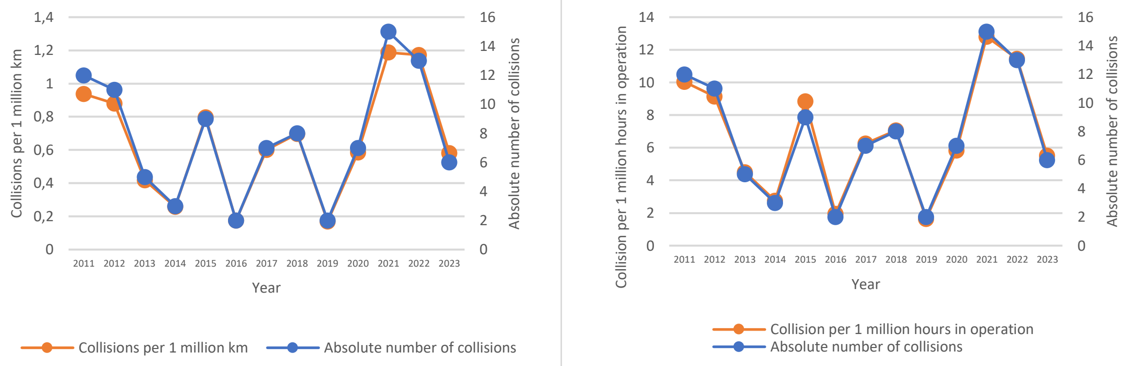
(c) Fleet-normalised collision rates

Figure 12: Trends in passenger ship collision frequency and exposure-normalised collision rates in Swedish waters: 2011 - 2023 (N = 309)

Source: VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen

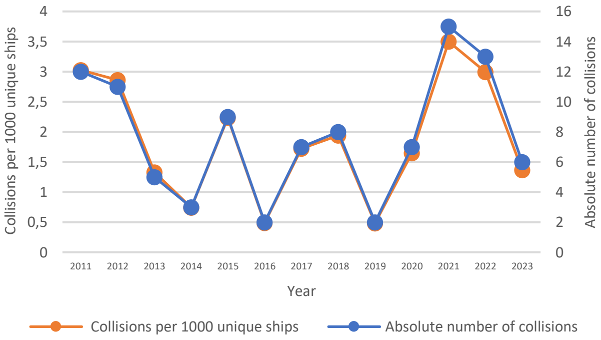
3.2.2 Collision trends among dry cargo ships

Trends for dry cargo ship collisions (Figure 13) indicate that absolute collision frequency and exposure-normalised rates exhibit a high degree of alignment across all three denominators, suggesting that variations in collision occurrence are largely driven by changes in operational activity rather than disproportionate increases in risk. The declining trend observed between 2011 and 2014, followed by fluctuations and a notable increase around 2019–2021 and steady decline between 2021 and 2023 is consistently reflected in distance -, time-and fleet-normalised rates, indicating that collision risk per unit of activity remained relatively stable over time. The peak observed in 2021 across all metrics suggests a system-wide increase in exposure or operational intensity, rather than an anomaly driven by a single denominator. Unlike passenger ships, dry cargo ships show more moderate variability and lower fluctuations, reflecting the more stable and continuous nature of cargo operations. Minor divergences between the three normalisation approaches, especially in time-based rates, indicate that operational intensity during active navigation phases may influence risk more strongly than distance sailed or fleet size alone.



(a) Distance-normalised collision rates

(b) Time-normalised collision rates



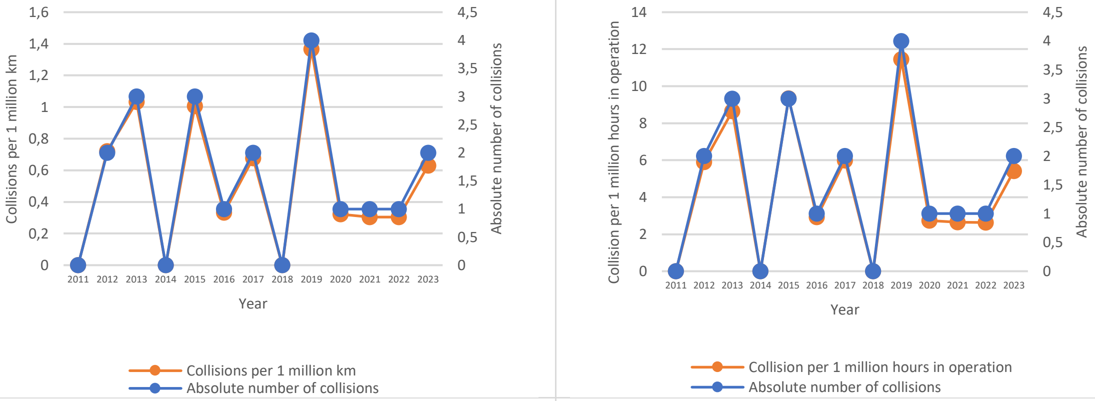
(c) Fleet-normalised collision rates

Figure 13: Trends in cargo ship collision frequency and exposure-normalised collision rates in Swedish waters: 2011 - 2023 (N = 100)

Source: VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen

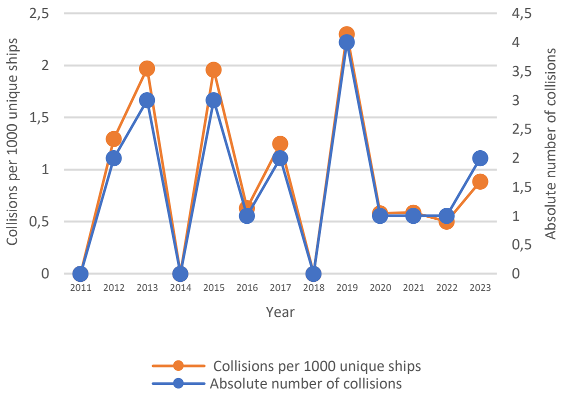
3.2.3 Collision trends among tankers

Trends for tanker collisions (Figure 14) exhibit high variability and discontinuity across all exposure-normalised measures, reflecting the influence of a small sample size rather than systematic changes in underlying risk. Unlike passenger and dry cargo ships, tanker collisions occur infrequently, resulting in year-to-year fluctuations that are highly sensitive to single events, as evidenced by zero values and sharp peaks. The close alignment between absolute counts and all three normalised metrics indicates that normalisation does not fundamentally alter the trend structure, but rather amplifies variability due to the low denominator and numerator values. Consequently, observed peaks should not be interpreted as sustained increases in collision risk. Absence of a clear temporal trend suggests that tanker collision risk is operationally constrained and not driven by gradual changes in exposure or safety performance. Instead, the results highlight that tanker collisions are stochastic in nature, where risk is better characterised by low probability but high consequence potential, rather than by frequency-based trend analysis.



(a) Distance-normalised collision rates

(b) Time-normalised collision rates



(c) Fleet-normalised collision rates

Figure 14: Trends in tanker collision frequency and exposure-normalised collision rates in Swedish waters: 2011 - 2023 (N = 20)

Source: *VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen*

3.2.4 Collisions per 1 million km: Passenger ships, dry cargo ships and Tankers

Distance-normalised collision rates reveal clear differences in risk intensity across ship types, indicating that collision likelihood per unit of navigational exposure is highest for passenger ships throughout the study period (Figure 15). Passenger ships consistently exhibit higher rates compared to dry cargo ships and tankers, with a peak in 2020, suggesting that collision risk is strongly linked to intensive short-distance operations and frequent manoeuvring rather than total distance sailed alone. In contrast, dry cargo ships maintain relatively low and stable rates, indicating that their collision frequency is proportionate to exposure and reflects more predictable operational patterns. Tanker rates remain low but highly variable, with occasional spikes driven by isolated collisions, reinforcing the interpretation that distance-based normalisation is sensitive to low-frequency occurrences in small datasets.

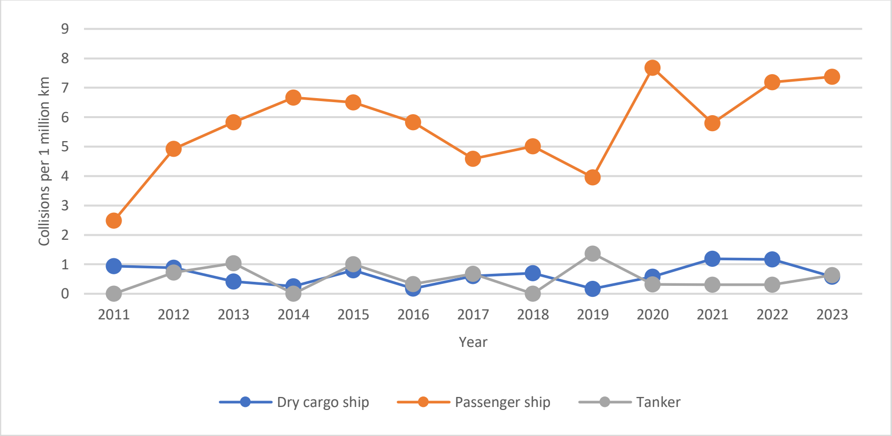


Figure 15: Collisions per 1 million km: 2011-2023 (N = 429)

Source: VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen

3.2.5 Collisions per 1 million hours in operation: passenger ships, dry cargo ships and tankers

Time-normalised collision rates (Figure 16) further show dominance of passenger ships in terms of collision risk per 1 million hours in operation, while also providing additional insight into the role of operational intensity. Passenger ships consistently show the highest rates, with notable fluctuations and peaks, indicating that collision likelihood is strongly associated with periods of active manoeuvring and high interaction intensity rather than simply distance sailed. The sharp decline observed around 2017, followed by recovery, suggests temporal variability in operational conditions or traffic patterns. In contrast, dry cargo ships show lower and more stable rates, although with moderate increases in later years, implying that risk remains broadly proportional to operational exposure but may be influenced by changes in traffic intensity or port activity. Tanker rates remain low but highly variable, with occasional spikes in 2019 reflecting the sensitivity of time-based normalisation to low-frequency events. Compared to distance-based metrics, the time-based measure captures operational exposure during active navigation more directly, highlighting that collision risk is closely linked to time spent in complex navigational conditions, especially for ships operating in congested or manoeuvring-intensive environments.

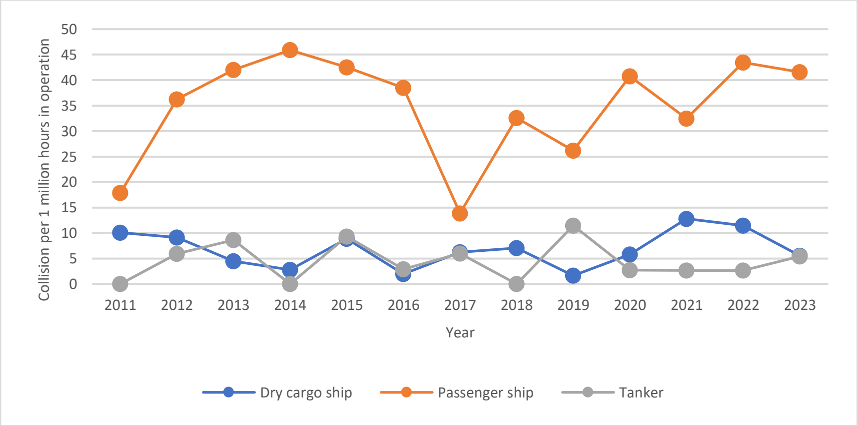


Figure 16: Collisions per 1 million hours in operation: 2011-2023 (N = 429)

Source: VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen

3.2.6 Collisions per 1,000 unique ships: passenger ships, dry cargo ships and tankers

Fleet-normalised collision rates (Figure 17) provide insight into collision risk relative to number of unique ships and further highlight high risk associated with passenger ships. Passenger ships consistently exhibit substantially higher rates than dry cargo ships and tankers, with a peak around 2020, indicating that collision frequency is not solely a function of fleet size but is strongly influenced by operational intensity and interaction density. This suggests that even when accounting for the number of unique ships, passenger ships remain exposed to higher interaction-driven risk due to frequent port calls and operations in congested environments. In contrast, dry cargo ships show relatively low and stable rates, implying that collision occurrence scales more proportionally with fleet size and reflects more uniform operational patterns. Tanker rates remain minimal but exhibit occasional fluctuations, again reflecting low-frequency, event-driven dynamics rather than systematic risk trends. Compared to distance-and time-based metrics, the fleet-based measure underscores that participation in the traffic system alone is insufficient to explain collision risk and that differences in operational behaviour and navigational context are critical determinants of collision likelihood.

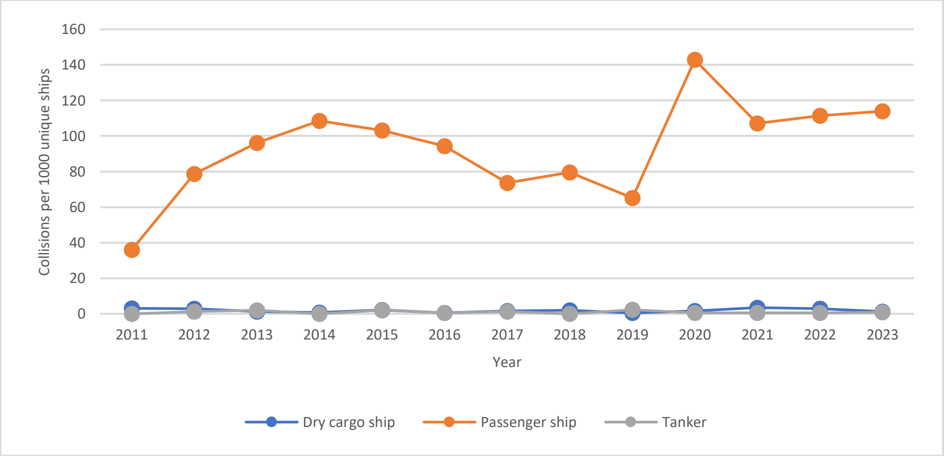


Figure 17: Collisions per 1,000 unique ships: 2011-2023 (N = 429)

Source: VTI's operational data calculated based on HELCOM's AIS-data; Transportstyrelsen

3.3 *Consequences of ship collisions*

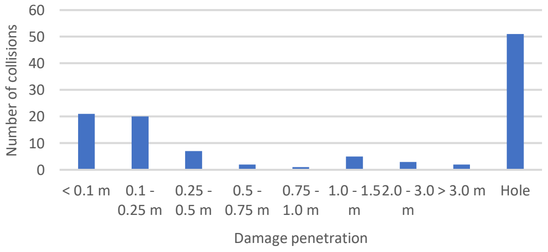
3.3.1 Consequences to humans

Fatalities from ship collisions at global level, continue to pose a serious safety concern. Allianz (2025) documents 342 collision-related fatalities between 1960 and 2015, while EMSA (2024) reports 650 fatalities associated with 444 serious maritime casualties from 2014–2023, of which 225 were directly attributed to collisions. Although collisions are often non-fatal, the figures demonstrate their capacity for severe consequences when they occur. In contrast, only two fatalities were recorded in Swedish waters during 2011 - 2024 period. The low count relates to majority of Swedish collision events taking place at low speeds and in port approaches.

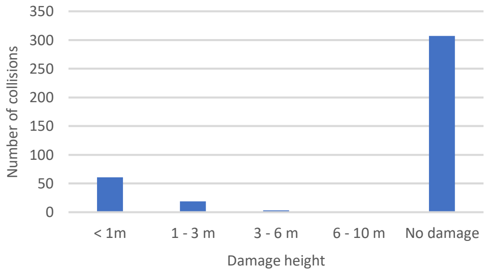
As for injuries, global and European regional data indicate a similar pattern. EMSA (2024) documents 3,535 injuries linked to collision events between 2014 and 2023 which highlights operational risks.

3.3.2 Consequences to ships

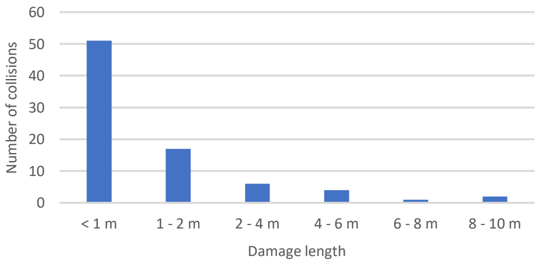
Consequences of ship collisions in Swedish waters are characterised by low-severity damage and limited structural penetration, reflecting the operational context in which most collisions occur. A majority of collisions result in either no damage (307 cases) or minor external damage below 1 metre in height, indicating that collisions typically involve low consequence energy and occur during controlled manoeuvring phases (Figure 18b). Penetration data further support this pattern, with most cases involving shallow damage or no hull breach, while severe penetrations and full structural breaches (e.g., holes) remain relatively low. The vertical distribution of damage shows a strong concentration between the summer load line and all-weather deck, suggesting that collisions primarily affect the side shell above critical watertight boundaries, thereby limiting the risk of flooding and loss of ship integrity. Longitudinally, damage is most frequently located at the bow and stern, indicating that collision events are largely associated with approach, berthing and manoeuvring interactions rather than high-speed midship consequences. Transverse damage patterns further confirm that consequences are distributed across port and starboard sides, consistent with multi-directional interactions in confined and congested navigation environments. The results indicate that ship collision consequences in Swedish waters are limited. However, the presence of occasional deeper penetrations and hull breaches highlights low-probability escalation pathways, where structural damage could lead to flooding or more severe consequences under less controlled conditions.



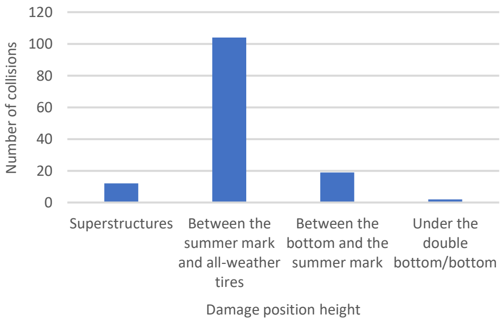
(a) Damage penetration (N=112)



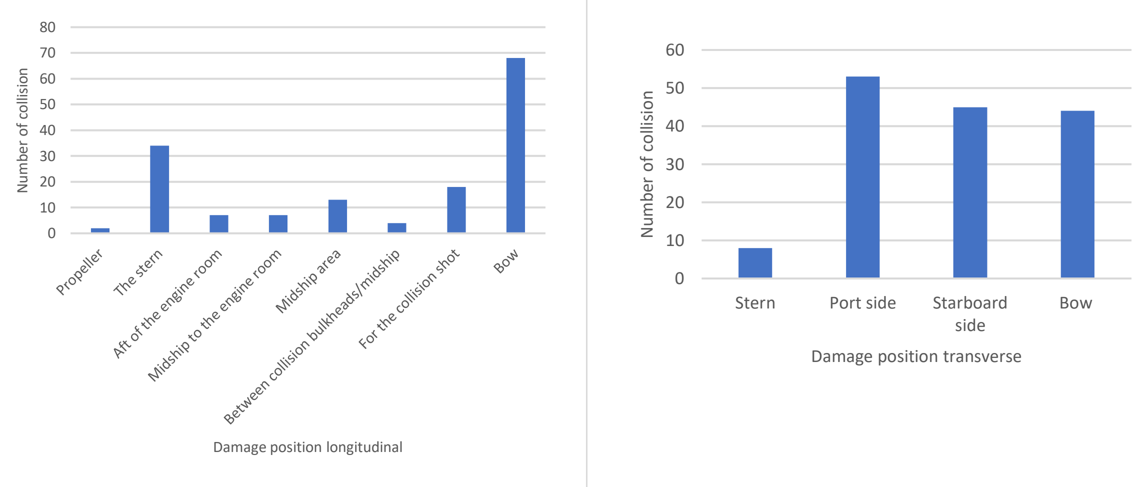
(b) Damage height (N=391)



(c) Damage length (N=81)



(d) Damage position height (N=137)



(e) Damage position longitudinal (N=153)

(f) Damage position transverse (N=150)

Figure 18: Consequences to ships’ structure following collision involving passenger ships, dry cargo ship and tankers in Swedish waters: 2011-2023 (N = 429)

Source: Transportstyrelsen

3.3.3 Consequences to the marine environment

Consequences to the marine environment of ship collisions in the Baltic Sea and Swedish waters are characterised by a low frequency of pollution events but a high potential for severe ecological consequence. Spatial analysis (Figure 19) of 3,150 shipping accidents in the Baltic Sea between 2011 and 2024, including 1,052 incidents in Swedish waters, indicates that pollution-related events are concentrated in high-traffic and navigationally complex areas, especially the approaches to Gothenburg and the Stockholm archipelago. This spatial clustering demonstrates that environmental risk is closely linked to traffic density and operational complexity, rather than being uniformly distributed across maritime space. Although most accidents do not result in pollution, those that do occur disproportionately in ecologically sensitive and confined coastal environments, where the consequences of even minor spills may be amplified.

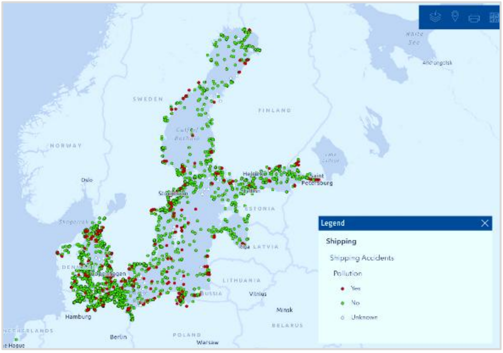


Figure 19: Shipping accidents in Baltic Sea involving marine pollution

Source: HELCOM

Long-term trends in major oil spills in the Baltic Sea (Table 1) reveal a decline in large-scale pollution events since the 1990s, largely attributable to regulatory improvements, including the adoption of double-hull tanker designs and strengthened international conventions.

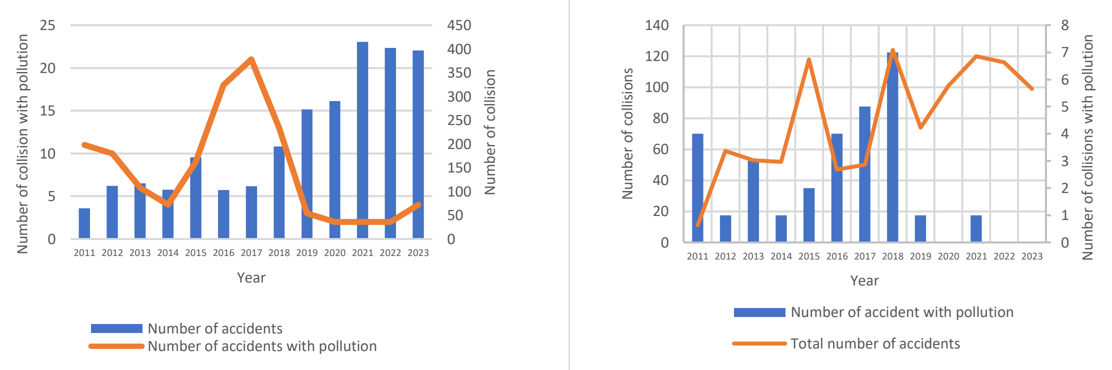
However, the persistence of smaller, recurrent spill events indicates that operational risk has not been eliminated but rather transformed, shifting from high-magnitude, low-frequency incidents to low-magnitude, recurrent releases associated with routine operations and minor accidents.

Table 1. Major accidental oil spills in the Baltic Sea

Source: HELCOM

Block year	Total volume (major spills)	Spill source - spill volume
1969 -1974	1660tn	• Palva - 200tn • S/S Eira - 50tn • M.T Raphael - 250tn • M.T Esso Nordica - 600tn • M.T Pensa - 500tn • M.T Pronto - 60tn
1975 -1979	5680tn	• M/S Altair - 80tn • M.T Antonio Gramsci - 5500tn • M/S Lloud Bage - 100tn
1980 -1984	19305tn	• Furenas - 200tn • Eva Oden - 250tn • Jose Marti - 1000tn • Sefir - 375tn • Globe Asimi - 16730tn • M/S Eira - 300tn • Ibn Roch - 450tn
1985 -1989	1590tn	• M/S Sotka - 370tn • Thuntank5 - 200tn • M/S Antonio Gramsci - 650tn • M/S Tolmiros - 250tn • Okba Bnou Nafia - 120tn • Thuntank
1990 -1994	1183tn	• Volgoneft - 900tn • Vastra Gotalands - 178tn • Jan Heweliusz - 105tn
1995 -1999	509tn	• Hual Trooper - 180tn • M/S Maersk Euro Quinto - 170tn • Halsingland - 70tn • Nunki - 89tn
2000 -2004	4150tn	• M.T Alambra - 250tn • Baltic Carrier - 2700tn • Fu Shan Hai - 1200tn
2005 -2009	200tn	• Proevestenen - 200tn
2010 -2014	150tn	• Golden Trader - 150tn
2015 -2019	0tn	• None
2020 -2025	0.5tn	• Butinge offshore oil terminal - 0.5tn

Comparative analysis further shows that, despite a slight increase in overall collisions, collision involving pollution remain consistently low in both the Baltic Sea and Swedish waters (Figure 20). Sweden, in particular, recorded only 0.705 tonnes of oil spill between 2011 and 2023, indicating a high level of environmental performance in terms of spill prevention. However, this low volume should not be interpreted as low environmental risk. The Baltic Sea’s semi-enclosed, brackish nature, limited water exchange and high ecological sensitivity mean that even small-scale spills can result in disproportionate and long-lasting environmental consequences. Consequently, environmental risk in Swedish waters is best understood as low-frequency but high-consequence, where rare events dominate overall risk despite their minimal contribution to total accident counts.



(a) Baltic sea

(b) Swedish waters

Figure 20: Shipping accidents with pollution in Baltic Sea and Swedish waters: 2011 - 2023

Source: HELCOM

3.4 *Likely cost of collisions in Swedish waters*

3.4.1 Costs associated with consequences to humans

Valuation of human consequences follows the current Swedish transport cost–benefit analysis framework (ASEK 8.0) which provides societal cost estimates for fatalities and injuries incorporating risk valuation (Value of a Statistical Life), healthcare costs, emergency response and loss of production for the road sector (ASEK-gruppen, 2024). Unit values enable the quantification of potential welfare consequences associated with collision scenarios, even in contexts where severe human consequences are limited. As shown in Table 2, societal cost of fatality exceeds USD 5.8 million (2019 value), increasing to USD 7.8 million under projected 2045 conditions which indicates that low frequency, high severity events carry serious economic implications despite being rare.

Table 2: Societal valuation of deaths and injuries in Swedish transport CBA (ASEK 8.0) (includes risk valuation, healthcare costs and lost production)

Source: ASEK 8.0 (2024)

	2019 (USD)	**2045 (USD)**
Death	5,828,680	7,844,100
Very seriously injured	2,085,820	2,758,470
Seriously, exclude very seriously injured	1,379,950	1,854,600
Seriously injured	1,616,780	2,166,780
Not seriously injured	81,840	109,340

In the Swedish context, where fatalities and serious injuries are limited, these valuations serve primarily as scenario-based indicators of potential consequence rather than reflections of observed consequences. The empirical accident data indicate that most collisions occur under low-speed, controlled conditions with minimal human consequences. However, the application of ASEK values for the road sector demonstrates that the economic significance of collision risk is driven disproportionately by rare high-severity events, reinforcing the importance of considering consequence severity alongside frequency in risk assessment.

Comparison with marine insurance data further highlights the distinction between societal and financial cost perspectives. Average personal injury claims reported by Swedish Club (Figure 21) show moderate variability over time, with a notable peak in 2020, but remain substantially lower than ASEK-based societal valuations for the road sector which shows differences in scope as insurance claims capture realised compensation and liability costs, whereas ASEK values for the road sector represent broader societal welfare losses, including intangible risk components. As such, the two approaches are complementary rather than interchangeable, providing a more comprehensive understanding of the economic consequences of collisions.

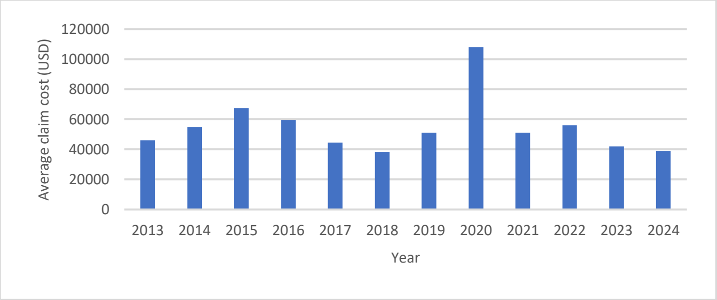


Figure 21: Average claim cost for personal injury (2013 - 2024)

Source: Swedish Club

3.4.2 Costs associated with consequences to ship

Although high-severity ship losses are rare in Swedish waters, global and regional datasets indicate that the financial consequences of collision events can escalate rapidly when structural damage, ship value and operational disruption are combined. In 2024, collision incidents involving tankers generated repair and recovery costs exceeding USD 10 million, with the largest insurance losses surpassing USD 30 million (Nordic Association of Marine Insurers, 2024). These cases highlight that economic risk is highly concentrated in low-frequency, high-severity events, where costs are driven not only by hull damage but also by salvage operations, cargo handling disruptions and loss of operational time.

Analysis of ocean hull claims further demonstrates that costs scale with ship characteristics and condition. The average claim per gross ton between 2015 and 2024 is approximately USD 1.588, although temporal variation is evident, with peaks reflecting years of higher severity incidents rather than systematic cost inflation (Figure 22). When disaggregated by ship age, ships in the 10 - 20-year range exhibit the highest cost per gross ton (Figure 23), indicating that such ships are more costly to repair following collision damage. This suggests that cost exposure is not linear with age but is instead influenced by a combination of remaining asset value, repair complexity and technological integration.

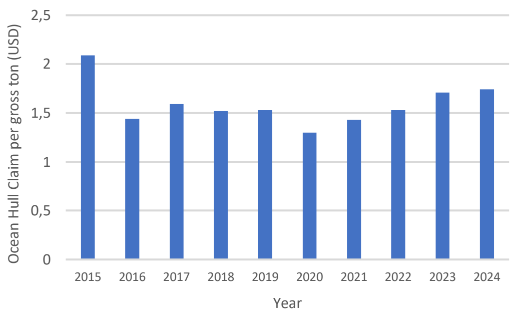


Figure 22: Ocean Hull Claim per gross ton by accident year in USD: 2015-2024

Source: NoMIS

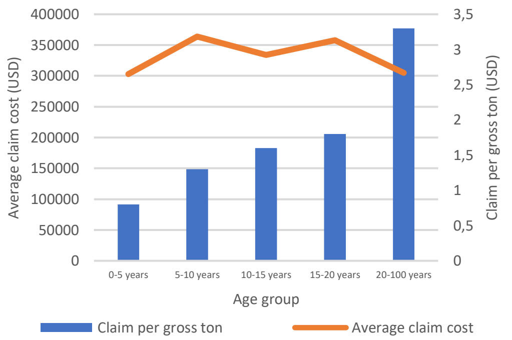


Figure 23: Ocean Hull Claim per gross ton and average claim cost by age group: 2019-2024

Source: NoMIS

Variation by ship type further reinforces the structural nature of cost risk. Tankers, bulk carriers and passenger ships exhibit among the highest average claim costs, reflecting their larger size, higher asset value and more complex onboard systems, all of which contribute to increased repair costs (Figure 24).

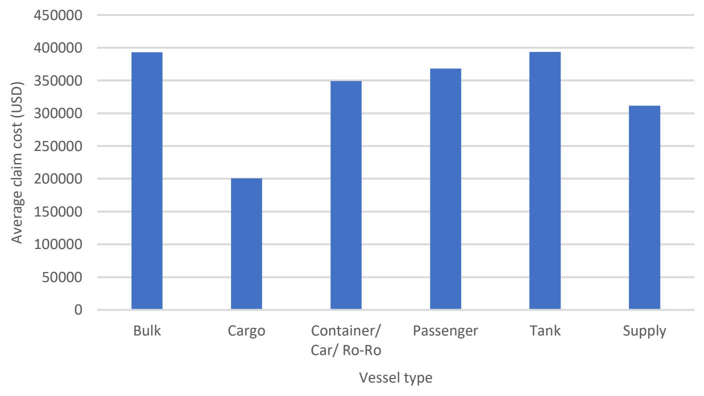


Figure 24: Ocean Hull Average claim cost, by ship type for accident period 2019-2024

Source: NoMIS

3.4.3 Costs associated with consequences to the marine environment

Economic consequences of marine pollution arising from ship collisions are highly variable and strongly dependent on environmental sensitivity, spill size and response complexity (ITOPF, 2025). Global evidence from ITOPF indicates that clean-up costs can escalate in coastal and confined environments, with historical incidents such as Nokhodka (1997), Erika (1999) and Solar I (2006) incurring unit costs ranging from approximately USD 14,000 to over USD 20,000 per tonne. The cases demonstrate that spill response costs are not linear with volume, but are instead driven by factors such as type of shoreline, logistical constraints and the need for ecological restoration.

In Baltic Sea context, region-specific modelling suggests clean-up costs of approximately USD 13,000 per tonne (Vanem et al., 2008). However, this estimate likely represents a lower-bound approximation, as the semi-enclosed nature, low salinity and high ecological sensitivity of the Baltic Sea can amplify both environmental damage and response costs. In Swedish waters, where archipelagic coastlines and shallow ecosystems dominate, spill consequences are likely to be spatially concentrated and operationally complex, requiring intensive shoreline remediation and long-term monitoring. Consequently, even relatively small spills can generate disproportionately high economic and ecological costs.

Although only 0.705 tonnes of oil spill were reported in Swedish waters between 2011 and 2023, this low volume should not be interpreted as indicative of low environmental risk. Instead, the findings highlight that environmental cost exposure is dominated by low-frequency, high-consequence events, where a single large spill could result in multi-million-dollar response costs and long-term ecological damage.

4 Representative ship collisions scenarios for Swedish waters

Representative collision scenarios were identified based on distribution of collision types and ship types (Table 2 and Figure 21) and operational context (Figure 22).

Table 3: Distribution of collision accidents by collision type, ship type and severity: 2011-2023 (N = 429)

Source: Transportstyrelsen

Type of collision	**Ship type**	**Minor accident**	**Serious accident**	**Total**
Collision between ships	Dry cargo ship	33	5	38
	Passenger ship	80	9	89
	Tanker	5	1	6
	Sub-total	118	15	133
Collision with floating objects (not ships)	Dry cargo ship	3	0	3
	Passenger ship	13	0	13
	Sub-total	16	0	16
Collision with quay, bridge, etc.	Dry cargo ship	50	1	51
	Passenger ship	161	5	166
	Tanker	14		14
	Sub-total	225	6	231
Collision with recreational ship	Dry cargo ship	8		8
	Passenger ship	37	4	41
	Sub-total	45	4	49
Total		404	25	429

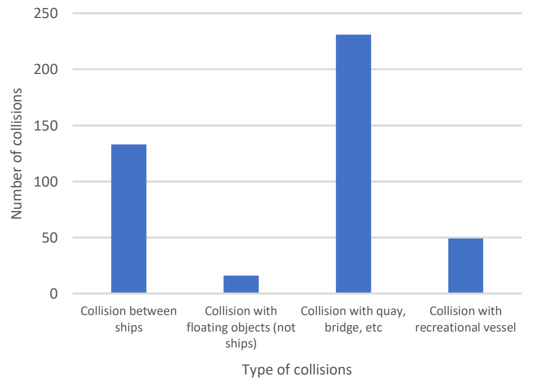


Figure 25: Type of collision: 2011-2023 (N=429)

Source: Transportstyrelsen

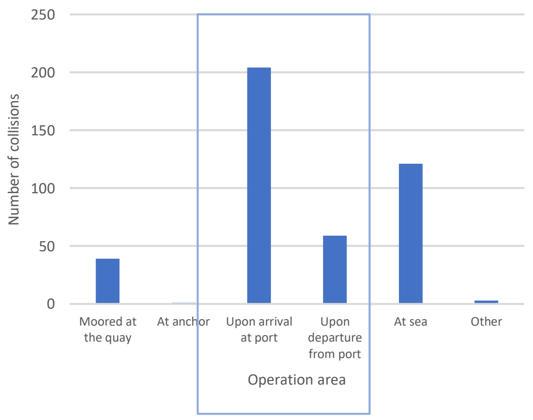


Figure 26: Type of ship operation (N = 427)

Source: Transportstyrelsen

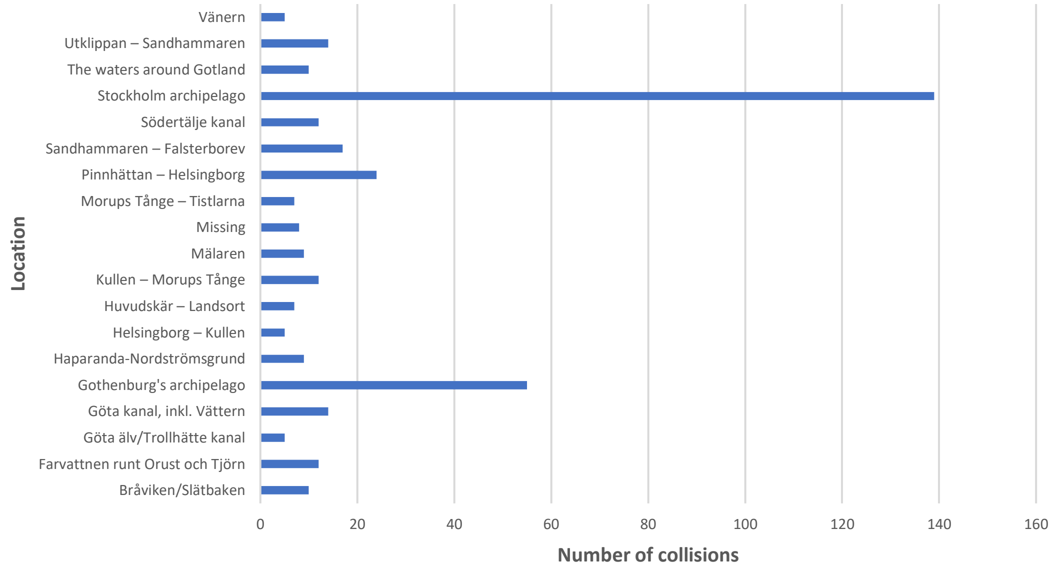


Figure 27: National area where collision occurred: 2011-2023 (N = 374)

(Locations with less than 5 collisions are excluded to make the graph more visible)

Source: Transportstyrelsen

4.1 *Most likely collision scenario: passenger ship colliding with quay, bridge, etc*

The most frequent collision scenario involves passenger ships colliding with quay, bridge, etc during manoeuvring in confined waters. This is the dominant collision type, accounting for 231 cases, of which 166 involve passenger ships, representing the largest single contribution across all ship-collision combinations (Table 3). Passenger ships exhibit comparatively elevated collision rates across distance-and time-based normalisation measures which indicates that their high collision frequency is not solely a function of traffic volume but is also influenced by operational exposure in constrained and high-density environments, where manoeuvring and port operations dominate (Section 3.2.4). The scenario is strongly associated with port approach and berthing operations (Figure 26) and high-density traffic areas such as Stockholm archipelago and Gothenburg (Figure 27). Consequences are predominantly minor accidents, limited structural damage in most cases and low environmental consequences. This scenario therefore represents a high-frequency, low-severity operational risk, driven by manoeuvring complexity rather than abnormal conditions.

4.2 *Second most likely collision scenario: collision between ships*

Collisions between ships represent the second most frequent collision category in Swedish waters, accounting for 133 cases within the dataset. Passenger ships constitute the majority of these events (89 cases), indicating their central role in ship – ship interaction dynamics (Table 3). This category also records the highest number of serious accidents (15 cases), suggesting a greater potential for severe consequences compared to other collision types. When examined using exposure-normalised measures, collision between ships exhibit higher variability, especially in time-based rates, indicating that risk is concentrated during periods of active navigation rather than passive transit Figure 12 (Section 3.2.5). The involvement of two actively navigating ships implies that collision occurrence in this category is associated with interaction processes, including negotiation, manoeuvring and traffic complexity in constrained waterways (Figure 27). The involvement of two actively navigating ships increases the likelihood of higher consequence energy and escalation, resulting in moderate to severe structural damage and a greater probability of injuries. This scenario therefore represents a moderate-frequency, higher-severity risk, where interaction processes rather than exposure alone determine collision occurrence.

4.3 Third most likely collision scenario: dry cargo ship colliding with quay, bridge, etc.

Dry cargo ship collisions with quay, bridge, etc represent the third most likely collision scenario in Swedish waters, accounting for 51 recorded cases (Table 3). These events occur primarily during port approach and departure operations, where ships interact directly with infrastructure under confined navigational conditions. The dominance of quay and bridge contacts by dry cargo ship indicates that such collisions are concentrated in manoeuvring-intensive environments, where spatial constraints and reduced safety margins increase the likelihood of contact. Exposure-normalised analysis shows that dry cargo ships exhibit lower distance-based collision rates compared to passenger ships, suggesting that their collision frequency is broadly proportional to operational activity rather than disproportionately elevated (Section 3.2.4). Consequences are typically limited to minor structural damage to ships and infrastructure, with negligible environmental consequence and few reported injuries.

4.4 Fourth most likely collision scenario: tanker collision

A tanker collision with another ship or infrastructure, has the potential for hull breach and oil spill. Tanker-related collisions are relatively rare (20 cases), with occurrences distributed across both collision with quay, bridge, etc (14 cases) and collision between ships (6 cases) (Table 3). Tanker collision rates show high variability across normalisation measures, especially in fleet-based and time-based metrics (Section 3.2.5-3.2.6). Despite being rare (Figure 3), tanker collisions carry a high risk-profile due to the potential for hull breach and oil spill. Consequences may include severe environmental damage, high economic costs associated with cleanup and compensation, and long-term ecological consequences in the sensitive Baltic Sea environment (Section 3.4.3). This scenario is characterised by low probability but high consequence, where consequence severity dominates overall risk considerations.

5 Policy implications for collision risk management

The findings of this study indicate that collision risk in Swedish waters is structured across distinct operational and consequence dimensions, requiring a differentiated and multi-layered policy response. Sweden already maintains a high standard of maritime safety governance, supported by advanced Ship Traffic Services (VTS), regulatory compliance with international conventions and strong environmental protection frameworks. The results presented here do not suggest deficiencies in existing systems, but rather provide empirical refinement of how collision risk is distributed across ship types, operational contexts and consequence domains.

A key implication is that risk is not uniformly distributed across the maritime system, but is concentrated in specific operational phases and ship categories. High-frequency collisions involving passenger ships are primarily associated with port approach, berthing and manoeuvring in confined and high-density environments, indicating that safety improvements should focus on operational precision, human performance and traffic coordination in these areas. This supports continued enhancement of VTS operations, pilotage practices and port traffic management, especially in complex regions such as the Stockholm archipelago and Gothenburg approaches. At the same time, collision between ships, which account for a higher proportion of serious accidents, highlight the importance of managing interaction risk, including navigational decision-making, communication and situational awareness in congested waterways.

The results also demonstrate that exposure-based metrics alone are insufficient to capture full risk profile, especially for ship categories such as tankers. While tanker collisions are rare, their potential consequences are high which underscores the need for continued emphasis on consequence-based risk management, including targeted spill prevention, contingency planning and rapid response capability. Existing Swedish preparedness systems, including national and regional spill response frameworks, remain critical in managing these low-probability, high-consequence events and should be maintained with particular focus on environmentally sensitive and high-traffic areas.

From an economic perspective, the analysis highlights that collision costs are highly skewed, with the majority of incidents resulting in low financial consequence. This has important implications for policy prioritisation, suggesting that safety investments should balance reducing frequent low-severity incidents with mitigating rare but high-cost events.

6 Conclusions

The study examined ship collision risk in Swedish waters using a multi-source, exposure-based analytical framework, integrating accident data with operational activity measures and consequence assessments. The results show that collision occurrence is primarily driven by operational exposure and navigational context, rather than being uniformly distributed across ship types. Passenger ships account for the majority of collisions and exhibit consistently higher exposure-normalised rates, reflecting intensive operations in confined and high-density environments such as port approaches and archipelagic waterways. Dry cargo ships display more stable and proportionate collision patterns, while tanker collisions are characterised by low frequency and high variability, limiting the applicability of conventional trend analysis. The identification of representative collision scenarios demonstrates that collision risk is across three dominant dimensions which include high-frequency, low-severity operational risks, interaction-driven risks with higher severity potential and low-frequency, high-consequence risks. The consequence analysis indicates that most collisions in Swedish waters result in limited human injury and fatality, minor structural damage and negligible environmental consequence, reflecting the predominance of low-speed, manoeuvring-related incidents. However, the potential for severe consequences remains, especially for tanker collisions, where environmental and economic consequences can be substantial despite being rare. The use of multiple exposure measures confirms that collision risk is multi-dimensional and cannot be adequately captured by a single metric, while also highlighting limitations in low-frequency datasets.

Author Contributions

Conceptualization, methodology, validation, formal analysis: A.H. & C.T.; Data curation, writing—original draft preparation: C. T.; Resources, writing—review and editing, visualization, supervision, project administration: A.H; writing—review, project administration: J-U. S-H & I. V. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data presented in this study can be made available subject to authorisation of release by the respective repositories.

Conflicts of Interest

The authors declare no conflicts of interest.

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