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Spatial distribution analysis of ship accidents in the Çanakkale Strait

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Abstract

This study used a spatial distribution analysis to identify the risky areas in the Çanakkale Strait – one of the narrowest waterways with high marine traffic – in terms of ship accidents. To accomplish this, a point density analysis, as part of the geographic information systems (GIS) methodology, was used to create accident density distributions and thematic maps. A total of 162 marine accidents in the Çanakkale Strait between 2007 and 2018 were taken into account. Detailed technical data of accidents were obtained from accident reports provided by the Turkish Maritime Search and Rescue Coordination Center (TMSRCC). The results showed that, among the 162 cases, bulk carriers have the highest accident rate, and most accidents at the Nara Turn were caused by engine failure. In addition, accidents due to navigational failure occurred in every region of the strait. Remarkably, factors directly and indirectly related to human error were still the determining factors in marine accidents. As a result, the risk of marine accidents was higher in the narrow portions of the waterway, and navigation was difficult, especially in areas such as the Nara Turn Point. In future research, it is recommended to consider a wider period of activities using different methods to provide more comprehensive results.

Introduction

Approximately 90% of worldwide trade by volume is carried by sea today, making ships an irreplaceable part of global trade (UNCTAD, 2019). The dramatic growth in global trade in recent years has led to an increase in the number, size, and voyages of ships (Branch, 2007). Although rapid developments in shipping technology and automation systems have increased operational efficiency, the expected decrease in the number of ship accidents has not been observed (Corovic & Djurovic, 2013; Ugurlu, Yildirim & Yuksekyildiz, 2013).

Marine accidents generally occur in waterways such as straits and canals with heavy traffic and geographical constraints (Chen et al., 2018; Luo & Shin, 2019). The Çanakkale Strait is a gateway that connects the Marmara Sea to the Aegean Sea and has a high risk of marine accidents such as grounding, collision, and drifting (Ilgar, 2015) due to the high ship traffic density (Ozcan, 2019). Ships crossing the Çanakkale Strait typically make an average of 10 route changes, with sharp route changes in the Nara Turn point and Kilitbahir region (Tatlisuluoglu, 2008). Determining the relationship between traffic density and the distribution of ship accidents has become one of the most important subjects of recent studies (Claramunt et al., 2007). Point density analysis is a popular spatial mapping methodology used by many researchers (Huang, Hu & Li, 2013; Acharya, Yoo & Lee, 2017).

However, few studies have attempted to determine the risky areas by spatially mapping marine accidents in difficult-to-navigate areas such as straits, narrow canals, and shallow waterways. Thus, the aim of this research is to identify the risky areas in terms of ship accidents in the Çanakkale Strait from 2007 to 2018 using point density analysis, which is a spatial mapping instrument in GIS.

Literature review

GIS is a methodology for storing, processing, and performing spatial analysis on geographical data (Burrough, 1986) and can be used to identify risky areas using the spatial distribution of accidents (Tuncuk & Karasahin, 2004). GIS instruments are used in many disciplines around the world to solve problems.

Spatial distribution analysis provides a visualization of the risk density distribution using hot spots on a map (Gundogdu, 2010). Spatial mapping of marine accidents can reveal the risk distribution and help prevent future accidents (Aerts et al., 2006). The spatial analysis of accidents can be used to identify areas that require precautions, as well as areas that must be protected (Erdogan et al., 2008). As an important tool for spatial mapping and tracking marine accidents, GIS has recently been used to investigate marine accidents and their effects (Dobbins & Abkowitz, 2010; Ugurlu et al., 2015; Ugurlu & Yildiz, 2016). Table 1 shows the selected studies based on the spatial analysis of marine accidents.

There are many studies in the literature involving the creation of spatial maps from accident data using quantitative approaches such as the kernel density methodology in GIS (Marven, Canessa & Keller, 2007; Shahrabi & Pelot, 2007; Giziakis, Kanellopoulos & Gialoutsi, 2013; Shin & Sung, 2017). As can be seen from Table 1, many have conducted a spatial analysis of marine accidents using GIS from 2004 to 2018. Using the kernel density methodology in GIS, Tufte et al. (Tufte et al., 2004) created an oil spill density map using the data of marine accidents in the Baltic Sea between 1998 and 2002. Shahrabi and Pelot (Shahrabi & Pelot, 2007) conducted a study to identify hazardous areas by performing a hot spot analysis that considered fishing boat accidents in Canadian waters. Ugurlu et al. (Ugurlu, Yildirim & Yuksekyildiz, 2013) performed a study based on thematic mapping of marine accidents to identify risky regions using data from 585 marine accidents that occurred between 2007 and 2011. Acharya et al. (Acharya, Yoo & Lee, 2017) revealed the spatial distribution of marine accidents

Table 1. Literature review of spatial analysis of marine accidents

Reference	Region	Methodology	Purpose	Data Set
Tufte et al., 2004	North Sea and Baltic Sea	Kernel Density Analysis (GIS)	Calculate oil spill distribution density	Marine accidents resulting in oil spill (1998–2002)
Shahrabi & Pelot, 2007	Canadian Atlantic Waters	Kernel Density Analysis (GIS)	Identify risky areas	Fishing boat accidents (1997–1999)
Marven, Canessa & Keller, 2007	Canadian Pacific Region	Kernel Density Analysis (GIS)	Spatial mapping of SAR incidents	1993–1999 SAR incident data
Shahrabi & Pelot, 2009	Atlantic Region	Kernel Density Analysis (GIS)	Identify risky areas	1997 to 1999 fishing accident data
Balaguer et al., 2011	Spanish Waters	Geo-spatial analysis (GIS)	Mapping of the anchorage area for recreational boats	2006 and 2007 (June-September) recreational boat data
Ugurlu, Yildirim & Yuksekyildiz,2013	Worldwide	Geo-spatial analysis (GIS)	Density mapping of marine accidents and identifying risky regions	2007–2011 (585 ship accidents)
Giziakis, Kanellopoulos & Gialoutsi, 2013	Greek Waters	Kernel Density Analysis (GIS)	Density mapping of oil spill distribution	2001 to 2011 oil spill accident
Ugurlu et al., 2015	Worldwide	Geo-spatial analysis (GIS)	Thematic mapping of marine accidents	1998–2010 (Oil tanker accidents)
Ugurlu & Yıldız, 2016	Global	Geo-spatial analysis (GIS)	Reveal marine accident risks on the transportation sector	1991–2015 passenger vessel accident data
Shin & Sung, 2017	Korea	Kernel Density Analysis (GIS)	Identify geomorphologic characteristics of marine accidents using hotspots	1997 to 2016 ship accidents data
Acharya, Yoo & Lee, 2017	Korea	Geo-spatial analysis (GIS)	Reveal the distribution of marine accidents	2007 to 2014 ship accident data
Buber et al., 2018	Turkey	Geo-spatial analysis (GIS)	Illustrate marine risk areas	2011 to 2016 ship accidents data

from 2007 to 2014 to define risky coasts. Buber et al. (Buber et al., 2018) performed a geospatial analysis to illustrate risky marine areas by considering 115 ship accidents between 2011 and 2016 in the Aegean region.

Materials and methods

The aim of this study was to determine the risky areas in terms of ship accidents in the Çanakkale Strait using GIS instruments based on ship accident data. To accomplish this we performed spatial analysis using MapInfo 8.0, a software that provides acceptable results for analysis and strategy for geographical, economic, political, cultural, and industrial problems (Velioglu, 2014, p. 18). The system reassesses the functions of storage, simulation, analysis, and visualization using real-time accident data (Ray et al., 2007). In this way, the GIS application uses the data from accidents to create a density distribution (Abousaeidi, Fauzi & Muhamad, 2016). Thus, GIS performs a spatial analysis that enables the creation of digital maps using location data (Huang, Hu & Li, 2013). In recent years, GIS methodology has been used in studies based on marine accidents (Acharya, Yoo & Lee, 2017).

In this study, a detailed report of each accident in the Çanakkale Strait was obtained first. Then, the data from the reports were converted into a format that could be put into the software. The "point density analysis", a methodology using the hot spots to define accident intensity, was used to create an accident risk distribution map. Point density analysis was used to observe how the point density of the samples in the study area was distributed. In this analysis, the density surface was created from the points. After performing a detailed feature analysis, the vector feature was converted to a raster surface. The point density was calculated with regards to the number of points in each pixel or in a defined cell (Maantay & Ziegler, 2006). This analysis evaluated the intensity of spot characteristics in each output raster cell. Technically, the amplitude per unit area within a neighbourhood was analysed. The total value of spots in the area was divided by the neighbourhood size to obtain the intensity rate of each cell (Er et al., 2010). With this analysis, the regional distribution of marine accidents is shown on the thematic map created using different colour codes. Sub-themes on the thematic map are divided into classes such as ship type, flag, and the cause and type of accident. Finally, the study area was divided into 2 km × 2 km grid cells to evaluate the number of accidents per area to create a density map, and four risk levels were specified according to the frequency of ship accidents. Marine areas were classified as low-risk ($x \leq 1$), medium-risk ($1 < x \leq 3$), high-risk ($3 < x \leq 5$), and very high-risk ($x \geq 6$).

Data

In this study, a total of 162 marine accidents in the Çanakkale Strait during the period between 2007 and 2018 were taken into account. The detailed technical data about accidents were obtained from accident reports provided by the Turkish Maritime Search and Rescue Coordination Center (TMSRCC, 2020). The accident distribution according to the ship type is shown in Figure 1.

As seen in Figure 1, among 162 cases, bulk carriers have the highest accident rate (62.3%), followed by ferries (9.8%) and tankers (9.2%). The distribution of the types of accidents by sector is shown in Figure 2.

As can be seen from Figure 2, the navigation zones in the Çanakkale Strait are divided into three sectors. Navigational safety is provided by VTS for each sector. It is observed that grounding accidents were especially common in the Kumkale region, and the risk of collision was high in the Gelibolu VTS region. The distribution of accidents by ship type is shown in Figure 3.

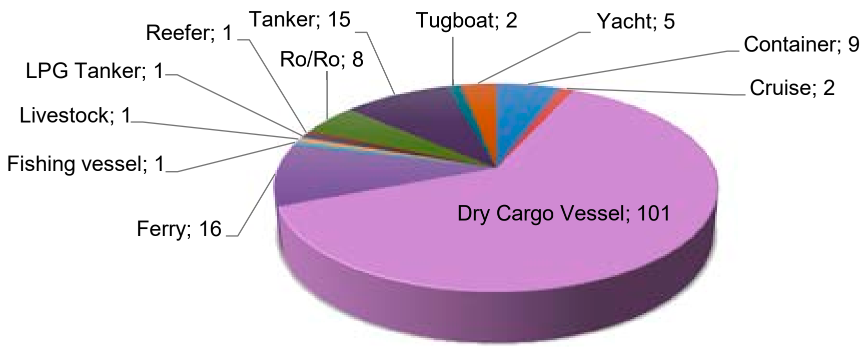


Figure 1. Distribution of accidents as a function of ship type

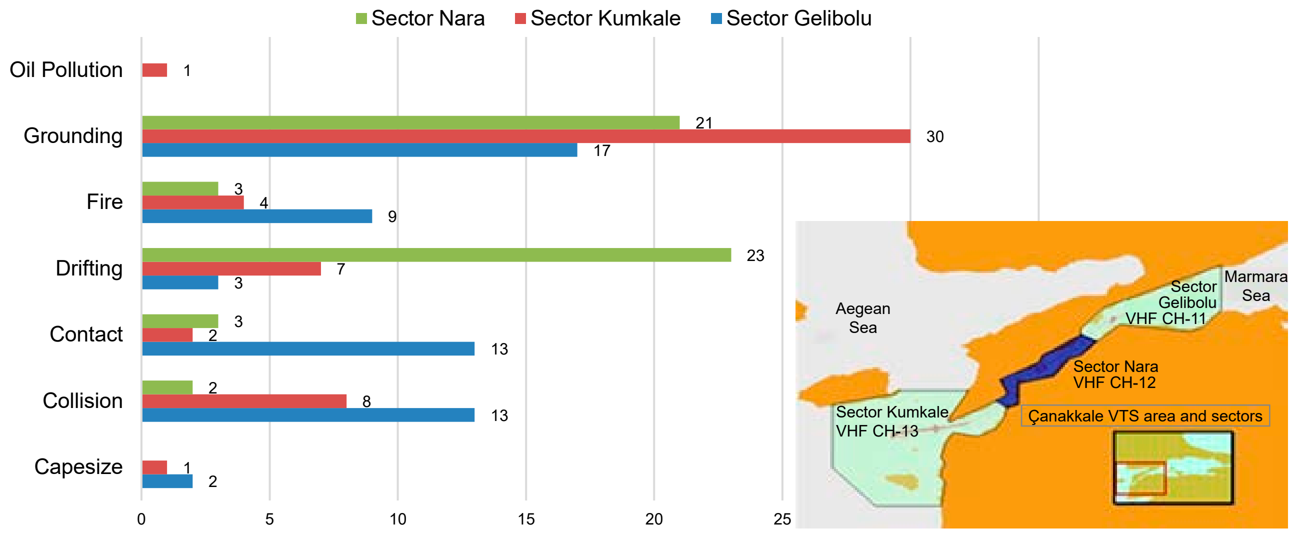


Figure 2. Distribution of accident type by sector

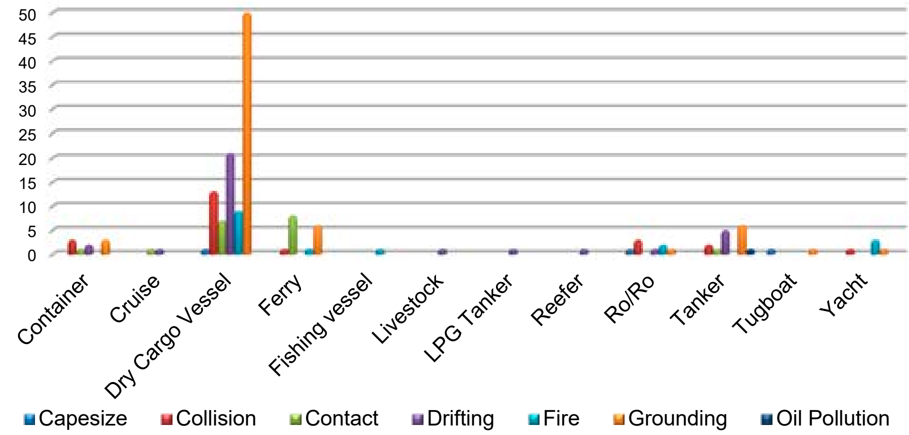


Figure 3. Distribution of accidents by ship type in the Çanakkale Strait

Figure 3 shows that accidents that result in grounding, collision, and drifting frequently occur in this region. It is also observed that the most frequent emergency situation on dry cargo vessels is grounding (73%) and ferries typically have accidents that result in frequent contact (44%).

Study area

The Çanakkale Strait is a narrow waterway that is very difficult to navigate due to its geographical restrictions (Ilgar, 2015), and it has been identified as one of the most accident-prone regions in the world (Kilic & Sanal, 2015). The Çanakkale Strait is located in a region that is very sensitive to the effects of marine accidents (Ilgar, 2015) and accommodates 50,000 ship passages per year (Akten, 2004; Usluer, 2016). This region has recently seen an increase in the quantity of dangerous cargo transported, along with an increase in overall maritime traffic.

The biggest risk factors in the straits are large ships, sub-standard ships, and ships carrying dangerous cargo passing through the Black Sea and Aegean Sea (Tatlisuluoglu, 2008). To improve the safety of navigation and mitigate marine accident risks in the Turkish Straits, the Vessel Traffic Service (VTS) was established (Essiz & Dagkiran, 2017). The Çanakkale VTS area is divided into 3 sectors: Sector Gelibolu (VHF Ch 11), Sector Nara (VHF Ch 12), and Sector Kumkale (VHF Ch 13) as shown in Figure 4 (Essiz & Dagkiran, 2017).

The figure shows that the strait is a curved waterway where frequent changes of course and speed are required, especially for the Nara Turn – the narrowest point of the Strait – which is one of the risky points where accidents frequently occur.

Finding and results

The data obtained from the accident reports were classified according to their technical details. They were then converted into a format suitable for the software. The region was divided into 2 km × 2 km

Figure 4. Aerial picture and VTS sectors of Çanakkale Strait (TSVTS, 2020)

grid cells, and accidents were distributed according to these grids. The risks were determined depending on the number of accidents per grid, and colour coding was made according to the risk severity. Then, thematic maps were created using the locations, types, flags, and root causes of each accident. Finally, the geographical distribution of marine accidents was composed as shown in Figures 5–7.

As seen in Figure 5a, accidents especially occurred in areas near the shore and where the canal was narrow. It was observed that dry cargo ship accidents occurred, especially in the Nara Turn area and Kumkale region, and ferry accidents frequently occurred in the Gelibolu region (Figure 5b).

As shown in Figure 6a, most of the accidents that occurred at the Nara Turn were caused by engine failure. It was also concluded that accidents due to navigation failure occurred in all regions of the strait. According to Figure 6b, grounding, a major portion of the accidents, occurred in the area between Kumkale and the Nara Turn. In addition, the Nara Turn stands out as the region where drifting accidents occurred most frequently, and collisions and contact accidents were frequently observed in the Gelibolu region.

As can be seen from Figure 7a, foreign-flagged ships (99; 61%) were more involved in accidents than Turkish flagged ships (63; 39%). In addition, the risk levels as a function of the location intensity of the accidents were divided into 4 groups: very high-risk, high-risk, medium-risk, and low-risk. According to the analysis, the Nara Turn was determined to be a very high risk (VHR) zone due to the high number of accidents per polygon. Besides, regions including the approach from Kumkale to Nara and the approach from Nara to Gelibolu were defined as high-risk (HR) areas. Other regions were determined to be medium-risk (MR) and low-risk (LR) regions.

Conclusions and discussion

In this study, we investigated marine accidents in the Çanakkale Strait, one of the busiest, narrowest, and curved waterways in the world. In this context, a total of 162 marine accidents in the strait between 2007 and 2018 were analysed. It was concluded that the risk of marine accidents was higher – especially in areas such as the Nara Turn – where the waterway was narrow and navigation was difficult. To increase navigational safety and reduce the geographical constraints of the region, the waterway can be expanded

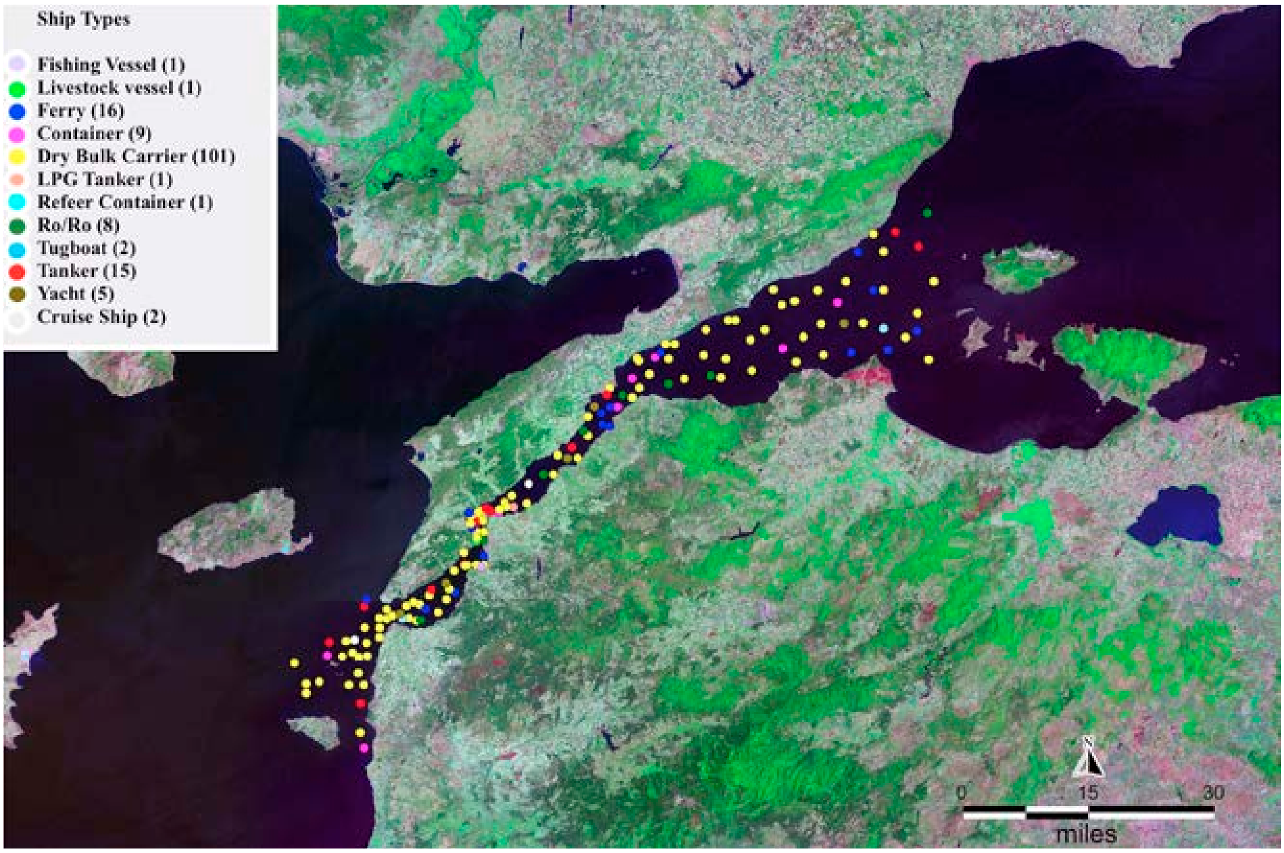
Additional measures should be taken to increase navigational safety to reduce accident risks. For instance, due to the unique navigational characteristics of the Çanakkale strait, it is necessary to encourage the embarkation of a pilot to reduce accident risk.

Marine accidents pose serious risks to life, property, and the environment in this region. Possible marine pollution can lead to environmental disasters. Thus, it is recommended to establish regional response centres to instantly react to accidents and to eliminate environmental risks arising from them.

The main factors causing accidents include navigational error, machinery failure, and other reasons that were not detailed. It is striking that the factors directly and indirectly related to human error were still the determining factors in marine accidents. For this reason, it is recommended to carry out necessary studies to take corrective and preventive measures by determining the factors contributing to human error. Vessel Traffic Services (VTS) operations should be carried out more intensely to eliminate risks, especially in risky areas.

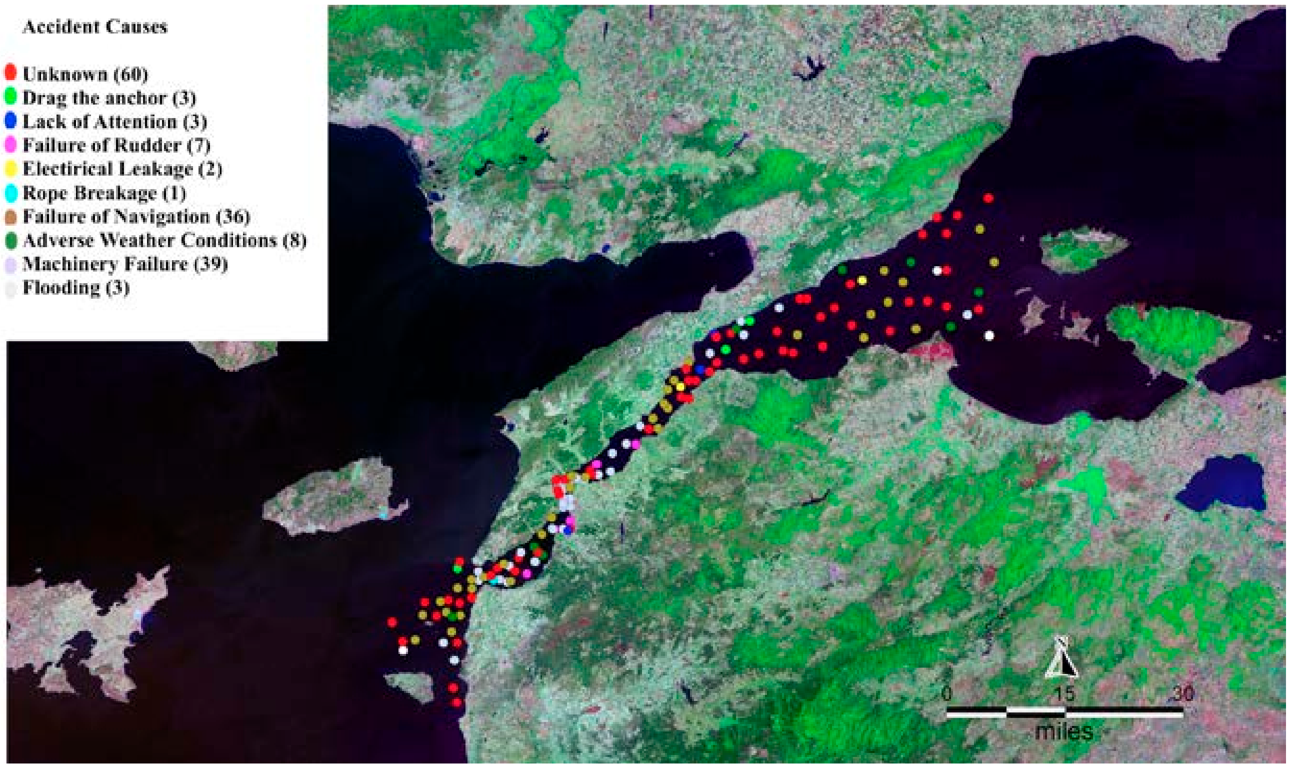
In summary, to reduce these risks, it is extremely important to perform a risk assessment in light of

(a)



(b)

Figure 5. (a)–(b) Spatial distribution of marine accidents and distribution mapping of ship types



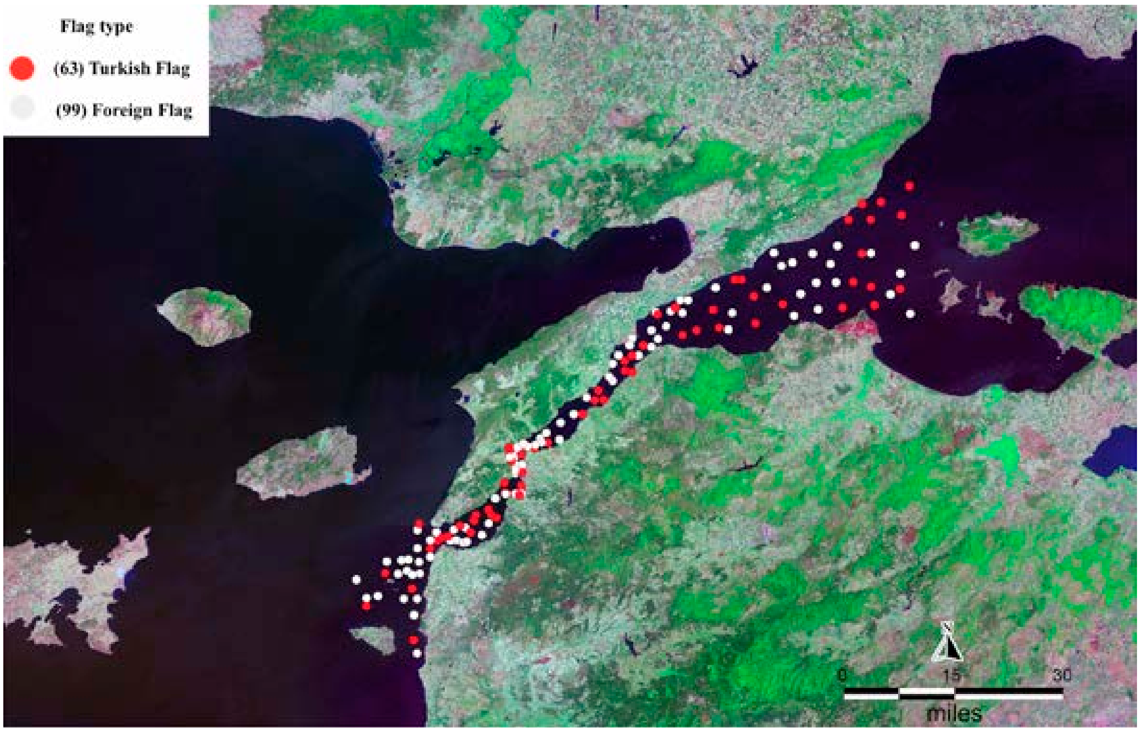
(a)

(b)

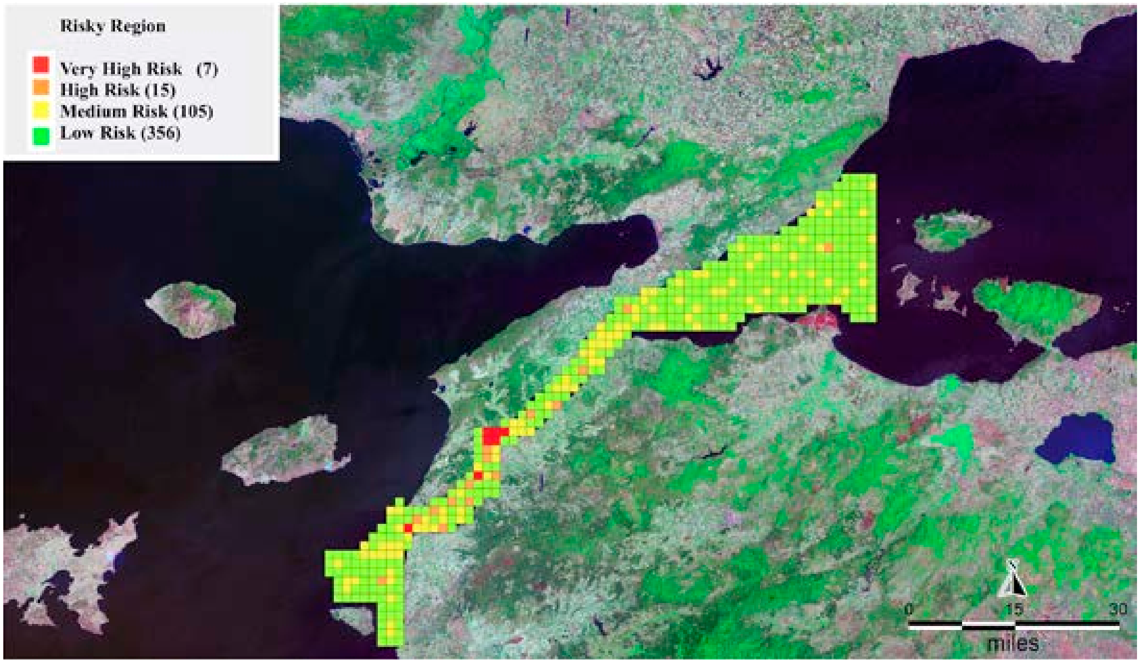
Figure 6. (a)–(b) Spatial distribution of marine accidents according to the accident cause and type

regional hazards, to ensure effective communication and coordination with ships, and to use necessary navigation tracking systems and guiding elements.

One of the most important limitations of this study is that detailed technical information was not included in the accident reports given by the administration and that the causes of many accidents were not disclosed. In this study, marine accidents in the Çanakkale Strait between 2007 and 2018 were examined, and the data before 2007 were excluded; thus, we recommend considering a wider period with more detailed technical information.



(a)



(b)

Figure 7. (a)–(b) Spatial distribution of marine accidents regarding flag and risk levels

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