

Analysis of Marine Accidents within the Jurisdiction of the Harbourmaster's Office Zadar: Identifying the High-Risk Areas

T. Mavra, A. Zekić, A. Gundić & L. Grbić

University of Zadar, Zadar, Croatia

ABSTRACT: The paper analyses marine accidents in the area under the jurisdiction of the Harbourmaster's Office Zadar. This research examines the categories of events, types of vessels, and the chronological distribution of accidents. Marine accident analysis has revealed a high incidence rate involving boats, predominantly in summer, and has highlighted several high-risk areas. The paper aims to identify the most common types of marine accidents and the times of year when they are most likely to occur. Furthermore, this paper proposes preventive measures to re-duce the risk of marine accidents and to enhance navigational safety. The recommendations include fostering cooperation between the Vessel Traffic Service and the masters, deploying smart cameras, providing maritime traffic safety education, implementing regular data collection proce-dures, prohibiting autopilot use in coastal waters, installing psychological floating barriers at des-ignated swimming areas, and increasing the frequency of inspections during the summer months. The authors suggest implementing preventive measures in high-risk areas, like Mali Ždrelac and Mala Proversa.

1 INTRODUCTION

The maritime transport sector is complex and risky. Marine accidents can cause casualties, losses of property and cargo, and environmental pollution. Marine accidents have posed a significant ongoing challenge to the international maritime community throughout history. In response to these accidents, the maritime industry has created international agreements improving safety standards, liability rules, and environmental protection. [2] Marine accidents often occur because of a series of errors rather than a single mistake [6].

Renowned for its stunning natural beauty, the Zadar archipelago is the Adriatic's most intricately indented archipelago, comprising four groups of islands: 24 larger islands and around 300 smaller islets and rocks, with only 17 being inhabited [12].

Favourable climatic conditions also contribute to the attractiveness of this area. Natural factors largely determine tourist activity. Zadar's strategic location makes it an important nautical tourism destination [12]. The highest concentration of nautical tourism activity occurs during July and August, with over 50% of marina visits and overnight stays reported [14]. Maritime traffic in the Zadar area also fluctuates seasonally. The seasonal nature of tourism creates disparities in tourist activity, demand, and traffic flow, both temporally and spatially [13]. Therefore, a study of marine accidents was performed on a monthly basis.

Maritime traffic considers the Mali Ždrelac and Mala Proversa passages in the Zadar area the busiest and riskiest. This is particularly true during the summer when the traffic is at its peak. The high concentration of vessels in these narrow and shallow sea areas increases the possibility of marine accidents.

In summer, there is a significant increase in the number of vessels, posing challenges regarding safety and maritime traffic management.

This paper examines marine accidents in the Port of Zadar area. The analysis details various aspects of marine incidents: the type of incident, the vessel involved, and their annual distribution. This analysis examines several facets of marine incidents, including type of event, vessel type, and yearly occurrence. The research aims to determine which types of marine accidents are most common, on which type of vessel, and in which period of the year they most often occur. Therefore, it is imperative to implement preventive measures to improve navigational and overall maritime safety, thus reducing maritime risk and protecting both the sea and the coastline.

The article's structure comprises five key sections. After the introduction, the second part defines marine accidents. The article emphasises the marine accident regulatory bodies in the Republic of Croatia. The third part of the article analyses marine accidents in the area under the jurisdiction of the Harbourmaster's Office Zadar over a five-year period. The researchers based their analysis on the event's nature, the vessel's type, and its annual occurrence. The fourth part presents the risk areas within the jurisdiction of the Harbourmaster's Office and proposes measures to improve safety. The last, fifth part, comprises concluding comments.

2 MARINE ACCIDENTS AND THE AREA UNDER THE JURISDICTION OF THE HARBOURMASTER'S OFFICE ZADAR

Definitions of marine accidents differ between countries and organisations that report them, making it difficult to compare statistics in different areas [4]. The term "marine accident" or "marine casualty" refers to an event or a sequence of events that has resulted in the loss or damage of a ship, cargo, or other property at sea. This type of accident often results in significant expenses and can also cause human casualties, including injuries or deaths among crew members, passengers, or other persons [15]. When they happen, marine accidents have a significant impact on the environment, society, and economy [2].

Marine accidents do not happen randomly; they stem from specific causes or a combination of various factors. Such incidents are frequently attributed to failures in human systems, structural system malfunctions, and environmental influences affecting these failures. [1,19]. These are typically attributed to natural events, such as weather and route visibility, the ship's hull stability and equipment condition, traffic congestion, and the navigator's knowledge, skills, and health [5]. Marine accidents can result in loss of life, environmental pollution, and damage to the cargo and vessels [21]. The most common types of marine accidents are collision/contact, grounding, foundering, fire, capsizing and sinking [3].

The consequences of marine accidents may include:

- the death or serious injury of a person occurring directly in connection with the operations of the ship or another watercraft,

- the loss of a person from a vessel resulting from or related to its operation or exploitation,
- the loss, presumed loss or abandonment of a ship,
- significant damage to a vessel,
- the stranding, disabling, or collision of a ship, or,
- damage to maritime infrastructure facilities caused by or related to the operation of the vessel,
- damage to the vessel that harms the marine environment and arises from or is associated with its operations [18].

In the Republic of Croatia, the Ministry of the Sea, Transport, and Infrastructure is responsible for surveying and investigating marine accidents.

The staff of the Harbourmaster's offices conduct marine accident investigations. The Harbourmaster's offices serve as the primary administrative authority for navigation safety, executing administrative and inspection duties within their legal framework [17]. They perform these activities to maintain safe, efficient, and environmentally responsible maritime operations within their jurisdiction.

There are eight Harbourmaster's offices in Croatia. Figure 1 displays their areas of jurisdiction.

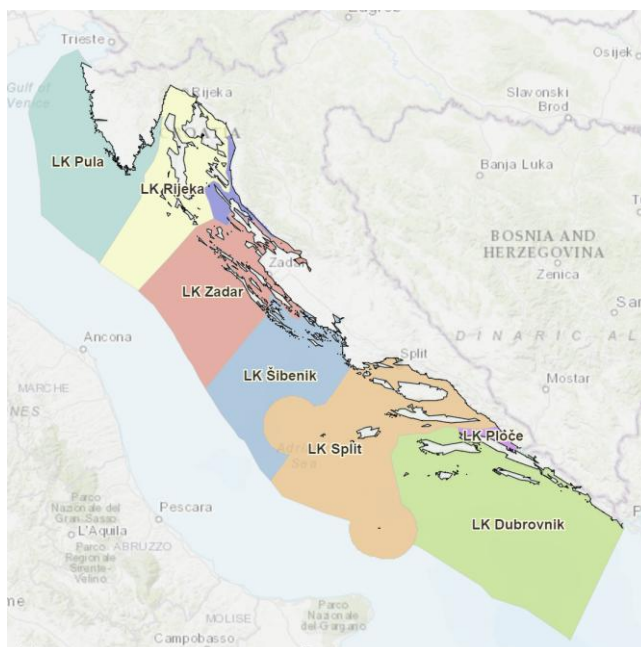


Figure 1. Areas under the jurisdiction of Harbourmaster's offices. Source: [7]

The area of jurisdiction of the Harbourmaster's Office Zadar, is marked in red. The Office comprises seven branch offices. These are Biograd na Moru, Novigrad, Starigrad Paklenica, Pag, Preko, Sali and Silba. The branch offices perform tasks within the scope of the head office in the cities and municipalities outside the head office.

The independent investigative body, the Air, Maritime and Rail Transport Casualty Investigation Agency, conducts safety investigations into marine accidents. The Agency's principal task is to determine the causes of accidents to improve safety and prevent similar marine accidents in the future. The agency conducts detailed investigations and analyses all relevant circumstances. Its findings often lead to recommendations for improving safety standards and procedures. The conclusion of each safety investigation

involves the release of a formal report summarising the results [20].

3 ANALYSIS OF MARINE ACCIDENTS WITHIN THE JURISDICTION OF THE HARBOURMASTER'S OFFICE ZADAR

3.1 The total number of marine accidents

The COVID-19 pandemic had a significant impact on the development of maritime transport. Travel restrictions implemented during the pandemic led to substantially reduced maritime operations. Figure 2 shows the total number of marine accidents between 2019 and 2023.

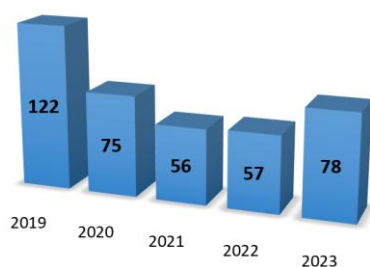


Figure 2. The total number of marine accidents, 2019-2023

The highest number of marine accidents was recorded in 2019. The following year saw a reduction of roughly 40%. The trend continued to decline in 2021. Marine accidents slightly increased in 2022 and were followed by a considerably larger rise in 2023. Reduced marine transport activities during the pandemic years led to fewer marine accidents. The reduction in marine accidents during global restrictions has emphasised the critical necessity of implementing preventive measures. These measures are crucial for improving safety in everyday maritime operations.

3.2 Marine accidents by type of event

The Harbourmaster's offices record marine accidents according to the nature of the event. Table 1 shows the total number of marine accidents categorised by the event type.

Table 1. The total number of marine accidents, 2019-2023.

Type of event / Year	2019	2020	2021	2022	2023
Damage	17	8	9	2	5
Collision	30	11	15	15	30
Contact/impact/ strike	9	16	5	10	15
Grounding	23	18	7	15	13
Failure/Breakdown	10	8	11	5	2
Sinking	6	5	2	3	6
Flooding	10	5	2	1	1
Fire	2	1	3	4	5
Death	0	0	0	0	0
Pollution	0	1	0	0	0
Other*	15	2	2	2	1

* Capsizing, sea water ingress, a lightning strike, injury, explosion, etc.

The highest number of damages was recorded in 2019, prior to the beginning of the COVID-19 pandemic. During the pandemic in 2020 and 2021, there was a substantial drop in the number of damages.

This could be attributed to the decrease in maritime traffic caused by the lockdown and movement restrictions. This resulted in reduced vessel operations and a lower incidence of potential damage. In 2022 and 2023, as measures gradually eased, a slight increase was observed, though it did not reach pre-pandemic levels.

Collisions were most frequent in 2019 and 2023. During the COVID-19 pandemic, the number of reported collisions significantly reduced. In 2023, the number of collisions was the same as in 2019. Collisions most commonly arise from non-compliance with COLREGs, failure to maintain a proper lookout and an overreliance on autopilots.

2020 saw a significant increase in ship contacts, with 16 recorded incidents during the pandemic. In 2021, the number of contacts dropped to five. It then increased again to 15 in 2023, after the end of the COVID-19 pandemic. The passage through Mali Ždrelac serves as a specific illustration of the contact accident. The issue at hand is the mast's contact with the bridge structure.

The number of groundings decreased from 23 in 2019 to seven in 2021, likely due to reduced maritime traffic during the pandemic. Following the relaxation of COVID-19 measures, there was a notable increase in the number of groundings recorded during 2022 and 2023. Adverse weather conditions at sea are the main factor contributing to the highest frequency of groundings. Factors contributing to vessels running aground include using unofficial or outdated navigation charts and publications, reliance on navigation aids such as plotters and autopilots, and navigator fatigue.

The number of breakdowns declined after 2021. The most frequent failures were related to the vessel's engines.

Reduced vessel activity during the COVID-19 pandemic correlates with the lower number of sinkings after 2019. In 2023, the resurgence of activity in maritime transport led to an increase in the number of sinkings. The most common reason for a vessel sinking was a lack of proper maintenance.

A significant decrease in the frequency of flooding events has been noted. Following the pandemic, the number of flooding incidents has stayed low. This observation may suggest an improvement in operational procedures and/or a reduction in the intensity of vessel operations.

Ship fires were the most common maritime incidents reported in 2023, possibly because of higher shipping activity. Most ship fires result from poor maintenance and insufficient crew training. Another important factor leading to fires on vessels is the neglect of proper bunkering procedures.

No deaths were recorded during the observed period. This might signify compliance with the safety protocols.

Only a single pollution incident was recorded during the monitored period; in 2020.

Marine accidents in the "other" category were the most frequent in 2019. However, their frequency dropped significantly during the pandemic years, indicating a reduction in operational challenges.

Accidents like masts colliding with the bridge structure in the Mali Ždrelac Passage pose a considerable threat to navigation safety and demand urgent responses to protect vessels and those involved in maritime traffic. To ensure the safe evacuation of damaged vessels and prevent further marine accidents, the Harbourmaster's Office Zadar had to temporarily close maritime traffic through the Mali Ždrelac Passage on several occasions. These measures require adjustments to frequently used shipping routes, resulting in longer vessel transit times, including for ferries and catamarans. Once an accident is resolved, maritime traffic typically returns to normal within two to three hours. This helps to restore regular and safe navigation conditions.

The rules governing the passage of vessels in the passage of Mala Proversa have not been clearly defined. This often results in a smaller vessel entering from one side of the passage while a passenger ship carrying tourists approaches from the other. Such situations usually lead to panic, resulting in risky manoeuvres by vessels to avoid collisions. It is not uncommon for vessels to come into contact with fenders, further increasing the danger and the risk of damage.

3.3 Marine accidents by type of vessel

The Harbourmaster's offices record marine accidents by type of vessel. According to the type of vessel, they are divided into the following categories: vessel, yacht, boat, fishing vessel, passenger vessel, RO-RO passenger, public vessel, and others. Figure 3 displays the total number of marine accidents categorised by vessel type.

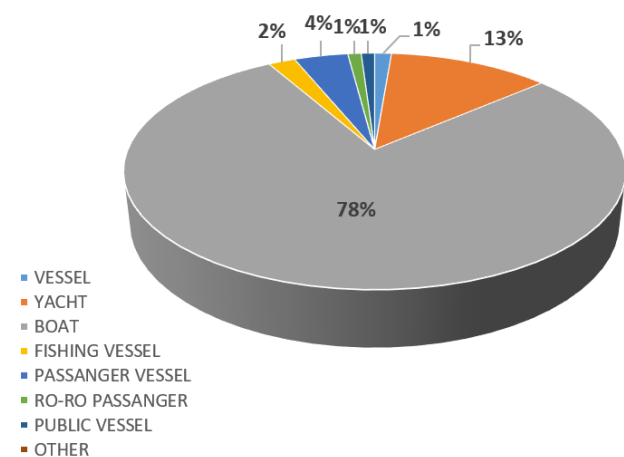


Figure 3. The total number of marine accidents by vessel type, 2019-2023

In 2019, the highest number of marine accidents, which was 87, concerned boats. There were 25 accidents involving yachts and seven involving passenger ships. The lowest number of accidents involved RO-RO passenger ships and public vessels, one for each. No marine accidents involving fishing vessels or other watercraft were recorded that year.

In 2020, the number of marine accidents involving boats and yachts decreased, with 51 incidents reported for boats and 15 for yachts. Two marine accidents were reported for ships, three for fishing boats, and two for passenger ships. Similar to the preceding year, a single

marine accident was recorded for RO-RO passenger and public vessels. No maritime incidents were recorded for other vessel types that year.

In 2021, the number of marine accidents involving boats continued to decline, reaching 47 incidents. As in the previous year, only one marine accident was recorded for yachts and three for fishing boats. Also, three marine accidents were reported for passenger ships. Ships, RO-RO passenger ships, and public ships each recorded one. Other types of vessels had no recorded marine accidents that year.

In 2022, the number of marine accidents involving boats increased slightly to 48. The number of marine accidents involving yachts also increased to three. Each type of vessel, including fishing boats and passenger ships, had one, while RO-RO passenger ships recorded two. Public ships and other types of vessels had no recorded marine accidents that year.

In 2023, boats again experienced an increase in marine accidents, totalling 69. Yachts recorded four, fishing boats one, passenger ships three, and public ships one marine accident. Ships, RO-RO passenger ships, and other types of vessels did not record marine accidents.

Analysis showed that boats were the most common vessels involved in marine accidents. The initial years saw fewer accidents, primarily attributed to the pandemic's impact on maritime activity. However, the number of marine accidents involving boats increased in 2023.

3.4 Marine accidents by month

Analysis of marine accident data from 2019 to 2023 reveals a clear seasonal pattern correlating accident numbers with maritime traffic density. Figure 4 shows the number of marine accidents each month, highlighting the safety impact of seasonal changes.

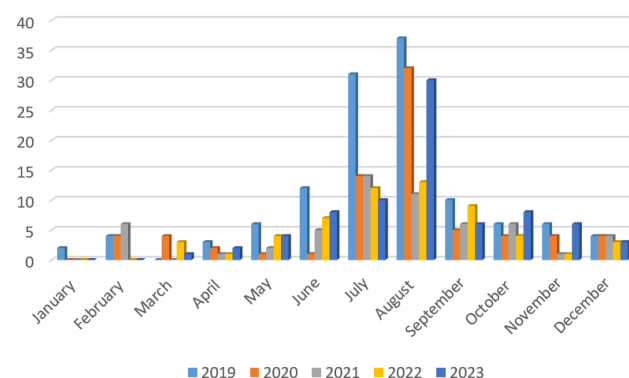


Figure 4. The total number of marine accidents by month, 2019-2023

The graph illustrates the seasonal patterns of marine accidents. During: High maritime traffic in the summer months leads to the highest incidence of marine accidents.

The start of 2019 was characterised by several marine accidents, two occurring in January and four in February. There were no marine accidents in March, while April recorded three. The number of marine accidents increased from May to August, culminating in 37 accidents in August. Marine accidents decreased

after summer: 10 in September, six each in October and November, and finally four in December. The number of marine accidents decreased after summer. There were 10 accidents in September, six in October, six in November, and four in December.

Unlike other months, no marine accidents were recorded in January 2020. In February, there were four reported accidents, as well as in March, while in April, the number of accidents dropped to two. In May and June, the number of marine accidents was low, with one accident reported each month. The number of marine accidents climbed to 14 in July, culminating in 32 in August. Fewer marine accidents were recorded by year's end: five in September and four in every of the following three months.

In 2021, there were no marine accidents in January and March. In February, there were six reported accidents. The data for the subsequent months is as follows: In April, there was one accident. In May, there were two accidents. June had five incidents. July saw a total of 14 accidents. August experienced 11 accidents. In September and October, there were six accidents each. November recorded one accident. In December, there were four incidents.

There were zero recorded marine accidents during the first two months of 2022. March recorded three, April one, and May four. During the summer months, there was a rise in marine accidents. Specifically, there were seven accidents in June, 12 in July, and 13 in August. Subsequently, the numbers decreased, with nine accidents reported in September, four in October, and a single one in November. In December, three marine accidents were reported.

As in the previous year, no recorded marine accidents occurred in January and February. In 2023, only one marine accident was recorded in March, two in April, and four in May. During the summer months, there was a noticeable rise in the number of marine accidents. Specifically, eight accidents were recorded in June, 10 in July, and 30 in August. Marine accidents decreased to six in September after the summer before rising to eight in October. Following this, marine accidents dropped to six in November and three in December.

The analysis of marine accidents between 2019 and 2023 reveals a distinct seasonality pattern in accident frequency. There is a notable rise in the number of accidents during the summer months, particularly in August. Accident numbers are typically lower early in the year, peak in the summer, and decrease in the fall and winter. The presented data necessitates the implementation of improved safety practices and preventive measures during periods of high maritime traffic.

4 HIGH-RISK AREAS AND RECOMMENDATIONS FOR SAFETY IMPROVEMENTS

Raising the level of safety at sea is essential to protect human lives and property and preserve the marine environment. In terms of navigational and maritime safety, the focus should be directed towards high-traffic areas that pose the most significant risk because of their unique navigational characteristics. These

include the Mali Ždrelac (Figure 5) and the Mala Proversa passages (Figure 6).

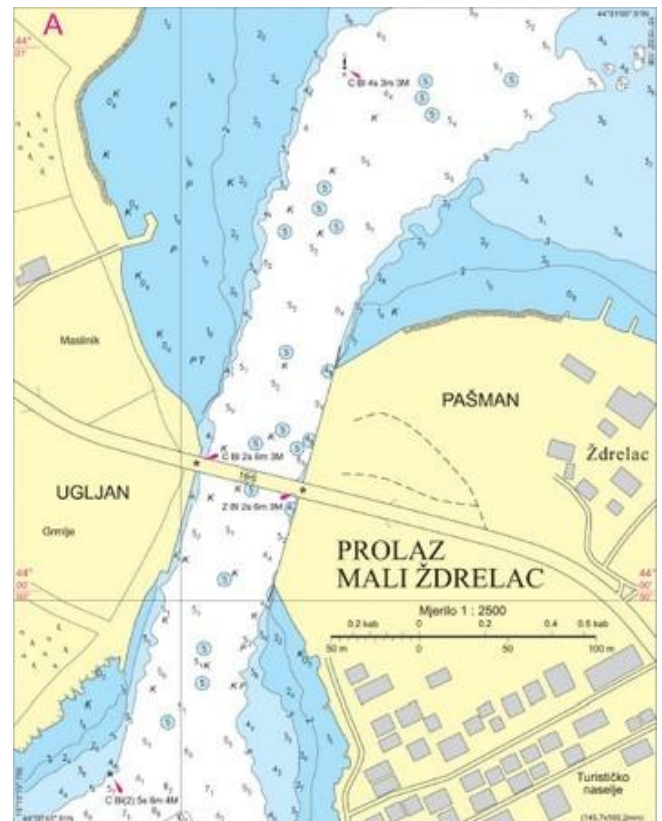


Figure 5. The Mali Ždrelac Passage. Source: [9]

The Mali Ždrelac Passage, situated between Ugljan and Pašman islands, links Srednji Kanal to Luka Ždrelac Bay and the Zadar Channel. The narrowest point of the passage, where the bridge is located, is 60 meters wide, at least 5 meters deep, and the bridge sits 16.5 meters above sea level [10]. The speed limit is 8 knots. Before entering the Mali Ždrelac Passage, ships and yachts are required to sound a prolonged blast and contact VTS over the VHF to announce their passage.

The Mali Ždrelac Passage accommodates the transit of various watercraft, ranging from small boats and yachts to large liners, cargo ships, and passenger ships. Over the past few summers, there has been an increase in maritime traffic in this area. However, the number of vessels passing through the passage is unknown.

The height markings on the bridge are attached to its structure. However, it is not unusual for sailboats to have their masts caught on the bridge, obstructing maritime traffic and operations.

There are beaches in the immediate vicinity of the Mali Ždrelac Passage. Swimmers often go far from the shore, which can endanger their lives and the safety of navigation.

Mala Proversa is a passage between Dugi Otok and Katina Island. It is approximately 34 meters wide, with a water depth of around 4.7 meters and a speed limit of 5 knots [11]. Given that this passage provides access to the Kornati National Park and the Telašćica Nature Park, maritime traffic experiences a significant increase during the summer months. Collisions in this passage are not uncommon.



Figure 6. The Mala Proversa Passage. Source: [8]

Despite the lack of serious maritime incidents in the Mali Ždrelac and Mala Proversa passages, it is essential to recognise their high traffic volume, particularly during the summer. Therefore, a comprehensive evaluation of the circumstances is necessary to minimise the risk of maritime incidents.

Yachts passing through the Mali Ždrelac Passage during the summer months pose a unique problem. They are required to report their transit to the Vessel Traffic Service (VTS); however, they often fail to do so.

Furthermore, ships mandated to report their movements do not always receive detailed information about increased traffic in the area. It is noteworthy that the Mali Ždrelac Passage has limited visibility. Additionally, the passage exhibits limited manoeuvrability. The influence of sea currents on manoeuvring is significant, with speeds reaching up to 4 knots and fluctuating directions. Consequently, vessels may encounter hazardous situations, including grounding, shore contact, etc.

The deployment of autopilots on vessels presents a specific challenge. Although autopilots offer several advantages, heavy maritime traffic, and adverse weather can reduce crew concentration, increasing the risk of marine accidents. Autopilots are beneficial for simple tasks, such as maintaining a course. Nevertheless, human intervention remains essential when quick reactions or adjustments are required in complex situations. Potential technical system failures present substantial safety risks. Although autopilots greatly aid in navigation, their use still requires crew presence and heightened vigilance to ensure safety at sea. While no significant marine accidents have occurred thus far, the rising number of vessels during summer and the increased activity of tourist and liner ships necessitate careful attention to reduce the risk of incidents. Therefore, the following measures are recommended:

- enhancing cooperation between VTS services and ship masters, particularly in the Mali Ždrelac Passage, where more detailed information on maritime traffic on both sides of the passage is required to prevent risky situations,
- installing smart cameras in key locations such as Mali Ždrelac and Mala Proversa to record the type of traffic and its density; based on the collected data,

implementing additional safety measures should be considered,

- placing extra information boards (with nighttime illumination) showing the marked clearance height under the bridge at multiple spots leading to the entrance, on both the north and south sides of the Mali Ždrelac Passage,
- installing a larger illuminated information board directly on the bridge in the Mali Ždrelac Passage to display the clearance height,
- installing shoreline signs that prohibit swimming and diving on the northern and southern approaches to the Mali Ždrelac Passage,
- enclosing the designated swimming areas with psychological floating barriers along the seaside,
- broadening the educational program for all individuals involved in maritime traffic and covering regulations and laws in Croatia to enhance awareness and compliance with the safety procedures,
- introducing a practical part of the examination for boat skippers' training, emphasise the need for authorised service personnel to conduct regular vessel maintenance,
- collecting and analysing data to monitor the number of vessels using the most common routes, aiming at a better understanding of seasonal and annual variations in maritime traffic; based on the collected data, consider implementing additional safety measures,
- prohibiting the use of autopilots in coastal areas,
- conducting more inspections during the summer months to enhance maritime traffic safety.

Implementing the above measures can significantly reduce the risk of marine accidents and increase maritime traffic safety in critical areas.

5 CONCLUSION

Analysing marine accident data by event type shows a notable decrease in almost all categories during 2020 and 2021. This decline can largely be attributed to a global reduction in activities and the stringent control measures imposed during the COVID-19 pandemic. Following the pandemic, maritime accidents in specific categories have been rising again. However, specific variations require further analysis and modification of safety measures to maintain the positive trends noted during the pandemic.

Boats recorded the highest number of maritime accidents during the analysed period. All other types of vessels reported fewer marine accidents, with occasional fluctuations.

The increase in maritime traffic during the summer months correlates with a rise in accidents. The number of marine accidents was highest in July and August, in contrast to the low numbers seen during the winter months.

Given the unique navigation characteristics of the Zadar area, the Mali Ždrelac, and Mala Proversa passages are the most frequented and potentially hazardous areas for maritime traffic. Implementing the proposed measures—such as enhancing collaboration between the VTS service and ship masters, installing smart cameras in key areas, clearly marking the

passage height, and offering additional training—could significantly reduce the risk of marine accidents. Furthermore, analyses of maritime traffic, improved surveillance, and more thorough inspections during the summer can help ensure the safety of maritime operations.

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