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Article

Analysis of Ballast Water Discharged in Port—A Case Study of the Port of Ploče (Croatia)

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Abstract: Ballast water is recognized as a major vector for the transfer of Harmful Aquatic Organisms and Pathogens (HAOP) and a source of sea pollution that negatively affects the environment and human health. Therefore, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention) in 2004. The BWM Convention introduced two standards, Ballast Water Exchange Standard (Regulation D-1) and Ballast Water Performance Standard (Regulation D-2). Ships are required to install Ballast Water Treatment (BWT) equipment in order to comply with Regulation D-2. However, the deadline for the installation of BWT is prolonged until September 2024, and many ships are still complying only with Regulation D-1. In addition, there are specific sea areas where Regulation D-1 cannot be complied with, and hence, HAOP could be easily transferred between ports. Consequently, it is essential to develop a system to protect the marine environment, human health and economy in coastal areas from the introduction of HAOP. This paper analyses ballast water discharged in the Port of Ploče (Croatia) according to ship type, age and flag they are flying. It was found that general cargo ships and bulk carriers discharged most of the ballast (87% of the total quantity) in the Port of Ploče. Moreover, discharged ballast water was analysed according to the origin, and it was found that 70% of discharged ballast originates from the Adriatic Sea. Based on the analysis of the research results and literature review, the ballast water risk assessment (BWRA) method was adopted, however, with certain modifications. The adopted method is modified by an additional risk factor (the deballasting ship's age), different risk scoring of the deballasting ship type and adding Paris MoU Grey and Black lists flag ships as high-risk ships. As a result, the BWRA method presented in the paper could be used as an early warning system and to facilitate the implementation of adequate measures to prevent pollution by discharged ballast water.

Keywords: ballast water management system; environmental protection; sustainable port operations; cargo ships

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1. Introduction

Over 90% of all global trade is transported over the sea, with more than 50,000 merchant ships sailing the world's oceans and seas [1]. Ships are built to sail the seas safely while transporting their cargo. However, when the ship has no cargo onboard, or only part of the cargo is loaded, the ship must take ballast due to several reasons, such as stability, manoeuvrability and safety of navigation. According to the International Maritime Organization (IMO), ballast water is "water taken on board a ship to control trim, list, draught, stability, or stresses" [2]. It is estimated that about 10 billion tonnes of ballast water are transferred annually worldwide [3]. It has been estimated that in 2003, about 5.6 million tons of ballast water were discharged in the Adriatic ports only and that the figure has recently climbed to 10 million tons [4].

Maritime transport is considered the most significant source of sea pollution through the transmission and introduction of alien aquatic organisms. When it comes to ships, there are three possible vectors of organisms transmission—ballast water, hull marine growth, including anchor chains and ships' sea ducts, and the cargo itself, with most organisms being transmitted through ballast water, which is an integral part of regular ship operations and the navigation process [5]. Almost all marine species spend at least part of their life cycle as plankton and, therefore, may be present in ballast water and transported to new areas. The introduction of Harmful Aquatic Organisms and Pathogens (HAOP) by ballast water into coastal waters has caused significant negative consequences for biodiversity, the economy and human health. According to the International Maritime Organization (IMO), "Harmful Aquatic Organisms and Pathogens are aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into fresh water courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas" [2]. It is important to emphasize that in addition to domicile species, which in altered environmental conditions can become invasive species, at the same time, each newly introduced species poses a potential danger of becoming an invasive species in the new environment. Invasive species are changing the composition of biological communities worldwide, and their effects are particularly dangerous in small closed seas, such is the Adriatic Sea [5].

"The Adriatic Sea is a unique and highly sensitive ecosystem. The coastal states' economic development and social existence strongly depend on the clean and preserved Adriatic Sea. However, the Adriatic Sea is also a seaway mainly used by international shipping transporting goods to or from Europe as a hinterland, with also intense local shipping. Increasing, a serious concern is the introduction of HAOP by ships' ballast water" [6]. One of the biggest problems of invasive species recorded in the Adriatic is the spread of green algae *Caulerpa taxifolia* and *Caulerpa racemosa*, which negatively affect the marine ecosystem by reducing the area's biodiversity. The sessile polychaete *Ficopomatus enigmaticus* also creates dense settlements and completely displaces the existing community in the affected area [5]. Another predatory marine invasive species that established its population in the Adriatic Sea, including the Neretva estuary (south-eastern Adriatic Sea), is the blue crab *Callinectes sapidus*. It originates from the western Atlantic Ocean, and it was introduced in European waters by ships [7]. The blue crab is an opportunistic predator that has been included in the list of "100 worst invasive species in the Mediterranean Sea", impacting biodiversity and the economy [8]. Another successful invader in the Adriatic Sea is the ctenophore *Mnemiopsis leidyi*. This species was introduced into Eurasian waters by ships from its original range along the Atlantic coast of North and South America [9].

The IMO realized the problem and diligently worked on a set of regulations that could prevent the transfer of HAOP through ballast water. Therefore, in 2004, the IMO adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments—Ballast Water Management Convention (BWMC). The goal of the BWMC is to "prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources which arise from the transfer of HAOP via ships' ballast waters and related sediments" [10].

However, adopting BWMC and its entering into force will not prevent HAOP transfer by itself. Therefore, there is a need to closely monitor and oversee ballast water operations on ships and sample ballast carried onboard ships and discharged ballast in ports to make adequate conclusions and effectively support and manage the BWMC implementation. Because the Adriatic Sea, as a part of the larger Mediterranean Sea, is one of the hot spots of invasive marine species [11], there is a need to continuously monitor and further develop ballast water management risk assessments. Furthermore, it is necessary to develop systems that will protect the Adriatic Sea from the introduction of HAOP.

Ships that load cargo simultaneously discharge ballast water in port, and if they do not have BWTS installed (or it is inoperative), there is a possibility that HAOP might be present in ballast water. Moreover, when cargo transportation by sea takes place within limited and shallow areas, such as the Adriatic Sea, ships cannot carry out ballast exchange in accordance with the provisions of the BWM Convention due to the lack of depth and insufficient distance from the nearest land. Because of this, within the northern Adriatic, organisms with similar characteristics can be easily transferred from one port to another [12].

Continuous implementation of the measures for protecting the Adriatic sea from BW pollution requires ongoing monitoring, data collection, verification and analysis [13]. Therefore, there is a need to assess the risk of discharging HAOP with ballast water and negatively affecting the marine environment and public health. To efficiently manage ballast water discharges in port, it is necessary to determine its' ballast water discharge profile. Developing a specific port's ballast water discharge profile will provide valuable insight into the risk of introducing HAOP, and analysis of collected ballast data will facilitate problem solving. Accordingly, this paper has two aims: (1) to determine a ballast water discharge profile of the Port of Ploče, and (2) to propose a ballast water risk assessment (BWRA) method for the Port of Ploče. Determining reported discharged ballast water quantities and origins, along with ship factors (type, age, flags they are flying, and voyage duration) and donor port factors (presence of HAOP, salinity, temperature and call frequency) will enable proposal of an adequate BWRA methodology.

The paper consists of six sections. Section 1 is the Introduction, where the problem of ballast water pollution is presented. In Section 2, the authors review some recent research dealing with ballast water pollution and measures to prevent the introduction of marine alien species to coastal areas. Section 3 deals with BWMC, while the research methodology is given in Section 4. Finally, the results and discussion are presented in Section 5, and concluding thoughts are provided in Section 6.

2. Literature Review

The negative economic impact of HAOP organisms spreading and their effect on coastal industries such as fishing, aquaculture and tourism are difficult to quantify, and thus, GloBallast Partnerships Project Coordination Unit published "Economic Assessments for Ballast Water Management: A Guideline" [14]. The purpose of the publication was "to help maritime administrations dealing with ballast water management, to assess and quantify (as appropriate and possible) the potential economic consequences of unintended marine species introductions" [14]. For example, using the methodology presented in [14], potential economic losses from HAOP introduction in Croatia are estimated to be USD 2.8 billion [15].

Although the United Nations recognized the problem, and IMO adopted BWMC as a tool to fight marine invasive species, as many countries did not ratify the Convention or did not implement effective protective measures. Numerous studies were conducted to reduce ports' vulnerability against the spread of HAOP. For example, in [16], the authors presented the main issues related to introducing and controlling marine alien species in the Black Sea's ports. Port of Constanta was taken as a case study, and the possibilities of discharging ballast to shore BWT facility and barge BWT were discussed. It was concluded that one BWTS container (shore facility) with a capacity of 300 m^3/h would suffice for deballasting; however, there is a possibility of an increased number of visiting ships, which might require larger treatment capacities ashore. Furthermore, it was concluded that adopting policies for monitoring compliance with BWMC in the Black Sea is a priority of all neighbouring countries. To adopt adequate and effective policies for protecting human health and the environment from ballast water pollution in specific coastal areas, it is necessary to collect and analyse the ballasting behaviours of arriving ships. In [17], the authors analysed the ballasting behaviours of ships arriving in the United States to develop and implement effective ballast water policy measures. Analysed data included BWM locations, the number of ship arrivals, total ballast quantities discharged, ballast quantities discharged per ship, and BWM methods used. Research results showed that the number of arrivals to the US increased, together with ballast water quantities discharged by a single ship. Furthermore, the analysis has shown that the most considerable quantities of ballast water recorded were discharged from bulk carriers and tankers. Prevention of pollution by ballast water and preservation of coastal areas largely depend on the risk assessment and management of ballast water. Therefore, in [18], the profile of ballast water discharges in ports was assessed and used as a tool for decision making in BW risk management. Two European ports (Port of Hamburg and Muuga Harbour, Port of Tallinn) ballast water discharges data were estimated and compared. The authors concluded that it is of the utmost importance to know discharged ballast quantities per ship, together with total quantities, the frequency of ballast water discharges, discharges profiles per ship type and the source of ballast water for discharging in port. If ballast water originates from a different sea region than the recipient port, it can be assumed that it contains alien marine organisms and the risk of spreading HAOP is elevated. Another important conclusion that could be drawn from the collected data would be the need for a ballast water reception facility and its capacity. It could be needed in cases where there is a need to treat high-risk ballast water due to some unexpected occurrences (emergencies such as the malfunctioning of BWTS or the inability of a ship to comply with ballast water exchange (BWE) regulations). Many countries or regions did not ratify BWMC, such as Taiwan, which is an important shipping hub and a hot spot for invasive marine species. Therefore, in [19], the authors collected views on ballast water management from the perspective of the shipping industry and analysed the shipping patterns of Taiwan's ports. The type of ships, ballast source, last port of call and other important data were collected from the Maritime Port Bureau and were analysed to propose ballast water management procedures for Taiwanese ports. Based on opinions collected during workshops and analyses of shipping and ballast data, the authors developed the Port State Control (PSC) system for BWM. The system consists of three levels, where the first level is PSC inspection focusing on BWM documentation. If violations are found, the ship (company) would be penalised, and a blacklist of violations would be maintained. In the second level, blacklisted ships would be inspected by the Coast Guard and again penalised if violations were found. In the third level, BW sampling would be mandatory for ships calling an epidemic area. Again, ships failing to meet set BW quality standards would be penalised, and furthermore, the risk level for potential areas of introduction and exploring improvement measures would be assessed.

One of the important terms in the BWMC is the "same location" concept. It is stated that exceptions from BWM may apply when ballasting and deballasting occur at the "same location", but how to interpret "same location"? Is it a port, an anchorage area, or even some larger sea area, such as, for example, the Adriatic Sea? Therefore, in [20], the concept to clarify the term and propose changes to the BWMC was discussed and interpreted. They collected samples from 15 ships calling Port of Koper, from which 13 were trading only within the Mediterranean Sea. BW samples of 10 out of 13 ships trading within the Mediterranean contained potentially harmful marine species. Moreover, seven sampled ships were trading only in the Adriatic Sea, and five out of seven samples contained harmful species, even though the Adriatic Sea could be considered as the "same location" since it is relatively small and semi-enclosed. The authors concluded that the shipping sector would benefit from having the "same location" as large as possible, but the opinion of the authors of [20] is that it should be the smallest practicable unit, such as the same harbour, anchorage or specific part of a bigger port. It is also predicted that many shipping companies will apply for permanent exceptions for their ships; however, it is up to coastal states to decide on a case-to-case basis of whether they will grant the exceptions [20]. Knowledge about discharged ballast water in port, besides assessment of the need for a ballast water reception facility, enables environmental impact assessment for discharged ballast water treated with active substances (chemicals), considering a worst-case scenario for accumulation of dangerous substances in the BW recipient port area [21]. Furthermore, discharged BW data could be used to support implementing management measures; for example, high-risk ballast water onboard, or high-risk ship might trigger PSC inspection to verify ship's BWM compliance. Since BW data are not available in some ports, the authors developed a Ballast Water Discharge Assessment (BWDA) model based on ship cargo operations and their size. The model was tested at the Port of Koper (Slovenia), and the results showed high confidence and confirmed that the model could predict whether the ship will discharge BW and the quantity that will be discharged. The authors gave several recommendations for BWM improvements in Europe, which could be applied worldwide, such as: (1) ratification of the BWMC, (2) usage of BWMS even before BWMC enters into force, (3) unification of BWM requirements to avoid confusion and complications and (4) introduction of BWM decision support system (DSS) in electronic format, what would facilitate reporting and exchange of information as well as enable quick and adequate decisions on BWM requirements [21].

Another important element of the BWM strategy is risk assessment methodology. In [22], three IMO-developed BWRA methods were discussed: (1) environmental matching, (2) species biogeographical and (3) species-specific method. These methods include the following risk factors: the source of BW to be discharged in the recipient port, the biogeographic region of the source and recipient port, environmental conditions (salinity and sea temperature), invasive marine species records in both source and recipient ports, native marine species records that can negatively affect human health, the environment and the economy in the recipient port, the capability of species to be introduced outside its native habitat, and the potential impact on human health, environment and economy. However, ship risk factors were not taken into account in these methods. The model presented in [23] considers that bioinvasion is a multistage process and includes three requirements that must be met for species to invade a specific port or area successfully: (1) the probability of being alien, (2) the probability of introduction, and (3) the probability of establishment. In addition, the model includes ship factors (deadweight, ship type and ship routes) and port data (temperature and salinity). In [24], the authors predicted global maritime traffic and its impact on biological invasions. The study's results forecasted that the risk of invasions would increase in Northeast Asia, and maritime traffic growth would have a greater effect on biological invasions than climate-driven environmental changes. Their model included factors such as shipping movements, ship types, gross domestic product (GDP), discharged ballast water data, seaport salinity and temperature, and distances between ports. In [25], Species Flow Higher-Order Networks (SF-HON) were used to estimate the risk of HAOP transfer. Factors used in the study included ship movement data, ballast discharge data, environmental data (temperature and salinity of seaports), biogeographical data (ecoregions) and non-indigenous species (NIS) data. As in [23], HAOP spread risk was estimated as a product of three independent probabilities: the probability of being non-indigenous to the ballast discharge port, the probability of introduction and the probability of establishment in the ballast discharge port. It was concluded that SF-HON enables more accurate HAOP spread risk predictions. The HAOP spread risk assessment and policy cost-effectiveness analysis were integrated in [26]. The HAOP spread risk assessment model was based on [25] and included three independent probabilities as in [23]. Furthermore, in [27], the cost-effectiveness of various ways to adequately protect high-risk regions and hub ports from the HAOP invasion was examined. The study used SF-HON as in [25] to estimate the alien species spread possibility, and spread risk was estimated as in [23,25,26]. The study's authors chose the Mediterranean Sea as the research area, and the results showed that Gibraltar, Suez and Istanbul were high-risk ports and hub ports for alien species introduction. In [28], four risk factors were included in the BWRA: donor port salinity, donor port sea temperature, duration of the voyage between the donor and recipient port and location of the donor port (inside or outside of the Baltic Sea). The authors of [28] estimated that each risk factor could be scored as low risk = 1, medium risk = 2, and high risk = 3. Therefore, the maximum risk value would be 12 (all four factors scores added), and it was determined that score 12 would be extremely high risk, 11 would be high risk, 9–10 would be a medium risk, and eight and less would be low risk. Therefore, besides environmental matching of donor and recipient regions, this study included voyage duration. To facilitate the targeting of BWM high-risk ships and improve compliance monitoring, in [29], the authors developed a risk assessment model based on experts' opinions (Delphi method). The study used ten factors and divided them into two groups: ballast water source and ship characteristics. The model was verified and found that it could serve as a tool for decision making and determining high-risk BW ships. The BWRA methods were further developed in [30,31]. Two-tiered BWRA was developed in these studies, and seven risk factors were included, namely: the difference between donor and recipient port salinity, the difference between donor and recipient port temperature, the biogeographic similarity of donor and recipient port, voyage duration between the donor and recipient port, frequency of calling recipient port, the flag of the visiting ship (Flag of Convenience) and type of visiting ship. Besides environmental and biogeographic matching and voyage duration, the developed methodology included deballasting ship data (flag, type and visiting frequency). The developed BWRA method can be used to facilitate the detection of high-risk ships for PSC inspections. It does not consider only environmental and species characteristics but includes visiting ship as a risk factor; therefore, it could be considered more precise. As BWMC is adopted and entered into force, adequately maintained and used BWTS onboard a ship is a key to the effective prevention of HAOP transfer between ports and regions. Therefore, the usage of ship data in RA methodology could be considered significant and necessary.

As already mentioned, the Adriatic Sea is a vulnerable environment and is susceptible to introducing HAOP. The authors of [32] discussed the implementation of the BWMC in the Adriatic Sea through the Adriatic States' cooperation. It was concluded that State cooperation on BWM is indispensable for adequate environmental protection on all levels and should focus on developing joint proposals towards European Union institutions. One of the recommended steps was to enable "further development of scientific and technical knowledge on environmental-related aspects of the BWM", which is considered a crucial point in the development of efficient management of ballast water.

From the literature review, it can be concluded that implementing the BWM policy is crucial for protecting the environment and public health. Therefore, States should become involved in solving the ballast water problem with all institutions and public organisations, introduce and apply adequate rules and procedures, rigorously check their implementation and penalise all those who do not abide by them. An adequate BWRA methodology is needed to facilitate ship inspections and to detect substandard ships. Moreover, collecting and disseminating ballast water data are essential for developing coastal states' adequate BWM strategies. BWMC is an international tool for preventing the spread of marine invasive species and should be periodically revised and updated as per the latest findings in the field.

3. Ballast Water Management Convention

The first regulator to prevent the spread of HAOP was the International Maritime Organization's committee dealing with the prevention and control of pollution from ships called the Marine Environment Protection Committee (MEPC). They developed "International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges" (Resolution MEPC.50(31)), adopted in July 1991 [33]. Next in line were "Guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges" (Resolution A.774(18)), adopted in November 1993 [33], and "Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens" (Resolution A.868(20)), adopted in November 1997 [34]. However, these regulations were not mandatory and were applied voluntarily. Nevertheless, there was a need to introduce mandatory measures that would prevent the spread of HAOP. As a result, the BWMC was adopted in February 2004. However, it took 13 years for BWMC to enter into force (September 2017) [2].

From that date onwards, all ships engaged in international voyages and under the jurisdiction of the BWMC parties must comply with the regulations laid down in the Convention. However, (a) ships flying the flag of a Party and operating only in the territorial waters under the jurisdiction of that Party, (b) ships of one Party operating in territorial waters under the jurisdiction of another Party (special authorization), (c) ships operating only in the territorial waters under the jurisdiction of one Party and on high seas, (d) ships unable to carry ballast water, (e) ships with permanent or sealed ballast tanks and (f) warships are not obliged to comply with the BWMC regulations [35]. An alternative to complying with the BWMC regulations is to deballast ships to the ballast reception facility (onshore reception facility [10] or barge-based ballast water treatment systems [36]).

BWMC contains 22 Articles dealing with definitions, general information, obligations, development, improvement, enforcement and implementation of the Convention. In addition, five Annexes (Sections A, B, C, D and E) contain 24 Regulations, including Appendix A. Section A deals with general provisions of the BWMC [2].

Section B defines management and control requirements for ships. Its Regulation B-1 stipulates carriage and implementation of the Ballast Water Management Plan (BWMP) for each ship. BWMP is a document developed for a specific ship and approved by the Administration (Recognised Organization—RO). It comprises detailed procedures for safe and efficient BWM regulations, compliance, and onboard practices such as crew familiarisation and responsibilities (designates officer in charge of ballast water), reporting requirements, ballast water management procedures, sediment management and contingency procedures. Regulation B-2 deals with the Ballast Water Record Book (BWRB), a purposeful document (either paper or electronic) for recording all ballast water management activities onboard a ship. The BWRB form is presented in Appendix A. BWRB can be integrated into another book or system, but it has to contain information as per Appendix A and must be available for Port State Control (PSC) inspection at all times. Furthermore, it must be kept onboard a ship at least two years after the last entry and within the Company's control for a minimum of three years more. Regulation B-3 sets out an implementation schedule for ships' compliance with the Ballast Water Performance Standard (Figure 1). Retrofitting a Ballast Water Treatment System (BWTS) on existing ships (keel laid before 8 September 2017) is linked to the International Oil Pollution Prevention Certificate (IOPPC) renewal, while new ships need to have the BWTS installed on delivery [2,37–39]. Ballast water exchange is stipulated in Regulation B-4. However, a ship will not be required to deviate from its intended route (or delay her voyage) for the ballast water exchange. Another important part of Section B is Regulation B-6, which requires that all crewmembers (officers and crew) are familiar with their duties in the scope of the ship's BWM and are knowledgeable of the BWMC requirements (appropriate to crewmember's duties).

Section C defines special requirements in certain areas [2].

Standards for Ballast Water Management are defined in Section D. Within the BWMC, there are two possible solutions to prevent or eliminate the HAOP transfer; either the ship needs to exchange ballast water (D-1) or have the number of viable aquatic organisms below the specified limits (D-2) [2,40]. Regulation D-1 specifies the Ballast Water Exchange Standard. It requires the efficiency of ballast water exchange of not less than 95% of the volume of each ballast tank onboard a ship (from which the ballast water will be discharged in the port of call). There are two commonly accepted methods, the sequential method and the flow-through method. Which method the ship will use must be specified in BWMP, as per Section B. Regulation D-1 applies to ships without installed and operational BWTS (Figure A1). Regulation D-2 is the Ballast Water Performance Standard, which sets the maximum permissible concentration of viable organisms and specifies indicator microbes in the discharged ballast. It implies installing Ballast Water Treatment (BWT) equipment onboard a ship, which is an essential part of a Ballast Water Management System (BWMS). BWT equipment is an apparatus installed onboard a ship to treat the ballast water taken onboard before discharging it into a new port to comply with BWMC regulations regarding the number of viable organisms. The IMO defines BWMS as any system which treats BW to comply with biological limits set in BWMC Section D, Regulation D-2. It includes ballast water treatment equipment and all accompanying piping arrangements, control and monitoring equipment and sampling facilities [35]. Therefore, the BWMS needs to comply with the regulations set in the BWMC. The most common way to meet the ballast water performance standard (D-2) is with the onboard installation of ballast water treatment systems (BWTS), but in theory, the standard may also be met by discharging ballast water to port reception facilities for treatment. However, the BWM Convention also provides for cases where vessels do not need to manage their ballast water. Exceptions are identified for specific cases when ballast water uptake, or discharge, is necessary in an emergency situation or is resulting from damage to a ship, or in order to avoid a pollution incident, or when uptake and discharge are conducted on the high seas or at the same location [2,20,41,42]. Regulations D-3, D-4 and D-5 deal with the approval requirements for BWTS, prototype BWT technologies and standards review [2]. BWTS installed on ships must be approved by the Administration (RO) as per Regulation D-3, which requires all tests to be carried out according to the "Guidelines for the type approval process of Ballast Water Management Systems" (IMO revised G8 Guidelines) [43] which were revised and converted into a "Code for Approval of Ballast Water Management Systems" (BWMS Code) [35].

Survey and Certification Requirements for Ballast Water Management are stipulated in Section E. Regulation E-1 deals with surveys of ships of 400 gross tonnage and above, on which BWMC applies. Regulations E-2 and E-3 stipulate the issuance or endorsement of a certificate by the Administration (Flag of a ship) or another Party. The form of the International Ballast Water Management Certificate (IBWMC) is prescribed in Regulation E-4, and details are given in Appendix A. IBMWC is mandatory for all ships on which BWMC applies, and it declares which BWM standard is implemented onboard and confirms the ship's compliance with BWMC regulations [2].

Since September 2017 (BWMC entered into force), the Port States have been accountable for enforcing the BW regulations by inspecting deballasting ships. Some of the cases where PSC inspection might be prompted are: if it is suspected that a specific ship is non-compliant with BWMC; if there is suspicion of untruthful BW reporting; if it is assessed that high-risk ballast water is to be discharged in port; or as a part of regular PSC inspection process. The inspections include verification of certificates, check of BWMP and BWRB, crewmembers' knowledge on BWM implemented on board a ship, condition of BWMS; and if some irregularities are found, a sampling of the ship's ballast water (according to IMO guidelines). Therefore, compliance monitoring is necessary to ensure that ships calling States' ports are operating in line with the BWMC. If PSC officers find clear evidence of non-compliance, the ship could be banned from discharging ballast water and penalised as well [22,44,45]. However, finding non-compliant ships is a challenging task, and existing PSC regional agreements do not specifically choose ships with high-risk for HAOP transfer for inspections [13]. For the Adriatic Sea area, the BALMAS project was of special importance since it developed a range of instruments for BW risk assessment and facilitating compliance onboard ships [13].

BWM deficiencies found during the Paris Memorandum of Understanding (MoU) PSC inspections are presented in Figure 1.

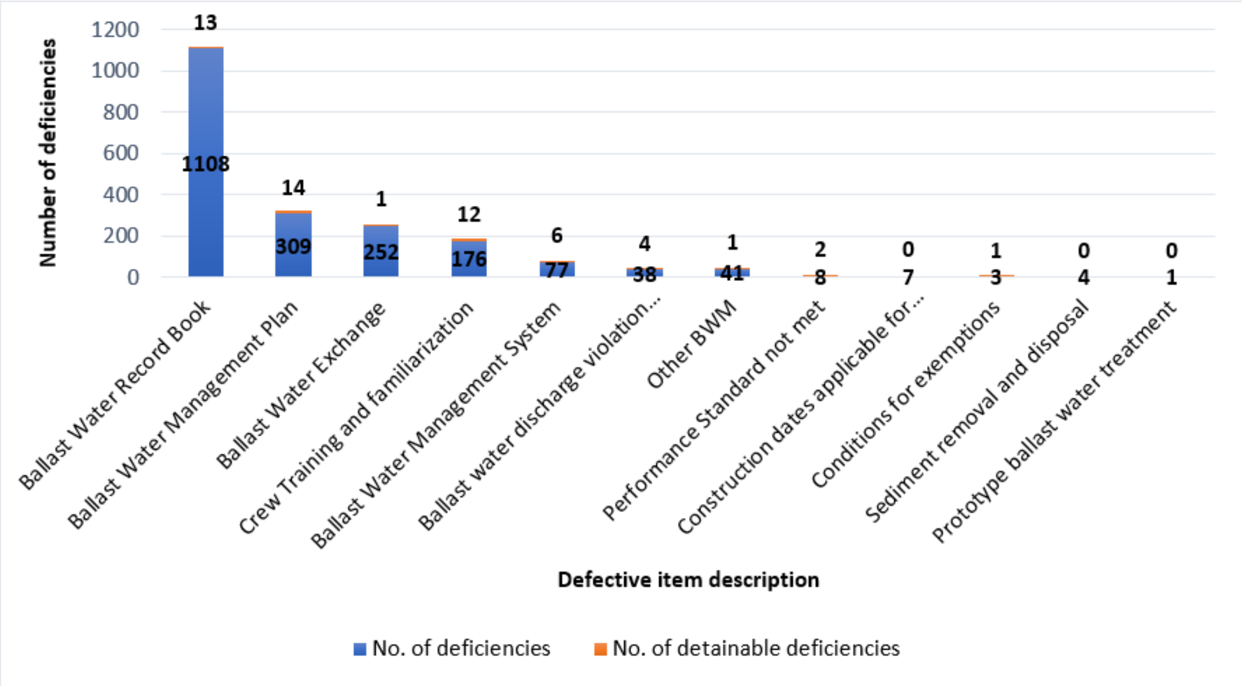

Figure 1. BWM deficiencies identified by the Paris MoU inspection regime from January 2019 to June 2022. Source: authors as per [46].

As can be seen from Figure 1, most of the deficiencies were related to the BWRB, followed by BWMP and BWE. It can be concluded that most of the non-compliance is record and procedure related. Defective BWMS and BW discharge violations were in fifth and sixth place on the defective items list. However, according to the American Bureau of Shipping (ABS) report from 2019, about 65% of all BWMS "were reported as inoperable or problematic" [47]. That is an alarming number of problematic systems, and it can be expected that a certain percentage of ships are non-compliant due to that. Therefore, states should be prepared and adequately react and enforce compliance with the BWMC.

To sum up the above, there are two ways of ballast management: Ballast Water Exchange (D-1) or Ballast Water Treatment (D-2). Because installation of BWTS for existing ships is connected to the renewal of the IOPP Certificate, only in 2024 will all ships to which the BWMC applies have to have a type-approved treatment system installed. However, based on the above, it can be concluded that not all ships visiting Croatian ports have BWTS installed and operational. However, they must comply with BWMC Regulation D-1 until retrofitting and have BWMP, where BWM and sediment procedures onboard are described and BWRB, where all BW operations are recorded. In addition, all crewmembers with some duties regarding Ballast Water Management have to be familiar with their duties, and the person in charge of BWM onboard a ship must have all the needed skills and knowledge to manage ballast water in a safe and environmentally friendly manner effectively. A risk assessment methodology must be developed to protect the marine environment effectively from HAOP transferred by ballast water. Ships engaged on short-sea voyages between specific ports or locations ("same location") may be granted an exemption from installing BWMS under the BWMC (regulation A-4) if it is assessed that the risk of HAOP transfer is relatively minor [48]. Although this approach is beneficial for liner ship shipowners in specific areas, regional administrations should bear in mind the results of [20] and carefully assess the risks before granting any exceptions.

Consequently, developing port-specific and specific area (or coast) BWRA is necessary. In order to adequately meet these requirements, it is necessary to determine the ballast discharge profile of a port or area and, based on the data obtained, develop an adequate BWRA method.

4. Methodology

The Port of Ploče is one of six Croatian ports open for international traffic and of considerable economic interest [49] and the second largest port according to the annual volume of cargo transhipment [50]. It is one of the main strategic Croatian ports for the transhipment of almost all types of goods in international maritime traffic, located on the southern part of the Adriatic coast, between Split and Dubrovnik, as the gateway to Corridor Vc, which is part of the pan-European network of transport corridors. Transhipment, storage and other accompanying services are performed at the terminals for general cargo, bulk cargo, liquid cargo, timber, containers, alumina and petroleum coke. The total annual transhipment capacity of the Port of Ploče is estimated at more than 5 million tons of general and bulk cargo, while the total storage capacity of liquid cargo is about 600,000 tons. The terminals are distributed on seven operational shores in Ploče with a draft of up to 18 m and can accommodate ships up to the Cape Size type. The terminals are directly connected to the gravity hinterland by railway tracks extending over the entire operational length [51]. The Port of Ploče had more than three million tonnes of cargo throughput in 2017, and future investments include the construction of the new liquid cargo terminal and petroleum and liquified petroleum gas (LPG) quay for tankers up to 88,000 deadweight tonnage. Furthermore, the second phase of construction of a container terminal with the capacity of 500,000 Twenty-Foot Equivalent Units (TEU) and the second phase of a terminal for bulk cargoes with a total capacity of six million tonnes are planned. Therefore, it can be expected that cargo transhipment volumes in the Port of Ploče will continue to grow, and more and more large ships will call the port. In addition, the Port of Ploče has access to road and railway networks connecting the Mediterranean and Central Europe [50], making it more interesting for the logistics network. Because of all aforementioned, the Port of Ploče was chosen as a Croatian port for which the ballast water discharge profile will be defined.

To adequately define the BW discharge profile of the Port of Ploče, the authors collected data about BW discharged in the port and ships that discharged the ballast. Data presented in this paper were collected from the Croatian Integrated Maritime Information System (CIMIS) and included data from July 2013 up to January 2022 (all available recorded data). Access to CIMIS was provided by the Ministry of the Sea, Transport and Infrastructure of the Republic of Croatia as a part of the ProtectAS project. CIMIS included the following ballast details: year and month of BW discharge, ship's voyage ID, flag, IMO number, gross tonnage (GT) and type of discharging ship, port or geographical coordinates (latitude and longitude) of BW intake and port and terminal (or geographical coordinates) of BW discharge, BW quantity taken onboard and quantity discharged, temperature and salinity of BW onboard. However, important data such as which BWM standard was applied (D-1 od D-2) were not available, and whether the ship carries BWMS and if it is operational were not included in the data. Therefore, the authors used available data to determine the BW discharge profile of the Port of Ploče.

Moreover, based on the flag and IMO number of BW discharging ships, the authors found their age using the MarineTraffic [52] online platform as a search tool. In addition, BW discharging ships were categorised according to Paris MoU White, Grey and Black lists [53], and Flag of Convenience [54]. It is assumed that ship flags found on the Black and Grey lists have poorer performance and higher risk than ships on the White List. In addition, ships on the Black List are usually targeted by PSC inspections and are more frequently inspected. In addition, reported ports and geographical coordinates of ballast water intake were categorised in sea areas (e.g., Adriatic Sea, Ionian Sea, North Sea, etc.) and in larger sea areas (e.g., Mediterranean Sea, Atlantic Ocean, etc.) to present the BW source more adequately (besides only port or location).

The authors analysed collected data in detail to determine the major sources (sea areas and ports) of BW discharged in the Port of Ploče and the types of ships discharging the largest quantities of ballast. In addition, minimum, maximum and average quantities of discharge BW were determined for each type of ship.

Consequently, based on the obtained discharged BW and deballasting ships data, this study adopted similar BWRA factors as in [30,31]. In addition, this study considers the ship's age as a risk factor that was not included in [30,31]. The authors included the ship's age as a risk factor since it could be considered that new build ships are delivered with BWTS installed and therefore reduced risk of HAOP transfer through BW discharges (if a system is operational and adequately operated). Furthermore, the risk scoring of specific ship types was estimated differently than in [30,31]. In this paper, it is estimated based on the average quantity of discharged BW per ship type and available port-based shore reception facilities. Voyage duration was also taken as a factor since it might be considered that ships on voyages shorter than three days present a significantly higher risk than ships on voyages longer than ten days [28,30,31]. In addition, call frequency from specific ports was taken as a risk factor, but unlike in [29,30], in this paper, frequency of ships' calls from specific ports was taken. In addition, we considered Paris MoU Black and Grey list flags ships as high-risk ships, while ships flying FOC were considered as medium-risk ships, while in [29–31], only FOC ships were considered as high-risk ships. As for the salinity and the sea temperature of the Port of Ploče, the authors adapted the methodology from [30,31]. The salinity for the Port of Ploče was 27–37%, and the sea temperature is considered warm (12–29 °C). Finally, the presence of HAOP in the donor port is considered as a high risk. Therefore, this paper presents BWRA methodology modified from [30,31] and tailored for the Port of Ploče. However, it could be applied to other small seaports, with certain limitations. BW risk factors were divided into two groups, ship factors and port factors. Ship factors include the ship's age (SA), ship type (ST) [29–31], voyage duration (VD) [28–31] and ship's flag (SF) [29–31]. Port factors include salinity difference (DPS), temperature difference (DPT) (environmental matching method) [22,28–31], presence of HAOP in the donor port (HAOP) [22] and call frequency (CF—frequency of visits from donor port to recipient port) [29–31]. Ship risk level (SRL) can be calculated using Formula (1).

$$SRL = SA + VD + ST + CF + SF + DPS + DPT + HAOP \tag{1}$$

Each risk factor adopted in this study was categorized as high, moderate and low, with scores of 3, 2 and 1, respectively. Eight risk factors are included, and the maximum risk value is 24. However, to facilitate risk estimation and place it between values 0 and 1, we have decided to divide scores 1, 2 and 3 with a maximum value of 24. That way, the maximum estimated risk score would equal 1. Based on the authors' expert opinion (three authors are experienced seafarers, two of whom are employed in an academic institution and one in the governmental office, while the fourth author is a marine biologist employed in an academic institution), it was decided to consider calculated ship's risk score from 0 to 0.6 as low risk, from 0.61 to 0.9 as medium risk, and from 0.91 to 1 as a high risk.

Based on the results of the study, a BWM plan for the Port of Ploče, including a contingency plan in case of a non-compliant ship, could be developed. Furthermore, a similar BWRA method could be applied to other small seaports, with some limitations.

5. Results and Discussion

According to collected and analysed data, a total of 1,035,490 m^3 of reported ballast water was discharged in the Port of Ploče in the analysed period (data for 2013 includes July to December). In 2021, the largest quantity of BW was discharged in the Port of Ploče (Figure 2), while February, September and August were the months when the least quantities of BW were discharged during the years (Figure A2).

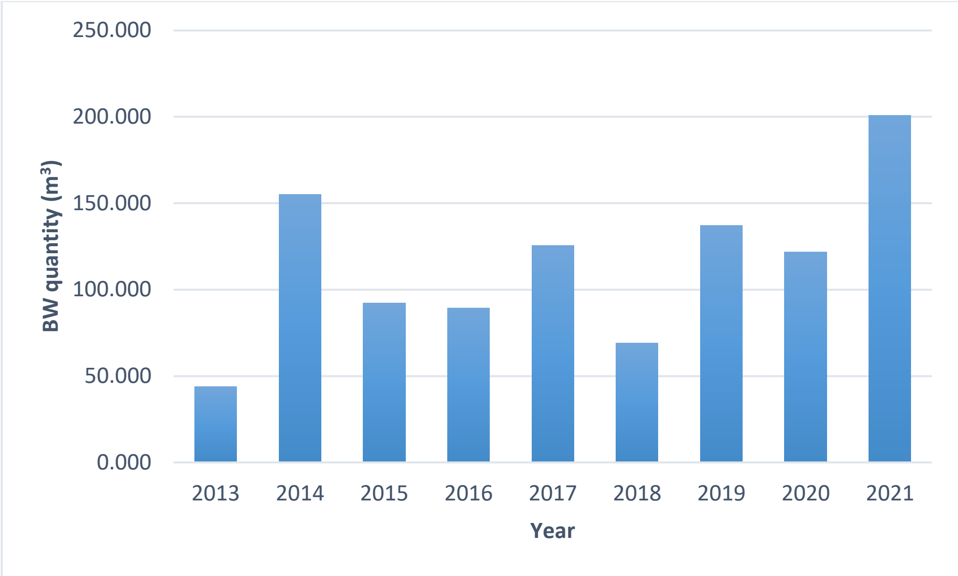

Figure 2. Annual quantities of BW discharged in the Port of Ploče.

The main reason for the increased quantities of discharged BW in 2021 was the recovery of industrial production in Bosnia and Herzegovina (since the Port of Ploče serves as a shipping port for the goods shipped from Bosnia and Herzegovina) [55]. When analysing BW quantities discharged by specific ship type, it was found that general cargo ships discharged more than half of the total amount of BW discharged in the Port of Ploče (52%), followed by bulk carriers (35%), as presented in Figure 3.

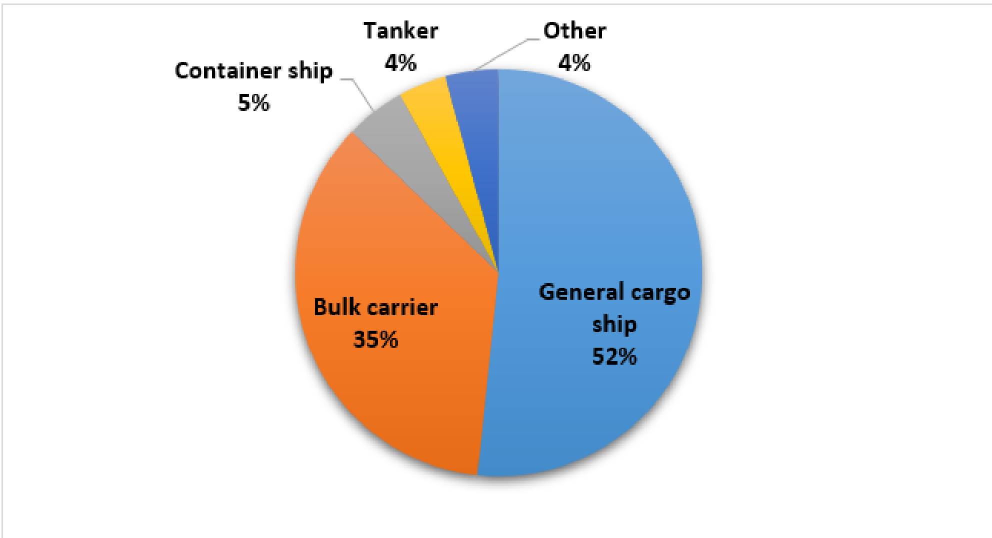

Figure 3. Percentage of total ballast discharged in the Port of Ploče by specific ship type.

Tankers included Oil/Chemical tankers and Oil Product tankers, while others included Heavy load carriers and Cement carriers (Figure 3).

As seen in Figure A3, only in 2019 did bulk carriers discharge more BW than general cargo ships. From July 2013 to January 2022, there was a total of 506 ship calls to the Port of Ploče. The frequency of ship calls per ship type is presented in Figure A4. General cargo ships have considerably more calls to the Port of Ploče than any other ship type, including bulk carriers. However, it is understandable due to their relatively small size compared with, for example, bulk carriers (Figure A4). The frequency of bulk carrier calls decreased until 2017, and from 2018, it is increasing (there were ten bulk carriers discharging BW in the Port of Ploče in 2021). In addition, the general cargo ship frequency of visits decreased until 2018, and from 2019, it increased again (65 calls during 2021). It is important to emphasize that general cargo ships discharged 535,178.6 m^3 of BW from 390 calls, while bulk carriers discharged 367,552.3 m^3 from 53 calls. This relation shows the difference between the quantities of ballast discharged by general cargo ships and bulk carriers per single ship.

Bulk carriers discharged the largest quantities of ballast by a single ship, followed by heavy lift ships (others). The smallest quantity of BW discharged from a single ship was from a general cargo ship (50 m^3), while the largest was from a bulk carrier (26,958.5 m^3), as presented in Figure A5. The largest BW quantity discharged from a single general cargo ship was 10,138.4 m^3, while the largest BW quantity discharged by other types of ships (heavy lift) was 14,423 m^3.

From Figure A5, it can be concluded that tankers and containerships discharged the smallest quantities of BW per single ship. In addition, it was necessary to determine the age of BW discharging ships. Compiled data analysis showed that ships of 10 years and younger discharged almost half (49%) of the BW discharged in the Port of Ploče in the surveyed period, or 515,706.7 m^3 (Figure A6). Ships from 11 to 15 years of age discharged 195,532.3 m^3 (19%), while ships older than 16 years of age discharged (32%) 324,250.9 m^3 of BW.

As BWMC entered into force on 8 September 2017, all new buildings delivered from that date had to have BWMS installed. In addition, some owners installed BWMS ahead of that date since they expected that BWMC would enter into force soon and wanted to be compliant. Therefore, it can be concluded that most of the newer ships (age less than ten years) will have BWMS installed, while on older ships, it depends on their age, price of installation, and value of the ship itself [56]. It can be expected that most of the shipowners of older ships trading in the Adriatic Sea area and calling the Port of Ploče (Figure 4) will apply for an exception since they consider that trading within the Adriatic Sea could be taken as the "same location".

Figure 4. Main Adriatic Sea routes calling the Port of Ploče. Source: adopted from [57].

The percentage of BW discharged by a ship flag is presented in Figure A7 (ten ship flags that discharged the largest quantities of BW). As seen, Malta and Panama flagged ships discharged 40% of BW in the Port of Ploče, followed by Liberia (8%) and Italy (5%).

Moreover, the authors analysed BW quantities discharged by ship flags according to the number of ship calls (Figure A8). Most frequent visitors were again Malta and Panama flagged ships (150 arrivals), followed by Turkey (53) and Albania (35) flagged ships.

Furthermore, according to Paris MoU White, Grey and Black List flags, the authors divided BW discharging ships into four groups. The other group was ships' flags which were not listed in either of the groups. As presented in Figure A9, White list flagged ships discharged 83% of BW (864,253.2 m^3) in the Port of Ploče.

The background of dividing BW discharging ships according to the Paris MoU Flag List performance is that the ships' flags on the Black and Grey list are considered to have poorer performance than ships on the White List; therefore, it might be considered that such ships will have some deficiencies regarding BWM. However, from Figures A9 and A10, it might be concluded that the vast majority of discharged ballast came from White list flagged ships.

Only in the years 2018 and 2020, were there more than 15,000 m^3 of BW discharged from Black list flagged ships; however, Paris MoU Black List flagged ships in the surveyed period discharged a total of 9% (91,732.1 m^3) of BW. Furthermore, when recorded BWM deficiencies found by Paris MoU inspectors were compared between Paris MoU Black and Grey list flagged ships and Panama and Malta flagged ships (flags that discharged most of the BW and most frequent visitors to the Port of Ploče), it was found that more deficiencies were recorded on Panama and Malta flagged ships. Data refer to all Paris MoU inspections from January 2019 to June 2022 (not only Croatia).

From Figure A11, it could be concluded that special attention should not be given only to Paris MoU Black and Grey list flagged ships but to Flags of Convenience (FOC) ships (Panama and Malta flags are considered a FOC) as well. In addition, as it is presented in Figures A9 and A10, Black and Grey list flagged ships discharged modest amounts of BW compared with other flags. Therefore, the conclusion could be drawn that not only Grey and Black List flagged ships according to Paris MoU could be considered as substandard regarding BWMC generally, but ships flying Flags of Convenience as well.

When discharged BW was analysed by port of intake, the Port of Ravenna was found to be a port which was the donor of the most significant BW quantities, followed by Brindisi and Fusina (Figure 5).

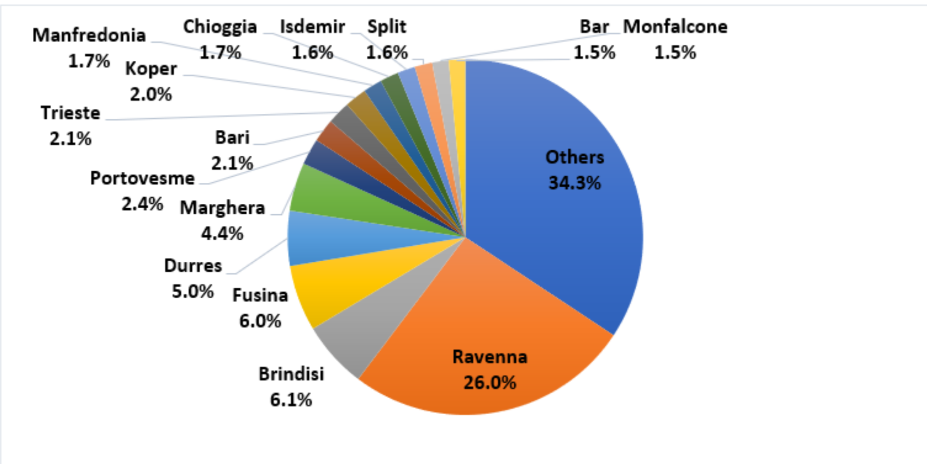

Figure 5. Percentages of BW discharged in the Port of Ploče by port of intake.

Others (34.3%) include 128 donor ports or BW intake geographical positions. When analysed by frequency of ship calls, as presented in Figure A12, the Port of Ravenna was again the most frequent last port of call and BW donor (91 ship calls), followed by Durres

(59 ship calls) and Bari (21 ship calls). The Port of Fusina, the third largest donor port by the quantity of discharged BW (61,823 m^3), had only three ship calls to the Port of Ploče.

When analysed by sea region, the Mediterranean Sea was the donor of 94.6% of BW discharged in the Port of Ploče, followed by the Atlantic Ocean, which had only 2.7% of the discharged BW quantity (Figure 6).

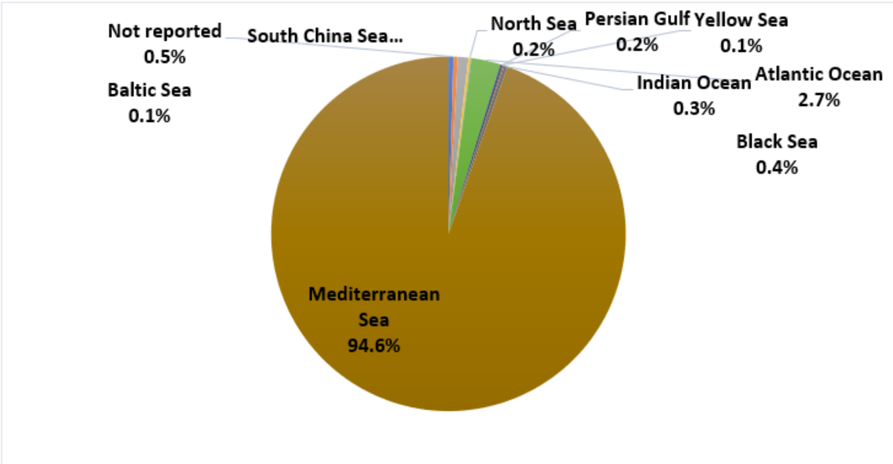

Figure 6. Percentages of BW discharged in the Port of Ploče by sea areas.

It is important to note that 0.5% of discharged BW did not have the source of uptake listed, meaning that there are still ships which do not comply with procedures and BWMC but still call European ports. Incomplete or improperly filled Ballast Water Reporting Forms are clear grounds for PSC inspections, and any deficiencies found should be penalised.

Analysing BW taken in the Mediterranean Sea, the most significant quantities were loaded in the Adriatic Sea (725,465.8 m^3 or 74%), which was also the most represented source of the discharged BW in total (70%) (Figure A13). When BW quantities taken in the Adriatic Sea were analysed by coastal states (Figure A14), Italy was the most significant donor (83% of the Adriatic Sea sourced BW), followed by Albania (7%) and Croatia (5%).

Besides all data obtained by the analysis, the Port of Ploče does not have a BW reception facility for cases of non-compliant ships. However, there is a specialised company that collects liquid waste from ships, and the capacity of their collecting tanks is 2500 m^3. Therefore, it can be concluded that in case of an arrival of a non-compliant ship in the Port of Ploče, 2500 m^3 of untreated ballast could be taken care of. As presented in Figure A5, storing that quantity of liquid would suffice for most general cargo ships and some tankers and containerships. However, on average, most bulk carriers and other types of ships discharged larger quantities of BW.

In addition, as mentioned in the Methodology section, the CIMIS tool does not include data about BWMC standards applied to BW carried. That means that there is no information on whether any of BWMC regulations were applied and, if it was, which one. That data would significantly improve data collecting and enable the development of a more adequate BW risk assessment for a specific port.

However, based on collected data, the authors suggested BWRA for the Port of Ploče (modified from [30,31]), as presented in Table 1.

Ship type risks were estimated according to average BW discharges and capacity of port reception facilities in the Port of Ploče. Since reception facilities could receive 2500 m^3 of BW, it could be considered that on average general cargo ships could discharge their ballast to port facilities and load their cargo, while, for example, bulk carriers could only discharge a small part of their BW and could not load full cargo. Therefore, general cargo ships could be considered as low-risk ships, with bulk carriers as high-risk ships. For example, in March 2021, a Maltese flagged general cargo ship that uplifted ballast in Ravenna arrived at the Port of Ploče. Accordingly, the ship is older than 10 years, and

SA = high risk; voyage duration is less than three days and VD = high risk; ship type is a general cargo ship and ST = low risk; call frequency from Ravenna is larger than Q3 and CF = high risk; donor port salinity is between 24–40 and DPS = high risk, donor port sea temperature difference is less than 3 °C and DPT = high risk; and HAOP is present in port and HAOP = high risk. Therefore, when Formula 1 is used to calculate the risk score, the following is obtained:

$$\mathrm{SRL} = 0.125 + 0.125 + 0.042 + 0.125 + 0.125 + 0.125 + 0.125 + 0.125$$

The ship risk score obtained is 0.917 and is therefore considered as a high-risk ship. However, it was not observed at the time of arrival, and no control or inspection of the ship and BWMS onboard was carried out.

Table 1. BWRA factors scoring for the Port of Ploče.

	Risk Score		
Risk Factor	**Low (1)**	**Medium (2)**	**High (3)**
Ship's age (SA)	Less than 5 years	Between 5 and 10 years	More than 10 years
Voyage duration (VD)	More than 10 days	Between 3 and 10 days	Less than 3 days
Ship type (ST)	General cargo ship	Container, Tanker	Bulk carrier, Other
Call frequency (CF)	≤the lower quartiles (Q1) of all call frequencies from ports	Frequency of calls from the port is between Q1 and Q3 of all call frequencies from ports	≥the upper quartiles (Q3) of all call frequencies from ports
Deballasting ship's flag (SF)	Other	Flag of Convenience (other than Paris MoU Grey and Black list flags)	Paris MoU Grey and Black list flags
Donor port salinity (DPS)	<21.9% or >42.1%	22–23.9% or 40.1–42%	24–40%
Donor port sea temperature (DPT)	difference > ±5 °C	difference between ±3 and ±5 °C	difference < 3 °C
Presence of HAOP in donor port (HAOP)	No	N/A	Yes

6. Conclusions

Analysis of discharged BW data for the Port of Ploče revealed the following:

- More than 90% of ballast discharged in Ploče originates from the Mediterranean Sea (70% originates from the Adriatic Sea).
- According to the quantity, the first three ports of ballast origin are the Italian Adriatic Sea ports Ravenna, Brindisi and Fusina (Ravenna is also the most frequent port of BW intake).
- General cargo ships, followed by bulk carriers, discharged the largest ballast quantities (390 general cargo ships discharged 535,178.6 m^3, and 53 bulk carriers discharged 367,552.3 m^3).
- Paris MoU White List flagged ships discharged 83% of ballast in Ploče (however, according to Paris MoU inspection results, it was found that Black and Grey list flagged ships do not have greater risk related to BW discharge). Therefore, attention should be paid to FOC ships.
- Ships younger than 11 years that discharged 49% of BW in the Port of Ploče (19% less than six years old) could be regarded as positive since these ships could be considered as relatively new and have BWTS installed.
- A reception facility receiving a total of 2500 m^3 BW could be considered insufficient in the case of untreated BW from medium to large bulk carriers. In addition, there is no treatment system installed; thus, it is unclear how discharged BW would be treated.

Based on the data obtained, BWRA methodology was developed for the Port of Ploče. Prior to arrival in the port, the ship would send a Ballast Water Reporting Form and ship particulars, where all data necessary for the proposed ballast water risk estimation can be found. Equation 1 could be used to estimate risk, and if it is a high risk, it is recommended to inspect the ship and verify that it is compliant with BWMC. The advantages of the proposed BWRA methodology include ease of data collection necessary for risk estimation, identification of high-risk ships for a specific seaport, and methodology application to other similar sized seaports (provided that the ballast discharge profile of the port is identified).

Furthermore, no appropriate protocol with harmonized and confirmed risk assessment tools has been established among the Adriatic states. Therefore, this paper suggested a tool that could be used to estimate the risk of ballast water discharge in a port. However, our method is developed based on data for the Port of Ploče, and it should be modified to be used in another port (the difference could be risk scoring of specific ship types).

Another important aspect of protecting Adriatic Sea coastal areas is implementing BW reception facilities (barge or shore-based). Therefore, Adriatic states should discuss and find the best available option for cost-effective and technically feasible solutions for reception facilities, including BWTS, which could be shared between states and used as needed.

In addition, penalties for non-compliant ships are not incorporated in national laws, and therefore, there are no means to penalise violating ships. Without clear regulations on penalties for violators, it can be expected that many ships will try to circumvent the rules of the BWMC and ignore BWM procedures. Besides penalties for violators and offenders, incentive schemes or port fee relaxations could be introduced for compliant ships (carrot and stick approach). In that way, it would be beneficial for shipowners to have BWMC-compliant ships.

Based on research findings and proposed BWRA methodology, suggestions for mitigating the risk of pollution from discharged ballast water in the Port of Ploče include:

- PSC inspections of ships where the estimated risk level was high (including random ballast water sampling and operations of BWTS) and additional training of PSC officers. Inspections should emphasise Ballast Water Management, including ballast water records and crewmembers' knowledge and familiarity with the BWMS onboard a ship.
- Introduction of penalties for all non-compliant ships (companies) and incentives for compliant ones.
- Introduction of shore-based BWTS (barge, truck or fixed) based on average ballast quantities discharged by a single ship (incorporate data from all Croatian seaports to find the best solution available).
- Inclusion of BW control action in CIMIS (compliance with D-1 or D-2).

This study has several limitations that should be taken into account:

- The ballast water discharge profile was determined for only one port, which was primarily called by general cargo ships and bulk carriers.
- Discharged BW data were available from July 2013.
- There were no data about compliance with BWM Convention (Regulation D-1 or D-2).
- Discharged BW data were self-reported and not verified; therefore, we are unsure whether the reported data were accurate or not.

Future research should focus on developing a plan for protecting Croatian ports from HAOP, together with specific risk assessments. Therefore, ballast water discharge profiles should be determined for all Croatian international ports (especially for cargo import ports) that would include BWMC regulation applied on carried BW onboard a reporting ship. In addition, a technical and economic feasibility study should be carried out for Croatian ports' shore-based BWTS. Furthermore, future research will concentrate on further developing BW risk assessment methodology.

Author Contributions: Conceptualization, N.H. (Nermin Hasanspahić) and M.P.; methodology, N.H. (Nermin Hasanspahić); software, N.H. (Nermin Hasanspahić); validation, M.P., N.H. (Niko Hrdalo) and L.Č.; formal analysis, N.H. (Nermin Hasanspahić); investigation, N.H. (Nermin Hasanspahić), M.P., N.H. (Niko Hrdalo) and L.Č.; resources, N.H. (Nermin Hasanspahić) and N.H. (Niko Hrdalo); data curation, N.H. (Nermin Hasanspahić); writing—original draft preparation, N.H. (Nermin Hasanspahić); writing—review and editing, M.P., N.H. (Niko Hrdalo) and L.Č.; visualization, N.H.

(Nermin Hasanspahić); supervision, N.H. (Nermin Hasanspahić), M.P., N.H. (Niko Hrdalo) and L.Č.; project administration, M.P.; funding acquisition, M.P. All authors have read and agreed to the published version of the manuscript.

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Appendix A

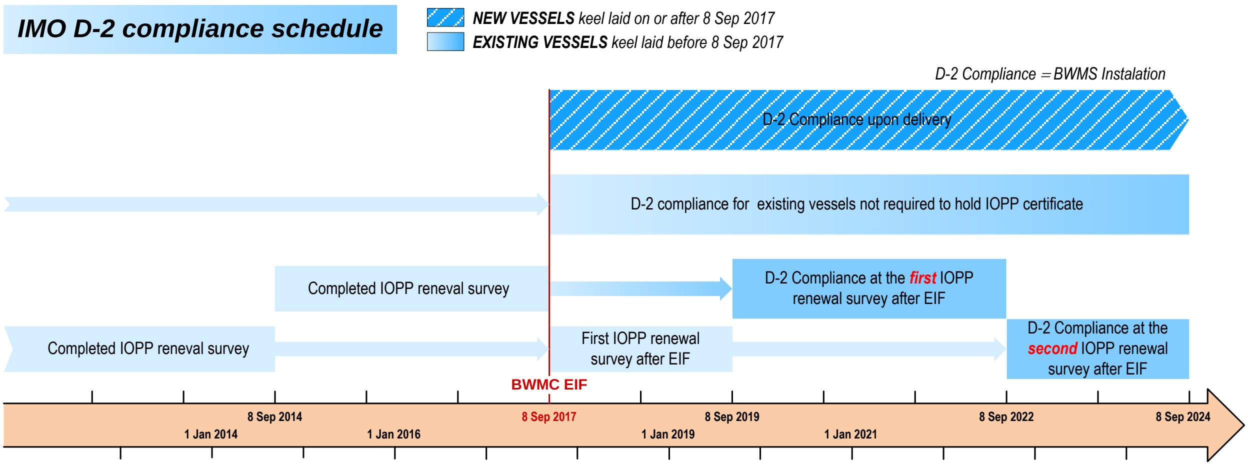

Figure A1. BWMC Regulation D-2 compliance schedule. Source: adopted from [34].

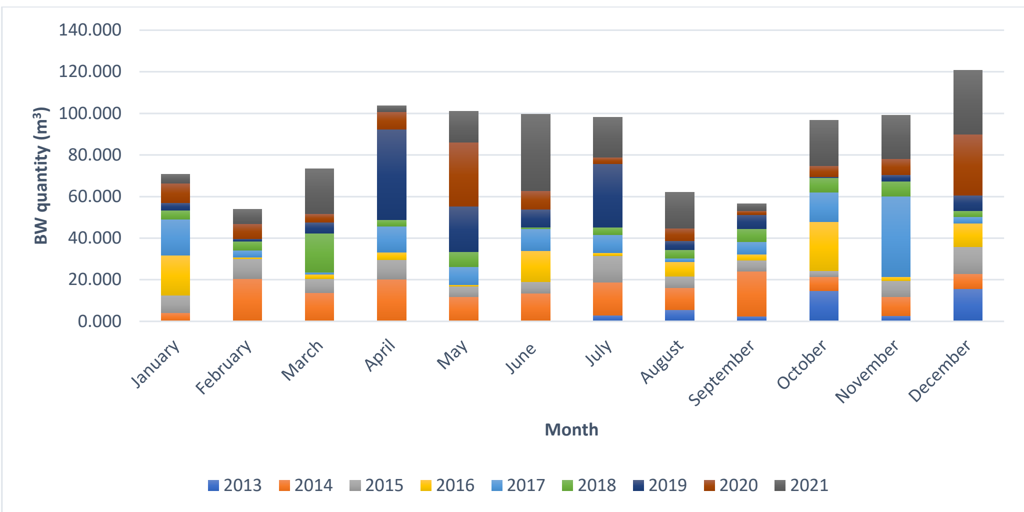

Figure A2. BW quantities discharged in the Port of Ploče by month.

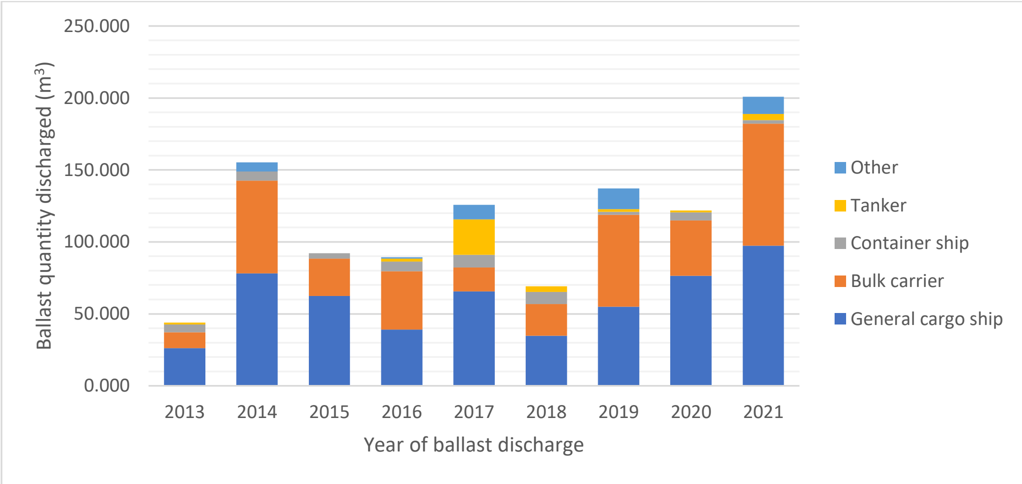

Figure A3. Annual BW quantities discharged by ship type.

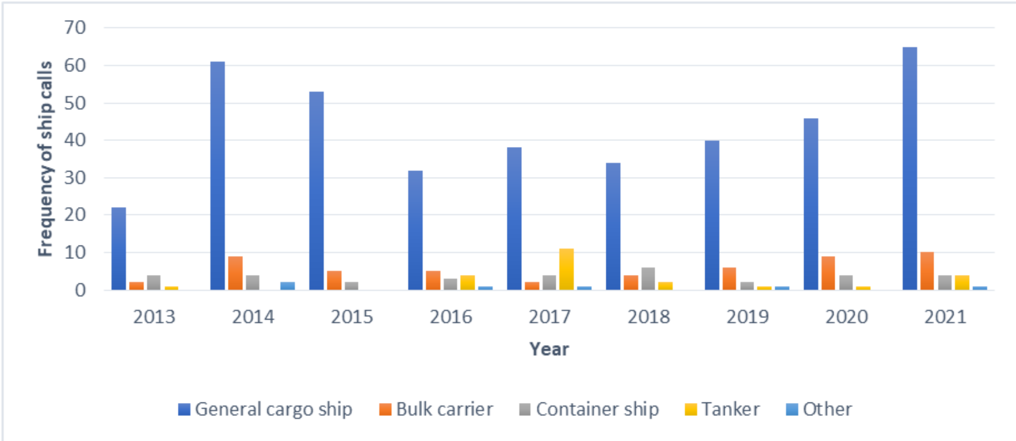

Figure A4. Annual frequency of ship calls by ship type.

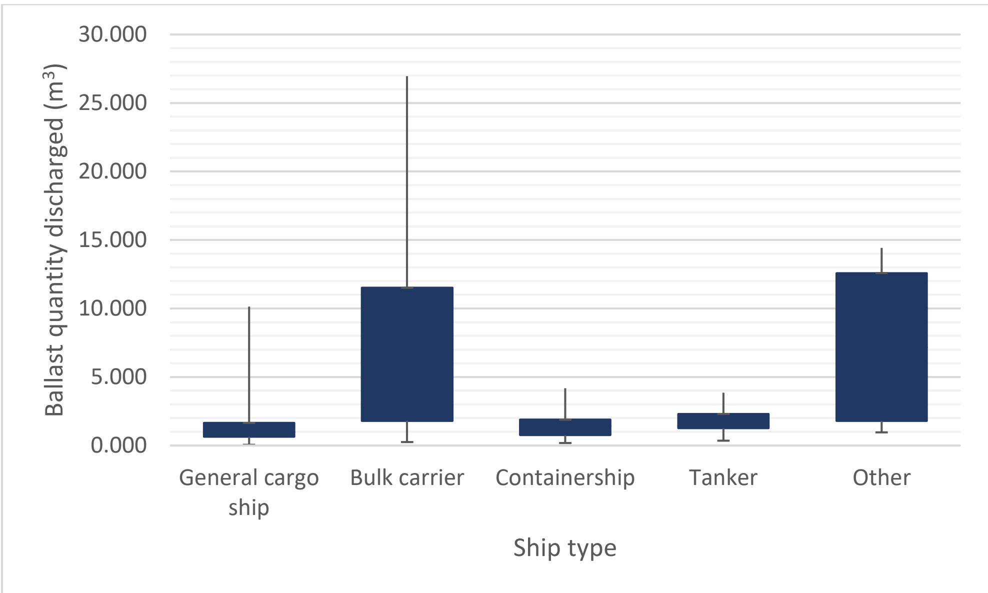

Figure A5. BW quantities discharged per single ship by ship type.

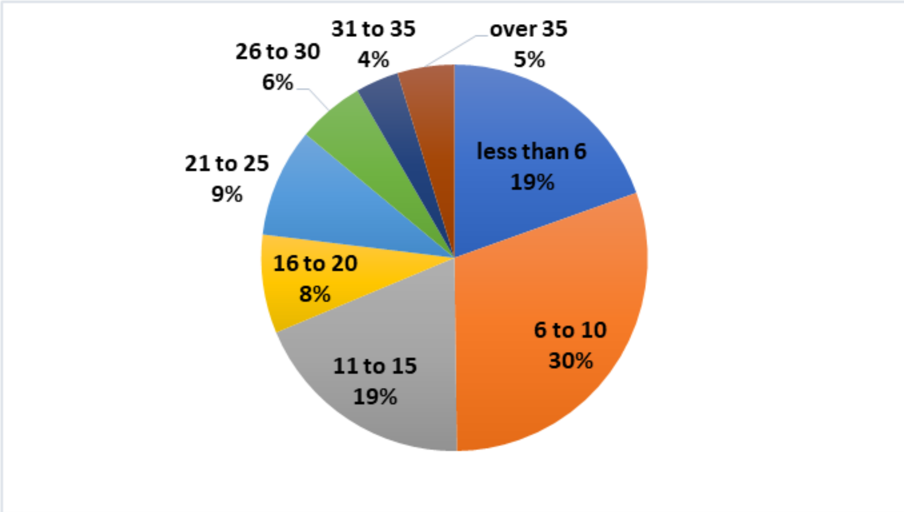

Figure A6. Percentages of BW discharged in the Port of Ploče by ship age.

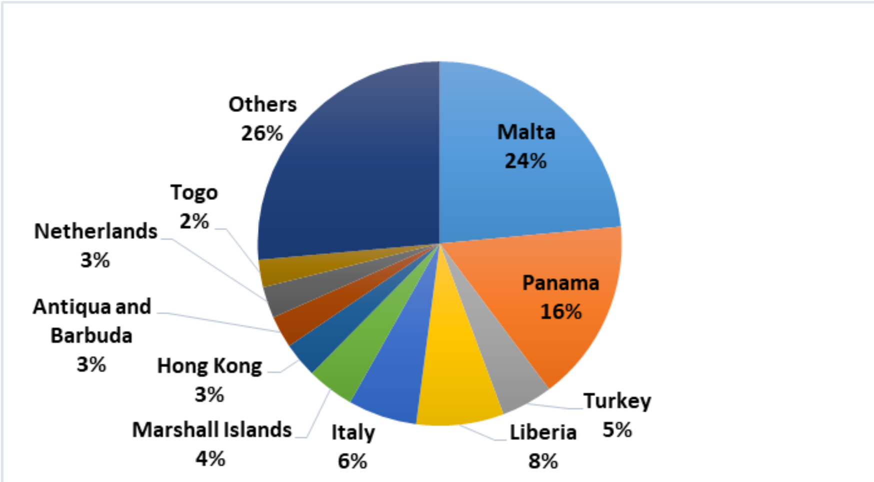

Figure A7. Percentage of BW discharged in the Port of Ploče by ship flag.

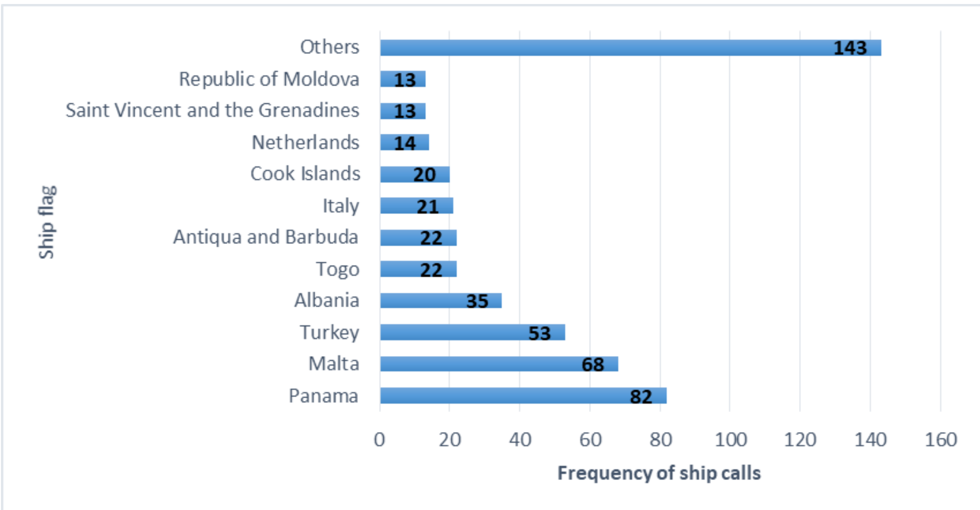

Figure A8. Frequency of BW discharging ships by ship flag.

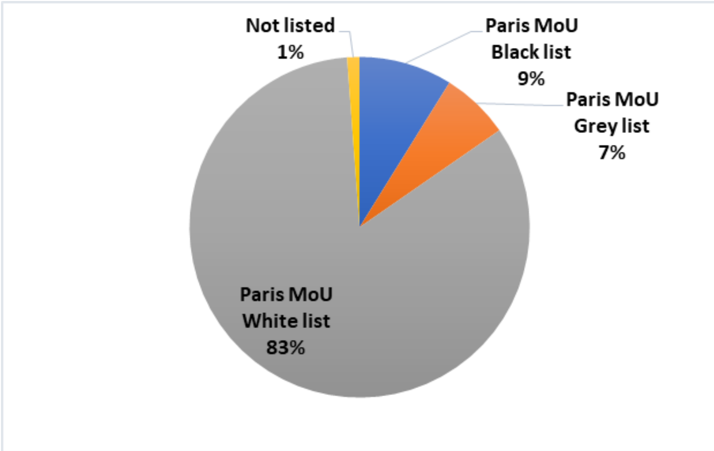

Figure A9. Percentages of BW discharged in the Port of Ploče by Paris MoU White, Grey and Black List flags.

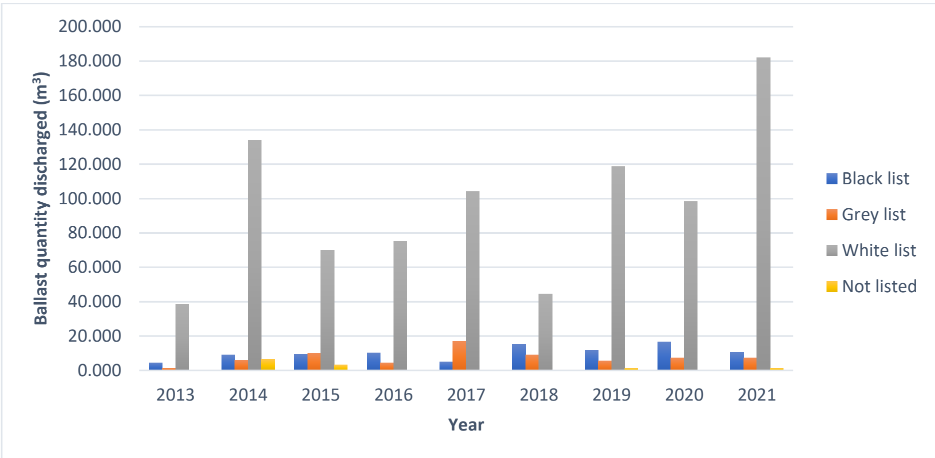

Figure A10. Annual BW quantities discharged in the Port of Ploče by Paris MoU White, Grey and Black List flags.

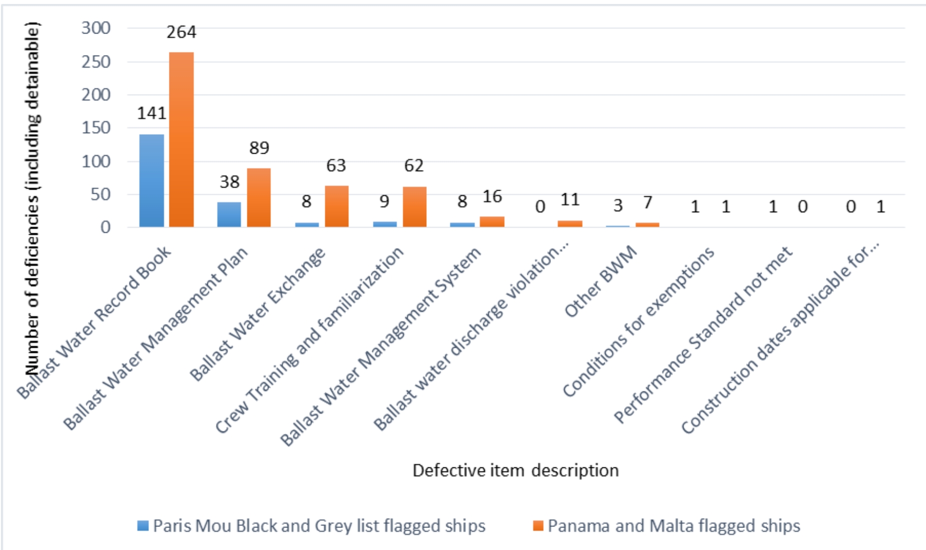

Figure A11. Comparing BWM deficiencies identified by the Paris MoU inspection regime from January 2019 to June 2022 by Paris MoU Black and Grey List flagged ships and Panama and Malta flagged ships.

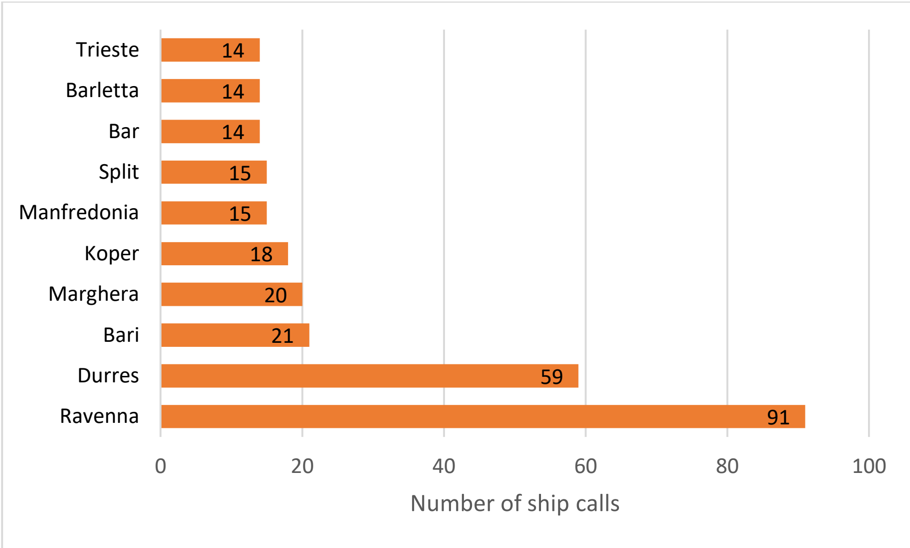

Figure A12. Frequency of ship calls where the last port of call was the Adriatic Sea port.

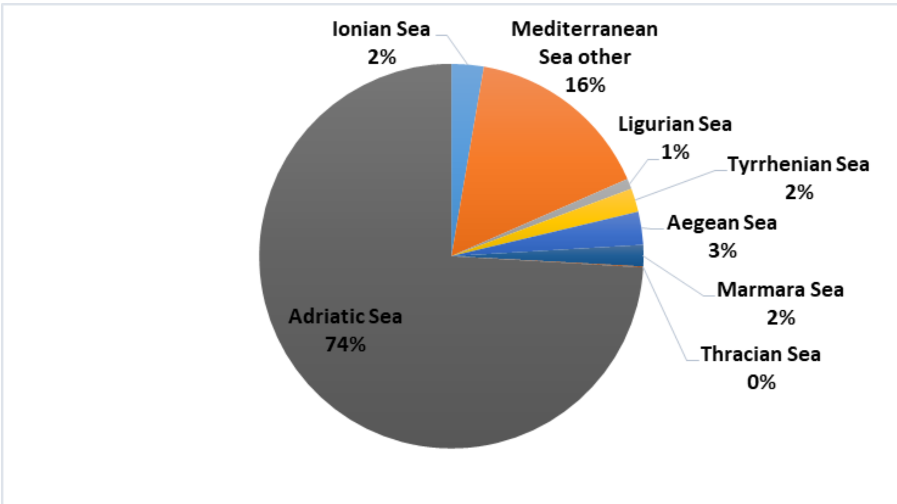

Figure A13. Percentages of BW discharged in the Port of Ploče sourced from the Mediterranean Sea.

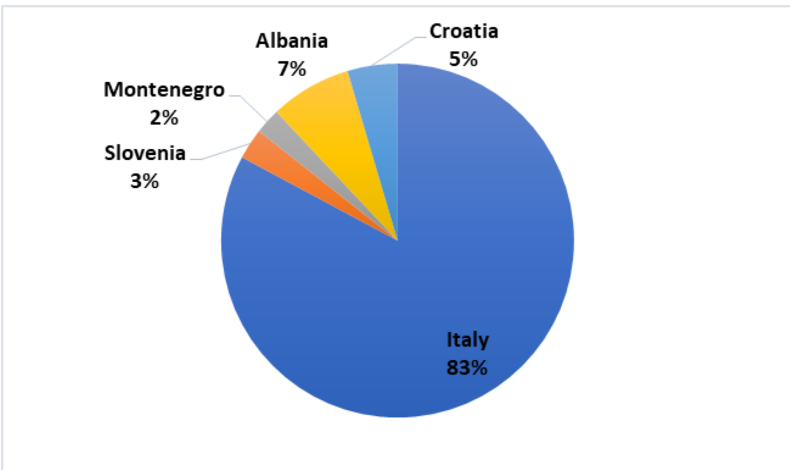

Figure A14. Percentages of BW discharged in the Port of Ploče sourced from the Adriatic Sea by coastal states.

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