Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 118 **2023**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2023.118.13

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Melnyk, O., Onyshchenko, S., Onishchenko, O. Development measures to enhance the ecological safety of ships and reduce operational pollution to the environment. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **118**, 195-206. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2023.118.13.

Oleksiy MELNYK[1], Svitlana ONYSHCHENKO[2], Oleg ONISHCHENKO[3]

DEVELOPMENT MEASURES TO ENHANCE THE ECOLOGICAL SAFETY OF SHIPS AND REDUCE OPERATIONAL POLLUTION TO THE ENVIRONMENT

Summary. Reduction of ecological risks of shipping is a challenging task that requires methods of legislative and regulatory control, organizational measures, and technical and technological support. Furthermore, the matter concerns not only the reduction of possible risks but also the level of existing impact on the marine environment because of exhaust gas emissions by ships, discharge of waste and ballast water, as well as control of ecological consequences of accidents. The purpose of this study is to analyse possible sources of environmental impact during ship operation cycles, identify significant risks, review existing potentials to reduce the risk of ship accidents and their environmental consequences, and develop solutions to existing problems. This study offers results, which can serve as the initial basis for the formation of comprehensive measures on the reduction of environmental risks, and consequences of possible accidents for the environment caused by ships and international shipping.

[1] Department of Navigation and Maritime Safety, Odesa National Maritime University, 34 Mechnikov Street, 65029 Odesa, Ukraine. Email: m.onmu@ukr.net. ORCID: https://orcid.org/0000-0001-9228-8459
[2] Department of Fleet Operation and Transport Technologies, Odesa National Maritime University, 34 Mechnikov Street, 65029 Odesa, Ukraine. Email: onyshchenko@gmail.com. ORCID: https://orcid.org/0000-0002-7528-4939
[3] Department of Technical Fleet Operation, National University "Odessa Maritime Academy", 8 Didrikhson Street, 65029 Odessa, Ukraine. Email: oleganaton@gmail.com. ORCID: https://orcid.org/ 0000-0002-3766-3188

Keywords: environmental safety, freight transportation, pollution prevention, ship operation cycle, safety of marine ecosystems, MARPOL, air pollution, water pollution, shipping management

1. INTRODUCTION

Environmental pollution is not only dangerous because of harmful substances entering the clean air and the marine ecosystem that are destructive to living organisms but also because of global changes in the climate caused by pollutants. Pollution from commercial activities has increased carbon dioxide concentrations by almost 30% over the last century. However, despite this, humanity continues to burn fossil fuels and destroy forests, which is indicative of the scale of these processes and steadily leads to global environmental problems.

The central environmental problem for the world's ocean ecosystem continues to be pollution from merchant ships or as a result of ship operations conducted on them. In addition, other aspects related to marine commercial activities can also be considered sources of pollution, the main ones being direct emissions of pollutants into the ocean, for example, oil products during transportation, direct access of pollutants during various shelf development and extraction of mineral resources. One major environmental problem arising from the pollution of the seas and oceans is the impact of oil and petroleum products on marine organisms. In addition to that, there are various kinds of effluents, both river and direct runoffs from the land, such as terrigenous runoff, as well as emergency discharges from ships or underwater pipelines. Another serious global issue being experienced by humanity today is the problem of atmospheric air pollution [1, 2].

Environmental effects of marine transportation [3] are increasing as various cargoes are being carried by water transport. Ways to reduce the risk of ship collisions with marine organisms were studied in [4]. Issues referring to oil refineries and water pollution in the context of sustainable development, modeling spatial dispersion of contaminants from shipping lanes and impact of maritime oil pollution in the marine environment, development of a mixed-source, single pesticide database for use in ecological risk assessment: quality control and data standardization practices in sources [5-8]. Marine pollution problems caused by the operation of ships, prohibition of pollution of marine environments: emerging issues, challenges and prospects in [9-11]. Features of implementation of new requirements for the environmental safety of ships and offshore installations were studied in [12, 13]. Progress report on addressing impacts of underwater noise and marine debris on marine and coastal biodiversity in [14] and ship’s ballast water pollution problems in [15]. Papers [16-20] were devoted to the influence of shipping accidents on the marine environment, environmental pollution by ships and environmental hazards methodologies for risk assessment and management. Development of a set of organizational measures to prevent operational pollution and measures to lessen and reverse the potential modal shifts due to environmental legislation to pollution were examined in [21-23]. Prevention pollution overview and technical and operational measures to reduce greenhouse gas emissions and improve the environmental and energy efficiency of ships were reviewed in [24-27]. Economic and legal impact of sulfur limit under Annex VI, MARPOL convention and the impact of the global sulfur cap on maritime CO_2 emissions were examined in papers [28, 29]. Works [30-33] were devoted to marine pollution by microplastics and its ubiquitous ingestion in marine turtles, waste abatement campaigns and government policies aimed at reducing plastic waste and plastic pollution challenges in marine and coastal environments.

Thus, based on scientific works studied in this research, the development of a set of measures aimed at preventing harmful discharges into the sea, air emissions and noise pollution, as well as providing measures to prevent pollution from ship operation, emerged as the most relevant and particularly demanded, considering the pace of fleet expansion and growth of world trade.

2. MATERIALS AND METHODS

In recent years, given the growing urgency of problems associated with marine pollution, the development of both organizational and technical measures aimed at preventing operational pollution of the environment during ships' operation on maritime and inland waterways is carried out at an intensive pace. Prevention of operational pollution of the environment from water transport activity is known to be regulated by many conventions, legal acts and requirements, which provide strategic approaches to the prevention of operational pollution from ships. They are based both on the use of shipboard technical means on the main power plants for sewage and oily water treatment and the use of onshore technical means. In combination, these means include a wide set of technical measures ensuring pollution prevention in an integrated way, which is more effective and expedient under conditions of ships' operation at sea. In practice, it is proved that a complex of organizational actions whose basic purpose is substantiation and choice of strategy of prevention of pollution of a sea ecosystem at the operation of ships provide the application of modern technical means on board the ships. While solving the problem of protecting maritime and inland waterways from pollution by ships, considering various conditions of nature protection arrangements during ship operation. The main possible ways to achieve these objectives are determined by the requirements for drainage of cleaned ship pollutants, the economic, production and intellectual capacities of shipping companies and fleet operators, as well as the navigational and climatic conditions during ship operation. The role of motivational aspects of ship crew activities in solving problems of pollution prevention of marine ecosystem during ship operation is equally important as well.

Environmental impacts resulting from international shipping include air pollution, water pollution, acoustic pollution, and oil pollution. Pollution of the marine environment is the most significant and includes, in addition to water pollution, pollution in the form of marine sediments that cause damage to the marine ecosystems; caused by the release of harmful substances, regardless of their nature or quantity. The main pollutants of the marine environment are shown in Figure 1.

The International Convention for the Prevention of Pollution from Ships, MARPOL 73/78 (MARPOL), provides a set of measures to prevent operational and accidental marine pollution from ships by oil; liquid substances carried in bulk; harmful substances carried in packaging; sewage; garbage; and air pollution from ships. It consists of articles introducing terms, definitions, obligations and sanctions, as well as protocols and six annexes. The Protocols lay down general provisions on the obligations of participating states to prevent marine pollution from ships. The Annexes introduce Regulations concerning marine pollution by specific pollutants: oil, noxious chemicals carried in bulk, substances carried in packaged form, sewage, garbage and air pollution from ships (Figure 2).

A ship, as a source of environmental pollution, impacts through several channels at once. These include pollution of the biosphere by wastes generated in the course of operational activities; accidents during which toxic cargoes are released (mostly oil and petroleum products); greenhouse gas emissions; noise pollution; and as a result of shipwrecking, sinking

or recycling. The main ways in which ship pollution occurs have been identified as follows: ballast water discharge, acoustic pollution, collision with mammals, atmospheric pollution, hydrosphere pollution, oily water discharge, operational waste discharge, and garbage discharge (Figure 2).

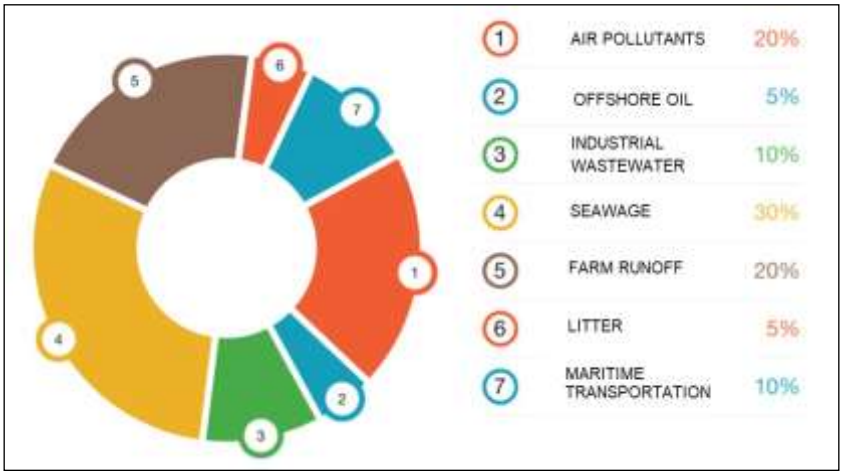

Fig. 1. Main pollutants of the marine environment

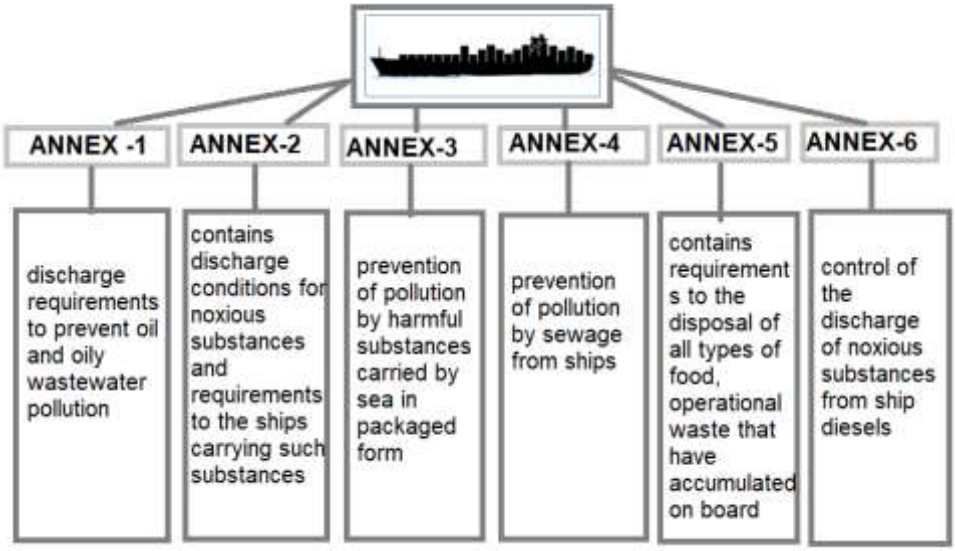

Fig. 2. The MARPOL-73/78 convention structure

To develop organizational and technical measures that ensure the environmental safety of the marine environment and detailed coverage of those normative documents regulating these aspects, it is necessary to focus on the threats and consequences for the environment that each type of pollution has.

The discharge of ballast water by ships negatively affects the aquatic environment. Ballast water and sediment discharges by ships worldwide are regulated under the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention), which came into force on September 8, 2017. It contains measures for the containment of organisms that cause problematic environmental effects outside their natural range. Some of the most undesirable species among these organisms are cholera vibrio (various

strains), cladocera, Chinese moss crab, and toxic algae. These aquatic organisms are of animal or plant origin, as well as viruses and bacteria that are harmful to the natural inhabitants of other natural areas. The damage caused by them to the environment, fisheries, aquaculture farms, and other areas of activity is very significant and can even cause infections.

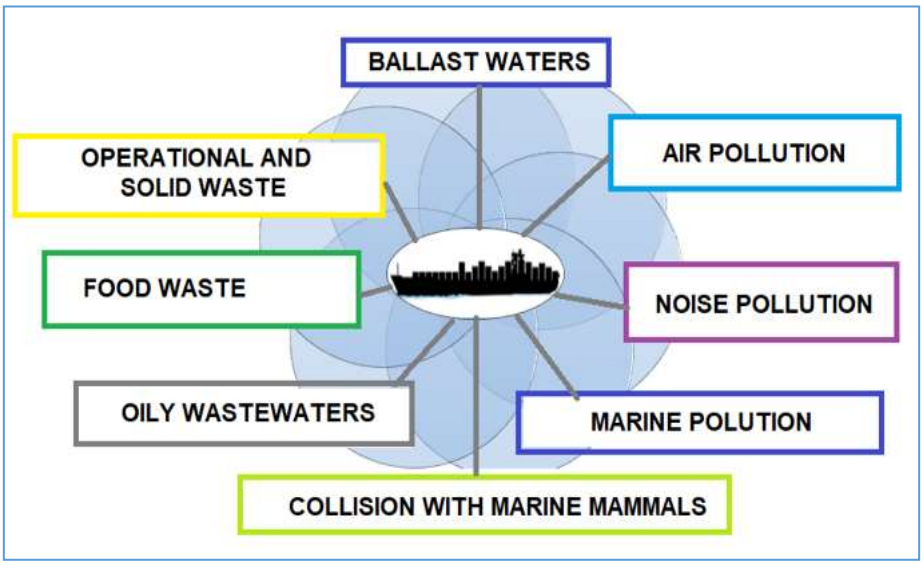

Fig. 3. Main sources of pollution from ship operations

Noise or acoustic pollution of the marine environment occurs due to human activities and commercial shipping, seismic surveys, oil exploration, and the use of military sonar. All of these types of noise pose a serious threat to marine life. This noise pollution affects a wide range of marine species, not just whales and dolphins. In 2012, the IMO adopted a provision in the International Convention for the Safety of Life at Sea (SOLAS) with the mandate that ships be built with reduced noise levels on board and that the personnel be protected from noise following the Code on noise levels on board ships. Noise intensity causes psychological stress or physiological disturbances in both humans and marine dwellers. Increased noise levels in the oceans are a threat to marine life and seaweeds that use sound to communicate and search for food. In 2014, the IMO Marine Environment Protection Committee (MEPC) approved guidelines to reduce underwater noise from commercial shipping to deal with its harmful impacts on marine life.

Collisions of marine mammals with ships or strikes against ships can result in death or serious injuries to marine mammals, such as large wounds, blood loss, broken bones, and propeller wounds. Marine mammals, such as whales and manatees, are at risk of colliding with ships, resulting in the animals' deaths. The purpose of the MEPC.1/Circ.674 IMO Circular is to guide member governments on reducing and minimizing the risk of ship strikes against cetaceans. Collisions with ships are among the leading causes of cetacean and dolphin mortality in the oceans and seas.

Air pollution from ships is produced by power plants that burn fuels containing high levels of sulfur, sulfur dioxide, nitrogen oxide and particulates, as well as carbon monoxide, carbon dioxide and hydrocarbons. Exhaust was classified by the Environmental Protection Agency (EPA) as a probable human carcinogen in 1997, and the IMO added a new annex (Annex VI) to MARPOL on air pollution from ships that address air pollution from sulfur and other hazardous waste such as nitrogen oxides and particulates. In 2011, IMO became the first

international transport regulator to adopt global mandatory energy efficiency requirements: these cover all ships, regardless of trade pattern or flag state, aiming to reduce greenhouse gas emissions from ships engaged in international shipping.

The main pollutants of the hydrosphere during ship operations are oil and petroleum products. Oil spills have devastating consequences. Polycyclic aromatic hydrocarbons (components of crude oil), which are very toxic to the aquatic environment, are very difficult to remove and remain in the water for many years. Hydrobionts continuously exposed to polycyclic aromatic hydrocarbons experience developmental problems, disease and abnormal reproductive cycles. The International Convention for the Prevention of Marine Pollution from Ships of 1973, as modified and amended by the Protocol of 1978, is formally called MARPOL 73/78 Annex 2. Oil pollution disrupts many natural processes and interrelationships, significantly changes the conditions of all kinds of living organisms and accumulates in biomass. Oil is a product of long-term decay, which very quickly covers the surface of waters with a dense layer of oil film, preventing access to air and light, and causing long-term damage to the life activity of organisms living in the coastal zone; on the bottom or the surface. It is a threat to the living conditions and habitats of birds, mammals, fish and plants. Consequently, fisheries, hotels and restaurants suffer huge losses from oil issues alongside other sectors of the economy, especially those businesses whose operations require large quantities of water. If an oil spill occurs in a freshwater reservoir, the local population (municipal water treatment services) and agriculture will be negatively affected.

The discharge of untreated or inadequately treated bilge water and sewage, as well as the discharge of wastewater that may contain harmful bacteria, pathogens, viruses, intestinal parasites and harmful nutrients, and the discharge of solid waste generated by vessels pose dangerous threats to the marine ecosystem. Discharges of untreated or inadequately treated sewage can lead to bacterial and viral contamination of hydrobionts. Nutrients in wastewater, such as nitrogen and phosphorus, contribute to excessive algal blooms that consume significant amounts of oxygen from the water, resulting in fish death. The discharge of unfiltered bilge water, destructive to the ecosystem, is strictly prohibited because the substances they contain not only harm the microorganisms that the larger animals feed on but also enter the food chain through mussels and fish, causing harm to humans.

All types of garbage and operational waste, excluding solid residues containing oil and petroleum products and other substances harmful to human health or marine living resources, which are generated during the operation of ships and shore facilities and formed as a result of various industrial and repair works on the ship or in the port, regulated by MARPOL Annex V - Regulations for Prevention of Pollution by Garbage from Ships, are potential sources of dangerous human and animal diseases. Wet hides of animals, wool and livestock transported onboard ships are considered the most dangerous. This kind of garbage is buoyant and breaks down in the natural environment for a long time, clogging up the water space. Also, the remains of nets, for example, wind up on the blades of propellers, causing shipwrecks. Furthermore, the damage from plastic is much worse than climate change and loss of biodiversity; hence to solve the problem of marine debris, the entire process, from the production of plastic to its uses and disposal, needs to be rethought.

3. RESULTS AND DISCUSSION

The environmental hazards of ships are represented by two components - operational and emergency. It is difficult to assume which of them is the most dangerous, as well as their degree

and level of danger to the environment. Pollution arising in the process of operation of ships and infrastructure facilities such as ports, shipbuilding and ship-repair enterprises is formed and discharged into the sea constantly, although in relatively small amounts. During accidental spills, large amounts of pollutants are discharged at once; however, they are limited to the accident area and adjacent territories. In case of an accidental discharge, mass death of hydrobionts is observed, while in the case of operational pollution, the aquatic ecosystem is chronically poisoned (Figure 4).

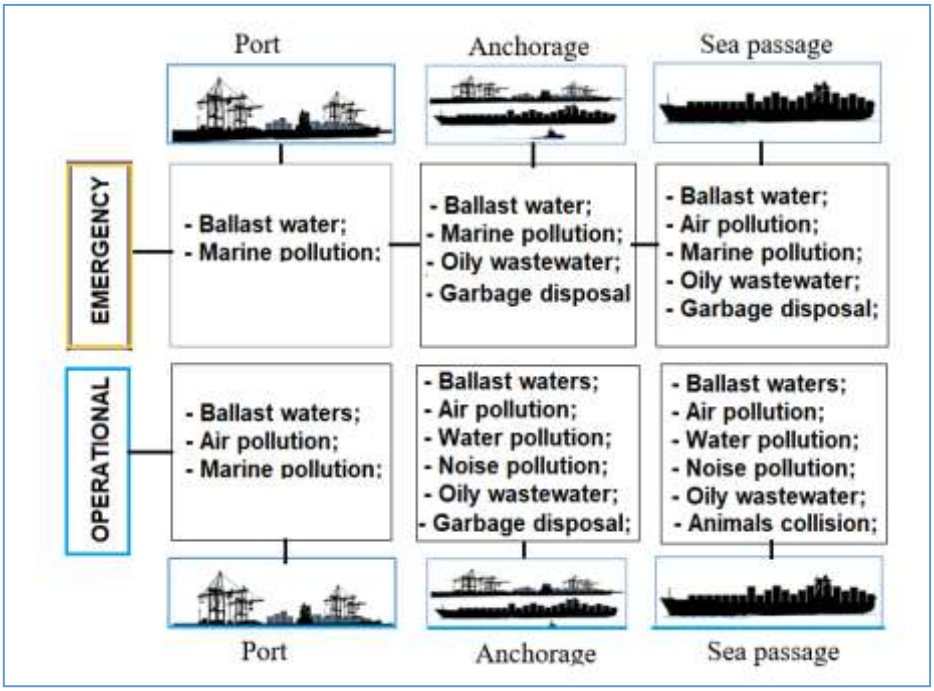

Fig. 4. Ship's operation cycle regarding possible pollution

Intensive development of international shipping requires active measures to prevent environmental pollution during ship operation and involves the development of both organizational and technical measures aimed at preventing operational pollution of the environment during the operation of ships, as presented in Table 1.

Tab. 1

Organizational and technical measures to prevent operational pollution from ships

Pollution risks	Emergence and causes of pollution	Solutions offered
Ballast water discharge	Violation of the requirements for ballast water operations, procedures for ballast treatment and exchange, and failure to comply with the required distance from the nearest shore.	Implementation of a ballast water management plan and a ballast water treatment system on board ships.

Acoustic pollution	High traffic density on shipping lanes and routes. Ship traffic congestion in constricted waters, canals, and straits. Oil and gas fields, military ships and exercises.	The use of less noisy marine engines. Introduction of stricter legislation on oil and gas seismic surveys and the use of hydroacoustic systems.
Collision with mammals	Growing intensity of shipping, increasing speed and maneuvering characteristics of ships.	Development of cetacean behavior management methods based on the integrated use of information, energy, and bioresonance signals.
Air pollution	No equipment and systems for cleaning exhaust gases on board. Powerful engines with huge fuel consumption; inexpensive fuel with high sulfur content, which is a waste product of oil refining.	Rejection of high-sulfur fuel oil and conversion to higher-quality diesel fuel containing less sulfur. Equipping ships with scrubbers exhaust gas-cleaning systems. Use of natural gas as an alternative fuel.
Marine pollution	Failure to comply with the bunkering procedure. Damage to the integrity of the vessel hull and its subsequent depressurization due to unsatisfactory technical conditions and/or mechanical damage, failure of the cargo system, damage to control sensors, including gauges, closing valves, and overfilling of oil storage tanks.	Compliance with the technological process of the operation, control of hull integrity, pipeline hermiticity and mechanical damage of flexible hoses, connecting assemblies, and systems and couplings. Monitoring of sensors, level gauges, shut-off valves, and the actual level of filling of tanks.
Oily wastewater discharge	Breach of requirements regulating bilge water discharge, failure to discharge to port facilities, and treatment plant malfunction.	Satellite monitoring and image analysis. Functionality of the installation of a wastewater treatment system (physic-chemical, electrochemical or biological type) Class approved. Proper functioning of the system for shredding and disinfecting wastewater and collection tanks with adequate storage capacity.
Discharge of Operational and solid waste	Breach of requirements for the collection, transportation, disposal and recycling of operational waste. Unauthorized dumping of waste that is buoyant.	Special waste must be delivered to special receiving ships with skin and respiratory protection equipment. Strict prohibition of mixing hazardous waste with solid garbage. Special waste should be stored in separate containers provided by the port service. Use of equipment: Waste collectors. Handling facilities. Waste treatment facilities.

Discharge of food waste	Breach of convention requirements, sanitary and veterinary rules, waste collection, storage, treatment and disposal technology. Inappropriate use of shipboard operating equipment for storage, treatment and disposal of garbage.	Incineration, collection and segregation. Use of food waste grinders and waste compactors.

4. CONCLUSION

Protection of the marine environment, as well as the prevention of pollution during ship operations, is a complex task, which is solved at many levels, starting from the adoption and observance of the international conventions to the implementation of these decisions on the spot by ship crews. Prevention of marine ecosystems' pollution demands the implementation of advanced technology solutions and the development of new approaches, including those for the reduction of accident risks. The task of minimization of negative human-induced factors of impact on aquatic ecosystems and reduction of ecological disaster risks must be solved by creating modern transportation systems that are reliable and harmless to the environment. The development of an efficient environmental management system is necessary to prevent environmental pollution in the process of ship operation and to ensure environmental safety in the long term.

References

1. Jacyna M., J. Merkisz. 2014. "Proecological approach to modelling traffic organization in national transport system". *Archives of Transport* 2(30): 43-56.
2. Jacyna-Gołda Ilona, Jolanta Żak, Piotr Gołębiowski. 2014. "Models of traffic flow distribution for various scenarios of the development of proecological transport system". *Archives of Transport* 32(4): 17-28. DOI 10.5604/08669546.1146994.
3. Walker Tony, Olubukola Adebambo, Monica Del, Aguila Feijoo, Elias Elhaimer, Tahazzud Hossain, Edwards Stuart Johnston, Courtney Morrison, Jessica Romo, Nameeta Sharma, Stephanie Taylor, Sanam Zomorodi. 2019. "Environmental Effects of Marine Transportation". Chapter 27. In: *World Seas: An Environmental Evaluation. Volume III: Ecological Issues and Environmental Impacts.* P. 505-530. Elsevier. ISBN: 978-0-12-805052-1.
4. Schoeman Renee, Claire Patterson-Abrolat, Stephanie Plön. 2020. „A Global Review of Vessel Collisions With Marine Animals". *Frontiers in Marine Science* 7: 292. DOI: https//doi.org/10.3389/fmars.2020.00292.
5. Radelyuk Ivan, Kamshat Tussupova, Jiri Klemeš, Kenneth Persson. 2021. „Oil refinery and water pollution in the context of sustainable development: Developing and developed countries". *Journal of Cleaner Production* 302: 126987. DOI: https://doi.org/10.1016/j.jclepro.2021.126987.

6. Maljutenko Ilja, Hassellöv Ida-Maja, Eriksson Karl, Ytreberg Erik, Yngsell Daniel, Johansson Lasse, Jalkanen Jukka-Pekka, Kõuts Mariliis, Kasemets Mari-Liis, Moldanova Jana, Magnusson Kerstin, Raudsepp Urmas. 2021. „Modelling spatial dispersion of contaminants from shipping lanes in the Baltic Sea". *Marine Pollution Bulletin* 173, Part A.
7. Farhan M. Al Fartoosi. 2013. "The impact of maritime oil pollution in the marine environment: case study of maritime oil pollution in the navigational channel of Shatt Al-Arab". World Maritime University Dissertations. No 318.
8. Cantasano Nicola. 2022. „Marine Pollution by Microplastics in the Mediterranean Sea". *Journal of Marine Science and Engineering* 10: 858. DOI: https://doi.org/:10.3390/jmse10070858.
9. Картамышева Е., Д. Иванченко, Е. Бекетова. 2018. „Судно как источник загрязнения окружающей". *Молодой ученый* 25(211): 12-15. [In Russian: Kartamysheva E., D. Ivanchenko, E. Beketova. „Ship as a source of environmental pollution". *Young scientist*].
10. Strain Elisabeth, Racliffe Lai, Camille White, Stefania Piarulli, Kenneth Leung, Laura Airoldi, Allyson O'Brien. 2022. „Marine Pollution - Emerging Issues and Challenges". *Frontiers in Marine Science* 9: 918984. DOI: https://doi.org10.3389/fmars.2022.918984.
11. Kirchner Stefan. 2020. „Marine Pollution: B. Vessel Source Pollution". *Yearbook of International Environmental Law* 31(1): 89-91. DOI: https://doi.org/10.1093/yiel/yvab004.
12. Melnyk Oleksiy, Svitlana Onyshchenko. 2022. „Ensuring Safety of Navigation in the Aspect of Reducing Environmental Impact". In: *International Symposium on Engineering and Manufacturing* LNNS(463):1-9. DOI: https://doi.org/10.1007/978-3-031-03877-8_9.
13. Тимофеев О., Н. Вальдман, М. Крыжевич. 2014. "Особенности внедрения новых требований к экологической безопасности судов и морских установок в северных морях и на арктическом шельфе". *Арктика: экология и экономика* 3(15): 79-85. [In Russian: Timofeev O., N. Waldman, M. Kryzhevich. „Features of implementation of new requirements for environmental safety of ships and offshore installations in the northern seas and on the Arctic shelf". *Arctic: Ecology and Economics*].
14. *Progress report on addressing impacts of underwater noise and marine debris on marine and coastal biodiversity. UNEP. Subsidiary Body on Scientific, Technical and Technological Advice*. 18th Meeting. Montreal, 2014. Available at: https://www.cbd.int/doc/meetings/sbstta/sbstta-18/official/sbstta-18-05-en.pdf.
15. Satir Tanzer. 2008. „Ship's Ballast Water and Marine Pollution". In: *Integration of Information for Environmental Security. NATO Science for Peace and Security Series C: Environmental Security.* DOI: https://doi.org/10.1007/978-1-4020-6575-0_30.
16. Gokce Ceyhun. 2014. „The impact of shipping accidents on marine environment: a study of turkish seas". *European Scientific Journal* 10(23): 10-23.
17. Khalikov Sarvar, Altynbek Smailkhan, Kamila Nukuyeva. 2020. „How Can Environmental Pollution by Ships be Minimized at the New Terminal of Cargo Offloading Facility of the Caspian Sea?" *Journal of Geoscience and Environment Protection* 8: 28-45. DOI: https://doi.org/10.4236/gep.2020.81003.
18. Schachter Oscar, Serwer Dfniel. 1971. „Marine Pollution Problems and Remedies". *The American Journal of International Law* 65(1): 84-111. DOI: https://doi.org/10.2307/2199296.

19. Grdovic Gnip Ana, Žiga Velkavrh. 2022. „To Pollute or Not To Pollute? Exploring MARPOL Efficiency in the Adriatic Sea". *Transactions on Maritime Science* 11: 219-236.
20. Dalezios Nicolas. 2017. „Environmental Hazards Methodologies for Risk Assessment and Management". *Water Intelligence Online.* DOI: https://doi.org/10.2166/9781780407135.
21. Reshnyak Valerii. 2017. „Development of a set of organizational measures to prevent operational pollution of inland waterways during navigation". *Bulletin of Admiral Makarov State University of Maritime and River Fleet* 5(45): 965-972.
22. Willis Kathryn, Clémentine Maureaud, Chris Wilcox, Britta Hardesty. 2017. „How successful are waste abatement campaigns and government policies at reducing plastic waste into the marine environment?" *Marine Policy* 96. DOI: https://doi.org/:10.1016/j.marpol.2017.11.037.
23. Petković Miro, Marko Zubčić, Maja Krcum, Igor Vujović. 2020. „Maritime Green Solution for Traffic Congestion". *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation* 14: 97-103. DOI: https://doi.org/:10.12716/1001.14.01.11.
24. Wainwright Brent, Louis Theodore. 2022. "Pollution Prevention Overview". In: *Pollution Prevention.* ISBN: 978100321086. DOI: https://doi.org10.1201/9781003210863-1.
25. Gil Mónica, Giarratano Erica, Carlos Andrade. 2022. "Challenges in Marine Pollution Diagnosis". *Frontiers in Marine Science* 9: 949864. DOI: https://doi.org10.3389/fmars.2022.949864.
26. Zis Thalis, Harilaos Psaraftis. 2018. „Operational measures to mitigate and reverse the potential modal shifts due to environmental legislation". *Maritime Policy & Management* 46: 1-16. DOI: https://doi.org/10.1080/03088839.2018.1468938.
27. Odeku Kola O. 2017. „Prohibition of pollution of marine environments: challenges and prospects". *Environmental Economics* 8: 127-136. DOI: https://doi.org/:10.21511/ee.08(3-1).2017.05.
28. Singh Abhay, Sanjeevi Shanthakumar. 2022. „Economic and Legal Impact of 2020 Sulphur Limit Under Annex VI, MARPOL". *European Energy and Environmental Law Review* 31: 241.
29. Perkins Daniel, Wenlin Chen, Andy Jacobson, Zechariah Stone, Mark White, Brian Christensen, Lula Ghebremichael, Richard Brain. 2021. „Development of a mixed-source, single pesticide database for use in ecological risk assessment: quality control and data standardization practices". *Environmental Monitoring and Assessment* 193. DOI: https://doi.org/:10.1007/s10661-021-09596-9.
30. Duncan Emily, Annette Broderick, Wayne Fuller, Tamara Galloway, Matthew Godfrey, Mark Hamann, Colin Limpus, Penelope Lindeque, Andrew Mayes, Lucy Omeyer, David Santillo, Robin Snape, Brendan Godley. 2019. „Microplastic ingestion ubiquitous in marine turtles". *Global Change Biology* 25(2): 744-752. DOI: https://doi.org/10.1111/gcb.14519
31. Willis Kathryn, Catarina Serra Gonçalves, Kelsey Richardson, Qamar Schuyler, Halfdan Pedersen, Kelli Anderson, Jonathan Stark, Joanna Vince, Britta Hardesty, Chris Wilcox, B.F. Nowak, Jennifer Lavers, Jayson Semmens, Dean Greeno, Catriona Macleod, Nunnoq Frederiksen, Peter Puskic. 2022. „Cleaner seas: reducing marine pollution*". Reviews in Fish Biology and Fisheries* 32: 1-16. DOI: https://doi.org/:10.1007/s11160-021-09674-8.

32. Vince Joanna Zofia, Britta Denise Hardesty. 2016. „Plastic pollution challenges in marine and coastal environments: From local to global governance". *Restoration Ecology* 25. DOI: https://doi.org/:10.1111/rec.12388.
33. Musu, Ignazio. 1997. „The Interdependence between Environment and Development: Marine Pollution in the Mediterranean Sea". DOI: https://doi.org/:10.1093/acprof:oso/9780198292203.003.0004.

Received 05.11.2022; accepted in revised form 30.12.2022