

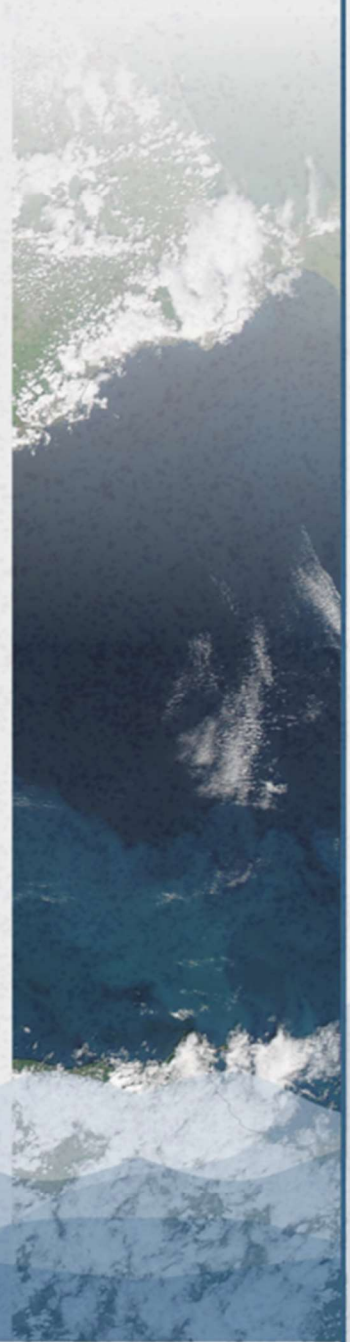
RESPONSE

Building Response Frameworks under existing
& new Marine Pollution Challenges in the Black Sea



Deliverable D1.3

Assessment report of types and impacts of marine pollution



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Executive Summary

The ecological status of the Black Sea ecosystem has been significantly degraded over the past few decades, largely due to human activities such as industrialization, urbanization, and intensive agriculture. These activities have introduced a variety of pollutants, ranging from nutrient overloads, heavy metals, and marine litter to oil spills and atmospheric contaminants, that threaten biodiversity and the ecosystem services vital to local communities.

Here, a systematic literature review was conducted to assess marine pollution in the Black Sea Basin, using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach to ensure transparency and reproducibility. The process began with the formulation of clear research questions focused on understanding the types and impacts of marine pollution, as well as evaluating training, monitoring, mitigation efforts, and relevant policies. Following a two-stage screening process a total of 435 articles (out of 1355 originally scanned) were included in the review.

Our analyses, demonstrated that marine pollution in the Black Sea takes many forms. Nutrient pollution from agricultural runoff and untreated wastewater is leading to eutrophication, causing oxygen-depleted dead zones that devastate marine life. Heavy metals like mercury, cadmium, and lead, primarily from industrial activities, pose long-term risks to both wildlife and human health. Marine litter, especially plastics, is extensive in the region, while oil spills exacerbate ecosystem degradation. The transboundary nature of pollution in the Black Sea, shared by six countries and influenced by large rivers such as the Danube and Dniester, makes regional cooperation essential for tackling these environmental threats.

Despite efforts to mitigate marine pollution, through regional initiatives, international agreements, and monitoring programs, the Black Sea remains highly vulnerable. In light of the ongoing war in Ukraine, the report also considers the environmental impacts of armed conflict on the marine environment, demonstrating that oil spills, chemical releases, and industrial destruction have intensified marine pollution in the Black Sea. Additionally, this report highlights the critical role of innovative technologies (e.g. AI, Remote Sensing) in enhancing the monitoring and management of pollution in the sensitive Black Sea. The findings of the report will guide the RESPONSE project's next steps by shaping the development of training curricula and programs focused on empowering stakeholders with the knowledge and tools to effectively monitor and manage marine pollution.

Project background and context

The RESPONSE, supported by the European Union EMFAF, under Grant Agreement no 101124661 has duration of 36 months, starting from 01.10.2023. The project consortium involves six partners from five different countries: Greece, Bulgaria, Romania, Ukraine and Georgia. Five of the participants are based in countries bordering on the Black Sea, and the lead beneficiary, the Aristotle University of Thessaloniki (AUTH), has a long history of working with the region and with members of the consortium. The partnership includes one university, two research institutes and three environmental NGOs: the Black Sea NGO Network (BSNN) regional NGO network based in Varna, Bulgaria; the National Institute of Marine Research and Development (NIMRD), based in Constanta, Romania, leading research institute for the Black Sea; the Institute of Market Problems and Economic-Ecological Research (IMPEER), Odesa, a public institution, part of the National Academy of Sciences of Ukraine; the Black Sea Branch of Ukrainian Environmental Academy of Sciences (BSBUEAS) is Odesa-based NGO with a team of professional researchers; and the Greens Movement of Georgia / Friends of the Earth (GMG/FoE) – Georgia, an NGO, part of the international environmental network. All three beneficiaries from EU Member States have extensive experience in marine pollution projects under the Horizon 2020 and Horizon Europe programmes.

RESPONSE aims to identify and promote the development and establishment of new-generation advanced training schemes and curricula to support early warning, region-wide mechanisms for monitoring natural and man-made disasters. Various training programs, platforms and curriculum have been implemented to monitor marine pollution and ensure knowledge integration and dissemination. Still, training material, best practices, standards and protocols often differ among platforms and programs, hindering progress towards implementing an integrated, transdisciplinary and multidisciplinary marine pollution training system. Peculiar events, such as armed conflicts, create new environmental and societal challenges that call for international, coordinated responses.

RESPONSE acknowledges the importance of deeper understanding of marine ecosystems and river-delta-sea connections, the need for development of harmonized procedures, standards and methodologies in marine monitoring across the Black Sea countries to support healthy and resilient seas and foster integrated marine governance. The sustainable changes that are required for the establishment of efficient, advanced training schemes that would be integrated with the challenges, goals and specificities of the scientific and social context and make the most of the untapped capacity of stakeholders to promote regional awareness in the field.

In view of the background and context described above, the four overarching objectives of RESPONSE are: 1) IDENTIFY and UNDERSTAND the institutional and societal gaps and needs for effective, integrated, transdisciplinary and multidisciplinary marine pollution training systems; 2) DEVELOP effective training programs by assembling, integrating, and improving the most promising approaches and results into a comprehensive framework that consists of a set of methodological training tools, databases, policy recommendations, and background information; 3) SUPPORT the implementation of the EU and Regional Strategies, by developing operational guidelines for effective application, updating, monitoring and management of training programs on marine pollution; 4) EMPOWER marine pollution training, monitoring and mitigation by involving, inspiring and influencing stakeholders through a broader vision of co-design, co-creation, co-establishment, co-implementation and co-assessment of the training programs.

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Aim of the Deliverable

This report aims to provide a comprehensive assessment of the types and impacts of marine pollution in the Black Sea Basin. It analyzes pollution sources, evaluates mitigation efforts, and highlights the importance of regional cooperation. By identifying key gaps and needs, the report aims to inform the development of training curricula and programs under the RESPONSE project. These curricula will focus on empowering stakeholders with knowledge and tools for monitoring and managing marine pollution. Furthermore, the report proposes the integration of innovative technologies to enhance monitoring capacity, helping to design the RESPONSE next steps.

CONTRIBUTORS

Table 1 Names and roles of contributors to this deliverable.

Name	Affiliation	WP Lead	Task Lead
Tsavdaridou Anastasia-Despoina	AUTH	AUTH	NIMRD
Mazaris Antonios	AUTH	AUTH	NIMRD
Nicoleta Damir	NIMRD	AUTH	NIMRD
Razvan Mateescu	NIMRD	AUTH	NIMRD
Andra Oros	NIMRD	AUTH	NIMRD
Luminita Lazar	NIMRD	AUTH	NIMRD
Valentina Coatu	NIMRD	AUTH	NIMRD
Dragos Niculescu	NIMRD	AUTH	NIMRD
Dragos Marin	NIMRD	AUTH	NIMRD

D1.3 ASSESSMENT REPORT OF TYPES AND IMPACTS OF MARINE POLLUTION

Elena Vlasceanu	NIMRD	AUTH	NIMRD
Elena Pantea	NIMRD	AUTH	NIMRD
Aleksandar Shivarov	BSNN	AUTH	NIMRD
Emma Gileva	BSNN	AUTH	NIMRD
Oleg RUBEL	BSB UEAS	AUTH	NIMRD
Yuliyia Kotelnikova	BSB UEAS	AUTH	NIMRD
Mamuka Gvilava	GMG/FoE-GE	AUTH	NIMRD
Nino Chkhobadze	GMG/FoE-GE	AUTH	NIMRD
Maka Tsereteli	GMG/FoE-GE	AUTH	NIMRD
Borys Burkynkyi	IMEER NASU	AUTH	NIMRD
Laiko Oleksandr	IMEER NASU	AUTH	NIMRD
Nina Khumarova	IMEER NASU	AUTH	NIMRD
Pavlo Bulanovych	IMEER NASU	AUTH	NIMRD
Olga Iermakova	IMEER NASU	AUTH	NIMRD
Olga Golikova	IMEER NASU	AUTH	NIMRD
Iryna Tsynalevska	IMEER NASU	AUTH	NIMRD
Oleksandra Vorobiova	IMEER NASU	AUTH	NIMRD
Hanna Tiutiunyk	IMEER NASU	AUTH	NIMRD

1. Introduction

The Black Sea Basin, one of the most ecologically and economically valuable regions in Europe, is facing significant environmental challenges due to marine pollution (Bakan & Büyükgüngör, 2000). This vast inland sea, supporting a rich diversity of marine life, provides essential services to millions of people, including food resources, transportation, and recreation. However, over the past few decades, the health of this unique ecosystem has been severely compromised, primarily as a result of human activities. Industrialization, urbanization, and intensive agriculture have introduced a variety of pollutants into the sea, threatening the biodiversity and the ecosystem services that sustain the livelihoods of communities around the basin (Pokazeev et al., 2021).

Marine pollution in the Black Sea takes various forms, including nutrient overloads, heavy metal contamination, marine litter, oil spills, and atmospheric pollution. Nutrient pollution, largely stemming from agricultural runoff and untreated urban wastewater, has resulted in severe eutrophication. This process, which leads to the excessive growth of algae, depletes oxygen levels in the water, causing dead zones that devastate marine life and disrupt the delicate ecological balance of the region (Bakan & Büyükgüngör, 2000; Pokazeev et al., 2021). Heavy metals such as mercury, cadmium, and lead, released from industrial activities, accumulate in the tissues of marine organisms, posing long-term risks to wildlife and human health (Simionov et al., 2019). Marine litter, especially plastics, poses a direct threat to marine animals (González-Fernández et al., 2022; Miladinova et al., 2020), while oil pollution from maritime traffic exacerbates the degradation of the Black Sea's ecosystems (Ivanov & Kucheiko, 2014).

Human activities are at the core of these pollution problems, with agriculture, industry, and urban wastewater management playing significant roles in the region's environmental decline (Pokazeev et al., 2021). What makes the situation even more challenging is the transboundary nature of the Black Sea Basin. It is shared by six countries—Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine—and is influenced by pollutants from a much wider region, including the vast catchments of the Danube, Dniester, and Don rivers (Bakan & Büyükgüngör, 2000). These rivers carry pollutants from inland areas, creating a complex web of pollution sources that no single country can tackle alone. The transboundary nature of the basin means that pollution generated in one country can quickly affect the waters and coasts of another, making regional cooperation essential for any effective solution (Avoyan et al., 2017).

In response to these mounting environmental pressures, efforts have been made to address marine pollution in the Black Sea. Regional initiatives, legislative frameworks, and international agreements, such as the Bucharest Convention and the Black Sea Environmental Programme, have been developed to reduce pollution and protect the sea's ecosystems (Avoyan et al., 2017; Loizidou et al., 2016). Monitoring networks have also been established to track pollution levels, while action plans have been created to mitigate the impact of pollutants and restore degraded ecosystems. However, despite these efforts, the challenges remain vast, and further cooperation, as well as the development of more effective pollution control measures, is needed to safeguard the future of the Black Sea (Avoyan et al., 2017).

This report aims to assess the current state of marine pollution in the Black Sea, examining the types of pollution present, their sources, and the impacts they have on this vital marine ecosystem. It will also explore the efforts undertaken to mitigate these issues and the extent to which regional cooperation and international frameworks have been effective in managing the pollution that

threatens the health of the Black Sea Basin. Given the ongoing war conflict in the region, the impacts of such conflicts have been assessed on a global scale to understand their potential effects on the marine environment. In addition, the report identifies and evaluates new and innovative technologies, along with updated monitoring approaches, to assess their applicability in enhancing the region's monitoring capacity. This report will contribute to the identification of key needs and guide the design of the next steps for the RESPONSE project, which aims to address these complex environmental challenges in a more effective and coordinated manner.

2. Marine pollution and response in the Black Sea basin area

A systematic literature review was conducted for the identification and evaluation in the Black Sea basin of the various types of pollution, their impacts and tools previously proposed for addressing key issues such as i) monitoring schemes and protocols; ii) impact mitigation, reduction and restoration measures; iii) control actions; iv) policies, frameworks and regulation for management.

The systematic literature review was performed using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to ensure systematization, transparency, and reproducibility.

The first step in the methodology for conducting a systematic meta-review is developing clear research questions that the study aims to answer. The next step involves identifying relevant literature to be included in the review. Once selected, the papers are categorized according to specific coding criteria. In the final step, the study's findings are presented, followed by suggestions for future initiatives. These methodological steps in detail are:

2.1 Research questions

The first step in conducting a literature review is to develop clear, focused, and concise research questions. These questions help establish the context of the research, refine the issue under investigation, and guide data collection. The goal is to construct a logical argument and uncover new insights from existing findings. The research questions aim to clarify the types and impacts of marine pollution in the Black Sea basin, while also examining the field's development, influence on scientific literature, and identifying research gaps and future directions. Additionally, they focus on whether key aspects of marine pollution, such as training, monitoring, and mitigation, are being addressed in research. As a result, the following research questions (RQs) were formulated:

RQ1: What types of marine pollution and their associated impacts are identified and studied in the Black Sea basin?

RQ2: To what extent does the existing research address key aspects of marine pollution, such as training, monitoring, and mitigation efforts?

RQ3: Does research focus on policies, frameworks, and regulations for managing marine pollution in the Black Sea basin?

RQ4: What are the links between the different aspects of marine pollution and their impacts on ecosystems?

2.2. Data collection

We then identified the relevant literature addressing the research questions. To select the studies for inclusion, we applied a set of predefined inclusion and exclusion criteria. The data collection took place in March 2024, exclusively using research articles from the Scopus database. A list of key terms was used as search queries (Appendix I). These keywords were entered into Scopus's default search form (Document Search), with the search field set to "Article Title, Abstract, Keywords." The term "Black Sea" was consistently used as a single concept in each query. Scopus filters were applied to

refine the results: document type was restricted to “Article,” the keyword “Black Sea” was mandatory, source type was limited to “Journal,” and only articles in English were included. Additionally, the search covered articles published between 2000 and 2024. This initial search generated (after removing any duplicates) 1355 article results.

We employed a two-phase process to filter out articles that were not relevant to our research and questions. In the first phase, we screened the titles and abstracts, selecting those that appeared relevant to our research questions. Specifically, we included articles that focused on the Black Sea basin and addressed marine pollution (e.g., pollution types, events, management).

In the second phase, we conducted a full-text review of the articles that passed the initial screening. During this stage, we assessed each article’s eligibility for inclusion in the systematic review. Articles were excluded if we could not access the full text or if they were irrelevant to the research questions or focused on other geographic regions outside the Black Sea basin.

After completing this two-step process, 435 articles were retained for inclusion in our systematic literature review (Appendix II).

2.3 Data analysis

In this step, the scientific articles selected for the systematic literature review were thoroughly examined and a range of research subjects (Table 2) were considered to extract key information from the articles, enabling the formation of a comprehensive understanding of marine pollution, its research, and management within the Black Sea basin region.

Table 2. The research subjects reviewed in each article.

Research subjects	Categories	Explanation
Pollution type	Eutrophication Contaminants Marine litter Noise Ballast water/Invasive species Atmospheric pollution/depositions Other	This refers to the types of pollution researched in the area of the Black Sea basin. “Other” refer to all other pollution types that may occur in an article.
Type of pollution source	Maritime traffic Rivers Off-shore activity Industrial activity Land-based sources Atmospheric inputs (land-based/concentrated, or sea-based/diffuse sources) Others (pollution from armed conflicts, hazardous and noxious substances from marine accidents)	This refers to the types of pollution sources researched in the area of the Black Sea basin. The types of pollution source are related to the pollution types. Multiple pollution source types might be identified in an article.
Ecosystem type affected	Marine Transitional Freshwater Coastal	This refers to the types of ecosystems impacted by the pollution described in the article. Multiple ecosystem types may be affected simultaneously.

D1.3 ASSESSMENT REPORT OF TYPES AND IMPACTS OF MARINE POLLUTION

Methodology	Field work Laboratory analysis Modeling Surveys Literature review Experiment Data analysis Other	This refers to the methodology applied in the article to study marine pollution. A combination of methods might be applied in an article.
Scale of study area	Local Regional Transboundary Black Sea basin	This refers to the scale of the study area where the methodology outlined in the article was implemented.
Record impacts of pollution	Yes No	This determines whether impacts of marine pollution are recorded in the article.
Reference on specific impacts	Degradation of human quality of life Degradation of water quality Degradation/loss of biodiversity (species) Degradation/loss of habitats Degradation/loss of ecosystem services	This determines whether there is reference on specific impacts of the marine pollution. Multiple specific impacts might identified in an article.
Reference on mitigation measures	Yes No	This determines whether mitigation measures of marine pollution are recorded in the article.
Types of mitigation measures	Monitoring Restriction/ban/reduction of use/ measures/ regulation/policies New advanced technologies/ approached Practices to increase efficiency (e.g. intensify treatment, increase rates of litter collection) Assessments/ research Raise awareness/ educate/ engage Efficient management activities Other	This refers to the mitigation measures of marine pollution that might be described in an article.
Reference on training or educational aspects to prevent pollution	Yes No	This determines whether there is a reference in an article related to training or educational aspects to prevent marine pollution.
Reference on training or educational aspects to control pollution	Yes No	This determines whether there is a reference in an article related to training or educational aspects to control marine pollution after a pollution event.
Reference on monitoring schemes and protocols	Yes No	This determines whether there is a reference in an article related to monitoring schemes and protocols for marine pollution.

D1.3 ASSESSMENT REPORT OF TYPES AND IMPACTS OF MARINE POLLUTION

Types of monitoring measures proposed	<p>Bioindicators/ biomarkers Monitoring environmental characteristics (e.g. water quality) Monitoring contaminants/organic pollution/heavy metals/ trace elements Visual observations Remote monitoring UAVs Satellite images Sampling (sediments, zoobenthos etc.) Intergrated environmental/ ecological monitoring Marine litter monitoring programs Monitoring programs at large integrated scales Citizen science monitoring programs Monitoring networks/systematic monitoring programs Other</p>	This refers to the different types of monitoring measures for marine pollution that might be described or proposed in an article.
Reference on restoration measures	Yes No	This determines whether there is a reference in an article related to restoration measures after a marine pollution event.
Types of restoration measures proposed	<p>Improve water quality (e.g. bioremediation of wastewaters) Clean-up operations Rehabilitation of affected ecosystems Enhancement of natural recovery processes Sustainable practices for resource management Removal of invasive species Species reintroduction</p>	This refers to the different types of restoration measures for an ecosystem impacted by marine pollution that might be proposed in an article.
Reference on control actions	Yes No	This determines whether there is a reference in an article related to control actions after a marine pollution event.
Types of control actions	<p>Implementation of safety protocols /enforcing international maritime pollution standards Marine litter removal Implementing advanced treatment methods Physical removal, Chemical treatments, Biological control Other</p>	This refers to the different types of control action in order to mitigate the impacts of a marine pollution event/accident etc.
Reference on policies/frameworks and regulation for management	Yes No	This determines whether there is a reference in an article related to policies/frameworks and regulation for management of marine pollution.

Types of policies/frameworks and regulation for management	International European Black Sea basin (conventions, protocols, action plans) National legislation Local and regional regulations Policies	This refers to the various types of policies, frameworks, and regulations related to the management of marine pollution, as mentioned in the article.
Reference on legislation on mitigation measures	Yes No	This determines whether there is a reference in an article related to legislation on mitigation measures for marine pollution.
Types of legislation on mitigation measures	International European Black Sea basin (conventions, protocols, action plans) National legislation Local and regional regulations Policies	This refers to the various types of legislation on mitigation measures of marine pollution, as mentioned in the article.

2.4 Results & Discussion

Following the inclusion criteria for the systematic literature review, 435 scientific articles were retained. The majority of these studies were conducted at local scales, with only around 13% focusing on the Black Sea basin as a whole (Figure 1). Additionally, most studies involved fieldwork with sample collection, which was combined with laboratory analyses (Figure 2). About 20% of the research articles employed modeling methodologies, while 16% used surveys. The majority of studies applied a combination of methodological tools.

As shown in Figure 3, fieldwork and laboratory analyses are the most commonly used methodologies for studies conducted at local and regional scales. However, modeling becomes more prevalent when the focus expands to the entire Black Sea basin. For models to be accurate, they require high-quality, harmonized, and up-to-date data. This emphasizes the need for a greater reliance on new technologies in monitoring and data collection, which can overcome the limitations of restricted area coverage. Methods such as satellite and Earth observation technologies are particularly valuable, as they enable the monitoring of the entire Black Sea region more effectively.

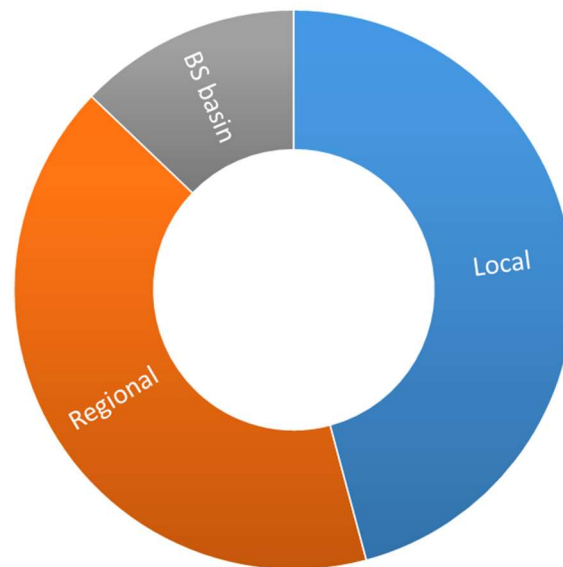


Figure 1. The 435 scientific articles of literature review grouped according to the extent of their study area.

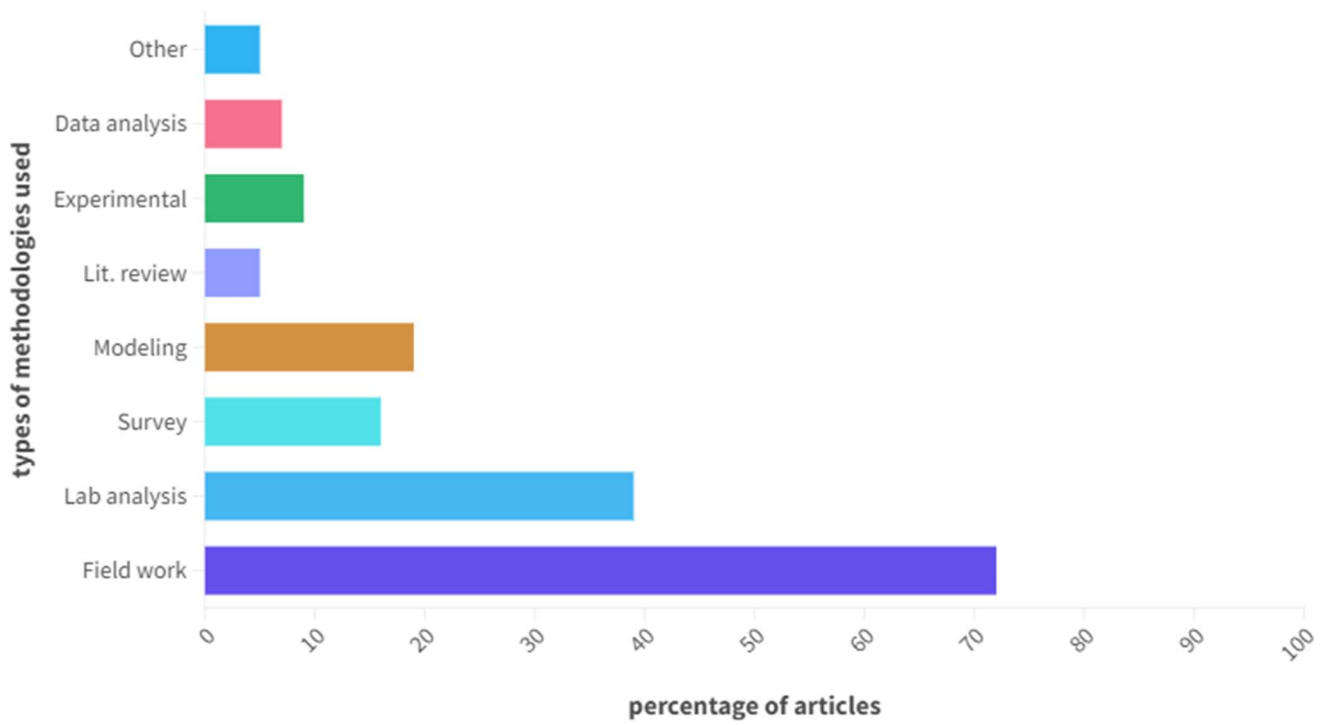


Figure 2. The methodologies used in the scientific articles from the literature review are represented on the Y-axis, while the X-axis shows the percentage of articles that utilize each approach. Multiple methodologies may be identified within a single article.



Figure 3. The scientific articles categorized based on the extent of their study area and the methodologies applied in each case.

2.4.1 Marine pollution in the Black Sea region

In approximately 3/4 of the reviewed scientific articles, pollution impacts were recorded, often affecting multiple aspects of human life and ecosystems. Most of these articles reported a decline in water quality, along with the degradation or loss of biodiversity and habitats (Figure 4). Habitat degradation or loss was also noted as a key consequence of marine pollution, followed by the decline of ecosystem services and a reduction in human quality of life.

In the majority of the scientific articles, the ecosystems most affected by various types of pollution were marine and coastal ecosystems (Figure 5), while nearly a quarter of the articles reported impacts on both. Additionally, some studies addressed the effects of pollution on transitional and freshwater ecosystems. Several studies also emphasized the cross-realm impacts of pollution, highlighting that freshwater, transitional, coastal, and marine ecosystems are all affected.

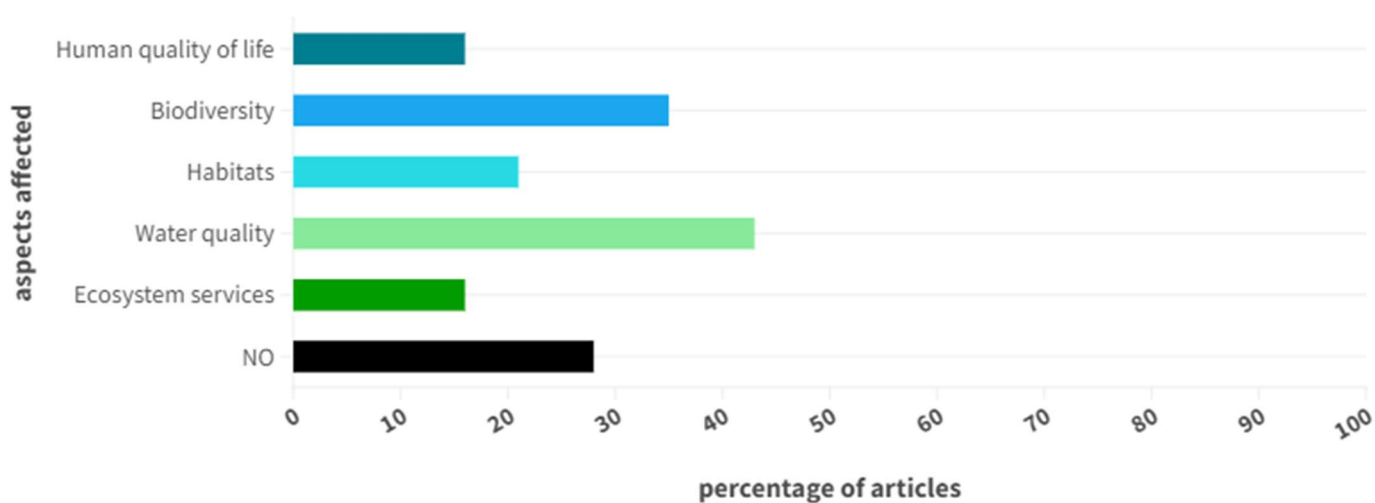


Figure 4. The different aspects affected by the marine pollution (Y-axis) and the percentage of scientific articles that refer to or identify these impacts (X-axis). Multiple impacts may be identified within a single article.

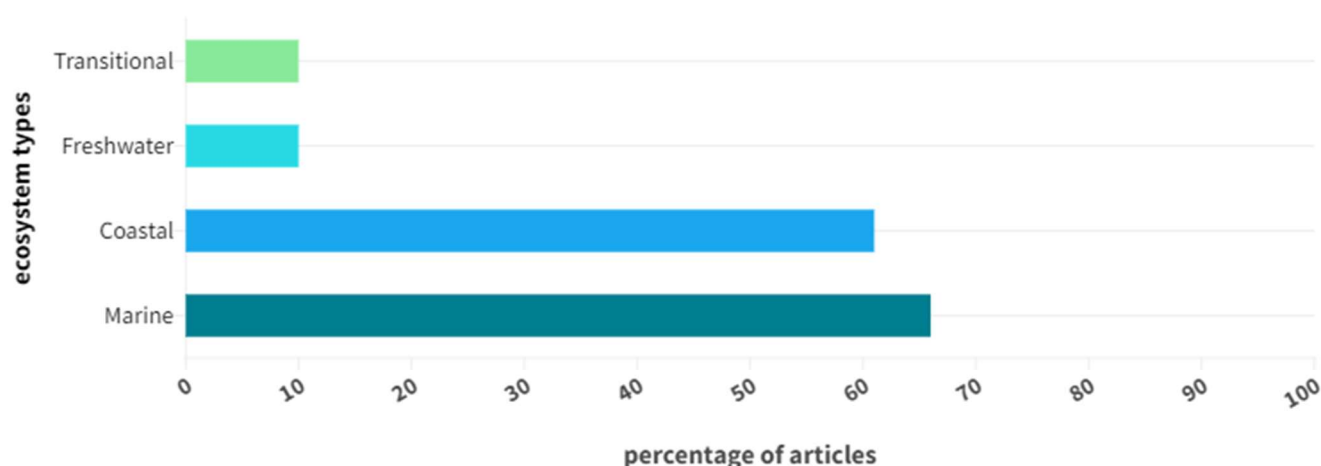


Figure 5. The ecosystems affected by the marine pollution (Y-axis) and the percentage of scientific articles that reference these impacts (X-axis). Multiple ecosystems may be identified as effected within a single article.

Most articles identified multiple sources of marine pollution. Land-based sources were the most commonly cited, mentioned in 68% of the studies (Figure 6). Nearly 40% of the articles also recognized industrial activity as a significant contributor to marine pollution. Rivers discharging into the Black Sea basin were noted as important pollution sources. Maritime traffic was highlighted in 26% of the articles as a major contributor to pollution in the region. Offshore activities, atmospheric inputs, and practices such as fishing and aquaculture were also identified as pollution sources. Additionally, four articles specifically recognized war conflict as a source of marine pollution in the Black Sea basin.

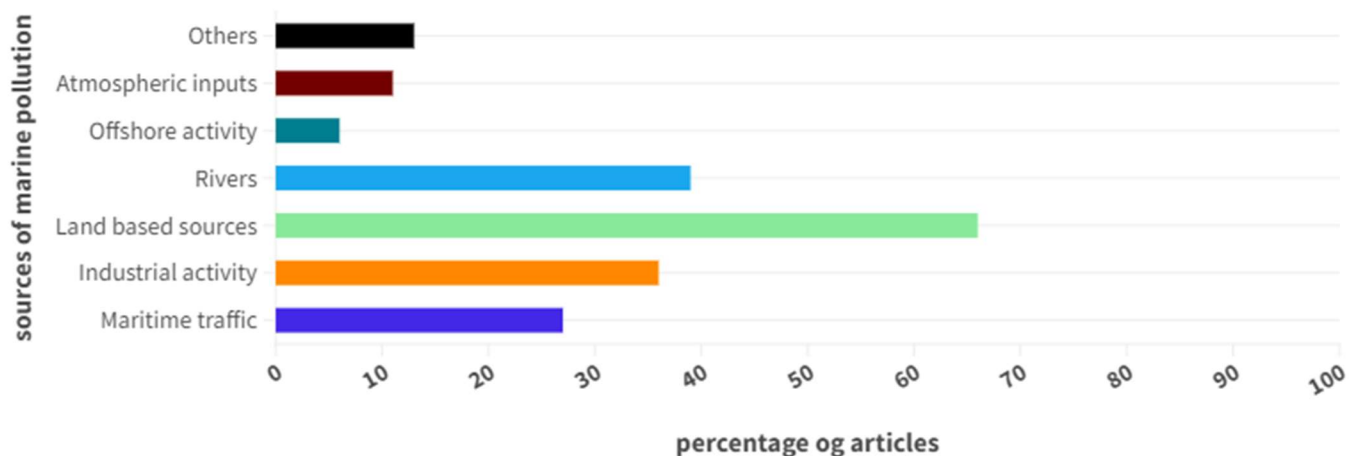


Figure 6. The sources of marine pollution in the Black Sea basin (Y-axis) and the percentage of scientific articles that reference these sources (X-axis). Multiple marine pollution sources may be identified within a single article.

The most frequently studied type of pollution, featured in more than half of the articles, were pollution by contaminants, followed by marine litter and eutrophication (Figure 7). Heavy metals were the most commonly researched contaminants, with several studies also addressing radioactive substances. Among the articles focused on marine litter, one-third specifically examined microplastic pollution. Additionally, oil pollution emerged as a significant concern in the Black Sea basin, attracting substantial scientific interest.

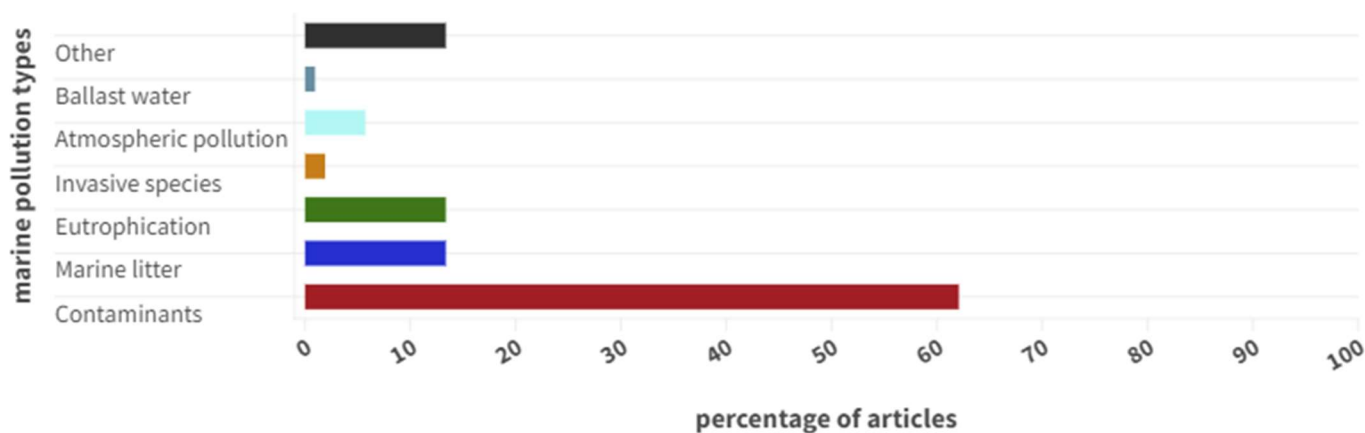


Figure 7. Types of marine pollution identified in the Black Sea basin (Y-axis) and the percentage of scientific articles that reference these marine pollution types (X-axis). Multiple types of marine pollution may be identified within a single article.

Heavy metals

Among the various types of contaminants identified as factors of marine pollution, heavy metals have been extensively studied for their detrimental effects (Oros, 2019). Heavy metals are a group of metallic elements that are toxic to organisms even in relatively low concentrations. They can enter the environment through various sources, including industrial waste, agricultural runoff, and natural processes. As highlighted also by the literature review, several heavy metals have been identified as significant pollutants in the Black Sea region, including (Oros, 2019; Pokazeev et al., 2021):

- **Mercury (Hg):** This highly toxic metal can bioaccumulate in marine organisms, posing a threat to human health through consumption of contaminated seafood.
- **Lead (Pb):** Lead pollution can come from industrial activities, such as smelting and battery manufacturing. It can have harmful effects on the nervous system, especially in children.
- **Cadmium (Cd):** Cadmium is often associated with industrial processes like mining and electroplating. It can accumulate in the kidneys and liver, causing health problems.
- **Arsenic (As):** Arsenic can occur naturally in groundwater and can also be released into the environment through human activities. It is a known carcinogen.
- **Copper (Cu):** While copper is essential for many biological processes, excessive levels can be harmful to aquatic organisms.
- **Zinc (Zn):** Zinc is another essential element, but high concentrations can be toxic to marine life.

The Black Sea region has faced significant challenges due to heavy metal pollution. Heavy metals can come from natural and anthropogenic sources. Some heavy metals can occur naturally in the geological formations of the region. As highlighted by the literature review, some of the major anthropogenic sources contributing heavy metals to the marine environment include industrial discharges, where wastewater from factories and industries contains high levels of heavy metals; agricultural runoff, where fertilizers and pesticides used in agriculture contribute to the pollution of rivers and streams that flow into the Black Sea; and urban wastewater, where untreated sewage from cities and towns enters the water (Oros, 2019; Pokazeev et al., 2021). It's important to note that the specific levels of heavy metals in the Black Sea can vary depending on location, time of year, and other factors. Ongoing monitoring and mitigation efforts are crucial to protect the marine ecosystem and human health.

Heavy metals can have severe consequences for ecosystems and biodiversity. Their detrimental effects can be seen at various levels of the food chain (Oros et al., 2003; Oros & Gomoiu, 2012). Specifically:

Ecosystem Impacts:

- **Habitat degradation:** Heavy metals can contaminate soil and water, making them unsuitable for many species.

- **Reduced primary productivity:** High concentrations of heavy metals can inhibit plant growth, reducing the availability of food for herbivores.
- **Disruption of nutrient cycles:** Heavy metals can interfere with essential nutrient cycles, such as nitrogen and phosphorus, leading to imbalances in the ecosystem.
- **Alteration of microbial communities:** Heavy metals can negatively impact beneficial microorganisms, such as those involved in decomposition and nutrient cycling.

Biodiversity Impacts:

- **Species loss:** Many species are sensitive to heavy metal pollution and can experience population declines or extinction.
- **Reduced genetic diversity:** Pollution can lead to the loss of genetic variation within populations, making them more vulnerable to threats like disease and climate change.
- **Disruption of food webs:** Heavy metals can bioaccumulate in organisms, leading to higher concentrations in predators at the top of the food chain. This can disrupt the entire food web.

Impacts on Human Health:

- **Contaminated food:** Heavy metals can accumulate in seafood and other food products, posing a risk to human health if consumed in excessive quantities.
- **Water pollution:** Contaminated water can lead to various health problems, including gastrointestinal issues, neurological disorders, and kidney damage.
- **Respiratory problems:** Exposure to heavy metals in the air can cause respiratory problems, such as asthma and bronchitis.

It's important to note that the specific impacts of heavy metals can vary depending on the type of metal, its concentration, and the sensitivity of the ecosystem or organism (Oros, 2019; Oros & Gomoiu, 2012).

Radioactive contamination

As revealed from the literature review, the Black Sea region has been impacted by various sources of radioactive contamination. Radioactive substances are elements that emit radiation, which can be harmful to living organisms. This radiation is typically in the form of alpha particles, beta particles, or gamma rays. These substances can occur naturally in the environment or be produced artificially. One major event in the Black Sea region was the 1986 Chernobyl disaster, which released large amounts of radioactive material into the atmosphere. The fallout from this disaster impacted the surrounding area, including the Black Sea coast (Yankovskyi, 2023).

Commonly identified radioactive substances in the Black Sea region include:

- **Cesium-137:** A long-lived radioactive isotope that was released in large quantities during the Chernobyl accident.
- **Strontium-90:** Another long-lived radioactive isotope that can contaminate food and water.
- **Radium-226:** A naturally occurring radioactive element found in rocks and soil.

- **Polonium-210:** A naturally occurring radioactive element that can be found in marine environments.

It's important to note that the levels of radioactivity in the Black Sea region have varied over time due to natural processes and human activities. Regular monitoring and research are conducted to assess the current state of radioactive contamination and to ensure the safety of the region's ecosystems and inhabitants (www.osti.gov; www.sipri.org).

The potential sources of radioactive pollution in the Black Sea Region are:

- **Nuclear Power Plants:** The presence of nuclear power plants near the Black Sea coast can pose a risk of radioactive pollution in case of accidents or improper waste management.
 - **Nuclear Research Facilities:** Research facilities that handle radioactive materials can also be potential sources of pollution if safety protocols are not strictly adhered to.
 - **Military Activities:** The use of nuclear weapons or radioactive materials in military activities can lead to significant contamination of the environment.
 - **Medical Facilities:** Hospitals and clinics that use radioactive isotopes for medical procedures must ensure proper handling and disposal to prevent pollution.
 - **Industrial Activities:** Certain industries, such as mining and metallurgy, may involve the use of radioactive materials that can contaminate the environment if not managed carefully.
 - **Natural Sources:** While less common, natural sources of radioactive materials, such as uranium-rich rocks, can contribute to pollution in certain areas.
 - **Accidental Releases:** Accidents during transportation or storage of radioactive materials can result in unintentional releases into the environment.
 - **Illegal Dumping:** Improper disposal of radioactive waste, including illegal dumping, can contaminate water bodies and soil.
- **Historical Events:** Past events, such as nuclear weapons tests or accidents, can leave lasting traces of radioactive contamination in the region.
- **Atmospheric Fallout:** Radioactive materials released into the atmosphere can travel long distances and eventually settle in the Black Sea region, contributing to pollution.

While specific, up-to-date data on the current status of radioactive substances in the Black Sea Basin may be limited, general trends and ongoing monitoring efforts can provide insights. Key factors influencing the levels of radioactive substances in the region include (Pokazeev et al., 2021):

- **Legacy of the Chernobyl Disaster:** The lasting effects of the Chernobyl accident in 1986 continue to impact the Black Sea Basin. Radioactive isotopes, such as cesium-137 and strontium-90, released during the disaster have been gradually dispersing and accumulating in various parts of the region.
- **Natural Sources:** The Black Sea Basin contains naturally occurring radioactive elements, such as radium and uranium, which can contribute to the overall radiation levels.

- **Human Activities:** Industrial activities, military operations, and the use of radioactive materials in research and medical applications can introduce additional radioactive substances into the environment.
- **Monitoring and Research:** Ongoing monitoring programs and scientific research are conducted to assess the levels of radioactive substances in the Black Sea Basin and to track their distribution over time.

It's important to note that the levels of radioactive substances can vary significantly within the region depending on factors such as:

- **Proximity to the Chernobyl disaster site:** Areas closer to Chernobyl are likely to have higher levels of radioactive contamination.
- **Sedimentation patterns:** Radioactive substances can accumulate in sediments at the bottom of the Black Sea, affecting local ecosystems.
- **Ocean currents and circulation:** The movement of water masses can influence the distribution of radioactive substances within the basin.

Radioactive substances can have significant negative impacts on ecosystems and biodiversity. When released into the environment, these substances can contaminate water, soil, and air, leading to:

- **Direct toxicity:** Radiation can directly harm organisms, causing cell damage, mutations, and death.
- **Indirect effects:** Radioactive contamination can disrupt food chains, alter ecosystem dynamics, and reduce biodiversity.
- **Long-term consequences:** The effects of radioactive pollution can persist for many years, even decades, due to the long half-lives of certain isotopes.

Radioactive substances can have significant negative impacts on ecosystems and biodiversity. Once released into the environment, they can contaminate water, soil, and air, leading to a range of harmful effects. Direct toxicity occurs when radiation damages cells in organisms, causing mutations and, in severe cases, death. Furthermore, radioactive contamination causes indirect effects as it can disrupt food chains and alter ecosystem dynamics, ultimately reducing biodiversity. In addition, the long-term consequences of radioactive pollution are particularly concerning, as certain isotopes have long half-lives, allowing the effects to persist for many years or even decades (Gulin et al., 2013). In the Black Sea region, impacts of radioactive substances on ecosystems and biodiversity may include:

- **Contamination of marine life:** Radioactive substances can accumulate in marine organisms, affecting their health and survival.
- **Damage to coastal ecosystems:** Wetlands, estuaries, and other coastal habitats can be negatively impacted by radioactive pollution.
- **Reduction in fish populations:** Radioactive contamination can reduce fish populations, affecting fisheries and local economies.

While the direct impacts on human health from radioactive substances in the Black Sea region are generally low, exposure to contaminated food or water can pose risks. Long-term exposure to high levels of radiation can increase the risk of cancer and other health problems (Gulin et al., 2013).

Nutrients

Another significant type of contaminant identified in the literature review as a major source of marine pollution in the Black Sea region is nutrients (Alkan et al., 2022). Nutrients are primarily nitrogen compounds commonly found in aquatic environments.. They can be naturally occurring or introduced through human activities. Nitrates are often converted to nitrites by bacteria, and both can have significant impacts on water quality and ecosystems. The Black Sea region has been affected by various sources of nitrate and nitrite pollution (www.anpm.ro). Agricultural runoff, wastewater discharges, and atmospheric deposition are among the primary contributors. These pollutants can lead to eutrophication, a process where excessive nutrients cause algal blooms, oxygen depletion, and the death of aquatic life.

Commonly identified nitrites and nitrates in the Black Sea region include:

- **Nitrate (NO₃-)**
- **Nitrite (NO₂-)**

It's important to note that the levels of nitrites and nitrates in the Black Sea can vary depending on factors such as seasonality, rainfall, and human activities. Regular monitoring and management are essential to protect the region's marine ecosystems and ensure safe drinking water supplies (Alkan et al., 2022; Pokazeev et al., 2021).

The potential sources of nitrate and nitrite pollution in the Black Sea Region are:

- **Agricultural Runoff:** One of the primary sources of nitrate and nitrite pollution in the Black Sea region is agricultural runoff. Fertilizers containing nitrogen compounds can leach into rivers and streams, eventually making their way into the sea.
- **Wastewater Discharge:** Untreated or inadequately treated wastewater from urban areas, industrial facilities, and agricultural operations can release significant amounts of nitrates and nitrites into the Black Sea.
- **Atmospheric Deposition:** Nitrogen oxides emitted into the atmosphere can be transported by wind and eventually deposited into the sea as nitrates and nitrites. This can occur through both natural processes and human activities, such as industrial emissions and vehicle exhaust.
- **Natural Sources:** While human activities are the primary contributors to nitrate and nitrite pollution in the Black Sea region, natural sources such as atmospheric nitrogen fixation and nitrogen-rich rocks can also play a role.

While specific, real-time data on the current status of nitrites and nitrates in the Black Sea Basin may be limited, general trends and ongoing monitoring efforts can provide insights ((Alkan et al., 2022; Lazăr et al., 2013). Key factors influencing the levels of nitrites and nitrates in the region include:

- **Agricultural practices:** The intensification of agriculture in the Black Sea region has led to increased use of fertilizers and pesticides, contributing to nutrient pollution.

- **Urbanization and industrialization:** The growth of coastal cities and industries has increased the discharge of wastewater and pollutants into the sea.
- **Climate change:** Changing precipitation patterns and rising temperatures can affect nutrient runoff from land and alter marine ecosystems.

It's important to note that the levels of nitrites and nitrates can vary significantly within the Black Sea Basin depending on factors such as:

- **Proximity to coastal cities and agricultural areas:** Regions closer to urban centers and agricultural lands are more likely to experience higher levels of nutrient pollution.
- **Ocean currents and circulation:** The movement of water masses can influence the distribution of nutrients within the basin.
- **Seasonal variations:** Nutrient levels can fluctuate throughout the year due to factors such as rainfall and agricultural activities.

Nitrites and nitrates can have significant negative impacts on aquatic ecosystems and biodiversity. When these pollutants enter water bodies, they can lead to:

- **Eutrophication:** Excessive nutrients can cause algal blooms, which can deplete oxygen levels and harm aquatic life.
- **Habitat degradation:** Eutrophication can degrade habitats and reduce biodiversity.
- **Fish kills:** High concentrations of nitrites can be toxic to fish and other aquatic organisms, leading to mass die-offs.
- **Human health risks:** Contaminated drinking water can pose health risks to humans, especially infants and young children.

Nitrites and nitrates can have severe negative impacts on aquatic ecosystems and biodiversity. When these pollutants enter water bodies, they contribute to eutrophication, which leads to excessive algal blooms. These blooms deplete oxygen levels in the water, harming aquatic life and degrading habitats, thereby reducing biodiversity. High concentrations of nitrites can also be toxic to fish and other aquatic organisms, resulting in mass die-offs (Alkan et al., 2022; Lazăr et al., 2013). Additionally, contaminated drinking water poses health risks to humans, particularly infants and young children. Furthermore, in the Black Sea region, impacts of nitrites and nitrates on ecosystems and biodiversity may include:

- **Reduced fish populations:** Nutrient pollution can harm fish populations and disrupt marine food webs.
- **Coral reef degradation:** In areas with coral reefs, nutrient pollution can contribute to the decline of these sensitive ecosystems.
- **Economic losses:** Impacts on fisheries and tourism can have significant economic consequences for coastal communities.
- **Public health concerns:** Contaminated drinking water can lead to health problems, such as gastrointestinal illnesses and blue baby syndrome in infants.

Pesticides

A type of contaminant also identified in the literature review as a factor in marine pollution in the Black Sea region is pesticides. Pesticides are chemical or biological agents used to control pests, such as insects, weeds, and rodents (Gileva, 2005). They can be harmful to both target and non-target organisms, and their improper use can lead to environmental pollution (Damir et al., 2022). Commonly identified pesticides in the Black Sea region include:

- **Herbicides:** Used to control weeds and vegetation.
- **Insecticides:** Used to control insects.
- **Fungicides:** Used to control fungi and mold.
- **Organochlorine pesticides:** Persistent organic pollutants that have been banned in many countries due to their harmful effects.

It's important to note that the levels and types of pesticides in the Black Sea can vary depending on factors such as agricultural practices, regulatory measures, and historical contamination (Damir et al., 2022).

Potential sources of pesticide pollution in the Black Sea Region include the following:

- **Agricultural Runoff:** One of the primary sources of pesticide pollution is agricultural runoff. When pesticides are applied to crops, they can be washed away by rain or irrigation, eventually making their way into rivers, streams, and the Black Sea.
- **Accidental Spills:** Accidents during the transportation, storage, or application of pesticides can lead to spills and releases into the environment.
- **Improper Disposal:** Improper disposal of pesticide containers and unused pesticides can contribute to pollution.
- **Historical Contamination:** The legacy of past pesticide use, including banned substances, can result in long-term contamination of the Black Sea region.
- **Industrial Activities:** Certain industries, such as manufacturing and chemical production, may use or produce pesticides that can contaminate the environment.

Key factors influencing the levels of pesticides in the region include:

- **Agricultural practices:** The intensification of agriculture in the Black Sea region has led to increased use of pesticides, contributing to pollution.
- **Regulatory measures:** The implementation of pesticide regulations and restrictions can help reduce pollution, but enforcement challenges may exist.
- **Historical contamination:** The legacy of past pesticide use, including banned substances, can result in long-term contamination of the region.

It's important to note that the levels of pesticides can vary significantly within the Black Sea Basin depending on factors such as:

- **Proximity to agricultural areas:** Regions closer to agricultural lands are more likely to experience higher levels of pesticide pollution.

- **Ocean currents and circulation:** The movement of water masses can influence the distribution of pesticides within the basin.
- **Seasonal variations:** Pesticide use and runoff can fluctuate throughout the year due to agricultural practices and weather conditions.

Pesticides can have significant negative impacts on ecosystems and biodiversity. When released into the environment, they can directly harm organisms, causing injury or death. Additionally, pesticides can lead to habitat destruction, reducing the availability of resources for wildlife. Certain pesticides may also bioaccumulate in the tissues of organisms, resulting in harm to both individuals and populations (Damir et al., 2022; Pokazeev et al., 2021). Furthermore, they can disrupt food chains by affecting prey species or their predators, leading to broader ecological imbalances. In the Black Sea region, impacts of pesticides on ecosystems and biodiversity may include:

- **Reduced fish populations:** Pesticide runoff can contaminate water bodies, harming fish and other aquatic organisms.
- **Loss of aquatic plants:** Pesticides can kill aquatic plants, affecting habitats and water quality.
- **Decline of bird populations:** Pesticides can harm birds directly or indirectly through the contamination of their food sources.
- **Reduction in biodiversity:** Overall biodiversity can be reduced due to the negative impacts of pesticides on various species.

While the direct impacts on human health from pesticide exposure in the Black Sea region are generally low, exposure to contaminated food or water can pose risks. Long-term exposure to certain pesticides has been linked to various health problems, including cancer, neurological disorders, and reproductive issues (Damir et al., 2022).

Marine litter

Marine litter pollution has emerged from the literature review as one of the most critical types of marine pollution in the Black Sea region. The most common forms of marine litter in this area are macroplastics and microplastics (Pokazeev et al., 2021). Macroplastics are large plastic items visible to the naked eye, including plastic bottles, bags, fishing gear, and fragments of larger objects. In contrast, microplastics are tiny plastic particles, typically less than 5 millimeters in size (<https://mp-1.itrcweb.org/>; www.plasticsoupfoundation.org). They can originate from the degradation of larger plastics (macroplastics) or be manufactured in small sizes. Both macroplastics and microplastics pose a significant threat to marine ecosystems and wildlife (Gao et al., 2022).

Regarding the macroplastics, common types identified in the region include:

- **Plastic bottles:** A ubiquitous form of plastic waste that can be found on beaches and in the water.
- **Plastic bags:** Lightweight and easily carried by wind and currents, plastic bags can pose a serious threat to marine life.
- **Fishing gear:** Lost or discarded fishing gear, such as nets and lines, can entangle and harm marine animals.

- **Plastic fragments:** Larger plastic items can break down into smaller fragments, which can be ingested by marine organisms.

In the Black Sea region, potential sources of macroplastic pollution are:

Land-based sources:

- **Waste management:** Inadequate waste management practices, including littering and illegal dumping, can lead to macroplastics entering rivers and streams, eventually making their way into the Black Sea.
- **Agricultural activities:** Plastic materials used in agriculture, such as mulches and packaging, can contribute to pollution if not disposed of properly.
- **Urban runoff:** Stormwater runoff from cities can carry macroplastics and other debris into the sea.
- **Rivers:** Rivers can act as conduits for macroplastics, transporting waste from inland areas to the Black Sea. Improper disposal of plastics in river catchments and runoff from land-based activities can worsen the problem, leading to substantial accumulation of macroplastics in the marine environment. Numerous large and smaller rivers flow into the Black Sea, including notable examples such as the Danube, Dnieper, Dniester, Kizilirmak, and Rioni. Consequently, large rivers that traverse extensive inland areas with significant human activity can transport macroplastics to the Black Sea, particularly if adequate measures are not implemented..

Marine-based sources:

- **Fishing industry:** Lost or discarded fishing gear, such as nets and lines, can be a significant source of macroplastic pollution.
- **Maritime activities:** Shipping and other marine activities can contribute to pollution through accidental spills, littering, and the loss of equipment.
- **Tourism:** Increased tourism in coastal areas can lead to increased plastic waste generation and improper disposal.

The Black Sea basin faces a significant challenge with macroplastic pollution. While specific data on the current status may vary, macroplastic accumulation—particularly in coastal areas and deep-sea trenches—raises multiple concerns (Miladinova et al., 2020). This accumulation poses a serious threat to marine ecosystems and biodiversity. Macroplastics can harm marine life in various ways:

- **Ingestion:** Marine animals may mistake macroplastics for food, leading to blockages, starvation, and other health problems.
- **Entanglement:** Marine organisms can become entangled in macroplastics, causing injuries or death.
- **Habitat destruction:** Macroplastics can disrupt marine habitats, affecting the survival of various species.

In the Black Sea basin several initiatives are underway to address and mitigate the issue of macroplastics pollution:

- **Waste management improvements:** Enhancing waste management practices in coastal communities and reducing plastic consumption can help reduce the amount of macroplastics entering the sea.
- **Fishing gear management:** Promoting sustainable fishing practices and implementing regulations to prevent lost or abandoned fishing gear can minimize macroplastic pollution from this source.
- **Research and monitoring:** Ongoing research and monitoring programs are essential to understand the extent of macroplastic pollution and its impacts on marine ecosystems.
- **International cooperation:** Collaboration between countries bordering the Black Sea is crucial for effective management of macroplastic pollution and coordinated efforts for mitigation.

Regarding the microplastics in the BSB, the most commonly identified include:

- **Fibers:** These are often derived from textiles, such as clothing and fishing nets.
- **Fragments:** These are broken pieces of larger plastic items, such as bottles, bags, and packaging materials.
- **Beads:** These are small, spherical particles used in personal care products and industrial applications.
- **Foams:** These are lightweight, buoyant materials often found in packaging and insulation.

These microplastics can enter the Black Sea through various sources, both land-based and marine, including rivers, wastewater treatment plants, and marine activities. Once in the sea, they can be ingested by marine organisms, leading to health problems and contamination of the food chain. More specifically, some of the primary contributors are:

Land-based sources:

- **Wastewater treatment plants:** Improperly treated wastewater can release microplastics into rivers and streams, eventually making their way into the sea.
- **Rivers and streams:** These waterways can transport microplastics from land-based sources, such as agricultural runoff, urban stormwater, and waste disposal sites.
- **Coastal communities:** Improper waste management practices in coastal areas can lead to the release of microplastics into the sea through littering and erosion.
- **Tire wear:** Microplastics can be released from tire wear, particularly from road traffic near coastal areas.

Marine sources:

- **Fishing gear:** Lost or abandoned fishing gear, such as nets and lines, can break down into microplastics over time.
- **Shipping activities:** Microplastics can be released from ships through paint abrasion, cargo spills, and wastewater discharges.

- **Recreational boating:** Activities such as boating and water sports can contribute to microplastic pollution through the release of microplastics from boat materials and equipment.
- **Microplastic-based products:** Products containing microplastics, such as personal care items and cleaning products, can release these particles into the environment when washed or used.

The Black Sea Basin is grappling with a significant microplastic pollution crisis. While the exact extent of the problem is still being researched, studies have shown alarming levels of microplastics in the waters, sediments, and marine organisms of the region. Some of the key findings of the literature review included:

- **High concentrations:** Microplastics have been detected in various parts of the Black Sea, including coastal waters, deep-sea sediments, and even within marine organisms.
- **Diverse sources:** The sources of microplastic pollution in the Black Sea Basin are manifold, ranging from land-based activities (e.g., wastewater discharge, agricultural runoff) to marine-based activities (e.g., shipping, fishing).
- **Negative impacts:** Microplastics pose a serious threat to marine ecosystems, as they can be ingested by marine organisms, leading to health problems and contamination of the food chain. Additionally, microplastics can disrupt marine habitats and alter nutrient cycles.

Microplastics pose a significant threat to marine ecosystems and biodiversity. Once in the water, these tiny particles can be ingested by marine organisms, leading to a range of negative consequences.

- **Ingestion:** Marine organisms, from plankton to large seabirds, may mistake microplastics for food, leading to blockages, starvation, and digestive problems.
- **Entanglement:** Microplastics can also entangle marine animals, causing injuries or even death.
- **Habitat disruption:** Microplastics can accumulate in marine habitats, such as seabeds and coral reefs, disrupting ecosystem functions and affecting biodiversity.
- **Chemical contamination:** Microplastics can absorb and release harmful chemicals, contaminating marine environments and the organisms that live within them.

While direct impacts on human health from microplastic ingestion are still being studied, there are potential concerns. For example, microplastics may accumulate in seafood, and if consumed by humans, could potentially pose health risks (Pokazeev et al., 2021). Additionally, the chemicals absorbed by microplastics could be transferred to marine organisms and ultimately to humans through the food chain.

Oil pollution

Another type of marine pollution highly recognizable as a significant threat to the marine environment and biodiversity is the oil/petroleum pollution. Petroleum is a naturally occurring liquid hydrocarbon mixture found deep beneath the Earth's surface. It is a complex mixture of various compounds, including alkanes, cycloalkanes, and aromatics (Pokazeev et al., 2021; Readman et

al., 2002). Petroleum is a valuable natural resource used as a fuel and raw material for various industries.

The most commonly identified types of petroleum products in the Black Sea Basin include:

- **Crude oil:** The unrefined form of petroleum, extracted from the ground.
- **Gasoline:** A refined petroleum product used as a fuel for vehicles.
- **Diesel fuel:** Another refined petroleum product used as a fuel for vehicles, especially heavy-duty ones.
- **Fuel oil:** A type of petroleum product used for heating and industrial purposes.
- **Lubricants:** Oils used to reduce friction between moving parts of machinery.
- **Bunker fuel:** A heavy fuel oil used by ships for propulsion.

Oil pollution in the Black Sea Basin can originate from various sources, both land-based and marine. Here are some of the primary contributors:

- **Accidental spills:** Tanker accidents, pipeline leaks, and offshore platform failures can lead to large-scale oil spills.
- **Operational discharges:** Routine discharges from ships, refineries, and other industrial facilities can contribute to oil pollution.
- **Natural seepage:** Oil can naturally seep into the marine environment from underground reservoirs.
- **Coastal activities:** Oil-contaminated runoff from land-based activities, such as industrial facilities and vehicle maintenance, can enter the sea.
- **Illegal dumping:** The illegal dumping of oil-containing waste materials into the Black Sea is another source of pollution.

These sources can lead to significant oil spills and chronic oil contamination, posing a serious threat to marine ecosystems and biodiversity.

The Black Sea Basin has a history of oil/petroleum hydrocarbon exploration and production. While the region has experienced significant economic benefits from these activities, it has also faced environmental challenges due to potential pollution risks (Readman et al., 2002; Țigănuș et al., 2016). Currently, the following are noted regarding the oil/petroleum pollution in the BS:

- **Offshore Exploration and Production:** Several countries in the Black Sea Basin, including Romania and Bulgaria, have engaged in offshore exploration and production of petroleum hydrocarbons. This activity has led to the discovery of significant oil and gas fields.
- **Environmental Concerns:** The extraction and transportation of petroleum hydrocarbons can pose environmental risks, such as oil spills, habitat destruction, and water pollution. Strict regulations and environmental impact assessments are essential to mitigate these risks.
- **Balancing Economic and Environmental Interests:** The Black Sea Basin faces the challenge of balancing the economic benefits of petroleum hydrocarbon exploration and production

with the need to protect the marine environment. Sustainable practices and responsible development are crucial to ensure long-term sustainability.

- **Ongoing Monitoring and Mitigation:** Regular monitoring of petroleum hydrocarbon levels in the Black Sea and the implementation of effective spill response plans are essential to address potential pollution incidents and protect marine ecosystems.

Petroleum hydrocarbons, when released into marine environments, can have devastating consequences for ecosystems and biodiversity. These substances can:

- **Smother marine life:** Oil spills can smother marine organisms, such as fish, birds, and marine mammals, leading to death or injury.
- **Contaminate food chains:** Petroleum hydrocarbons can contaminate marine food chains, affecting the health of organisms at all levels.
- **Habitat destruction:** Oil spills can destroy critical marine habitats, such as coral reefs and seagrass beds, impacting biodiversity.
- **Long-term effects:** The effects of petroleum hydrocarbon pollution can be long-lasting, as these substances can persist in the environment for many years.

While direct impacts on human health from petroleum hydrocarbon exposure are typically associated with acute incidents like oil spills, there are also concerns about long-term exposure through contaminated seafood and exposure to pollutants associated with oil refining and combustion (Readman et al., 2002).

Pollution due to war conflicts

In the Black Sea basin, a significant threat to the marine ecosystem has been identified due to war conflicts, particularly the ongoing war in Ukraine. This conflict has contributed to a rise in pollution from multiple sources, impacting the Black Sea Basin (Hryhorczuk et al., 2024). While the full extent of the damage may not yet be fully understood, several key areas of concern have emerged.

- **Oil spills:** Damaged or sunk ships, as well as accidental spills from military operations, have resulted in significant oil pollution in the region, contaminating the sea and harming marine life.
- **Chemical pollution:** The use of munitions, explosives, and other chemical substances can contaminate water, soil, and air, posing risks to both ecosystems and human health.
- **Explosive remnants of war (ERW):** Unexploded bombs, mines, and other explosive ordnance pose a serious threat to marine ecosystems and human safety.
- **Habitat destruction:** Military activities, such as coastal fortifications and infrastructure development, can destroy critical marine habitats, impacting biodiversity.
- **Noise pollution:** The use of sonar, weapons, and other military equipment can disrupt marine ecosystems and biodiversity (e.g. marine mammals) through noise pollution.

These types of pollution can have long-lasting consequences for the Black Sea Basin, affecting marine biodiversity, water quality, and the livelihoods of coastal communities. The potential sources of pollution from war conflict in the Black Sea Basin could be:

- **Damaged or sunk ships:** Warships, merchant vessels, and other maritime assets damaged or sunk during conflict can release oil, chemicals, and other pollutants into the sea.
- **Military operations:** Naval battles, airstrikes, and land-based operations can result in accidental spills or the release of pollutants from military equipment.
- **Explosive remnants of war (ERW):** Unexploded bombs, mines, and other explosive ordnance can contaminate the environment with chemicals and debris.
- **Infrastructure damage:** War-related damage to oil pipelines, refineries, and other industrial facilities can lead to spills and pollution.
- **Waste disposal:** Improper disposal of military waste, including hazardous materials, can contaminate the environment.
- **Agricultural activities:** Disrupted agricultural practices due to conflict can lead to increased runoff of pollutants, such as fertilizers and pesticides, into waterways.
- **Industrial activities:** The disruption of industrial operations can result in the release of pollutants into the environment.
- **Human displacement:** Large-scale displacement of people due to conflict can lead to increased pollution from informal settlements and inadequate waste management.

In the Black Sea basin, the significant consequences of pollution from war conflict on marine ecosystems and biodiversity include (<https://ceobs.org/>; <https://reliefweb.int/>):

- **Habitat destruction:** Military activities, such as coastal fortifications and infrastructure development, can destroy critical marine habitats, such as wetlands, coral reefs, and seagrass beds.
- **Oil spills:** Oil spills from damaged or sunk ships can smother marine organisms, contaminate food chains, and disrupt ecosystem functions.
- **Chemical contamination:** The use of munitions, explosives, and other chemical substances can contaminate water, soil, and air, harming marine life and impacting ecosystem health.
- **Explosive remnants of war (ERW):** Unexploded bombs, mines, and other explosive ordnance pose a serious threat to marine ecosystems, as they can disrupt habitats, injure or kill wildlife, and contaminate the environment.
- **Noise pollution:** The use of sonar, weapons, and other military equipment can disrupt marine ecosystems through noise pollution, affecting the behavior and survival of marine organisms.
- **Long-term effects:** The impacts of pollution from war conflict can be long-lasting, as contaminated environments and damaged habitats may take years to recover.

In addition to these ecological impacts, pollution from war conflict can also have significant consequences for human health. Exposure to contaminated water, soil, and air can lead to various health problems, including respiratory illnesses, skin diseases, and cancer (Hryhorczuk et al., 2024; Tahmid et al., 2023).

2.4.2 Links and magnitude of marine pollution aspects

Understanding the interconnectedness between the various marine pollution aspects sources is critical to comprehend the broader environmental impacts and consequently to adapt more efficient measures to tackle marine pollution. Therefore, we further analyze the results of the literature review to identify potential links and their magnitude between the different marine pollution aspects.

Our analysis revealed the connections between the different marine litter types and their sources (Figures 8-10). Specifically, the spread of heavy metals and chemical contaminants is linked to multiple sources, including land-based and industrial activities, river inputs and maritime traffic (Figure 9a & c). Moreover, marine litter is strongly associated with both inland (land-based sources & river inputs) and marine sources (maritime traffic), reflecting the dual origin of this type of pollution (Figure 9b). Furthermore, our analysis demonstrates that oil pollution primarily originates from offshore activities (e.g. offshore oil drilling, pipeline leaks, accidents during the extraction and transportation of oil) and maritime traffic (e.g. oil spills from ships, either due to accidents or illegal discharges). Industrial and urban sources contribute to oil contamination (Figure 9e). In addition, the analysis identifies land-based sources and river inputs as the primary contributors to eutrophication. (Figure 9d).

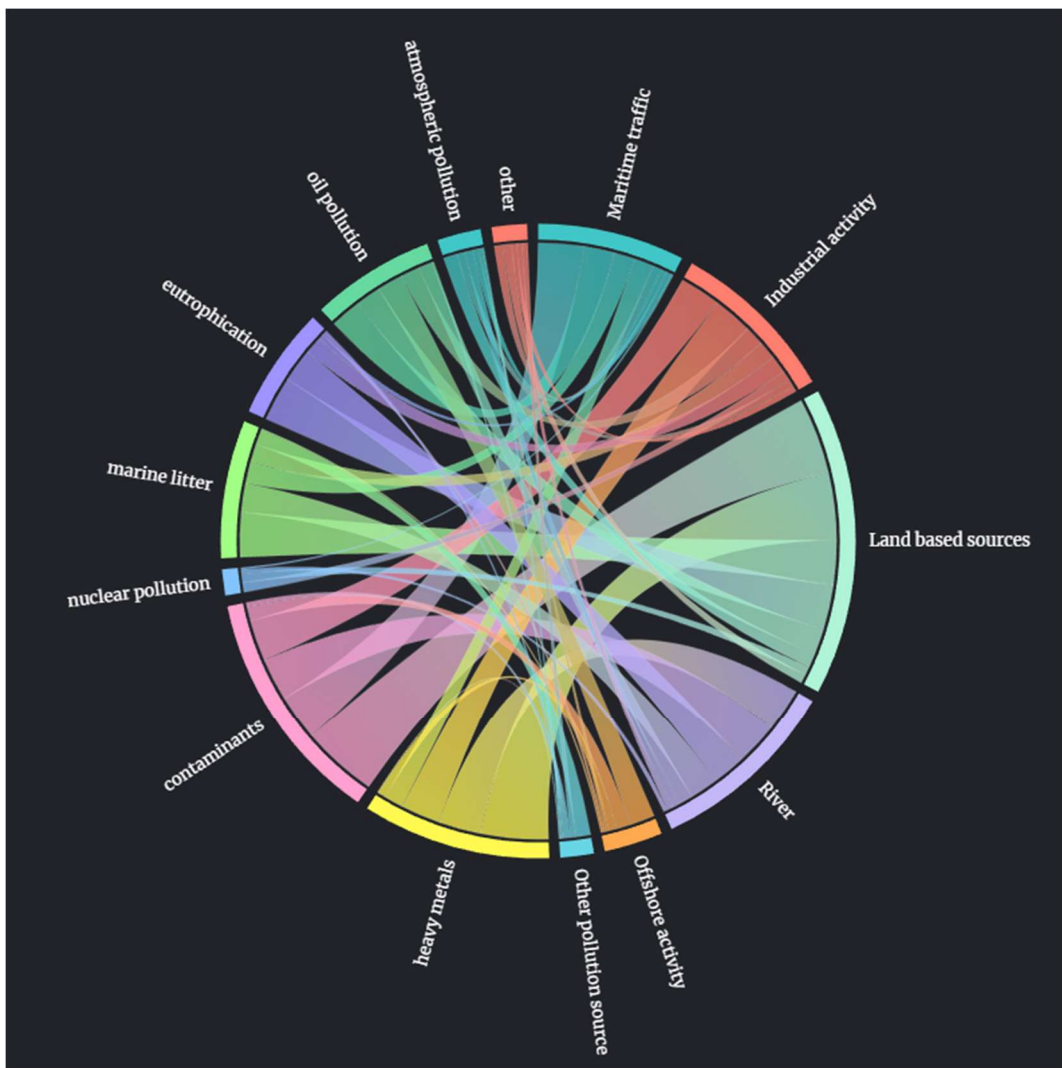


Figure 8. Magnitude of links between the various marine pollution types and their sources. For visualization purposes, the pollution types "Invasive species" and "Ballast water" were grouped under the category "Other."

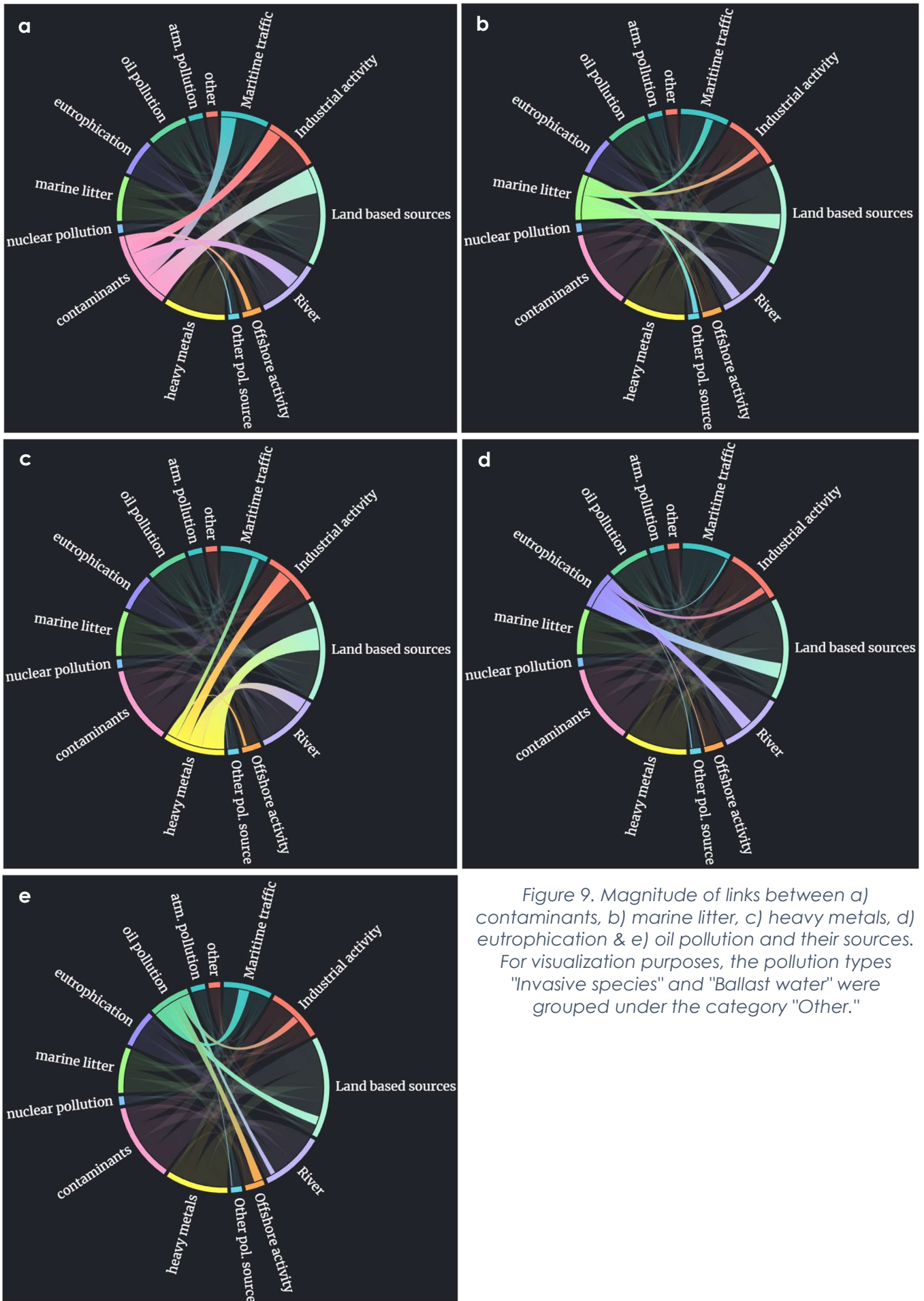


Figure 9. Magnitude of links between a) contaminants, b) marine litter, c) heavy metals, d) eutrophication & e) oil pollution and their sources. For visualization purposes, the pollution types "Invasive species" and "Ballast water" were grouped under the category "Other."

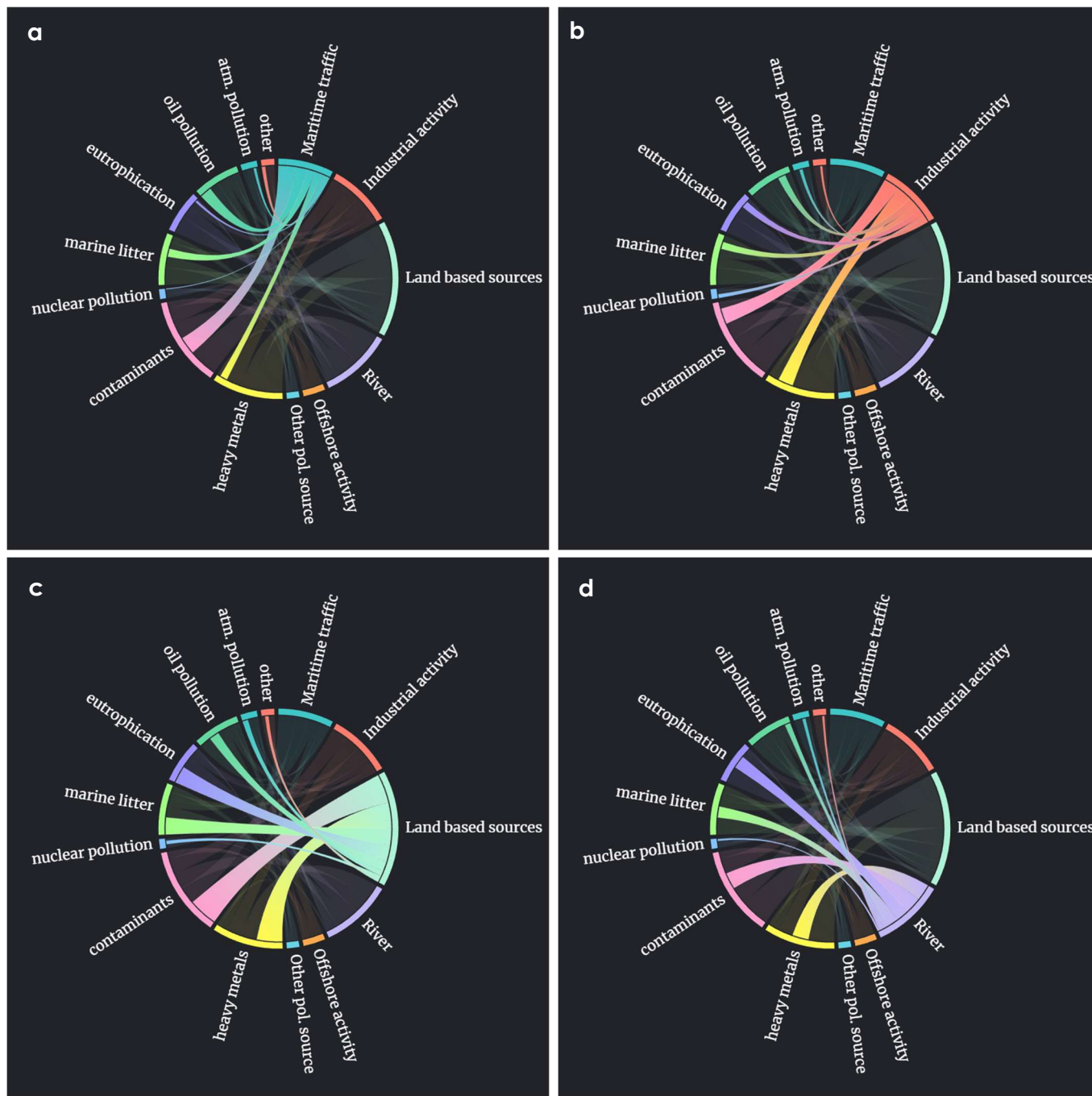


Figure 10. Magnitude of links between a) Maritime traffic, b) Industrial activities, c) Land-based sources, d) River inputs and the various marine pollution types. For visualization purposes, the pollution types "Invasive species" and "Ballast water" were grouped under the category "Other."

Furthermore, the analysis of potential links between various marine pollution types, their sources, and the ecosystems they impact revealed a complex network of interconnections (Figure 11). The strong ties between pollution sources and their widespread effects on different ecosystems highlight the interconnected nature of environmental degradation. Marine ecosystems, for instance, are heavily affected by oil pollution, marine litter, and contaminants, which predominantly originate from offshore activities, maritime traffic, and land-based sources (Figure 12a & b). Coastal ecosystems, closely linked to marine environments, also face significant threats from eutrophication and heavy metals, primarily due to inputs from rivers and industrial activity.

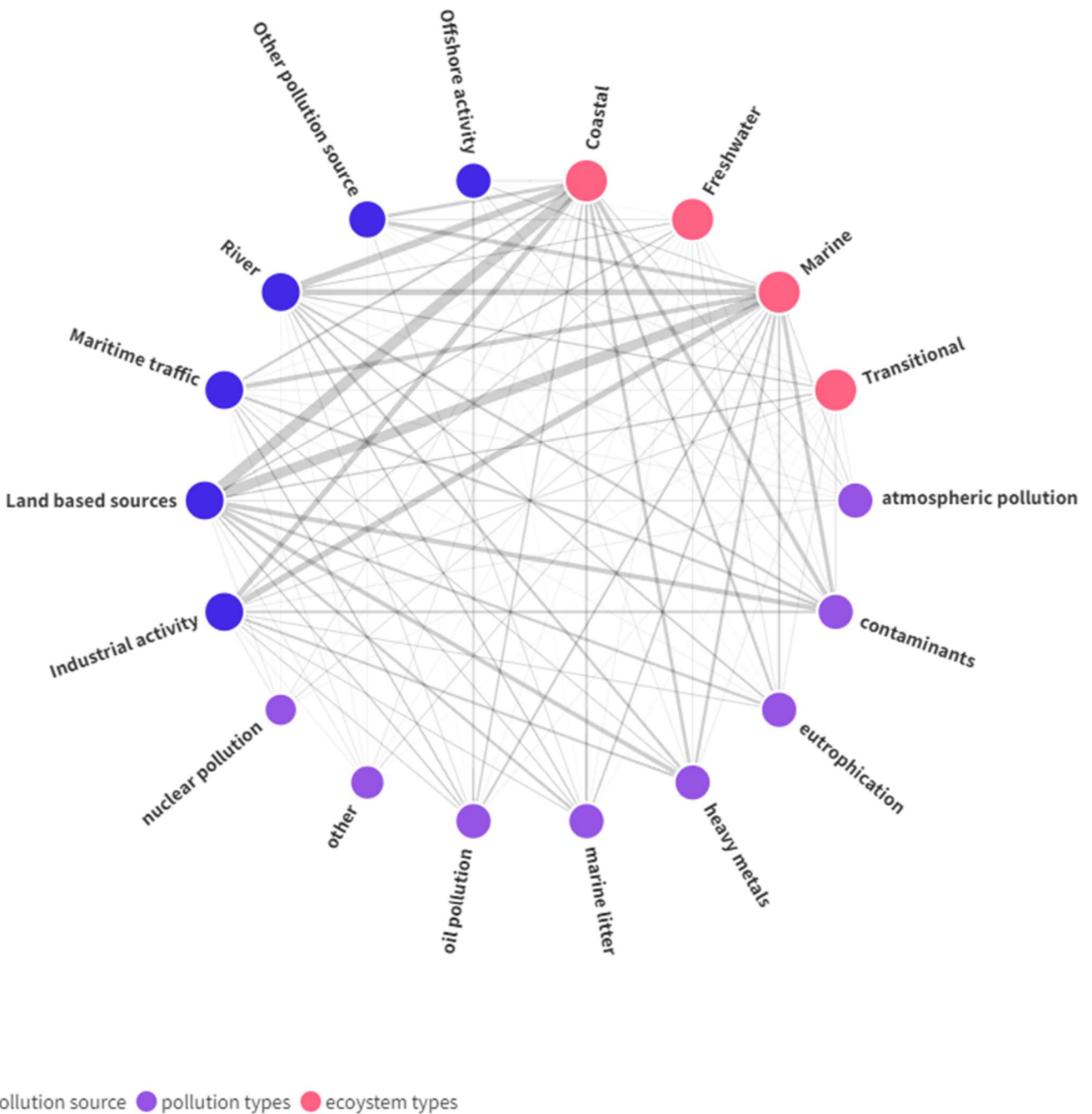


Figure 11. The interconnected network of the different marine pollution aspects. Blue circles represent the diverse marine pollution sources, while purple circles categorize specific pollution types. Red circles depict the different ecosystems affected by these pollutants, highlighting the complex interplay and interconnections that drive environmental degradation in marine environments.

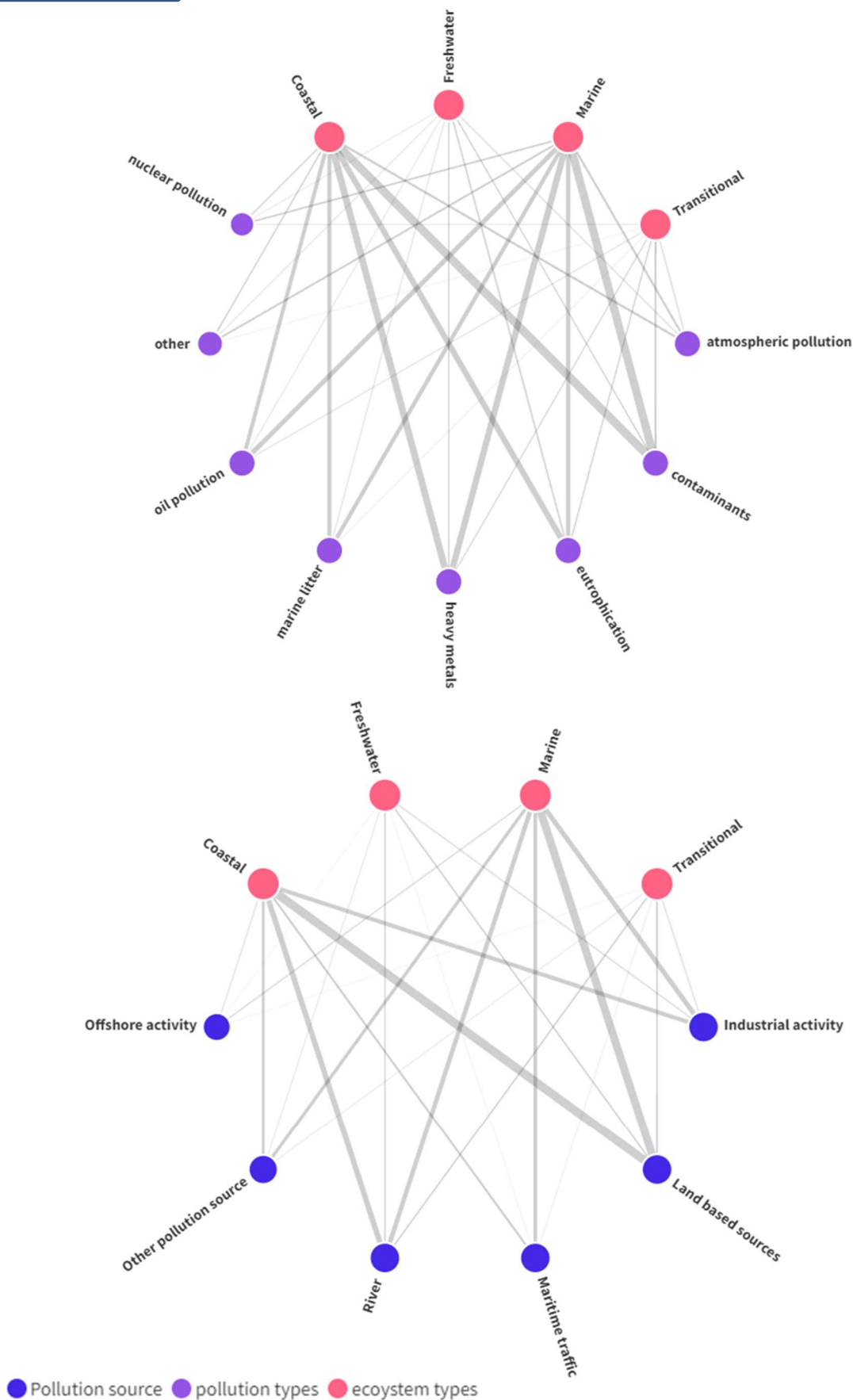


Figure 12. The network of the different marine pollution aspects, focusing on the connections among a) the different ecosystems affected (red circles) and the categories of specific pollution types (purple circles and b) the different ecosystems affected (red circles) and the diverse marine pollution sources (blue circles).

An analysis was also conducted to study the links between the sources of marine pollution, the various marine pollution types and the reference on specific impacts (Figure 13). The key pollutants, heavy metals and other contaminants, as well as eutrophication and oil pollution are highly linked with the degradation of water quality and of biodiversity. Marine litter also contributes to degradation of habitats, while atmospheric pollution and nuclear pollution, though lesser in frequency, also play a significant role in environmental degradation, highlighting the complex and interconnected nature of pollution sources and their broad-reaching consequences. Moreover, the decline in human quality of life is a key outcome, as pollution disrupts not only marine ecosystems but also fisheries, tourism, and the overall health of coastal populations. The impacts are traced back to the range of pollution sources, with –as has already been shown – land-based sources, river inputs, industrial activity and maritime traffic being the most prominent contributors.

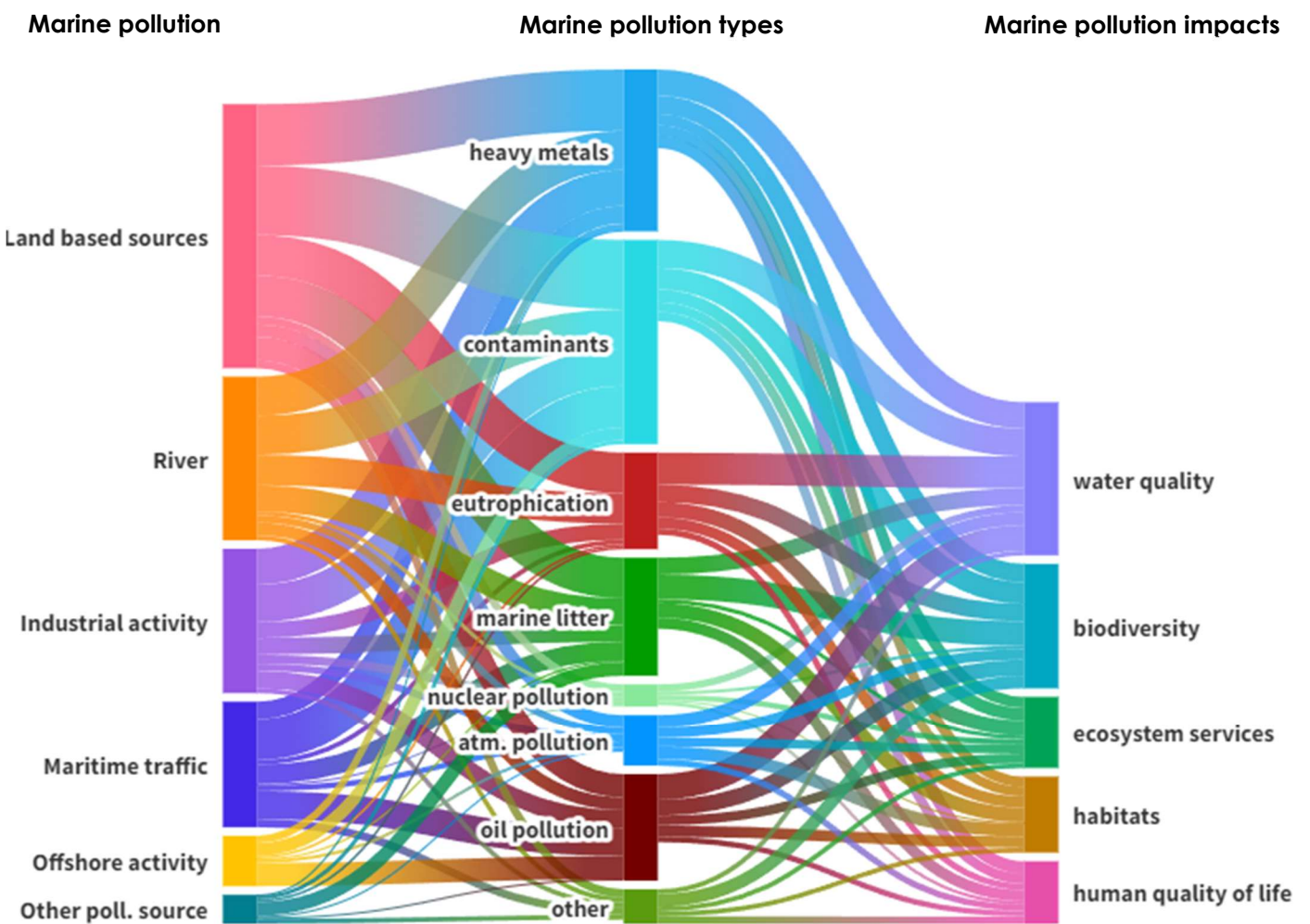


Figure 13. Interconnections between the various marine pollution sources, the marine pollution types and their resulting impacts on the environment and human well-being.

2.4.3 Monitoring

Almost half (44%) of the articles mention monitoring schemes or protocols for marine pollution in the Black Sea basin. Of these, 23% focus on developing monitoring networks and implementing systematic monitoring programs. An equal number highlight the use of bioindicators and biomarkers as effective tools for monitoring marine pollution in the basin. In 16% of the articles, the monitoring targets contaminants, particularly heavy metals, and organic pollution. Some articles introduce marine litter monitoring programs, while others discuss the use of remote sensing, including airborne and satellite methods, for tracking marine pollution.

These findings highlight the critical need for effective and updated marine pollution monitoring programs in the Black Sea region. Although there are existing monitoring frameworks and initiatives across the Black Sea countries, most are national in scope and lack regional synchronization. A comprehensive regional program is essential to address the growing marine pollution problem, and this program must integrate innovative methods to meet the emerging challenges, such as the rise of microplastics. Monitoring strategies should be harmonized, with countries adopting the same methodologies to ensure frequent, systematic, and coherent data collection. Furthermore, data should be open and easily accessible, adhering to the FAIR principles (Findable, Accessible, Interoperable, and Reusable). While the Black Sea Integrated Monitoring and Assessment Program (BSIMAP) created under the Convention on the Protection of the Black Sea Against Pollution, serves as a valuable foundation, further improvements are needed. Increasing the number of monitoring stations, incorporating near real-time monitoring technologies, and establishing early alert systems for marine pollution incidents are crucial to minimizing response times. Long-term projects as EMBLAS are leading efforts in this direction, promoting enhanced collaboration and technological adaptation to improve the monitoring of marine pollution in the Black Sea.

2.4.4 Mitigation measures and control actions

Less than 1/3 of the reviewed articles discuss mitigation measures for marine pollution. Among those, regulatory measures, policies, and restrictions or bans are the most commonly proposed solutions, mentioned in 44% of the articles. Monitoring schemes are cited in 40% of the articles a finding that underscores the importance of effective monitoring schemes. Some articles also highlight the need for more efficient management practices and improved implementation of existing marine pollution mitigation efforts. Additionally, raising public awareness, educating, and engaging stakeholders are frequently mentioned as key strategies. Further assessments, research, and the use of advanced technologies are also proposed in several articles.

Only a small number of articles (3%) reference control actions taken after a marine pollution incident, while nearly triple that amount (8%) mention restoration measures for ecosystems degraded by marine pollution. The most commonly discussed control actions include implementing safety protocols, standards, and processes following a pollution event, as well as using various methods to remove pollutants depending on the pollution type—for example, physical removal for marine litter, and chemical or biological treatments for oil spills and contaminants. The most frequently mentioned restoration measures include ecosystem rehabilitation and clean-up operations, with some articles also suggesting the adoption of sustainable resource management practices.

The limited reference to specific measures and control actions before and after a marine pollution incident in the literature could highlight a significant gap between research findings and the development of practical strategies. There is a clear need for stronger connections between research topics and the creation of applied strategies, policies, and actions aimed at both preventing marine pollution and mitigating its effects, including control measures and ecosystem restoration. By bridging the gap between research and actionable solutions, both prevention and response efforts in protecting marine ecosystems can be enhanced in the Black Sea region.

2.4.5 Legislation frameworks

Only 1/5 of the articles in the literature review reference legislation related to marine pollution mitigation measures, with the majority focusing on national laws. In addition, approximately 20% of the articles in the literature reference policies, legislative frameworks, and regulations aimed at managing marine pollution in the Black Sea basin. Most of these articles focus on international and European frameworks, directives, and strategies, such as the International Convention for the Prevention of Pollution from Ships (MARPOL), the European Marine Strategy Framework Directive (MSFD), the EU Plastics Strategy, and the EU Water Framework Directive. These legislative instruments play a crucial role in shaping national policies and providing guidance for marine pollution management in the region.

Specifically, the MARPOL Convention, established in 1973 and updated in 1978, plays a central role in the international regulation of marine pollution caused by ships. It addresses a wide array of pollutants through six technical annexes, each targeting different sources of pollution such as oil, noxious substances, sewage, garbage, and air pollution. The convention has been widely adopted by all Black Sea countries (although Georgia has not yet ratified Annex VI, which deals with air pollution from ships). The comprehensive framework of MARPOL helps guide national legislation in preventing both operational and accidental marine pollution from ships.

In addition, the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) is another key piece of legislation, designed to achieve Good Environmental Status (GES) in EU marine waters. By requiring member states to develop marine strategies that include environmental assessments, target-setting, and the implementation of monitoring programs, the MSFD provides a structured approach to preserving marine ecosystems while balancing environmental health with economic activity. This directive has greatly influenced how EU member states, including those with Black Sea coastlines, approach marine conservation and pollution management.

A smaller number of articles emphasize legal frameworks specific to the Black Sea region, including the Convention on the Protection of the Black Sea Against Pollution (Bucharest Convention), the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea, and the Black Sea Biodiversity and Landscape Conservation Protocol. These regional agreements are instrumental in coordinating the efforts of Black Sea coastal countries in mitigating marine pollution and protecting the marine environment.

In detail, in the context of the Black Sea region, the Bucharest Convention, signed in 1992 and ratified in 1994 by all six Black Sea coastal countries (Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine), serves as the primary legal framework for preventing and addressing marine pollution. The Convention includes protocols aimed at controlling pollution from land-based sources, dealing with oil spills and other hazardous substances, and regulating pollution caused by dumping. The

adoption of the Black Sea Emergency Plan in 2006, as a response mechanism for oil spills, further strengthens the region's preparedness and response capabilities.

Complementing the Bucharest Convention, the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea was adopted in 2009. This plan, along with a 2009 protocol aimed at addressing land-based sources of pollution, is crucial in guiding regional efforts to prevent and eliminate marine pollution. However, the entry into force of the 2009 protocol is still pending, highlighting the need for further action and cooperation among Black Sea countries.

Together, these international, European, and regional legislative frameworks form the foundation of national legislation in Black Sea coastal states, providing essential guidance for addressing marine pollution. They collectively shape the policies and strategies that govern marine environmental protection, offering a structured approach to mitigating pollution and safeguarding the Black Sea's ecological health. However, the reference to specific legislative frameworks in the literature review was limited. Therefore, additional focus should be given by the research community to better link the different types of marine pollution they study with the legislative frameworks related to pollution management and mitigation measures. This would help address the challenges in implementing effective solutions for marine environmental protection in the Black Sea region, particularly through close collaboration with government agencies. As concluded in Del 1.1, these agencies are the primary actors in all Black Sea countries, with clearly defined responsibilities under existing legislation for responding to and managing marine pollution incidents.

2.4.6 Educational schemes

It is worth noting that references to educational aspects—such as educational programs, curricula, or methods related to both the prevention of marine pollution and the control of pollution after an incident—are found in only about 10% of the reviewed articles. This suggests that these topics are not thoroughly studied, and the available information is limited, highlighting a gap in knowledge or the scarcity of existing educational initiatives.

This finding aligns with the conclusions drawn from our stakeholder analysis, online survey, and face-to-face interviews (Del 1.1 & 1.2), which revealed that in-house training programs are limited, and few multi-institutional initiatives exist to encourage coordinated responses to marine pollution events. While contingency plans for addressing oil spills at sea are well-developed, other types of pollutants are not adequately covered by current plans or training programs. This gap often leads to delays in decision-making and lost time when institutions encounter new and unfamiliar challenges.

3. Armed conflicts and marine pollution - A global overview

While discussions about the environmental effects of war often focus on terrestrial impacts, the repercussions for marine ecosystems are equally significant. Marine biodiversity is particularly sensitive to military activities due to the interconnectedness of water bodies (Bełdowski et al., 2020; Sanderson et al., 2010). Armed conflicts threaten the marine environment through various forms of pollution, resulting in the release of hazardous substances into the ocean, whether intentionally or as collateral damage from military operations (Table 3). The environmental impact of such pollution is profound, affecting marine ecosystems, biodiversity, and the livelihoods of coastal communities. Some of the most common types of marine pollution linked to war include oil spills, chemical discharges, debris from destroyed infrastructure, and unexploded ordnance (UXO) (Bełdowski et al., 2020; Ndungu et al., 2017; Teixeira et al., 2021).

Table 3. Marine pollution types due to war conflicts

Marine Pollution Types Due to War Conflicts
▪ Chemical pollutants
▪ Heavy metals
▪ Debris
▪ Unexploded ordnance (UXO)
▪ Radioactive substances
▪ Freshwater pollution
▪ Nutrient pollution
▪ Noise pollution
▪ Ship wrecks
▪ Population movement
▪ Oil spills

One of the most prevalent forms of marine pollution during conflicts is oil pollution. Military activities often involve the targeting of oil rigs, tankers, and refineries, resulting in large-scale oil spills that severely damage marine ecosystems (Mostafawi, 2001). Oil spills create extensive slicks on the water surface, blocking sunlight, depleting oxygen, and harming marine life. Oil can also accumulate on beaches, causing long-term damage to coastal habitats and wildlife. The persistence of oil in marine environments can lead to long-term ecological imbalances, making it one of the most critical pollution types during conflicts (Mostafawi, 2001; Ndungu et al., 2017).

Apart from oil, chemical pollution from military activities is a serious concern. Weapons containing chemicals, such as chlorine or nerve agents, have been dumped into seas, posing long-lasting risks to marine life (Sanderson et al., 2010). For example, sea-dumped chemical weapons post-World War II continue to leach toxic substances into marine ecosystems. These chemicals are not only toxic but also persistent in the environment, causing bioaccumulation in the food web and posing threats to human health via seafood consumption (Hemström et al., 2020).

Heavy metal contamination is a significant form of pollution caused by war, primarily through the destruction of industrial infrastructure and the presence of explosives and UXO. Metals like lead, mercury, cadmium, and arsenic are commonly found in industrial facilities, but they are also key components in many explosives and military munitions (Bełdowski et al., 2020; Ndungu et al., 2017). During conflicts, these heavy metals are released into the environment when industrial sites are

damaged or when ordnance is deployed and left unexploded. Once in the ocean, heavy metals are absorbed by marine organisms, leading to a range of toxic effects, including developmental problems, reproductive failure, and increased mortality. In some cases, exposure can cause genetic mutations, further threatening population stability. Heavy metals also bioaccumulate, meaning their concentrations increase as they move up the food chain, ultimately impacting larger predators, including fish consumed by humans (Bełdowski et al., 2020; Bergmann et al., 2024). This not only poses severe health risks to marine ecosystems but also threatens human health, as heavy metal exposure is linked to neurological disorders, cancer, and other chronic diseases. The persistence of heavy metals in the environment—whether leached from UXOs or carried as runoff from conflict zones—means that these pollutants can continue to affect marine life and contaminate sediments for decades. Combined with the continuous flow of these substances from war-torn regions, heavy metal pollution remains a long-lasting threat to marine biodiversity and the communities that rely on these ecosystems for food and livelihood (Bergmann et al., 2024; Sanderson et al., 2010).

Debris pollution is a significant and often overlooked consequence of war, particularly when it comes to its impact on marine environments. The destruction of buildings, bridges, industrial facilities, and other critical infrastructure during conflicts results in vast quantities of debris entering nearby rivers, lakes, and ultimately, the ocean (Tahmid et al., 2023). This debris can include a wide variety of materials, such as concrete, metal, wood, and plastics, all of which pose distinct threats to marine ecosystems. Large debris, like chunks of concrete and metal, can physically alter marine habitats, destroying coral reefs, seagrass beds, and other vital ecosystems that support marine biodiversity. In shallow waters, debris can smother benthic organisms, alter water flow, and reduce available light, further disrupting the delicate balance of marine life (Tahmid et al., 2023).

Moreover, the remnants of war often include UXO, such as mines, bombs, and other munitions, which sink to the ocean floor and present long-term risks. These UXOs not only pose immediate physical dangers to marine life and human activities, like fishing and shipping, but they also threaten to release hazardous substances, including chemical agents and explosive materials, into the water if disturbed (Bełdowski et al., 2020; Bergmann et al., 2024). Over time, the casing of UXOs can degrade, leading to the slow leakage of toxic substances that can poison marine organisms, contaminate sediments, and enter the food chain. In areas heavily impacted by conflict, UXOs can litter large portions of the seabed, making it difficult to restore ecosystems and creating a persistent danger for generations. The combination of physical destruction and chemical contamination from debris and UXOs contributes to the long-lasting environmental degradation of marine ecosystems long after the war has ended (Bergmann et al., 2024).

Furthermore, war conflicts significantly contribute to sonar and noise pollution, which can have detrimental effects on marine ecosystems (Węgrzyn et al., 2023). Military activities, such as the use of naval sonar systems, underwater explosions, and ship traffic, generate intense noise that disrupts the acoustic environment of marine species. Many marine animals, particularly cetaceans like whales and dolphins, rely on sound for communication, navigation, and hunting. The loud, disruptive sounds from military sonar and explosions can cause disorientation, stress, and even physical harm, such as hearing loss or internal injuries, in marine life. In extreme cases, noise pollution can lead to mass strandings of marine mammals (Węgrzyn et al., 2023). Additionally, the constant noise from increased naval traffic during conflicts interferes with the ability of marine animals to

detect predators or locate prey, further threatening their survival. Long-term exposure to elevated noise levels can disrupt entire ecosystems, reducing biodiversity and altering natural behaviors.

Freshwater pollution, caused during war conflicts, can significantly increase the risk of marine pollution. The destruction of industrial facilities, the dumping of ammunition and war equipment, and the decomposition of explosive residues often result in toxic chemicals leaching into rivers, lakes, and groundwater. These polluted freshwater systems, which are vital sources of drinking water, eventually flow into seas and coastal areas, carrying hazardous substances with them (Hryhorczuk et al., 2024). Additionally, the flooding of abandoned mines and the destruction of hydraulic structures, water treatment facilities, and pumping stations exacerbate this issue, as untreated wastewater and contaminated mine water are discharged into surface waters. As these rivers and streams flow into the ocean, they introduce a range of pollutants, from heavy metals to toxic chemicals, that pose severe risks to marine ecosystems and biodiversity. The combination of disrupted freshwater systems and uncontrolled runoff of pollutants into the sea creates a long-term environmental crisis, affecting both inland and marine habitats (Hryhorczuk et al., 2024).

A significant threat to the environment is noted during armed conflicts through the release of radioactive substances, particularly when nuclear facilities are targeted, nuclear weapons are used, or nuclear-powered ships are damaged or sunk (Hryhorczuk et al., 2024). Attacks on nuclear power plants can lead to catastrophic releases of radioactive material, as seen in past incidents such as Chernobyl, but exacerbated by the instability of war. When containment systems are damaged or breached, radioactive isotopes such as cesium-137 and iodine-131 can be released into the atmosphere and water, contaminating vast areas and spreading through wind and ocean currents. The use or accidental release of nuclear weapons during conflicts or even tests also introduces radioactive fallout into the environment, with long-lasting effects on ecosystems and human health. Additionally, the sinking of nuclear-powered ships or submarines poses a severe risk of radioactive leakage into marine environments. In such cases, the surrounding waters can become contaminated with radioactive materials, which are then absorbed by marine life, leading to bioaccumulation and long-term ecological damage (Scherrer et al., 2020). These radioactive pollutants persist in the environment for decades or even centuries, posing enduring risks to both marine and terrestrial ecosystems, as well as to the populations that rely on them for food and water (Hryhorczuk et al., 2024).

Shipwrecks resulting from war pose both immediate and long-term environmental risks, contributing to marine pollution (Maser et al., 2023; Rogowska et al., 2010). During conflicts, naval battles and the deliberate sinking of ships lead to vessels, often laden with fuel, ammunition, and hazardous materials, settling on the ocean floor. These wrecks can release large amounts of oil, fuel, and other toxic substances into the surrounding water, creating severe pollution that impacts marine ecosystems. Over time, as the metal structures of these ships corrode, they can leak dangerous chemicals, heavy metals, and UXO into the environment, further contaminating marine habitats (Maser et al., 2023). Notable examples include the many shipwrecks from World War I and World War II that remain on the ocean floors around the world, slowly leaking oil and hazardous materials. The toxic substances released from wrecks can spread through water currents, affecting a wide range of marine life, from corals and fish to larger predators, and can also accumulate in sediments, posing long-term threats to biodiversity (Rogowska et al., 2010). Additionally, shipwrecks pose navigational hazards and can obstruct fishing activities, while the potential for UXO to detonate represents an ongoing danger to both marine life and human activities in the area. These war-

related wrecks contribute significantly to the overall burden of marine pollution, with their environmental impact lasting for decades or even centuries (Bergmann et al., 2024; Rogowska et al., 2010).

War-induced population movements and overpopulation could also place significant pressure on marine environments, particularly in coastal areas. As conflicts force large numbers of people to flee their homes, often to coastal regions or areas near water bodies, the sudden surge in population can overwhelm local infrastructure and lead to increased pollution (Aldawsari, 2024). Overcrowded refugee camps or temporary settlements frequently lack proper waste management and sanitation systems, resulting in untreated sewage and solid waste being discharged directly into rivers, lakes, and the ocean. This can lead to nutrient pollution, which contributes to algal blooms and the degradation of marine ecosystems. Additionally, the increased demand for food and resources in these regions often leads to overfishing, depleting marine life and disrupting the balance of local ecosystems (Aldawsari, 2024). The strain on resources can also result in habitat destruction, as coastal areas may be cleared for temporary shelters or agricultural activities. Overall, the pressures caused by large-scale population displacement and overpopulation during wars significantly exacerbate the degradation of marine environments, threatening biodiversity and the livelihoods of local communities.

When it comes to the ongoing war in Ukraine, the environmental impacts in the Black Sea are profound, as various forms of marine pollution have intensified (Tahmid et al., 2023). The conflict has triggered a surge in pollution from multiple sources, including oil spills, chemical releases, debris, and the destruction of industrial and military infrastructure. These pollutants are not only affecting marine ecosystems but also posing long-term risks to biodiversity and the health of surrounding communities (Hryhorczuk et al., 2024; Leal Filho et al., 2024).

In conclusion, the environmental impact of war extends far beyond terrestrial ecosystems, severely affecting marine environments through various forms of pollution. From oil spills and chemical discharges to debris, heavy metals, and unexploded ordnance, the consequences of military activities are profound and long-lasting. Marine biodiversity, already sensitive to environmental changes, faces significant threats from these pollutants, which disrupt ecosystems, endanger species, and compromise the livelihoods of coastal communities. Furthermore, conflicts intensify risks to human health, particularly through contaminated seafood and polluted water supplies. As seen in recent conflicts like the war in Ukraine, the destruction of infrastructure and military operations continue to harm marine ecosystems, underscoring the urgent need for mitigation efforts to address these environmental crises and protect marine life for future generations.

4. Updated and new monitoring approaches and technologies for marine pollution

The growing threat of marine pollution demands the application of effective monitoring methods to safeguard marine ecosystems and mitigate adverse environmental impacts. Marine pollution, which includes contaminants such as heavy metals, oil spills, plastic debris, and eutrophication, poses significant challenges to biodiversity, human health, and economic activities such as fisheries and tourism (Ma et al., 2023). The rapid industrialization and urbanization in coastal areas have exacerbated these issues, contributing to the persistent flow of pollutants into marine environments. To address these challenges, effective monitoring systems are essential for detecting pollutants early and implementing timely mitigation measures. Conventional methods for monitoring marine pollution, such as in-situ sampling and laboratory testing, while valuable, often prove limited by high costs, time constraints, and the inability to cover large marine areas comprehensively (Anthony et al., 2023; Bellas et al., 2020).

In recent years, the advancement of new technologies and approaches has emerged as a crucial solution for overcoming the limitations of traditional monitoring frameworks. Methods such as remote sensing, satellite imaging, wireless sensor networks (WSN), autonomous underwater vehicles (AUVs), artificial intelligence (AI) and citizen science have proven to be highly effective in tracking pollutants across vast marine areas in real-time (Anthony et al., 2023; Bellas et al., 2020; Demetillo et al., 2019; Ma et al., 2023; Yang et al., 2022). These innovations allow for the continuous monitoring of pollution sources and the ability to detect changes in the marine environment quickly. By utilizing real-time satellite imaging and synthetic aperture radar (SAR), for example, response times to pollution events like oil spills can be drastically reduced (Zhu et al., 2021). Early detection enables faster intervention, which is crucial for minimizing the environmental and economic damage caused by such incidents. AI and machine learning models further enhance detection and prediction capabilities by analyzing complex datasets, enabling researchers and policymakers to anticipate pollution trends and develop more targeted mitigation strategies (Sannigrahi et al., 2022).

The importance of adopting these new technologies and approaches in marine pollution monitoring lies in their ability to address the scale and complexity of contemporary marine pollution challenges. By reducing response times, these monitoring methods allow for quicker containment and remediation of pollution events, ultimately limiting the spread and impact of contaminants. Moreover, integrating these advanced and updated approaches with existing monitoring frameworks will not only improve the detection and management of pollutants but also help address emerging threats such as microplastics and chemical contaminants (Ma et al., 2023). The incorporation of AI, remote sensing, and other novel methods into marine pollution management can significantly enhance the decision-making processes and thus the protection of marine ecosystems, ensuring the sustainability of marine resources and reducing the long-term effects of pollution (Bellas et al., 2020; Obura et al., 2019).

Wireless Sensor Networks for Real-Time Monitoring

Wireless sensor networks (WSNs) are transforming the monitoring of marine environments by enabling real-time and continuous data collection, which is crucial for the timely identification and management of pollution events (Demetillo et al., 2019; Ma et al., 2023). A typical WSN

consists of numerous sensor nodes deployed across various marine locations. These nodes are equipped with sensors that measure critical environmental parameters such as pH levels, water temperature, salinity, and dissolved oxygen. The data collected by each node is transmitted wirelessly to a central database or control center for analysis, often via protocols like ZigBee, GSM, or LoRa (Demetillo et al., 2019).

One of the key advantages of WSNs is their ability to operate in remote or difficult-to-access areas of the ocean. This is particularly important for monitoring pollution in locations where manual sampling would be dangerous, costly, or impractical. Recent research (Demetillo et al., 2019) provides examples of designing a WSN system that uses low-cost sensors to monitor large marine areas. This system can scale to cover extensive regions while providing continuous, real-time data, reducing the reliance on human operators and minimizing operational costs.

Despite their benefits, WSNs face several challenges, particularly in harsh marine environments where corrosion, biofouling, and strong currents can damage sensors and disrupt communication between nodes. Additionally, maintaining the energy supply for these sensors is a critical issue, especially for deployments in remote areas where regular maintenance is not feasible. Researchers are exploring energy-efficient designs, such as solar-powered nodes, to extend the operational life of WSNs and reduce maintenance needs. Moreover, the ability of these networks to integrate with other technologies, such as artificial intelligence and autonomous vehicles, enhances their utility by facilitating real-time decision-making based on continuous data streams.

In the Black Sea, the application of a regional WSN for real-time marine pollution monitoring at regional scale holds great potential, but it requires careful consideration of the potential challenges. When it comes to the WSN components the aggressiveness of seawater corrosion should be considered, as well as biofouling while energy-efficient solutions such as solar-powered nodes should be prioritized for continuous, low-maintenance operation in remote areas. Beyond technical challenges, the geopolitical instability in the region and the ongoing military conflict, may disrupt the deployment and transmission of data, adding another layer of complexity.

Given these challenges, strong collaboration among Black Sea coastal countries is crucial for the successful deployment of a WSN. Joint design efforts, effective data sharing, and coordinated pollution monitoring strategies will be essential to create a cohesive and integrated monitoring network that shares real-time data. The Convention on the Protection of the Black Sea Against Pollution and BSIMAP can serve as a guiding framework for this initiative, with coordination overseen by the Commission on the Protection of the Black Sea Against Pollution. By building on existing legal and institutional frameworks, Black Sea countries can work together to tackle both the technical and operational challenges of establishing a comprehensive real-time pollution monitoring system.

Artificial Intelligence in Marine Pollution Detection

Artificial intelligence (AI) has gained prominence in marine pollution monitoring, offering advanced capabilities in data analysis, pattern recognition, and predictive modeling. AI algorithms, particularly deep learning models such as long short-term memory (LSTM) networks, are increasingly being used to analyze historical water quality data and identify pollution

sources. By examining trends and correlations in large datasets, AI systems can predict future pollution events, allowing authorities to take preventive actions (Wang et al., 2019; Xu, 1711).

One of the most significant advantages of AI in marine pollution monitoring is its ability to model complex interactions within marine ecosystems. AI models can simulate the behavior of pollutants under different environmental conditions, such as changing currents or temperatures. This ability is particularly useful in understanding how pollutants disperse over time and space. For example, AI systems can trace the origin of an oil spill by analyzing satellite imagery and oceanographic data, providing critical information for cleanup efforts and for preventing future incidents (Wang et al., 2019).

AI also enhances the visualization of marine pollution data by generating real-time, multidimensional maps of pollution levels. These maps provide a clear and detailed representation of pollution spread, helping policymakers and environmental agencies allocate resources more effectively. However, the accuracy of AI predictions depends on the availability and quality of data. In regions with limited historical data, AI models may struggle to make accurate predictions. As a result, improving data collection methods, such as through WSNs or citizen science initiatives, is essential for maximizing the potential of AI in marine pollution detection (Garcia-Garin et al., 2021; Wang et al., 2019).

Despite its promise, AI's application in marine monitoring faces several challenges. AI models require extensive training datasets to make reliable predictions, and acquiring such datasets in marine contexts can be difficult due to the remote and dynamic nature of the ocean. Additionally, AI models need to be regularly updated to account for new variables or unforeseen environmental changes. Furthermore, the computational power required to run complex AI algorithms can be substantial, necessitating robust infrastructure that may not always be available in marine settings (Wang et al., 2019).

AI holds significant promise for addressing marine pollution challenges in the Black Sea region as well. However, the obstacles outlined above—such as the need for extensive, high-quality datasets and the limitations of existing infrastructure—are also present in this area. Moreover, the effective implementation of AI technologies requires personnel with specialized expertise and continuously updated training. To overcome these challenges, comprehensive and well-designed monitoring frameworks are essential. These frameworks can ensure the consistent collection of high-quality, extensive data that AI models rely on for accurate analysis and predictions. Additionally, the development of targeted training programs and curricula would equip local personnel with the necessary knowledge and skills to leverage AI tools effectively in monitoring marine pollution. By combining AI with robust data collection and well-trained staff, the Black Sea region can take a more proactive and informed approach to managing pollution and protecting its ecosystems.

Remote Sensing and Satellite Monitoring (Earth Observation)

Remote sensing, particularly satellite-based monitoring, has become a crucial tool in the large-scale detection of marine pollution. Satellites equipped with advanced sensors can capture high-resolution data on various environmental parameters, such as surface temperatures, chlorophyll concentrations, and oil spills. This technology is invaluable for monitoring vast and

remote areas of the ocean, providing a macroscopic view of pollution distribution and movement (Ma et al., 2023; Mahrada et al., 2020).

One of the primary advantages of satellite remote sensing is its ability to continuously monitor large swathes of the ocean. For example, the European Space Agency's Sentinel satellite series is designed to detect pollutants such as oil slicks, harmful algal blooms, and chemical discharges (Le Traon et al., 2019). These satellites provide near-real-time data that can be used to track pollution events and their impact on marine ecosystems. Remote sensing also allows for the detection of pollution in areas that are difficult or dangerous for human operators to reach, such as the deep ocean or polar regions (Ma et al., 2023).

While satellite remote sensing offers significant benefits, it is not without its limitations. For instance, cloud cover and surface reflections can interfere with the sensors, reducing the accuracy of the data collected (Ma et al., 2023; Mahrada et al., 2020; Melet et al., 2020). Moreover, while satellites provide an excellent overview of pollution patterns on the ocean's surface, they are less effective at detecting pollution in deeper waters. This limitation highlights the need for complementary technologies, such as autonomous underwater vehicles (AUVs), which can monitor subsurface pollutants. Additionally, the cost of launching and maintaining satellite systems can be prohibitive, although advancements in technology are driving down these expenses. To address these challenges, ongoing research is focused on improving the accuracy of satellite sensors and developing more sophisticated algorithms to process the data they collect. In addition, integrating satellite data with other monitoring methods, such as WSNs and AUVs, can provide a more comprehensive picture of marine pollution, improving the ability of authorities to respond to environmental threats (Melet et al., 2020; Sannigrahi et al., 2022).

The applicability of satellite remote sensing in the Black Sea region holds great promise, as evidenced by findings from Del 1.2 and the insights gathered during face-to-face interviews with stakeholders. Organizations responsible for marine pollution monitoring in the area are already utilizing satellite-derived data for environmental monitoring. However, there remains a critical gap in training and up-to-date knowledge regarding the effective use of these technologies. Integrating satellite data with in situ monitoring methods can enhance the accuracy and comprehensiveness of pollution assessments in the Black Sea, enabling authorities to respond more effectively to environmental threats. Moreover, research initiatives have demonstrated the successful application of these remote sensing methods within the region (e.g. for detecting oil spills and assessing marine litter), highlighting their potential to improve environmental management. Nonetheless, to fully leverage these technologies, there is an urgent need to invest in training and capacity-building for personnel who will be responsible for data manipulation and interpretation, ensuring that the benefits of satellite remote sensing can be fully realized for the protection of the Black Sea's marine ecosystems.

Autonomous Underwater Vehicles (AUVs)

Autonomous underwater vehicles (AUVs) represent the next frontier in marine pollution monitoring. These self-guided vehicles are equipped with a variety of sensors capable of measuring the chemical and physical properties of seawater, including pollutants that cannot be detected from the surface. AUVs can be programmed to follow predetermined routes or can adapt their paths in real time based on the environmental data they collect (Yang et al., 2022).

AUVs have a distinct advantage over static sensors, such as buoys, because they can move across large areas and reach greater depths. This mobility allows them to gather detailed data from locations that are otherwise difficult or impossible to access, such as deep-sea regions or areas affected by extreme weather conditions (Garcia-Garin et al., 2021; Mahrada et al., 2020). AUVs are especially useful in monitoring pollution events such as underwater oil spills, where they can track the movement of oil plumes and assess their impact on marine life. Additionally, AUVs equipped with AI systems can optimize their search patterns, focusing on areas with higher concentrations of pollutants.

However, AUVs also face several challenges. Operating in deep and turbulent waters requires robust design to withstand high pressure and strong currents (Aracri et al., 2021). Furthermore, AUVs are energy-intensive, and their missions are often limited by battery life. Researchers are exploring solutions to these issues, including the development of more efficient propulsion systems and the use of renewable energy sources, such as solar power, to extend the operational range of AUVs. Another challenge is the high cost of deploying and maintaining AUVs, which limits their widespread use (Mahrada et al., 2020; Yang et al., 2022).

AUVs hold great potential for systematic marine pollution monitoring in the Black Sea region. However, their acquisition, operation, and maintenance come with high costs, which pose significant challenges given the limited funding for monitoring initiatives, as highlighted by stakeholders in Deliverable 1.2. Additionally, operating AUVs requires specialized expertise, both from scientific and technical personnel, to effectively use the equipment and manage the data collected. To overcome these challenges, increased funding is necessary, along with the development of targeted training programs to equip local experts and technicians with the skills needed to deploy and maintain AUVs. By addressing these issues, the Black Sea region can make significant strides in improving its marine pollution monitoring capabilities.

Smart Buoy Systems

Smart buoys, equipped with advanced sensors and wireless communication technologies, are increasingly being used in marine pollution monitoring. These buoys can measure a wide range of water quality parameters, including temperature, pH, turbidity, and dissolved oxygen, and transmit this data to central control systems in real time (Obura et al., 2019). One of the key innovations in smart buoy systems is their use of solar power, which allows them to operate for extended periods with minimal maintenance. By continuously monitoring marine environments, smart buoys provide valuable data that can be used to detect pollution events and assess the health of aquatic ecosystems.

Smart buoys offer several advantages over traditional monitoring methods. They can be deployed in remote or inaccessible areas, providing continuous data collection without the need for human intervention. Additionally, their ability to transmit data wirelessly in real time allows for rapid responses to pollution events, minimizing environmental damage. For example, smart buoys deployed in industrial harbors can detect sudden increases in pollutants and alert authorities, enabling them to take immediate action (Demetillo et al., 2019).

However, smart buoy systems are not without their challenges. Like WSNs, buoys deployed in harsh marine environments are vulnerable to corrosion, biofouling, and mechanical damage from strong currents or waves. Maintaining the integrity of these systems over long periods can

be costly and labor-intensive. Moreover, the initial investment required to develop and deploy smart buoys can be high, although recent advances in technology are helping to reduce these costs (Demetillo et al., 2019; Dzemydienė & Radzevičius, 2020).

The application of smart buoy systems in the Black Sea region holds significant potential, particularly in high-risk pollution areas such as harbors and river deltas. These systems could play a crucial role in enabling rapid responses to marine pollution incidents and mitigating their environmental impacts. However, similar to other advanced monitoring technologies, the high costs associated with deploying and maintaining smart buoys remain a challenge, as does the need for trained personnel to operate the systems and manage the data they collect. The maintenance of these buoys, especially in the face of biofouling and mechanical damage in harsh marine conditions, adds to the financial and operational burdens. Despite these challenges, strategic deployment in key pollution hotspots could significantly enhance the region's ability to monitor and respond to pollution events in real time, reducing long-term environmental damage and protecting vulnerable ecosystems.

Citizen Science and Crowdsourced Data Collection

Citizen science has emerged as a valuable and innovative approach to marine pollution monitoring, particularly in regions where formal monitoring efforts are limited by resources or logistical challenges (Earp & Liconti, 2020; Rambonnet et al., 2019). By equipping members of the public with low-cost sensors and mobile apps, individuals can actively participate in the collection of water quality data, contributing to larger datasets that enhance our understanding of marine pollution. This crowdsourced approach not only increases the volume of data available for analysis but also raises public awareness of marine pollution issues, fostering a sense of community involvement in environmental protection (Obura et al., 2019).

Citizen science initiatives have been particularly successful in coastal regions and areas where governmental or institutional monitoring may not be feasible. For example, community members can use mobile applications to report visible pollution, such as oil spills or plastic debris, in real time. These reports can then be aggregated into larger databases, providing valuable information for environmental agencies and researchers (Maximenko et al., 2019). Additionally, citizen scientists can use portable sensors to measure water quality parameters such as pH, turbidity, and dissolved oxygen, contributing to more comprehensive monitoring efforts.

While citizen science offers many benefits, it also presents several challenges. Data collected by non-experts may be less accurate than data gathered by trained professionals, and the quality of the sensors used in these initiatives can vary widely (Rambonnet et al., 2019). To mitigate these issues, it is important to provide proper training for participants and ensure that the sensors used are calibrated and reliable. Additionally, managing and analyzing the large volumes of data generated by citizen science projects requires sophisticated data management systems, which may not always be available in developing regions (Nelms et al., 2022).

In the Black Sea Basin, citizen science is a promising tool for expanding marine pollution monitoring efforts and engaging the public in environmental stewardship. There are already examples of citizen science initiatives in the region), while research has demonstrated innovative approaches, such as using data from social media platforms and the internet to identify marine mammal strandings (Węgrzyn et al., 2023), further showcasing the potential of crowdsourced

information in monitoring marine ecosystems. However, additional efforts are needed to make the use of citizen science and crowdsourced data more systematic. While organizing these initiatives is demanding, there is valuable experience from various projects that can guide future efforts. Adequate resources and proper training are essential to ensure the effectiveness and reliability of data collection. With the right support and coordination, citizen science can play a crucial role in enhancing marine pollution monitoring in the Black Sea region.

In conclusion, the use of advanced technologies and innovative approaches is essential to effectively monitor and address the growing threat of marine pollution in the Black Sea region. From remote sensing and AI-powered predictive models to the deployment of AUVs, WSNs, and smart buoy systems, these tools offer unprecedented capabilities in detecting, analyzing, and responding to pollution events in real time. However, the successful implementation of these technologies requires overcoming several challenges, including high costs, the need for specialized training, and infrastructural limitations. At the same time, citizen science offers a promising avenue to complement formal monitoring efforts, expanding data collection and fostering public engagement in environmental protection. To fully realize the potential of these technologies and approaches, strong collaboration between Black Sea coastal countries is vital, alongside continued investments in training, infrastructure, and resource allocation. By integrating these advanced monitoring systems with existing frameworks, such as the BSIMAP and the Convention on the Protection of the Black Sea Against Pollution (Bucharest Convention), the region can take significant strides toward safeguarding its marine ecosystems and mitigating the long-term impacts of pollution.

5. Conclusions

The assessment of marine pollution in the Black Sea Basin has revealed the complexity and severity of the environmental challenges facing this unique ecosystem. The region's ecosystems, which provide essential services such as food resources, transportation, and recreation to millions of people, are under intense pressure due to a variety of pollutants introduced primarily by human activities. These pollutants—ranging from nutrient overloads, heavy metal contamination, and marine litter to oil spills and atmospheric pollution—have already caused significant harm to marine life, biodiversity, and the overall health of the Black Sea ecosystem.

In response to these challenges, the next phase of the RESPONSE project would prioritize the development of comprehensive training programs and curricula specifically designed to address the different types of marine pollution, their sources, and their impacts. These training schemes would aim to equip key stakeholders involved in marine pollution monitoring and control—including policymakers, environmental agencies, and local communities—with the knowledge and tools necessary to effectively mitigate pollution. The findings of this report underscore the significance of contaminants such as heavy metals and oil, alongside issues like eutrophication and marine litter, as the most pressing pollution threats in the region. Given that these pollutants are also common in many marine ecosystems globally, RESPONSE will draw on examples of best practices from around the world to build a successful framework for the Black Sea.

Incorporating innovative technologies into these training programs is crucial for improving pollution monitoring and mitigation. This report's assessment of modern technologies and updated monitoring approaches emphasizes their potential to enhance pollution tracking and data collection. Therefore, the training schemes should focus on the practical application of these technologies, ensuring that local, national, and regional agencies, as well as researchers, can effectively utilize them to better monitor and mitigate pollution.

To move the RESPONSE project forward, it is essential to develop tailored curricula that address both the technical and policy-related aspects of marine pollution. This includes training stakeholders on how to more effectively implement existing legislative frameworks and action plans, as well as fostering stronger cooperation among the countries in the region. Additionally, raising awareness at the community level and promoting education are vital components of the RESPONSE initiative. Engaging all stakeholders—from local fishermen to industrial actors—is key to fostering collective responsibility for protecting the Black Sea environment.

In conclusion, this report underscores the urgent need for coordinated regional efforts to tackle marine pollution in the Black Sea. By developing targeted training programs that integrate cutting-edge technologies and updated monitoring techniques, the RESPONSE project will enhance the region's capacity to manage pollution and contribute to the long-term sustainability of the Black Sea's ecosystems. Through these initiatives, the region can move towards more effective and resilient environmental governance, ensuring a healthier Black Sea for future generations.

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How does war damage the environment? - CEOBS. <https://ceobs.org/>

<https://www.unep.org/resources>

Microplastics Home: Provides a comprehensive overview of microplastics, including definitions, sources, and impacts. <https://mp-1.itrcweb.org/>

OSTI.GOV: This website offers a research paper on radioactivity in the Romanian Black Sea sector, focusing on measurements and trends after the Chernobyl accident. <https://www.osti.gov/etdeweb/servlets/purl/603190>

Plastic Pollution Foundation: A non-profit organization dedicated to raising awareness and addressing plastic pollution, including microplastics. <https://www.plasticsoupfoundation.org/en/>

Romanian Environmental Protection Agency: The Romanian government agency responsible for environmental protection has published reports and data on nutrient pollution in the Black Sea. <https://www.anpm.ro/>

SIPRI Report: This report provides a comprehensive overview of nuclear security threats in the Black Sea region, including the impact of the Russian invasion of Ukraine on nuclear installations. <https://www.sipri.org/publications/2023/policy-reports/nuclear-security-ukraine-and-black-sea-region-new-threats-new-risks-new-consequences>

Ukraine conflict environmental briefing: The coastal and marine environment - CEOBS. <https://ceobs.org/>

Witnessing the Environmental Impacts of War - Environmental case studies from conflict zones around the world - World | ReliefWeb. <https://reliefweb.int/>

Appendix I – List of key terms used as search queries

a/a	List of key terms
1	Marine pollution AND "Black Sea"
2	Marine pollutants AND "Black Sea"
3	Shore heavy metals pollution AND "Black Sea"
4	Sources of pollution AND "Black Sea"
5	Environmental pollution AND "Black Sea"
6	Assessment marine pollution AND "Black Sea"
7	Pollution mitigation plans AND "Black Sea"
8	Armed conflict pollution AND "Black Sea"
9	Bioindicators pollution AND "Black Sea"
10	Marine pollution monitoring AND "Black Sea"
11	Marine pollution Bulgaria AND "Black Sea"
12	Marine pollution Ukraine AND "Black Sea"
13	Marine pollution Georgia AND "Black Sea"
14	Marine pollution Romania AND "Black Sea"
15	Marine pollution NW AND "Black Sea"
16	Hydrocarbons pollution AND "Black Sea"
17	Oil pollution AND "Black Sea"
18	Pesticides pollution AND "Black Sea"
19	Microplastics pollution AND "Black Sea"
20	Maritime traffic impact AND "Black Sea"
21	Nutrients pollution AND "Black Sea"
22	Petroleum hydrocarbons pollution AND "Black Sea"
23	Influence of waste water AND "Black Sea"
24	Influence of human activities AND "Black Sea"
25	Emergency Response, Marine Accident AND "Black Sea"
26	Contingency Plan, Marine Accident AND "Black Sea"
27	Environmental safety, pollution accidents AND "Black Sea"
28	Shoreline type, pollution AND "Black Sea"
29	Underwater noise pollution, armed conflict AND "Black Sea"
30	Underwater noise pollution AND "Black Sea"
31	Seafood contaminants AND "Black Sea"
32	Radiation, energy pollution AND "Black Sea"

Appendix II – Scientific articles of literature review

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