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Enhancing public health through ocean research—a model for global partnership

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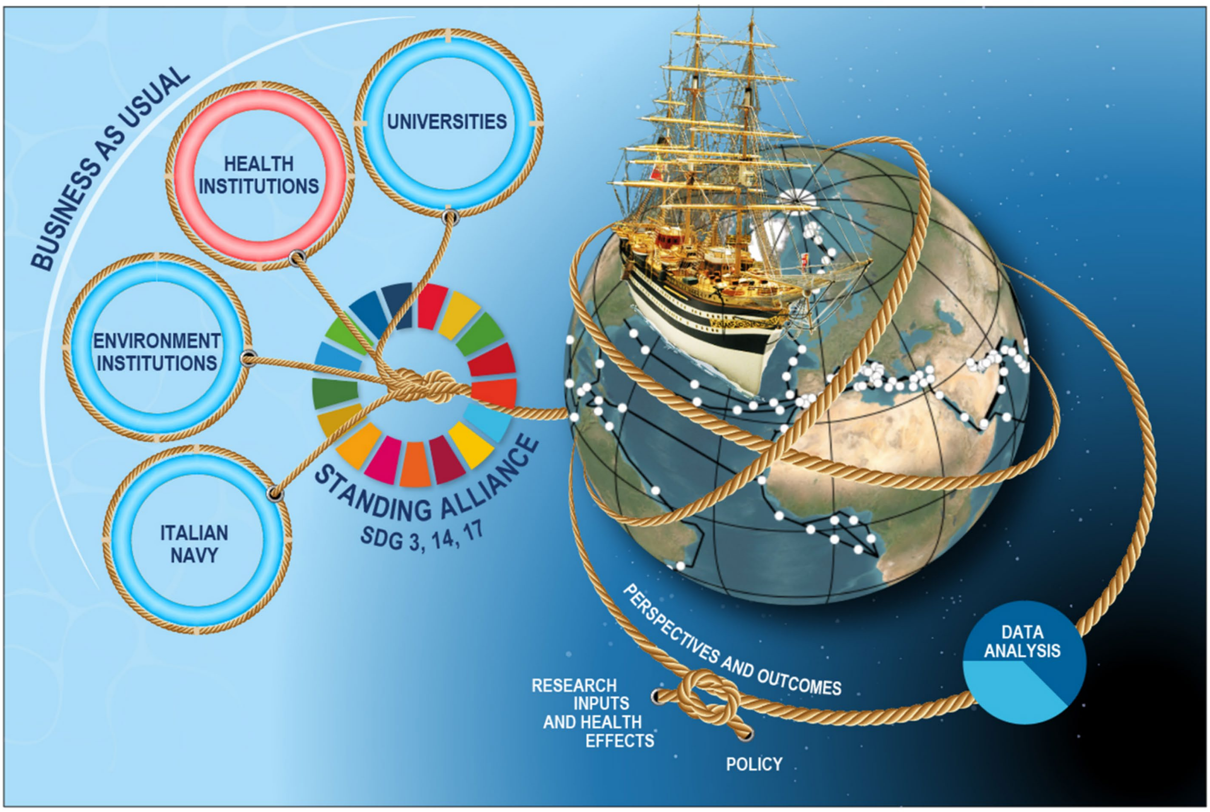
Understanding the connection between ocean health and human health is currently limited and fragmented, calling for transdisciplinary research and strategic action. The contribution of public health experts alongside marine scientists are essential for a comprehensive understanding of the health-environment-climate nexus in a Planetary Health perspective. This paper proposes a novel Model for a standing Global Partnership, the SeA Care project. This initiative aims to align efforts within the framework of the Sustainable Development Goals merging the principles of Planetary Health with the "One Water" approach. By doing so it seek to foster the development and assessment of new strategies for oceanwide surveillance focusing on adaptation, mitigation and prevention.

KEYWORDS
global health, planetary health, ocean sustainability, health monitoring policy, ocean and human health (OHH), global partnership

Highlights

- We present and propose an effective model for the creation of standing scientific partnerships coordinated by health experts and involving universities and research institutions as well as governmental (e.g., the Navy) and non-governmental institutions.
- We successfully implemented this model in the SeA Care project—large-scale study of anthropogenic impacts on the planet's oceans associated with possible adverse effects on human health.
- The model aims to share high-quality, harmonized data in open-access dashboard repositories. Data may be used to define aggregate indices of anthropogenic contamination capable of informing local and global public health and environmental prevention and response policies.
- The model can be expanded transnationally and/or replicated in other contexts.



GRAPHICAL ABSTRACT

1 Introduction

1.1 The model for global partnership and its implementation in the SeA Care project

The emergence of Planetary Health as a discipline aimed at preserving and improving human health in the face of major environmental challenges, has identified several crucial research priorities (Horton and Lo, 2015; Whitmee et al., 2015), mainly dealing with restricted scope and comparability of studies, lack of transdisciplinary research, and limited funding. Investigating threats to human health associated with the disruption of natural systems, including climate change, becomes particularly challenging when addressing the links between ocean health and human health (Demaio and Rockström, 2015; Fleming et al., 2021, 2023). Despite numerous gaps and uncertainties in our understanding, both ocean and human health are undeniably impacted by the triple crisis which encompasses the intertwined challenges of climate change, pollution and loss of biodiversity insisting on marine ecosystems, coastal waters, high seas, and the vast expanses of the deep seabed. Changes include water warming, acidification, sea level rise, changes in salinity, persistent water contamination and are exacerbated by complex synergies that intensify the effects of already unsustainable direct and indirect anthropogenic pressures, impacting on economic and social systems as well as on health (The Lancet Planetary Health, 2019; Landrigan et al., 2020). An understanding of these complex and interdependent relationships is crucial to inform policy and promote sound and effective action towards sustainability and health (Visbeck, 2018; Jenkins et al., 2023; The Lancet Planetary Health, 2023).

This topic has been addressed in several international projects. Indeed, there is a great deal of interest, particularly on the issue of antimicrobial resistance, which is the focus of the BlueAdapt project (BlueAdapt, 2024), one of many funded by the European Centre for Environment and Human Health, to study how viruses and bacteria in coastal areas respond to climate change and how this may pose a risk to human health. Seas, Oceans and Public Health in Europe (SOPHIE), (2025), funded by EU's Horizon Europe - Research and innovation - European Commission[1] program, aims to bring together oceanographic and public health specialists to address issues such as seafood and marine biodiversity. Overall, the European Union seems to be at the forefront of these issues, also with other projects funded by the European Marine Board, such as RHE-MEDiation (RHE-MEDiation, 2025), which has, among its many objectives, the development of remediation technology based on microalgae to absorb pollution from the seas and to develop both fixed and mobile monitoring systems to study pollutants in both surface and deep waters. In the United States, harmful algal blooms (HAB's) have received much attention and since 2012 the Woods Hole Center for Oceans and Human Health (WHCOHH, 2025) has been dedicated to studying this phenomenon, its influence on climate change, and its impact on human health through the study of the cellular and molecular mechanisms. Despite their focus on the intricate relationship between Ocean and Human Health (OHH) (Fleming et al., 2023), these initiatives lack of a global dimension.

1 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

To address this need, we harnessed multisectoral and transdisciplinary principles to create the "SeA Care" project (Salute, Ambiente e Clima nella vision della Planetary Health), a replicable model of long-lasting partnership capable of supporting national and transnational research projects that can be sustained over the long term. This model involves government institutions, the scientific community and civil society working together and creating synergies to optimize resources and maximize results.

The added value of the model lies in the fact that it enables the cost-effective, long-term systematic production of harmonized, high-quality data on a global scale, carried out by institutions committed to a common research objective and plan. The institutions involved integrate the project's research-related activities into their routine operations by negotiating adaptive measures, thus maximizing benefits while containing costs and preventing needless duplication.

Moreover, the model is highly adaptable. Indeed, in the spirit of the Planetary Health approach, data generated by SeA Care, or other programs following the Model for Global Partnership (Goal 17|Department of Economic and Social Affairs, 2025), can be used to promote not only human health but also ocean health, global ecosystem health and climate stabilization.

The SeA Care partnership was recently presented by Italy at the United Nation (UN) Water Agenda, and approved by the UN as an official national commitment for Italy (United Nations, 2025a). The project, led by the health sector, leverages Sustainable Development Goal (SDG) 17 to promote at least four other SDG goals—good health (SDG3), clean water (SDG6), climate action (SDG13), life below water (SDG14) (United Nations, 2025b). Research activities are guided by a "from source-to-sea" approach (Granit et al., 2017; Mathews et al., 2019), aligning with the "One Ocean" (UNESCO Ocean Literacy, 2025) perspective as reflected in the UN treaty on the conservation and sustainable use of the high seas known as "High Seas Treaty" (The Lancet Planetary Health, 2023; United Nations, 2023).

The project involves the Italian National Institute of Health (ISS), the Italian Navy, the National System for Environmental Protection (SNPA) and other national centers of excellence such as the Regional Agency for Environmental Protection of the Region Emilia Romagna (ARPA-ER), the Sapienza University of Rome, and the University of Padua. The project is self-financed by the participating institutions, as there is no single source of national or international funding for the project. As a result, the individual activities of the different research groups are part of the institutional activities that do not require the allocation of specific funds.

The scientific activities rely on a harmonized methodology and quality assurance system, aiming to address the limitations often encountered in large datasets produced by aggregating data from different studies (Whitmee et al., 2015; Brett et al., 2020). A case in point is the European Marine Observation and Data Network (EMODnet) [European Marine Observation and Data Network (EMODnet), 2025], a data repository focusing on the marine environment funded by the European Commission and supported by the EU's integrated maritime policy, which collects and affords access to data from different scientific organizations. This is an essential activity, but data are collected using different criteria and methodologies, without a shared data governance framework, and are uploaded mainly on a voluntary basis. Another international network collecting marine data is GEOTRACES (GEOTRACES, 2025), which offers an attractive global perspective, but focuses only on trace elements.

Our partnership welcomes other national and international research institutions sharing the goal of better understanding the interplay between marine and human health.

In the framework of the SeA Care project, we are currently studying the distribution and exposure pathways of several selected anthropogenic substances, pathogens, antibiotic resistance genes and the changing genetic diversity of marine bacterial communities. This foundational data will support the development of integrated, algorithm-based indices also utilizing Artificial Intelligence systems (AIs) and automated Internet of Things (IoTs), to identify health risks from anthropogenic contamination of the marine environment. These indices will serve as tools to inform public health policy, and the resulting data will be published in public, open-access repositories.

AI will support the identification of complex patterns, hidden correlations, and emerging trends, improving the understanding of the relationships between human health and ocean health, and contributing to the development of predictive models and integrated indices.

2 Methods and analysis

2.1 SeA Care metodologies

The project consists of 12 operational units comprising approximately 60 scientists, technicians and administrative staff from each participating institution. Figure 1 presents the research activities carried out by each institution.

The project consists of different phases, the first of which was dedicated to the selection of sampling areas and of variables of interest, mostly anthropogenic pollutants linked to adverse health outcomes, and to the optimization of cooperation between participants—both at the institutional and operational level. This included the establishment of procedures and cooperation protocols, communication strategies, the development and quality assurance of sampling and analytical methods, the acquisition of preliminary data and the monitoring of performance to maximize the effectiveness of future activities.

The selection of sampling areas was based on the following criteria: (1) direction of sea currents; (2) mapping of anthropogenic impact sources along the coast as a function of organic load; (3) direction and intensity of maritime traffic; (4) levels of chemical and physical parameters capable of affecting the distribution of pollutants in the marine environment (e.g., salinity, temperature, pH); (5) availability and optimal allocation of resources (Supplementary Tables S1–S4).

The choice of sampling sites sought to take into account the most important of these factors through the analysis of available satellite data; currents were analyzed from Copernicus Marine Service (2025) and Earth nullschool (n.d.); anthropogenic impacts were studied through several platforms such as EMODnet, and The Global Wastewater Model (Tuholske et al., 2021; Global Wastewater Model, 2025) which maps nitrogen inputs from wastewater systems, Marine Traffic for the study of merchant vessel traffic; TheOceanCleanUp (Meijer et al., 2021; River Plastic Pollution Sources, 2025) for mapping plastic spills from rivers. The frequency of the sampling has been set on an annual basis and it is linked to the routes of the Italian Navy

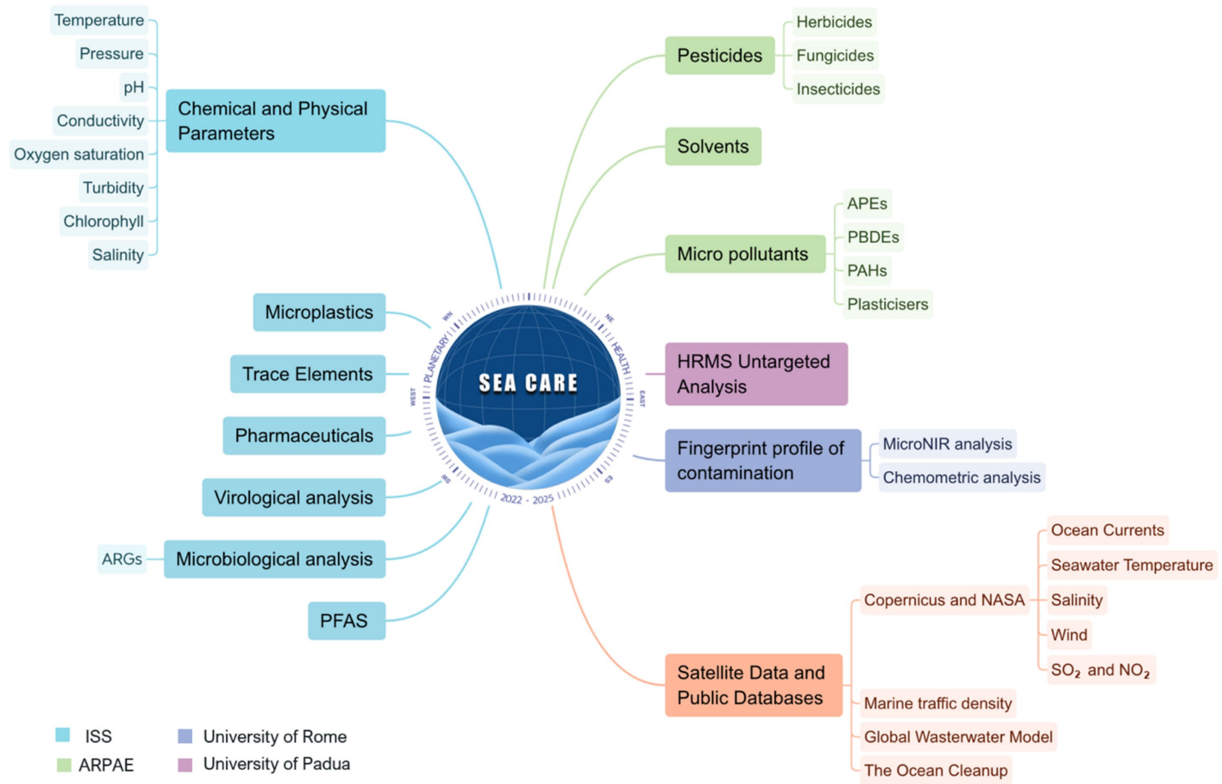


FIGURE 1
SeA Care's research institutions and their respective research activities: investigated chemical and biological pollutants, physical and chemical parameters studied and additional data used (PFAS: Per- and Polyfluoroalkyl substances; ARG: Antimicrobic Resistance Genes; APE: alkylphenols; PBDE: Polybrominated diphenyl ethers; PAH: Polycyclic Aromatic Hydrocarbons; MicroNIR: Micro Near Infrared Spectroscopy).

vessels. Due to the spatial scale of the project, it will not be possible to repeat sampling in all areas in the short term, nor has it been possible to follow the seasonality.

In order to determine the sampling frequency, a preliminary study (unpublished data) was carried out on transects covering an area of approximately 78 square nautical miles, with sampling points located at 1 and 5 nautical miles, to confirm the scientific evidence that marine waters can be considered as relatively homogeneous masses of water in offshore areas. This study showed that even in closed marine environments such as the Mediterranean, a single point sample can be representative of a larger geographical area.

Technical meetings were held with naval personnel to obtain detailed information on the location, type and operation of all discharges at sea in order to avoid sample contamination due to ship characteristics. The sampling protocol required that all sea outlets be closed 10–15 min prior to sampling. In the case of the so-called grey ships, which are operational vessels equipped with dinghies, all sampling was carried out on board the dinghy, except for sample for virus's analysis, which were sampled directly from the ship by lowering a submersible pump into the sea. The 500-litre volume of seawater was then filtered on board using a special filtration system. On board the Amerigo Vespucci, an historic Italian Navy sailing vessel, sampling was almost always carried out from the ship, by lowering the multiparameter probe and water sampling instruments from the side of the ship far from the outlets. In addition, preliminary tests were carried out on the sampling methods in proximity and at a distance from the vessel. The results of these preliminary tests (unpublished data) indicate that the characteristics of the vessel involved in the activities and the materials do not exert any influence or contamination on the microbiological and virological samples, with respect to the sampling procedures employed.

The map of desired sampling areas was presented to the Navy, whose staff assessed their compatibility with the Navy's routes and when necessary, adjusted them to meet the research objectives, so that to date, the project's sampling plan includes all of the proposed sampling areas (Figure 2). During each mission, we had a limited number of stops for sampling, it was therefore preferred to optimize this resource by collecting the greatest number of samples as possible in each area and by maximizing the number of parameters to be studied.

The chemical substances selected for study belong to several classes of dangerous and persistent contaminants of the marine environment, as reported in Table 1. These include chemical elements (whose isotopic ratio can provide evidence of natural or anthropogenic presence), perfluoroalkyl compounds (PFAS), pesticides, hydrocarbons, endocrine disruptors, pharmaceuticals, surfactants and microplastics. They were selected based on four criteria: (1) molecules that are dangerous and persistent in water and the marine environment; (2) substances that are massively produced and distributed, especially if no limits to discharge are set; (3) substances that have direct or indirect health effects; (4) the presence of knowledge gaps.

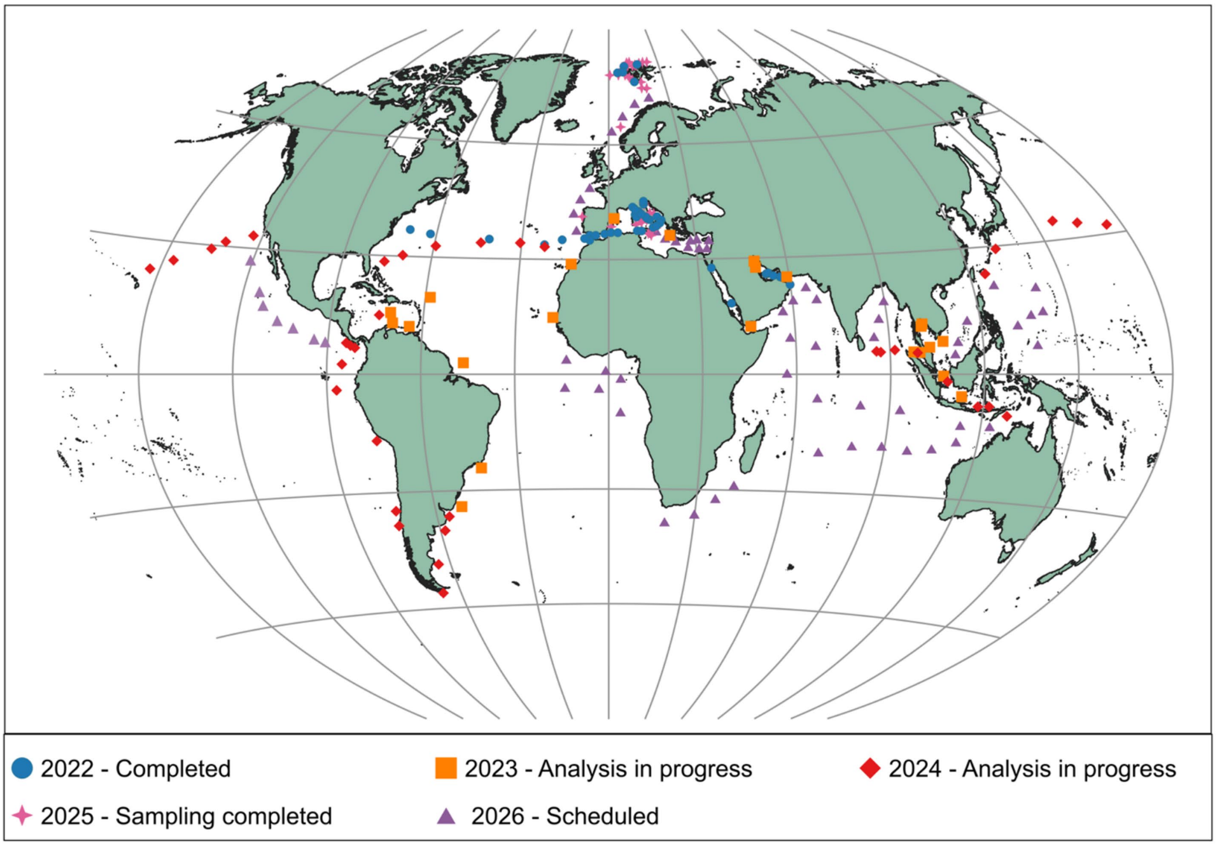


FIGURE 2
SeA Care project activity 2022–2025.

We also examine the large-scale distribution of bacterial and viral populations as well as the spread of antibiotic resistance genes in the marine environment. Table 2 summarize key facts about microorganisms and antimicrobial resistance in the oceans, including their sources, distribution patterns, and impact on human health and marine ecosystems, and indicates knowledge gaps which our project will aim to fill.

Finally, under the heading of Pioneering Approaches (Table 3), we adopted two additional analytical methodologies with the aim of complementing the information obtained using standard chemical and microbiological methods as described above. One is the untargeted analysis of sea water for contaminants using high-resolution mass spectrometry in the lab, and the other is the targeted analysis of sea water for the rapid identification of specific pollutants using a miniaturized, portable spectrophotometer on board the ship.

The methodologies employed in the collection and analysis of SeA Care targeted and untargeted analytes are detailed in Appendix Tasks 1–6.

Sampling activities started in May 2022 and are still ongoing. It has mainly been carried out beyond 200 nautical miles from the coast, but, where considered of research interest, sampling has been carried out within national EEZs following specific request to each country. The sampling frequency has been set on an annual basis as it is linked to the routes of the Italian Navy ships, but specific areas are already planned to be monitored again.

During the preparatory work, standard procedures for sampling, sample preparation and quality assurance were optimized for the different types of biological and chemical analyses. The applicability of these procedures was verified during the first expedition. The procedures were implemented on board (Figure 3), and training of both research and Navy personnel was carried out as necessary during subsequent expeditions. The procedures can now be implemented under different operating conditions and are reproducible in different units of the Italian Navy, with their operational and logistical specificities. The laboratory methods for each analytical class and the specific compounds investigated in the project are reported in Supplementary Tables S5, S6, respectively.

3 Results and discussion

3.1 Tasks and outcomes

SeA Care was launched in 2022. Now, having concluded its first phase, we are presenting key results from a number of selected tasks and reporting on the effectiveness of its underlying Model for Global Partnership. The complete results from the first phase of the study are presented in Supplementary Tables S4, S6–S10.

The strategy of cooperation between researchers and cargo ship owners has already been presented by other authors (She et al., 2023; Macdonald et al., 2024) in the so-called Ships of Opportunity scenario,

TABLE 1 Anthropogenic chemical pollutants monitored in the SeA Care project.

Target pollutant	Environmental concern	Production and use	Health effects	Knowledge gaps	Ref.
Microplastics	Ubiquitous and highly persistent in marine environments; they bioaccumulate in organisms and act as carriers for chemicals and pathogens, increasing ecological and health risks.	Massive production and distribution. Every year 19–23 million metric tons of plastic are dumped into the oceans.	Behavioral and physiological changes in exposed marine taxa. Transport along the trophic chain can expose humans to potential risks.	Current studies are limited to specific regions and lack of comparability.	United Nations (2017) and Bruno et al. (2022)
Trace elements	Persistent and prone to bioaccumulation and biomagnification; they alter the natural state of marine ecosystems and pose risks to higher trophic levels.	Sources: windblown debris, forest fires, volcanic eruptions, biogenic processes but also mining, pesticide use and industrial waste.	Not readily metabolized or transformed in the human body. Ability to increase their toxic potential as they move to a higher trophic level.	Mainly studied in coastal areas (Directive, 2008).	Aparicio-González et al. (2012), Briand et al. (2018), Lu and Wang (2019), Heinze et al. (2021), Mitra et al. (2022), and Zaynab et al. (2022)
Per- and polyfluoroalkyl substances (PFAS)	Extremely stable “forever chemicals”; highly soluble, mobile in water, and widely distributed; they bioaccumulate in aquatic organisms and raise global environmental and health concerns.	Large, complex group of synthetic chemicals commercially produced since the 1940s (although their toxicity was not established until the late 1990s), massively and universally used since the 1950s; over 12,000 compounds, 100–1,000 tons/year. Components of industrial applications, detergents, textiles, paper coatings, food containers, metal plating, and firefighting foams. Also found in many everyday products, such as kitchen utensils, cosmetics, sunscreen, medical devices, clothing, carpets, and shoes.	Bioaccumulate and toxic substances associated to a wide variety of adverse health outcomes, including oxidative stress, dyslipidemia, hypertension, altered immune and thyroid function, preeclampsia, liver and kidney diseases, lipid and insulin dysregulation, adverse reproductive and developmental effects, increased risks for some cancers.	Mainly studied in coastal areas (Directive, 2008), with only a few studies carried out in offshore waters. None have investigated their distribution in the water column, particularly in sensitive areas and on the high seas.	Yamashita et al. (2008), Kato et al. (2011), and Khalil et al. (2016)
Pesticides	Persistent and toxic compounds widely applied in agriculture; they accumulate in aquatic systems, threatening biodiversity and food safety.	Three million tons of pesticides are used, and more than 700 tons of active pesticide are discharged into the oceans every year.	Many pesticides are carcinogenic, toxic, and bioaccumulate. They are responsible for neurodevelopmental disorders and act as endocrine disrupters. Many pesticides are banned in the EU.	Data are mainly available for coastal areas and few for remote areas such as the North and South Pole.	Landrigan et al. (2018), Liu et al. (2018), Ya et al. (2019), Pouch et al. (2021), and Maggi et al. (2023)
Surfactants	Synthetic and recalcitrant; octylphenols and nonylphenols are classified as priority environmental hazards due to endocrine-disrupting effects.	Widely used in household and industrial detergents. They enter the aquatic environment mainly because wastewater treatment cannot remove them completely.	They bioaccumulate in the human body and can mimic the effects of hormones such as 17-β-estradiol by interfering with the endocrine system.	Data are mainly available for coastal areas and are limited in space and time.	Kannan et al. (2000), Acir and Guenther (2018), and Salgueiro-González et al. (2019)

(Continued)

TABLE 1 (Continued)

Target pollutant	Environmental concern	Production and use	Health effects	Knowledge gaps	Ref.
PAH and PBDE	Hydrophobic and persistent; attach to suspended particles, enabling long-range transport; toxic and carcinogenic, they pose risks to aquatic and human health.	PAHs come from manufacturing industries, drilling on offshore platforms, burning of petroleum products, but also from fires and volcanoes. PBDEs are widely used as flame retardants in many formulations.	PAHs are carcinogenic and toxic. PBDEs are endocrine disruptors and have toxic effects on the immune and reproductive systems.	Data are mainly available for coastal areas and are limited in space and time.	Yogui and Sericano (2009), Weijs et al. (2015), Tong et al. (2019), Neroda et al. (2020), and Pouch et al., 2021
VOCs	Volatile and toxic; recognized as priority pollutants since 1990s due to persistence, bioaccumulation potential, and human health hazards.	They reach the oceans via atmospheric deposition or riverine effluents, where they are mainly present due to discharges from sewage treatment plants. Degradation in the marine environment is slow, taking between 10 and 100 years.	Neurotoxic and carcinogenic effects.	Data are mainly available for coastal areas and are limited in space and time.	Dewulf and Van Langenhove (1997) and Huybrechts et al. (2005)

but the proposed dimension was limited to specific routes, to a small number of analytes and chemical/physical parameters, focusing on regions that are mostly close to the coast. This approach would have been difficult to apply on a global scale, as it would have required numerous agreements with different shipowners, which would have been a major organizational and economic challenge. In Italy, the Italian Navy carries out many missions both in the Mediterranean Sea, which is of direct national interest, and around the world in response to various international and geopolitical, but also commercial, commitments. The Italian Naval Force is also a public body, and this has made cooperation easier, allowing to take researchers and technicians on board the vessels, along with scientific equipment, and guaranteeing the possibility of collecting an adequate number of samples at the various sampling sites to cover the different areas of study.

The partnership model is based on the sharing of research objectives and logistical and financial resources, moving away from the logic of apex funding. This choice was dictated by the need to tackle a particularly complex problem such as OHH on a global scale. This is certainly an ambitious objective, but above all a very demanding one in economic terms. The level of resources required to cover this type of research on a global scale, on a very large number of anthropogenic pollutants, over a period of at least three years, would have made the project unfeasible in the short term.

Between May 2022 and November 2024, around 3,500 marine water samples were collected at 101 sampling sites during seven sampling expeditions on board of six different Italian Navy vessels: Amerigo Vespucci, Caio Duilio, Alliance, Paolo Thaon di Revel, Francesco Morosini and Raimondo Montecuccoli. These expeditions covered a wide range of geographical areas, including the Mediterranean Sea, the Persian Gulf, the Arabian Sea, the Red Sea, the Atlantic Ocean, Pacific Ocean, and the Arctic Ocean (Figure 2).

During this period, collaboration with multiple institutions were established such as IADO in Argentina, the Pontificia Universidad Católica de Valparaíso in Chile, and the Hydrographic Institute of the Brazilian Navy. Concurently, numerous conferences were organized during the stopovers in the ports of the many cities visited (Ferrara and Muratore, 2023; Mattei and De Angelis, 2023; Muratore, 2023a, 2023b; Ferrara, 2024a, 2024b; Mattei and Notargiacomo, 2024), in collaboration with the local embassies. During these conferences, the project, the research model and the methodological approach were presented. The objective of these efforts was to encourage other scientific and governmental institutions to participate in the process of expanding the production of data on the contamination of the high seas (Supplementary Figures S1–S4).

The results presented in the following sections refer to a subset of 43 sites collected in 2022–2023.

3.2 Task 1—bacterial communities and antimicrobial resistance

The composition of the bacterial communities was determined in all samples: 31 different phyla and more than 400 genera were detected. Proteobacteria was the most abundant phylum followed by *Cyanobacteria, Bacteroidota, Actinobacteriota, Firmicutes, Verrucomicrobiota, Marinimicrobia and Campylobacterota*.

The taxonomic richness within microbial communities, as measured by α-diversity indices (Chao 1, Simpson, Shannon), revealed the greatest diversity of taxa in samples collected in the Mediterranean.

Principal Coordinate Analysis (PCoA metric) of β-diversity distances, revealed a significant separation (unweighted UniFrac PERMANOVA: $p < 0.01$) between microbial communities. As expected, bacterial communities tended to cluster according to geographical location (Figure 4). Bacteria of the genus *Vibrio* were found in 40% of the samples analyzed, and were not detected in low-temperature waters (Figure 5), as previously reported (Semenza et al., 2017). We are currently performing molecular characterization of the different Vibrio species found.

The study analyzed the distribution and co-occurrence patterns of antibiotic resistance genes (ARGs), specifically beta-lactamases

TABLE 2 Bacteria, viruses, and antimicrobial resistance main factsheet.

Target microorganism/ components	Source and spread	Health effects	Knowledge gaps	References
Bacteria	Ubiquitous inhabitants of marine ecosystems, found in both benthic and planktonic forms. They play a crucial role in regulating biogeochemical cycles, trophic chains and marine productivity through photosynthesis. Chemical pollution and environmental stressors, including climate change, can affect the distribution, diversity, structure and activity of microbial communities.	Some bacterial species naturally occurring in marine ecosystems can affect humans and marine organisms (e.g., pathogenic Vibrio, Aeromonas). Increasing antimicrobial resistance as a result of human activities on land and at sea.	Studies are generally limited to specific geographical areas. Metagenomic Next Generation Sequencing (mNGS) can provide information on the dynamic nature of microbial communities and their impact on the environment, animals and human health.	Nogales et al. (2011), Semenza et al. (2017), Raiyani and Singh (2020), Reintjes et al. (2020), and Pinhassi et al. (2022)
Viruses	The oceans serve as a dynamic reservoir for viruses from a variety of sources, including marine microorganisms, plankton and other aquatic organisms. Many human activities introduce viruses into the marine environment, where their spread is influenced by currents, water circulation and interactions with marine life.	Anthropogenic Viruses in the oceans can affect marine biodiversity, ecological dynamics, fisheries, and carbon cycling, while also contributing to the risk of transmission to marine mammals. They have potential health implications for humans, including the risk of waterborne disease and transmission through seafood consumption.	Existing research on viral diversity in the oceans provides valuable insights, but tends to be limited in scope, focusing on specific regions, time periods or subsets of viral populations.	Brum et al. (2015), Jian et al. (2021), Dominguez-Huerta et al. (2022), and Marx (2022)
Antimicrobial resistance	Antimicrobial resistance (AMR) in the oceans is caused by human activities, such as wastewater discharge, agricultural runoff and shipping, which release antibiotics. The spread is facilitated by ocean currents.	The presence of antibiotic resistant bacteria or antibiotic resistance genes in the oceans can have several health implications, including the global spread of resistance, potential human exposure through the marine environment and effects on the marine food chain.	The widespread presence of resistant bacteria and resistance genes in the oceans underlines the urgent need to understand the factors contributing to the spread of AMR in marine environments. To fully address the complexity of this issue, more studies are needed in larger geographical regions and over longer time scales.	Hatosy and Martiny (2015), Jang et al. (2022), and Xu et al. (2023)

($bla_{\text{OXA-48}}$, $bla_{\text{CTXM-15}}$, bla_{TEM}), tetracycline (*tet*A), sulphonamides (*sul*1) and class 1 integrons. The results showed *sul*1 to be widespread, even ubiquitous. Furthermore, the Mediterranean exhibited a higher proportion of samples showing multiple ARGs, indicating an increased anthropogenic impact. Notably, a single sample from the Svalbard Islands in the Arctic was contaminated with all investigated ARGs (Bonanno Ferraro et al., 2024). These findings demonstrate regional variations and suggest that human activities can exert negative impacts even in remote environments like the Arctic. Figure 5 displays the positive results for *Vibrio*, ARGs, and Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2).

3.3 Task 2—viruses

Results on the detection of SARS-CoV-2 in samples collected in the framework of the SeA Care project have been published recently (La Rosa et al., 2024). The presence of genomic traces of the virus in remote ocean waters (Figure 5, in black) may be attributable to untreated sewage discharges, other sources of land-based contamination or anthropic marine activities including shipping, recreational boating and fishing. Winds, waves and ocean currents greatly facilitate the spread of the virus, allowing it to reach distant areas far beyond its original source.

TABLE 3 Pioneering approaches—targeted and untargeted investigation of pollutants in oceans.

Type of approach	Methodology	Improvement/novelty	Knowledge gaps	References
Fingerprint profiles	Near Infrared spectroscopy (NIR) allows the direct determination of compounds in untreated matrices and the identification of the fingerprint profiles in a matter of seconds. It provides fast and reliable results comparable to traditional confirmatory techniques.	The miniaturized and portable device (MicroNIR) can provide a complete characterization of a sample by identifying chemical bonds. The most remarkable improvements relate to: - On-site analysis - Speed and accuracy of the response. - Coupling with chemometrics for standardization of profiles and for the development of predictive models. - Automation and connection to an IoT (Internet of Things) system.	A number of critical reviews on the MicroNIR/ Chemometrics approach focus on rapid quality control of products, raw materials, and ingredients in the food, pharmaceutical and environmental matrices. Studies on seawater contaminants still lacking.	Martin Bland and Altman (1986), Huang et al. (2010), Moros et al. (2010), Kumar et al. (2014), Risoluti et al. (2019, 2020), Bwambok et al. (2020), and Nagy et al. (2022)
Untargeted analytes	Innovative way to detect unexpected molecules, maximizing the number of analytes detected to provide detailed sample profiles.	Characterization, identification and quantification of unknown contaminants based on modern advanced technology with high sensitivity to clearly elucidate their structure, such as High-Resolution Accurate Mass Spectrometry (HRMS).	Untargeted analysis can reduce the knowledge gap on the distribution, concentration and impact of unknown contaminants in the high seas.	Bonnefille et al. (2023), Selwe et al. (2023), and Troxell et al. (2024)

FIGURE 3
Sampling activities, above, checking the bottles for samples; below, monitoring the multi-parameter probe readings during its descent along the water column on the PC.

Preliminary metagenomic data show that the most abundant viral species are phage viruses that infect cyanobacteria of the genera *Prochlorococcus* and *Synechococcus*, which are the primary oxygen producers in the ocean. The *Myoviridae* family is dominant in all four regions, followed by *Siphoviridae*, *Podoviridae*, *Autographiviridae*, *Phycodnaviridae* and *Mimiviridae*.

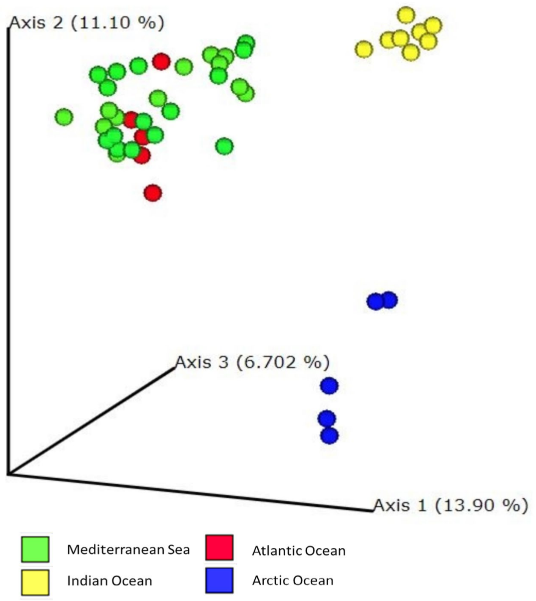


FIGURE 4
Principal coordinate analysis (PCoA metric) of β-diversity distances between microbial communities by sampling area. Samples collected in the same region tended to cluster together in the plot.

These initial virological analyses revealed considerable methodological challenges, primarily due to limitations in filtering large volumes of water, resulting in low recovery rates. This was confirmed in recovery experiments in which we added a process control virus (Mengovirus) to the sample. Significant sample inhibition was also observed. In preparation for subsequent sampling rounds, a comprehensive methodological study is planned with the aim of improving recovery rates and reduce the levels of inhibition.

3.4 Task 3—PFAS

A highly sensitive and specific method was developed to unambiguously determine very low levels of PFAS in marine waters. The Limits of Detection (LODs) for each analyte were evaluated from the lowest calibration level, i.e., 0.02 ng/L, taking into account the transition with the worst S/N (qualifier/diagnostic). Good linearity was achieved over the selected range of interest, with R^2 values greater than 0.998 for all of the selected analytes. The method proved to be robust, with LODs ranging from 0.0003 to 0.0050 ng/L for all target compounds. Due to the high sensitivity of the method and the ubiquity of these substances in the environment, a Limit of Quantification (LOQ) was set, based on studies using synthetic sea water (blank samples).

This method was applied in the analysis of 101 samples collected in the first phase of the project. All but one of the samples analyzed (100/101) tested positive for the presence of PFAS.

The highest levels of PFAS were found in open waters off the Italian coast, with concentrations ranging from 0.007 ng/L to 8.22 ng/L, while the lowest levels were found off the coast of North Africa with concentrations ranging from 0.001 ng/L to 0.80 ng/L.

Interestingly, smaller PFAS molecules, such as PFBS, FBSA, 4:2 FTS or PFHxA, having a higher mobility, were detected mainly in the Atlantic Ocean, with concentrations ranging from 0.006 ng/L to 0.327 ng/L, and in the North Pole, with concentrations ranging from 0.026 ng/L to 4.70 ng/L. Data are summarized in Supplementary Tables S7 and Figure 6.

3.5 Task 4—microplastics

Preliminary results on the presence of microplastics (MPs) in samples from the Mediterranean Sea, the Atlantic Ocean, the Red Sea and the Persian Gulf (Supplementary Table S9; Figure 7) show different distributions of these contaminants in terms of number, polymer type, size, shape and color, in agreement with previously published studies (Nunes et al., 2023). The evidence provided by these samples allows to study how different variables, such as currents, anthropogenic pressures, and maritime traffic, affect the concentrations of plastics in the oceans.

As shown in Figures 6, a higher MPs concentration was observed closest to coastal areas with high anthropogenic impact, such as the Mediterranean Sea, while the number of MPs decreases in open marine areas with low anthropogenic impact, such as the Atlantic Ocean, the Persian Gulf and the Red Sea (where little plastic litter reaches the sea thanks to the paucity of rivers).

Despite the small number of the sample analyzed some evidence suggests different variables, such as currents, anthropogenic pressures, and maritime traffic, may affect the concentrations of plastics in the oceans.

The plastic material collected, ranging from 21 µm to 5 cm in size, was isolated and analyzed. It predominantly consisted of widely used commercial polymers such as polyethylene (PE), polypropylene (PP) and polystyrene (PS), mainly originating from the packaging industry. At the morphological level, MPs appear mainly in the form of fibers, fragments or spheroids of different colors (in most cases white or transparent, followed by black, blue, pink, orange, green and yellow).

All of the trends described above are in agreement with those reported in the literature (Nunes et al., 2023).

3.6 Task 5—pioneering approaches

Pioneering approaches have been incorporated into the SeA Care project with the aim of contributing both to the methodologies available for the study of the distribution of contaminants in seas and oceans worldwide and to the body of knowledge in this field.

3.6.1 MicroNIR/chemometrics platform

A novel miniaturized, portable instrument (MicroNIR) for the targeted analysis of contaminants was used to acquire profiles of the distribution of chemical pollutants in sea water samples in real time.

The chemometric analysis of spectroscopic data provided by the portable MicroNIR instrument yielded optimized models that allowed us to accurately identify the presence of target anthropogenic pollutants (specificity > 97%, measurement errors < 0.2%).

This method was applied also to the analysis of microbial communities in filters, and were able to obtain specific profiles for the different sampling sites, confirming the potential of this new approach to enable the creation of anthropogenic pollution indices and the

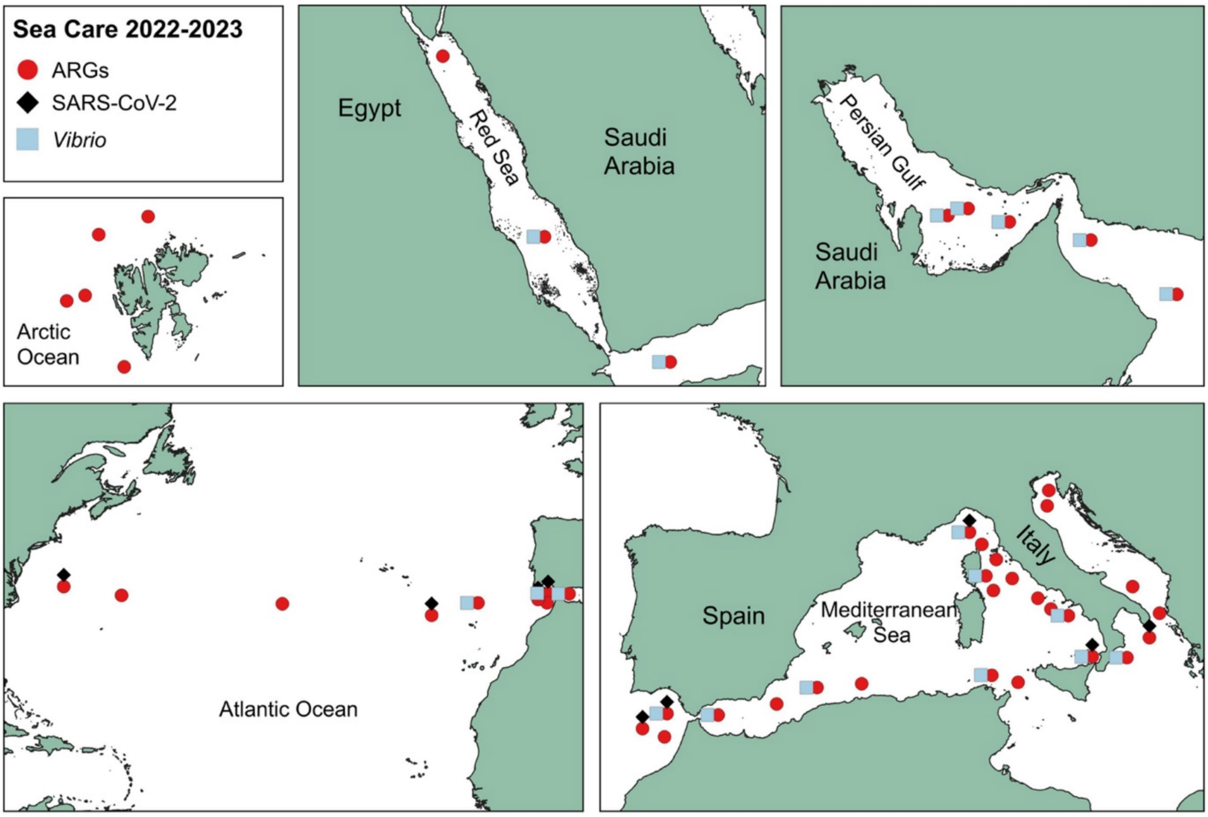


FIGURE 5
Selected microbiological and virological parameters by sampling area.

correct estimation of the possible correlation of these indices with various aspects of public health and Planetary Health.

The innovative potential of the chemometric analysis of MicroNIR signals, an approach proposed for the first time on the international scene, lies in its ability to provide a simultaneous evaluation of the presence of multiple analytes in sea water samples, resulting in different profiles of marine contamination.

Future sampling activities, planned for the coming expeditions, will provide the basis for the creation of a database of fingerprint profiles corresponding to the different geographical locations sampled, and which can be used as a tool for the continuous monitoring of the state of health of the seas and for the assessment of potential risks to human health.

The preliminary data reported in Figure 8 demonstrate that the innovative platform is capable of identifying differences between water samples from different sites, as clusters of samples located in the same region of the PCA scores plot.

3.6.2 Untargeted analysis

Untargeted analysis was performed with the aim of identifying potentially harmful molecules other than those tested in conventional monitoring. The main goal here is to evaluate the presence of known and unknown contaminants belonging to different classes, such as pesticides, pharmaceuticals, personal care products and chemicals related to industrial activities. In this light, novel advanced methodologies can contribute to the identification of molecules or classes of molecules of high concern and/or point to their presence in different areas of the planet for possible future monitoring. Although the results of untargeted analyses are semi-quantitative, they can contribute to the mapping of emerging contaminants and to the understanding of possible links to anthropic activities.

The main chemicals identified were pesticides (i.e., dinoterb, N,N-Diethyl-m-toluamide, fipronil), chemicals related to plastic production (dibutyl phthalate, dioctyl phthalate, bisphenol S, 2-mercaptobenzothiazole), surfactants (alkylbenzene sulfonates, diethanolamines and betaines of different chain lengths) and other anthropic markers (benzalkonium chloride, benzisothiazolone, prednisolone, 2,6-di-tert-butyl-4-nitrophenol (Alexander et al., 2001), arachidoyl ethanolamide).

Preliminary results showed that surfactants, phthalates, dinoterb, N,N-Diethyl-m-toluamide, 2,6-di-tert-butyl-4-nitrophenol and benzalkonium chloride were generally present and correctly identifiable in all the collected samples, with similar presumed abundance.

Other anthropic markers, i.e., prednisolone, 2-mercaptobenzothiazole and arachidoyl etanolamide were identified in several samples collected from the Mediterranean Sea, whereas fipronil, bisphenol S and benzisothiazolone were present in samples collected from the Atlantic and the Artic Oceans. No significant differences were observed between superficial and deep-sea water in the same area.

A summary of the data is reported in Supplementary Table S9.

3.7 Ethics and dissemination

Planetary Health hinges on a multitude of dynamic interrelationships and interdependencies between terrestrial and

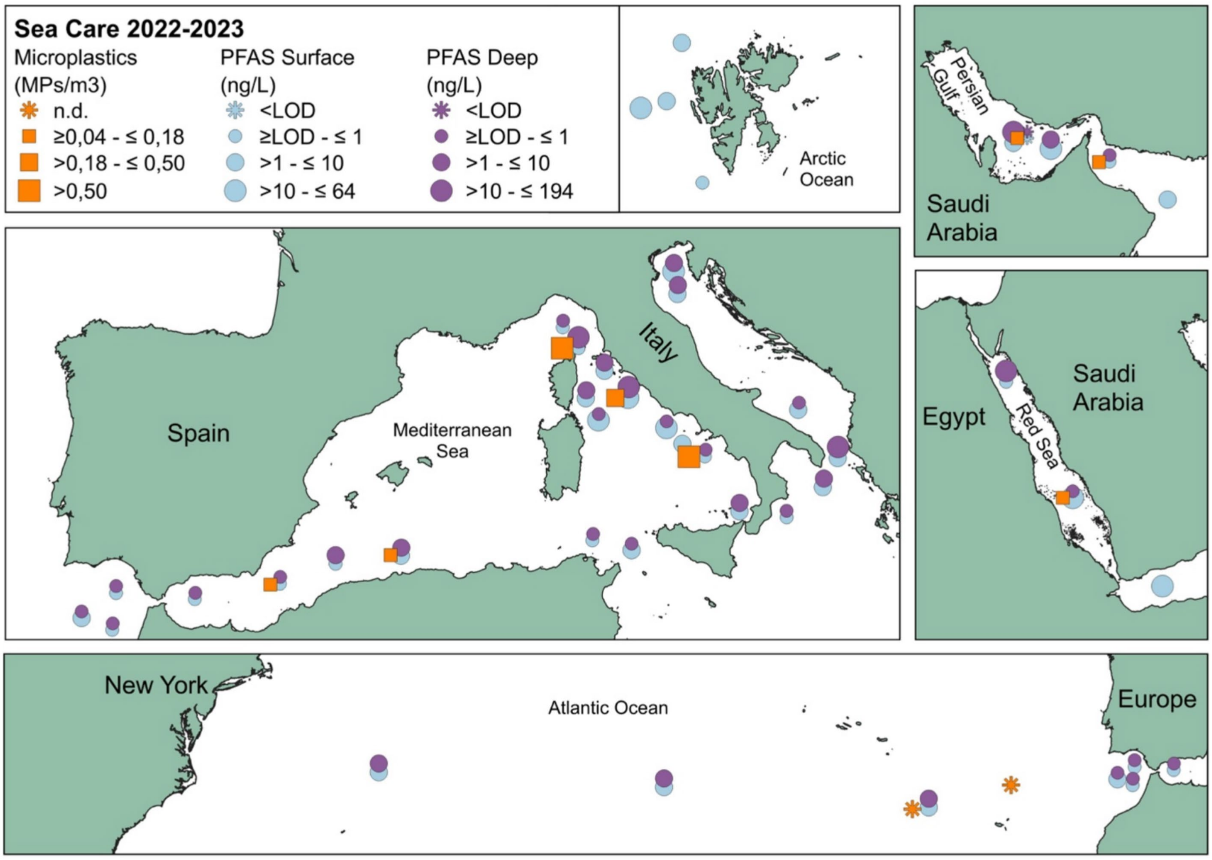


FIGURE 6
Presence of PFAS and microplastics by sampling site.

marine environmental health, human health and a broader global context. The marine environment is one of the most challenging ecosystems to study, owing to the scale and intrinsic complexity of the processes involved, and to the dramatic impact that the triple planetary crisis (i.e., pollution, biodiversity loss and climate change) has on the high seas.

The difficulties and costs of studying marine areas beyond national jurisdiction on a regular basis may have contributed to the fact that the monitoring of the sea largely remains limited to coastal regions. By contrast, for land-based sources of pollution (e.g., municipal, industrial and agricultural wastes, wastewater, surface and groundwater) environmental health regulations establish effective monitoring and control systems.

Nevertheless, a number of encouraging trends are underway. Actions are being taken to prevent land-based pollution, including the adoption of the "from source-to-sea" approach. Efforts to contrast biodiversity loss in the high seas are being made, as evidenced by the recent historical milestone known as the "High Seas Treaty" (United Nations, 2023), a legally binding agreement signed by 85 countries to protect biodiversity in international waters (United Nations, 2023). Increasingly, new publicly available repositories are collecting data on the health of marine ecosystems, although limitations remain in terms of harmonization, quality assurance, global coordination and commitment (Brett et al., 2020).

The study of marine ecosystems and of anthropogenic impacts on the high seas, however, has thus far generally been mainly conceived of as the concern of marine scientists. Indeed, despite growing recognition that environmental health impacts human health, the medical and public health communities still tend to devote inadequate attention to the health of seas and oceans. In fact, over 200 medical journals have recently warned that human health is directly harmed by both the climate crisis and the nature crisis (Abbasi et al., 2023), calling for the health sector to play a greater role in research within the environmental health sphere.

We have decided to accept the challenge because, while we consider it a health priority to create an international legislation framework for the routine monitoring of the high seas, with legally binding national commitments, we also believe that some urgent measures and actions to promote human and Planetary Health could already be designed and implemented. This can be achieved by creating long-standing partnerships, using existing national and institutional resources—financial, material and human resources—and integrating research and monitoring tasks into the routine activities of the institutions involved. The resulting harmonized, high-quality data will then be shared in publicly available repositories to be used, among other things, in order to produce valuable indices to inform public health and environmental policy.

After completing the first phase of the SeA Care project, we can conclude that its underlying collaborative model—built on long-standing institutional partnership, where all stakeholders actively participate in the research and objectives, and share their logistical and financial resources—has proven effective (United Nations, 2025a).

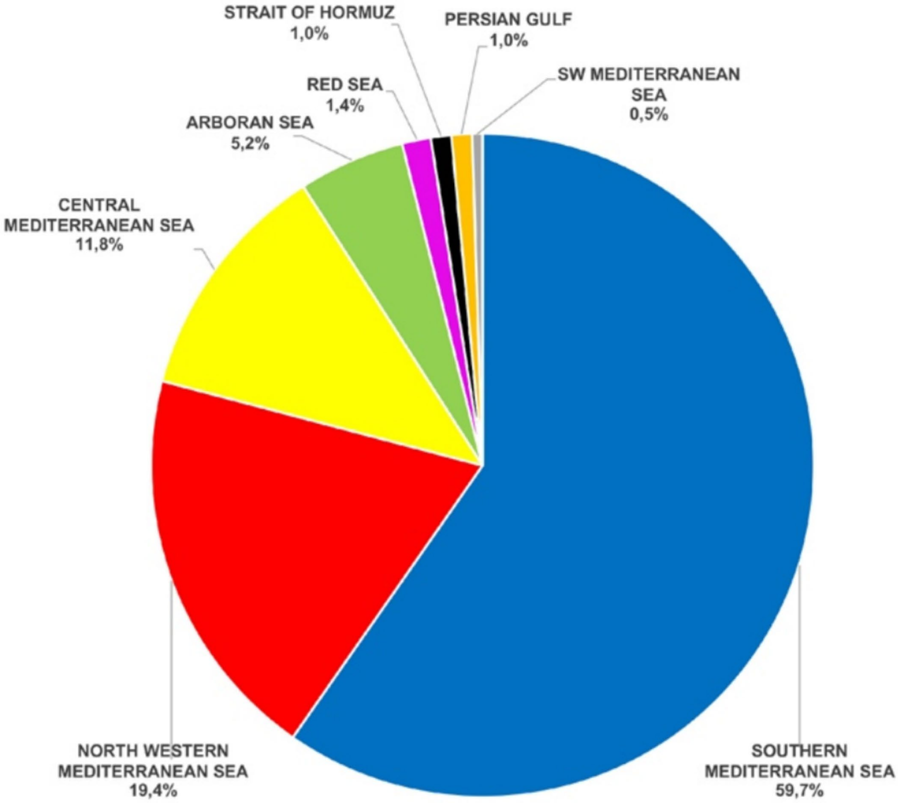


FIGURE 7
Percentage distribution of microplastics by sampling area.

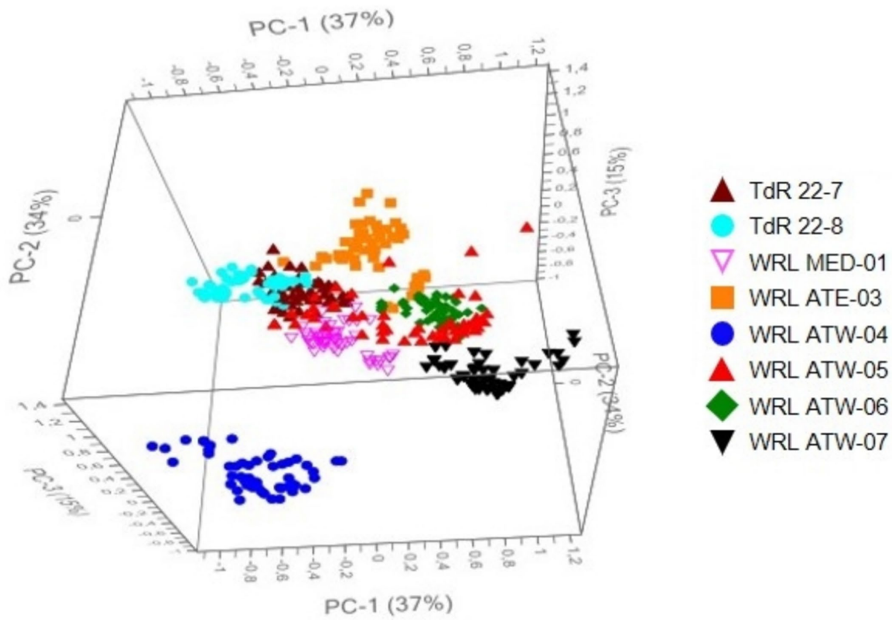


FIGURE 8
PCA scores plot of sea water samples collected in the first phase of the SeA Care project. Samples collected in the same region tended to cluster together in the plot.

Through meticulous planning and dialogue, along with robust and advanced sampling and analytical procedures, we were able to acquire high-quality data from seas and oceans worldwide. Additionally, incorporating artificial intelligence platforms, with algorithms capable of comprehensive and online monitoring of marine pollutants, will provide novel predictive tools offering new insights into the ocean health and integrated indices for the ocean sustainability.

This approach, if consistently applied over the long term, is likely to deliver the necessary information for a comprehensive analysis of the spread and distribution of anthropogenic contamination and its direct and indirect effects on human and Planetary Health. Some of our findings, such as evidence of the presence of contaminants in remote oceanic regions, suggest that existing monitoring tools like the EU Marine Strategy may fall short of providing sufficiently detailed and extensive quality data for this purpose. We wish to propose this Model for Global Partnership to fellow researchers worldwide in the hope that it be replicated in other national and international contexts for maximum geographic and scientific coverage.

Ethics statement

This study did not involve human participants or animals and therefore did not require ethical approval by an institutional review board or ethics committee. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

Author contributions

AP: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. LL: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AM: Data curation, Formal analysis, Investigation, Visualization, Writing – review &editing. RR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. RB: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. GLR: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. LN: Data curation, Formal analysis, Investigation, Writing – review & editing. GM: Data curation, Formal analysis, Investigation, Writing – review & editing. DM: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. FNDG: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. EV: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. SB: Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing. GB: Funding acquisition, Resources, Writing – review &editing. FF: Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review &editing. SCT: Data curation, Investigation, Visualization, Writing – review & editing.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2025.1670665/full#supplementary-material

References

Abbasi, K., Ali, P., Barbour, V., Benfield, T., Bibbins-Domingo, K., Hancocks, S., et al. (2023). Time to treat the climate and nature crisis as one indivisible global health emergency. *BMJ*:2355. doi: 10.1136/bmj.p2355

Acir, I., and Guenther, K. (2018). Endocrine-disrupting metabolites of alkylphenol ethoxylates—a critical review of analytical methods, environmental occurrences, toxicity, and regulation. *Sci. Total Environ.* 635, 1530–1546. doi: 10.1016/j.scitotenv.2018.04.079

Alexander, W. K., Briggs, G. B., Still, K. R., Jederberg, W. W., MacMahon, K., Baker, W. H., et al. (2001). Toxicity of 2,6-Di-tert-butyl-4-Nitrophenol (DBNP). *Appl. Occup. Environ. Hyg.* 16, 487–495. doi: 10.1080/10473220117206

Aparicio-González, A., Duarte, C. M., and Tovar-Sánchez, A. (2012). Trace metals in deep ocean waters: A review. *J. Mar. Syst.* 100-101, 26–33. doi: 10.1016/j.jmarsys.2012.03.008

BlueAdapt (2024). Available online at: https://blueadapt.eu/ (Accessed December 16, 2024).

Bonanno Ferraro, G., Brandtner, D., Franco, A., Iaconelli, M., Mancini, P., Veneri, C., et al. (2024). Global quantification and distribution of antibiotic resistance genes in oceans and seas: anthropogenic impacts and regional variability. *Sci. Total Environ.* 955:176765. doi: 10.1016/j.scitotenv.2024.176765

Bonnefille, B., Karlsson, O., Rian, M. B., Raqib, R., Parvez, F., Papazian, S., et al. (2023). Nontarget analysis of polluted surface waters in Bangladesh using Open Science workflows. *Environ. Sci. Technol.* 57, 6808–6824. doi: 10.1021/acs.est.2c08200

Brett, A., Leape, J., and Abbott, M. (2020). Ocean data need a sea change to help navigate the warming world. *Nature* 582, 181–183. doi: 10.1038/d41586-020-01668-z

Briand, M. J., Bustamante, P., Bonnet, X., Churlaud, C., and Letourneur, Y. (2018). Tracking trace elements into complex coral reef trophic networks. *Sci. Total Environ.* 612, 1091–1104. doi: 10.1016/j.scitotenv.2017.08.257

Brum, J. R., Cesar Ignacio-Espinoza, J., Roux, S., Doulcier, G., Acinas, S. G., Alberti, A., et al. (2015). Patterns and ecological drivers of ocean viral communities. Science (1979:348. Available online at: https://www.science.org

Bruno, C., Blasi, M. F., Mattei, D., Martellone, L., Brancaleone, E., Savoca, S., et al. (2022). Polymer composition analysis of plastic debris ingested by loggerhead turtles (Caretta caretta) in southern Tyrrhenian Sea through ATR-FTIR spectroscopy. *Mar. Environ. Res.* 179:105676. doi: 10.1016/j.marenvres.2022.105676

Bwambok, D. K., Siraj, N., Macchi, S., Larm, N. E., Baker, G. A., Pérez, R. L., et al. (2020). Qcm sensor arrays, electroanalytical techniques and nir spectroscopy coupled to multivariate analysis for quality assessment of food products, raw materials, ingredients and foodborne pathogen detection: challenges and breakthroughs†. *Sensors (Switzerland)* 20, 1–42. doi: 10.3390/s20236982

Copernicus Marine Service (2025). Available online at: https://marine.copernicus.eu/about (Accessed August 28, 2024).

Demaio, A. R., and Rockström, J. (2015). Human and planetary health: towards a common language. *Lancet* 386, e36–e37. doi: 10.1016/S0140-6736(15)61044-3

Dewulf, J., and Van Langenhove, H. (1997). Chlorinated c1 -and c2-hydrocarbons and monocyclic aromatic hydrocarbons in marine waters: an overview on fate processes, sampling, analysis and measurements. *Water Res.* 31, 1825–1838. doi: 10.1016/S0043-1354(97)00017-1

Directive (2008). 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), Available online at: http://data.europa.eu/eli/dir/2008/56/oj

Dominguez-Huerta, G., Zayed, A. A., Wainaina, J. M., Guo, J., Tian, F., Pratama, A. A., et al. (2022). Diversity and ecological footprint of Global Ocean RNA viruses. Science (1979):1202–1208. Available online at: https://www.science.org

Earth nullschool. Earth: A global Map of Wind, Weather, and Ocean Conditions. (n.d.). Available online at: https://earth.nullschool.net/ (Accessed January 10, 2025).

European Marine Observation and Data Network (EMODnet) (2025). Available online at: https://emodnet.ec.europa.eu/en/about_emodnet (Accessed January 11, 2024).

Ferrara, F. (2024a). Enhancing public health through ocean research. in Vespucci meets the marine ecosystem, (Darwin: Embassy of Italy en Canberra). Available online at: www.imos.org.au

Ferrara, F. (2024b). Enhancing public health through ocean research, in underwater: how to enhance the awareness and its sustainable use, (Tokyo). Available online at: https://www.youtube.com/watch?v=u01Zu7HTrnw

Ferrara, F., and Muratore, A. (2023). Sea care project: the protection of human health through the care of the sea and the activity of the sea care project, in sea and health: scientific collaboration and institutional partnership to undestand and monitor the link between the global ocean and huaman health, Las Palmas De Gran Canaria: Embassy of Italy in Madrid, Consolato di Arona. Available online at: https://consarona.esteri.it/news/dal_consolato/2023/08/studio-sugli-effetti-del-cambiamento-climatico-e-delle-attivita-umane-a-bordo-dellamerigo-vespucci-progetto-sea-care/

Fleming, L. E., Creencia, L. B. A., Gerwick, W. H., Goh, H. C., Gribble, M. O., Maycock, B., et al. (2023). Oceans and human health: Opportunities and impact. *Second* Edn. London: Academic Press.

Fleming, L. E., Depledge, M., Bouley, T., Britton, E., Dupont, S., Eatock, C., et al. (2021). The ocean decade- opportunities for oceans and human health programs to contribute to public health. *Am. J. Public Health* 111, 808–811. doi: 10.2105/AJPH.2021.306229

GEOTRACES An International Study of the Marine Biogeochemical Cycles of Trace Elements and Isotopes (2025). Available online at: https://www.geotraces.org/ (Accessed January 11, 2024).

Global Wastewater Model (2025). Available online at: https://www.globalwastewatermodel.com/webmap.html (Accessed January 10, 2025).

Goal 17|Department of Economic and Social Affairs (2025). Available online at: https://sdgs.un.org/goals/goal17 (Accessed October 2, 2025).

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., and Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. *Water Policy* 19, 673–691. doi: 10.2166/wp.2017.126

Hatosy, S. M., and Martiny, A. C. (2015). The ocean as a global reservoir of antibiotic resistance genes. *Appl. Environ. Microbiol.* 81, 7593–7599. doi: 10.1128/AEM.00736-15

Heinze, C., Blenckner, T., Martins, H., Rusiecka, D., Döscher, R., Gehlen, M., et al. (2021). The quiet crossing of ocean tipping points, *Proc. Natl. Acad. Sci. U.S.A.* 118:e2008478118. doi: 10.1073/pnas.2008478118

Horton, R., and Lo, S. (2015). Planetary health: a new science for exceptional action. *Lancet* 386, 1921–1922. doi: 10.1016/S0140-6736(15)61038-8

Horizon Europe (2020). Research and innovation - European Commission. Available online at: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

Huang, J., Romero-Torres, S., and Moshgbar, M. (2010). Practical considerations in data pre-treatment for NIR and Raman spectroscopy. America Pharmaceutical Review. Available online at: https://www.americanpharmaceuticalreview.com/Featured-Articles/116330-Practical-Considerations-in-Data-Pre-treatment-for-NIR-and-Raman-Spectroscopy/ (Accessed January 16, 2024).

Huybrechts, T., Dewulf, J., and Van Langenhove, H. (2005). Priority volatile organic compounds in surface waters of the southern North Sea. *Environ. Pollut.* 133, 255–264. doi: 10.1016/j.envpol.2004.05.039

Jang, J., Park, J., Hwang, C. Y., Choi, J., Shin, J., Kim, Y. M., et al. (2022). Abundance and diversity of antibiotic resistance genes and bacterial communities in the western Pacific and southern oceans. *Sci. Total Environ.* 822:153360. doi: 10.1016/j.scitotenv.2022.153360

Jenkins, A. P., Lancaster, A. M. S. N., Capon, A., Soapi, K., Fleming, L. E., and Jupiter, S. D. (2023). Human health depends on thriving oceans. *Lancet* 402, 9–11. doi: 10.1016/S0140-6736(23)01162-5

Jian, H., Yi, Y., Wang, J., Hao, Y., Zhang, M., Wang, S., et al. (2021). Diversity and distribution of viruses inhabiting the deepest ocean on earth. *ISME J.* 15, 3094–3110. doi: 10.1038/s41396-021-00994-y

Kannan, N., Yamashita, N., Petrick, G., and Duinker, J. (2000). Polychlorinated biphenyls and nonylphenols in the sea of Japan. *Environ. Sci. Technol.* 32, 1747–1753. doi: 10.1021/es970713q

Kato, K., Wong, L. Y., Jia, L. T., Kuklenyik, Z., and Calafat, A. M. (2011). Trends in exposure to polyfluoroalkyl chemicals in the U.S. population: 1999-2008. *Environ. Sci. Technol.* 45, 8037–8045. doi: 10.1021/es1043613

Khalil, N., Chen, A., Lee, M., Czerwinski, S. A., Ebert, J. R., De Witt, J. C., et al. (2016). Association of perfluoroalkyl substances, bone mineral density, and osteoporosis in the U.S. population in NHANES 2009–2010. *Environ. Health Perspect.* 124, 81–87. doi: 10.1289/ehp.1307909

Kumar, N., Bansal, A., Sarma, G. S., and Rawal, R. K. (2014). Chemometrics tools used in analytical chemistry: an overview. *Talanta* 123, 186–199. doi: 10.1016/j.talanta.2014.02.003

La Rosa, G., Mancini, P., Iaconelli, M., Veneri, C., Bonanno Ferraro, G., Del Giudice, C., et al. (2024). Tracing the footprints of SARS-CoV-2 in oceanic waters. *Sci. Total Environ.* 906:167343. doi: 10.1016/j.scitotenv.2023.167343

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., et al. (2018). The lancet commission on pollution and health. *Lancet* 391, 462–512. doi: 10.1016/S0140-6736(17)32345-0

Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., et al. (2020). Human health and ocean pollution. *Ann. Glob. Health* 86, 1–64. doi: 10.5334/aogh.2831

Liu, L., Tang, J., Zhong, G., Zhen, X., Pan, X., and Tian, C. (2018). Spatial distribution and seasonal variation of four current-use pesticides (CUPs) in air and surface water of the Bohai Sea, China. *Sci. Total Environ.* 621, 516–523. doi: 10.1016/j.scitotenv.2017.11.282

Lu, G. Y., and Wang, W. X. (2019). Water analysis | seawater: inorganic compounds for environmental analysis. *Encycl. Anal. Sci.* 10, 353–358. doi: 10.1016/B978-0-12-409547-2.14498-1

Macdonald, A. M., Hiron, L., McRaven, L., Stolp, L., Strom, K., Hudak, R., et al. (2024). A framework for multidisciplinary science observations from commercial ships. *ICES J. Mar. Sci.* 82. doi: 10.1093/icesjms/fsae011

Maggi, F., Tang, F. H. M., and Tubiello, F. N. (2023). Agricultural pesticide land budget and river discharge to oceans. *Nature* 620, 1013–1017. doi: 10.1038/s41586-023-06296-x

Martin Bland, J., and Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 327, 307–310. doi: 10.1016/S0140-6736(86)90837-8

Marx, V. (2022). Why the ocean virome matters. *Nat. Methods* 19, 924–927. doi: 10.1038/s41592-022-01567-3

Mathews, R. E., Tengberg, A., Sjödin, J., and Liss Lymer, B. (2019). Implementing the source-to-sea approach: a guide for practitioners. SIWI, Stockholm.

Mattei, G., and De Angelis, S. (2023). Sea Care: saùde clima mejo ambiente navisao do Planetary Health, in Encontro Científico "Itália-Brasil: Nos Passos do Amerigo Vespucci, do Mediterrâneo ao Atlântico," Fortaleza: Embassy of Italy in Brasilia, Institute of Marine Science (LABOMAR) of the Federal University of Ceara. Available online at: https://ambbrasilia.esteri.it/pt/news/dall_ambasciata/2023/09/fortaleza-se-prepara-para-o-encontro-cientifico-italia-brasil-nos-passos-do-amerigo-vespucci-do-mediterraneo-ao-atlantico/

Mattei, G., and Notargiacomo, L. (2024). The sea care project: health environment and climate in a planetary health vision, in Desde el Mediterraneo al Pacifico: la tutela de la biodiversidad marina, (Valparaiso: Pontificia Universidad Católica de Valparaíso, Embassy of Italy in Santiago del Chile, Istituto Italiano di Cultura Santiago, Asociacion Cultural Italiana). Available online at: https://www.pucv.cl/pucv/noticias/vida-universitaria/pucv-y-embajada-de-italia-realizan-seminario-sobre-biodiversidad-marina

Meijer, L. J. J., Van Emmerik, T., Van Der Ent, R., Schmidt, C., and Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advance 7. Available online at: https://www.science.org

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., et al. (2022). Impact of heavy metals on the environment and human health: novel therapeutic insights to counter the toxicity. *J. King Saud Univ.* 34. doi: 10.1016/j.jksus.2022.101865

Moros, J., Garrigues, S., and de la Guardia, M. (2010). Vibrational spectroscopy provides a green tool for multi-component analysis. *TrAC Trends Anal. Chem.* 29, 578–591. doi: 10.1016/j.trac.2009.12.012

Muratore, A. (2023a). Sea and human health connection and action. In atelier de partage Sur la gestion durable de ressources marines, (Dakar: Ambasciata d'Italia Dakar). Available online at: https://ambdakar.esteri.it/it/news/dall_ambasciata/2023/07/nave-vespucci-a-dakar-attivita/

Muratore, A. (2023b). Sea and human health, connection and action., in Visionando al via con un progetto di interculturalità tra l'Italia e la Repubblica Dominicana in occasione dell'arrivo a Santo Domingo della nave Amerigo Vespucci, (Santo Domingo: ONG Visionando). Available online at: https://visionando.org/it/eventi/agosto-2023

Nagy, M. M., Wang, S., and Farag, M. A. (2022). Quality analysis and authentication of nutraceuticals using near IR (NIR) spectroscopy: a comprehensive review of novel trends and applications. *Trends Food Sci. Technol.* 123, 290–309. doi: 10.1016/j.tifs.2022.03.005

Neroda, A. S., Goncharova, A. A., and Mishukov, V. F. (2020). PAHs in the atmospheric aerosols and seawater in the north—West Pacific Ocean and sea of Japan. *Atmos. Environ.* 222:117117. doi: 10.1016/j.atmosenv.2019.117117

Nogales, B., Lanfranconi, M. P., Piña-Villalonga, J. M., and Bosch, R. (2011). Anthropogenic perturbations in marine microbial communities. *FEMS Microbiol. Rev.* 35, 275–298. doi: 10.1111/j.1574-6976.2010.00248.x

Nunes, B. Z., Huang, Y., Ribeiro, V. V., Wu, S., Holbech, H., Moreira, L. B., et al. (2023). Microplastic contamination in seawater across global marine protected areas boundaries. *Environ. Pollut.* 316:120692. doi: 10.1016/j.envpol.2022.120692

Pinhassi, J., Farnelid, H., García, S. M., Teira, E., Galand, P. E., Obernosterer, I., et al. (2022). Functional responses of key marine bacteria to environmental change—toward genetic counselling for coastal waters. *Front. Microbiol.* 13. doi: 10.3389/fmicb.2022.869093

Pouch, A., Zaborska, A., Mazurkiewicz, M., Winogradow, A., and Pazdro, K. (2021). PCBs, HCB and PAHs in the seawater of Arctic fjords—distribution, sources and risk assessment. *Mar. Pollut. Bull.* 164:111980. doi: 10.1016/j.marpolbul.2021.111980

Raiyani, N. M., and Singh, S. P. (2020). Taxonomic and functional profiling of the microbial communities of Arabian Sea: a metagenomics approach. *Genomics* 112, 4361–4369. doi: 10.1016/j.ygeno.2020.07.024

Reintjes, G., Smetacek, V., and Wegener, A. (2020) in Marine microbiology: Ecology & Applications: third edition. ed. C. B. Munn. Third ed.

RHE-MEDiation (2025). Available online at: https://rhemediation.eu/index.html (Accessed October 2, 2025).

Risoluti, R., Gullifa, G., Battistini, A., and Materazzi, S. (2019). "Lab-on-click" detection of illicit drugs in Oral fluids by MicroNIR-Chemometrics. *Anal. Chem.* 91, 6435–6439. doi: 10.1021/acs.analchem.9b00197

Risoluti, R., Gullifa, G., Battistini, A., and Materazzi, S. (2020). Monitoring of cannabinoids in hemp flours by MicroNIR/Chemometrics. *Talanta* 211:120672. doi: 10.1016/j.talanta.2019.120672

River Plastic Pollution Sources. The ocean cleanup (2025). Available online at: https://theoceancleanup.com/sources/ (Accessed January 10, 2025).

Salgueiro-González, N., Campillo, J. A., Viñas, L., Beiras, R., López-Mahía, P., and Muniategui-Lorenzo, S. (2019). Occurrence of selected endocrine disrupting compounds in Iberian coastal areas and assessment of the environmental risk. *Environ. Pollut.* 249, 767–775. doi: 10.1016/j.envpol.2019.03.107

Seas, Oceans and Public Health in Europe (SOPHIE). Seas, Oceans & Public Health in Europe. (2025). Available online at: https://sophie2020.eu/ (Accessed December 16, 2024).

Selwe, K. P., Sallach, J. B., and Dessent, C. E. H. (2023). Nontargeted screening of contaminants of emerging concern in the Glen Valley wastewater treatment plant. Botswana: Environ Toxicol Chem.

Semenza, J. C., Trinanes, J., Lohr, W., Sudre, B., Löfdahl, M., Martinez-Urtaza, J., et al. (2017). Environmental suitability of vibrio infections in a warming climate: an early warning system. *Environ. Health Perspect.* 125:107004. doi: 10.1289/EHP2198

She, J., Christensen, A., Garaventa, F., Lips, U., Murawski, J., Ntoumas, M., et al. (2023). Developing realistic models for assessing marine plastic pollution in semi-enclosed seas. *Oceanography* 36, 54–57. doi: 10.5670/oceanog.2023.s1.17

The Lancet Planetary Health (2019). Pollution and our oceans. *Lancet Planet Health* 3:e154. doi: 10.1016/S2542-5196(19)30062-2

The Lancet Planetary Health (2023). Hope on the high seas. *Lancet Planet Health* 7:e265. doi: 10.1016/S2542-5196(23)00060-8

Tong, Y., Chen, L., Liu, Y., Wang, Y., and Tian, S. (2019). Distribution, sources and ecological risk assessment of PAHs in surface seawater from coastal Bohai Bay, China. *Mar. Pollut. Bull.* 142, 520–524. doi: 10.1016/j.marpolbul.2019.04.004

Troxell, K., Ceccopieri, M., and Gardinali, P. (2024). Unraveling the chemical fingerprint of the Miami River sources: insights from high-resolution mass spectrometry and nontarget analysis. *Chemosphere* 349:140863. doi: 10.1016/j.chemosphere.2023.140863

Tuholske, C., Halpern, B. S., Blasco, G., Villasenor, J. C., Frazier, M., and Caylor, K. (2021). Mapping global inputs and impacts from of human sewage in coastal ecosystems. *PLoS One* 16:e0258898. doi: 10.1371/journal.pone.0258898

UNESCO Ocean Literacy (2025). Available online at: https://oceanliteracy.unesco.org/about (Accessed September 30, 2025).

United Nations (2017). 2017 Mediterranean quality status report.

United Nations (2023). Agreement under the United Nations convention on the law of the sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction United Nations 2023. Available online at: https://docs.un.org/en/a/conf.232/2023/4

United Nations. Sea care: a model of partnership investigating the global ocean to strengthen public health (2025a). Available online at: https://sdgs.un.org/partnerships/sea-care-model-partnership-investigating-global-ocean-strengthen-public-health#description (Accessed January 11, 2024).

United Nations. THE 17 GOALS|Sustainable Development (2025b). Available online at: https://sdgs.un.org/goals (Accessed October 2, 2025).

Visbeck, M. (2018). Ocean science research is key for a sustainable future. *Nat. Commun.* 9:690. doi: 10.1038/s41467-018-03158-3

Weijs, L., Dirtu, A. C., Malarvannan, G., and Covaci, A. (2015). "Bioaccumulation and biotransformation of brominated flame retardants" in Comprehensive analytical chemistry (Elsevier B.V), 433–491.

WHCOHH (2025). Available online at: https://www2.whoi.edu/site/whcohh/ (Accessed December 16, 2024).

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., De Souza Dias, B. F., et al. (2015). Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation-lancet commission on planetary health. *Lancet* 386, 1973–2028. doi: 10.1016/S0140-6736(15)60901-1

Xu, N., Qiu, D., Zhang, Z., Wang, Y., Chen, B., Zhang, Q., et al. (2023). A global atlas of marine antibiotic resistance genes and their expression. *Water Res.* 244:120488. doi: 10.1016/j.watres.2023.120488

Ya, M., Wu, Y., Wu, S., Li, Y., Mu, J., Fang, C., et al. (2019). Impacts of seasonal variation on organochlorine pesticides in the East China Sea and northern South China Sea. *Environ. Sci. Technol.* 53, 13088–13097. doi: 10.1021/acs.est.8b00105

Yamashita, N., Taniyasu, S., Petrick, G., Wei, S., Gamo, T., Lam, P. K. S., et al. (2008). Perfluorinated acids as novel chemical tracers of global circulation of ocean waters. *Chemosphere* 70, 1247–1255. doi: 10.1016/j.chemosphere.2007.07.079

Yogui, G. T., and Sericano, J. L. (2009). Polybrominated diphenyl ether flame retardants in the U.S. marine environment: a review. *Environ. Int.* 35, 655–666. doi: 10.1016/j.envint.2008.11.001

Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., et al. (2022). Health and environmental effects of heavy metals. *J King Saud Univ Sci* 34:101653. doi: 10.1016/j.jksus.2021.101653