Oceanography & Fisheries
Open access Journal
ISSN: 2476-0536

Juniper PUBLISHERS key to the Researchers

Opinion
Volume 19 Issue 3 - April 2026
DOI: 10.19080/OFOAJ.2026.19.556012

Oceanogr Fish Open Access J

Oceans Pollution and Antimicrobial Resistance: Planet's Health Disastrous Threats

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Submission: March 23, 2026; **Published**: April 01, 2026

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Abstract

Oceans, which comprise 97% of the hydrosphere and cover approximately 70% of Earth's surface, harbor an extraordinary diversity of life. This vast biological reservoir has increasingly been explored as a source of novel antimicrobial compounds, as well as a rich repository of resistant bacteria and antibiotic resistance genes. In this context, the oceans are now recognized as important reservoirs of antimicrobial resistance. Ocean pollution is a well-known and largely uncontrolled mixture of toxic metals, plastics, synthetic chemicals, oil, urban and industrial waste, pesticides, fertilizers, pharmaceutical residues, antibiotic compounds, agricultural runoff and sewage. More than 80% of these pollutants originate from land-based sources and reach marine environments via rivers, atmospheric deposition and direct discharge. Together, ocean pollution and antimicrobial resistance represent interconnected global threats, affecting ecosystems and human health on a planetary scale. This concise document reports the implications of these challenges within a "One Health approach".

Keywords: Oceans; Pollution; Antimicrobial resistance; Planet health; One Health

Abbreviations: FAO: Food and Agriculture Organization of the United Nations; UNEP: United Nations Environment Programme; WOAH, founded as OIE: World Organization for Animal Health; WHO: World Health Organization; AMR: Antimicrobial resistance; UERJ: UERJ Rio de Janeiro State University

Introduction

According to the United Nations Environment Programme (UNEP), the global authority on environmental matters within the United Nations system, pollution and waste constitute one of the three major planetary crises, alongside climate change and biodiversity loss. Established in 1972, UNEP works to reduce the adverse impacts of pollution and chemical exposure on both human health and the environment (https://www.unep.org/). The deterioration of planetary health is closely linked to declining water quality driven by pollution. Marine environments have been subjected to decades of contamination from effluents, chemical residues and plastic waste, with direct consequences for marine ecosystems and effects across all forms of life on Earth [1-3].

Given their fundamental role in sustaining life on Earth, oceans represent a vast reservoir of microorganisms, encompassing a huge diversity of bacteria and the bioactive compounds they produce, as well as those derived from marine [4,5].

Covering approximately 70% of Earth's surface and comprising 97% of the hydrosphere, oceans reach depths of up to 11,000 m and form one of the most extensive and dynamic ecosystems on the planet. The benefits provided by oceans are manifold, spanning ecological, social and economic dimensions. They contribute to oxygen production, climate regulation and water cycling, while also serving as essential sources of food, livelihoods, recreation and global economic activity [6]. In addition, oceans harbor an extraordinary diversity of microorganisms, plants and marine animals. Despite their importance, this vast reservoir of biodiversity is increasingly threatened by widespread water pollution and the growing burden of antimicrobial resistance [7].

Ocean pollution exerts profound negative effects on marine ecosystems. Petroleum-derived contaminants impair photosynthesis in marine microorganisms, thereby disrupting primary productivity. Concurrently, increased oceanic uptake of carbon dioxide drives acidification, with extreme impacts including coral reef degradation, impaired calcification in mollusks, dissolution of calcium-based microorganisms at the base of the food web, and enhanced toxicity of certain pollutants [7].

A growing body of evidence has documented the toxicological impacts of antibiotics on aquatic microorganisms. Many antibiotics are inefficiently removed during wastewater treatment and consequently persist in surface waters. Their widespread and often indiscriminate use has led to the continuous release of antibiotic residues into the environment, where they impose selective pressure on microbial communities. This pressure promotes the emergence and proliferation of antimicrobial-resistant strains and facilitates the dissemination of resistance. In addition, antibiotics can exert direct ecotoxicological effects on non-target aquatic microorganisms, particularly sensitive groups such as cyanobacteria and ammonia-oxidizing bacteria [8].

Oceans represent both a promising source of antimicrobial compounds and a reservoir of resistance genes distributed across a wide range of bacterial taxa, including species of clinical relevance. In a previous study, we described a strain of *Pseudomonas putida* (Mm3) isolated from the marine sponge *Mycale microsigmatosa*, abundant along the coast of Rio de Janeiro - Brazil, which produces a potent antimicrobial compound active against multidrug-resistant bacteria. These findings highlight the potential of marine environments as a source of novel antimicrobial agents for the treatment of infections caused by resistant pathogens [4].

From an evolutionary perspective, antimicrobial resistance is a natural phenomenon. Microorganisms that produce antimicrobial compounds in marine environments often harbor intrinsic protective mechanisms against their own metabolites, a process referred to as self-resistance. Consequently, marine ecosystems may also act as selective environments for bacteria resistant to antimicrobial agents. Over recent decades, antimicrobial resistance has increasingly been examined within a broader conceptual framework, particularly through a One Health lens. A substantial body of experimental, review and conceptual studies has emphasized this integrative perspective, reflecting the scale and severity of antimicrobial resistance as a global threat to planetary health [9-12].

A study evaluated the spread of AMR in urban aquatic environments in Rio de Janeiro by analyzing the diversity of antibiotic-resistant bacteria present in aquatic environments in the state of Rio de Janeiro, Brazil, subject to different levels of anthropogenic impacts. The work concluded that the great diversity of antibiotic-resistant bacteria in the aquatic habitat is influenced by pollution, which ultimately contributes to the spread of AMR [13].

Several studies have shown that seawater is contaminated with bacteria carrying resistance genes, or even with resistance genes free in the water or present in sediments and fish intestines, which can serve as reservoirs of virulent and antibiotic-resistant bacterial strains; this pollution interferes with the quality of seafood, which may harbor antimicrobial-resistant bacteria, posing an imminent risk to human and animal health [14-16]. A study revealed that tet gene, which codes for resistance to the antibiotic tetracycline, detected in ocean sediments, had a human and terrestrial origin and became established in marine bacterial communities [14]. Other studies have shown that sul1, 2, and 3 genes, which code for sulfonamide resistance, found in ocean currents, end up accumulating in marine bacterial communities [15]. Bacteria carrying *erm*B, *mec*A, *mup*A, *qnr*A and B, and *tet*L genes that encode resistance to erythromycin, mupirocin, quinolones, and tetracyclines were isolated from marine sponges of the species *Petromica citrina* from the marine coast of Rio de Janeiro, Brazil [16]. A great diversity of antibiotic-resistant bacteria was detected in various aquatic environments in the State of Rio de Janeiro, such as Ilha Grande, Praia da Barra da Tijuca, Baía de Guanabara, and Canal de Cunha such as *Pseudomonas aeruginosa* resistant to ceftazidime, aztreonam, and gentamicin, *Klebsiella pneumoniae* resistant to tetracycline and kanamycin, *Vibrio cholerae* resistant to cefepime and meropenem. The data showed that the great diversity of antibiotic-resistant bacteria in aquatic habitats is influenced by pollution, which enhances resistance [13].

Furthermore, there are many reports in the literature of resistant bacteria present in marine animals, such as, for example, resistant *Pseudomonas aeruginosa* in wild Mediterranean mussels *(Mytilus galloprovincialis)* [17]; resistant *Aeromonas* spp. isolated from sea cucumbers [18]; resistant *Vibrio parahaemolyticus* present in sea turtles [19].

A study published recently for our team described the bacterial *Aeromonas caviae* subsp. aquatica subsp. nov., a novel multi-resistant subspecies isolated from a drinking water storage tank. This strain carried a variety of genes conferring resistance to different classes of antibiotics and resistance mechanisms. As drinking water reservoirs have been identified as critical points for the emergence of AMR in several countries, the need for public education campaigns on the proper maintenance of tanks

How to cite this article: Flávia L. P. C. Pellegrino, Alexander M. Cardoso. Oceans Pollution and Antimicrobial Resistance: Planet's Health Disastrous Threats. Oceanogr Fish Open Access J. 2026; 19(3): 556012. DOI: 10.19080/OFOAJ.2026.19.556012

and the use of advanced disinfection technologies and real-time monitoring systems is urgent in tackling water pollution with antimicrobials and resistant microorganisms, a serious public health problem that affects the human–animal–environment interface. These findings are directly related to the threat of AMR to the therapeutic success of antibiotic use in human respiratory, gastrointestinal, kidney, urinary, genital, skin, and other types of infections [20].

In response to the growing threat of antimicrobial resistance, coordinated international efforts have been established to preserve the effectiveness of existing antimicrobials and limit the spread of resistant pathogens [21]. Key priorities include reducing inappropriate antimicrobial use and strengthening environmental measures, particularly the effective treatment of industrial, domestic and agricultural waste, to curb pollution and restrict the expansion of the environmental resistome, especially in aquatic systems. Consequently, many countries and international agencies have incorporated the One Health approach into their national and global action plans [22].

The Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), World Organization for Animal Health (WOAH, formerly OIE) and the World Health Organization (WHO) together form the "Quadripartite Organizations" (QPT), a collaborative framework aimed at advancing One Health. This initiative operates across human, animal, plant and environmental interfaces at global, regional and national levels, promoting integrated, multisectoral and interdisciplinary strategies to address complex health challenges, with particular emphasis on antimicrobial resistance and emerging zoonotic diseases [23].

Conclusion

Oceans pollution and AMR, two serious interconnected global public health problems, constitute real threats with disastrous impacts to Planet's health. From the One Health perspective, which considers the human-animal-environment interface, there is a global call from the Quadripartite Organizations and wide engagement from various researchers and non-governmental organizations aimed not only at controlling the harmful effects of these threats but also at containing and eradicating actions that led to ocean pollution and the spread of AMR before life on the planet is exterminated.

Acknowledgement

We would like to express our sincere appreciation to the members of UERJ for their valuable support and collaboration throughout this research.

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DOI: 10.19080/OFOAJ.2026.19.556012

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