Deep-sea micropollutants: A double-edged sword for deep-sea ecological risk

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Received: July 17, 2024; Accepted: December 2, 2024; Published Online: December 12, 2024; https://doi.org/10.59717/j.xinn-geo.2024.100111

Citation: Lyu L. and Zhang S. (2025). Deep-sea micropollutants: A double-edged sword for deep-sea ecological risk. *The Innovation Geoscience* **3**:100111.

DEEP-SEA MICROPOLLUTANTS: TRACE PRESENCE, BROAD IMPACTS

Deep-sea micropollutants refer to pollutants that exist in deep-sea environments at extremely low concentrations, typically in parts per billion or even lower concentrations. The trace concentrations of micropollutants increase their detection difficulty and make their impact more hidden. With the development of monitoring techniques, various types of micropollutants such as persistent organic pollutants (POPs), pharmaceuticals and personal care products (PPCPs), pesticide, heavy metals etc., have been detected successively in the deep sea environments.[1-2] With the expansion of human activities and the acceleration of industrialization, deep-sea micropollutants have gradually become a focus of environmental science research.

At present, with the advancement of detection technology, various highly sensitive methods such as high performance liquid chromatography- and gas chromatography-high resolution mass spectrometry have been employed to analyze deep-sea micropollutants. However, the types of micropollutants that can be detected in the deep sea remain relatively limited, primarily including chlorinated paraffins, PPCPs, and heavy metals.[1-2] Even though some micropollutants have been detected, research on their ecological impact is minimal or even completely absent. Currently, it is generally believed that micropollutants have negative impacts on deep-sea ecosystems, but any potential positive effects they might have are often overlooked. This "paradox" reminds us that it is important to fully consider their potential multiple effects when assessing the risks of micropollutants to deep-sea ecosystems in the future. A comprehensive evaluation of both the positive and negative impacts of micropollutants on deep-sea ecosystems is crucial to secure the deep-sea ecosystems.

CURRENT VIEWPOINT: MICROPOLLUTANTS THREATEN DEEP-SEA ECOLOGICAL SECURITY.

Based on the limited knowledge of micropollutants' effects on marine ecosystems, it is generally believed that the entry of micropollutants into fragile deep-sea ecosystems may pose a threat to their ecological balance. These micropollutants may affect the ecological niche selection of deep-sea organisms and the microbial communities. Different types of micropollutants may pose varying threats to deep-sea ecology. POPs and PPCPs are gradually becoming one of the major issues in the deep-sea environment.[3-4] They can accumulate in the food chain, resulting in the reduction of deep-sea biological populations. Furthermore, POPs and PPCPs may interfere with the endocrine systems of deep-sea organisms, affecting their reproduction, growth, and development, and even causing cancer and immune system damage. In addition to organic micropollutants, inorganic pollutants of heavy metals are important components among deep-sea micropollutants. Trace heavy metals, such as mercury, lead, and cadmium are toxic and bioaccumulative. Thus, these heavy metals may affect the physiological functions of deep-sea organisms, leading to abnormal growth and development, behavioral changes, and reproductive damage.

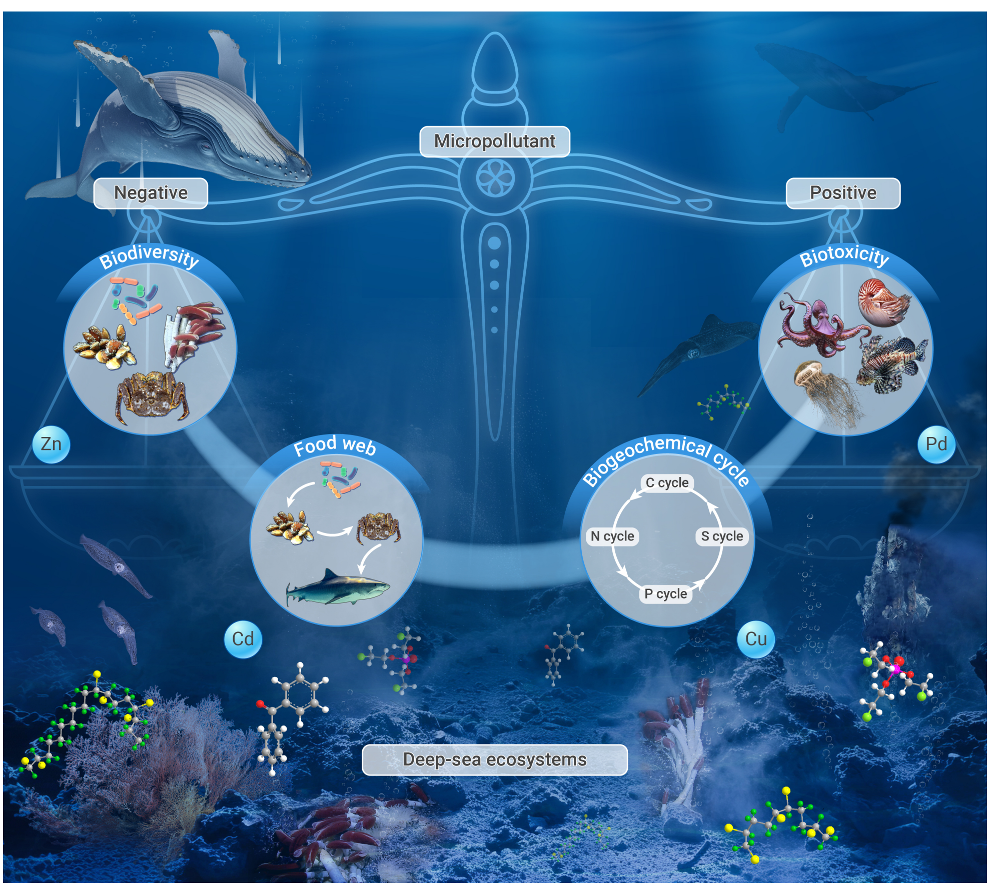

Figure 1. The ecological risks of micropollutants in deep-sea ecosystems.

In summary, the potential negative effects of micropollutants on deep-sea ecosystems may involve various aspects. However, there is a major shortage of long-term monitoring data on deep-sea micropollutants. This is largely due to high technical challenges, costly equipment, difficulties in site deployment, a lack of skilled personnel, and outdated policies and regulations. These difficulties collectively hinder the long-term implementation of deep-sea micropollutant monitoring and the effective accumulation of data. Additionally, there are also many limitations in the ecological risk assessment of micropollutants. Most studies are conducted in laboratory settings, focusing on the exposure of model organisms to individual micropollutants. However, in natural environments, organisms are generally exposed to complex mixtures. Especially in the deep-sea environment, due to its unique conditions of low temperature, high pressure, darkness, and oligotrophic conditions, the ecological impacts of micropollutants may be unique. However, relevant studies have not been fully documented. Therefore, while laboratory research can assess the environmental behavior and toxicity of micropollutants under controlled conditions, a comprehensive risk assessment of deep-sea micropollutants requires additional measures. Future efforts should fully utilize existing large scientific equipment, such as the R/V Discovery and the Deep-Sea Warrior. Additionally, it is important to integrate these with the ongoing construction of cold seep installations and to develop new equipment that can work in conjunction with these equipments. The ultimate goal is to establish a comprehensive underwater laboratory to conduct in situ experimental research on deep-sea micropollutants. Currently, it remains unclear whether there is a possibility that the positive effects of micropollutants outweigh their negative impacts in such extreme environments. We need a more comprehensive understanding of the effects of micropollutants to more effectively protect deep-sea ecological security.

NEW PERSPECTIVE: MICROPOLLUTANTS CONTRIBUTE TO DEEP-SEA ECOLOGICAL SECURITY?

While micropollutants are typically characterized as pollutants, this does not imply that they have no positive effects on deep-sea ecosystems. The impact of micropollutants in the deep sea may be more complex than our understanding. Due to the limitations of existing detection technologies and *in situ* studies, it is difficult to accurately quantify the potential positive effects of micropollutants on deep-sea ecosystems. Although there are currently no reports demonstrating significant positive impacts of micropollutants on deep-sea ecosystems, we speculate that they could play unexpected beneficial roles and contribute positively to the ecological safety of the deep sea.

Similar to hydrogen sulfide in deep-sea hydrothermal vents, which is toxic to most organisms, but serves as a "feast" for chemoautotrophic microorganisms, supporting the development of the entire hydrothermal ecosystem. Similarly, micropollutants of POPs and PPCPs may also pose toxicity to organisms in deep-sea environments. However, these micropollutants may provide carbon sources for deep-sea microorganisms, thereby promoting their growth and increasing the diversity of deep-sea ecosystems.[5] Additionally, microorganisms can convert these complex organic substances into simpler nutrients, creating more ecological niches and attracting a wider variety of organisms, thus forming new ecological chains. The increase in food resources and ecological niches may lead to greater microbial diversity, resulting in a more complex food web structure, that helps deep-sea ecosystems better cope with external environmental changes and pressures.

Microorganisms play a crucial role in deep-sea ecosystems and are key drivers of elemental cycling processes. Micropollutants can alter the ecological functions and metabolic activities of these microorganisms. This alteration may result in enhanced complexity and diversity in elemental cycling patterns within the deep-sea environment. In particular, the microbial degradation of POPs and PPCPs, which contain essential elements like carbon, nitrogen, and sulfur, is directly related to the biogeochemical cycling of these key elements in typical deep-sea ecosystems. Additionally, heavy metals are generally considered toxic substances, but certain heavy metals (such as iron, zinc, and copper) are essential trace elements for living organisms. In appropriate amounts, these heavy metals can promote the growth and development of deep-sea organisms. Moreover, with prolonged exposure to trace heavy metals, deep-sea organisms may gradually develop adaptability and tolerance to these metals, enhancing their survival abilities and ecological competitiveness in specific environments. In summary, while deep-sea micropollutants may have negative impacts on ecosystems, they can also potentially yield positive effects in the deep-sea environment. We should quantitatively assess whether the positive effects of micropollutants outweigh their negative effects through a series of steps that include defining impact indicators, collecting relevant data, developing statistical models, and calculating the net impact. By simultaneously understanding both the positive and negative impacts of micropollutants, targeted and effective measures can be implemented to better protect the security of deep-sea ecosystems.

CLOSING REMARK AND FUTURE OUTLOOK.

The extent and direction of micropollutants' impact on deep-sea ecosystems are largely unknown. Given the significant role of the deep sea in global elemental cycling and addressing global climate change, it is essential to consider both the positive and negative impacts of micropollutants when assessing deep-sea ecological security. By comprehensively evaluating the scale and nature of their roles in this context, effective measures can be taken to protect deep-sea ecological security. Future research could focus on several key aspects: (1) expanding the monitoring of micropollutant types, and accurately analyzing their concentrations, sources, and fluxes; (2) quantitatively assessing the toxic effects of micropollutants on deep-sea organisms, with particular attention to key ecological functional groups and flagship species; (3) investigating the environmental behavior and ecological impacts of micropollutants in typical deep-sea ecosystems, and uncovering potential new mechanisms involved in key processes affected by these micropollutants. By integrating these studies, we can achieve a more comprehensive understanding of the complex impacts of micropollutants on deep-sea ecosystems. This will enable us to develop more effective responses, ensuring the sustainable development of these vital ecosystems.

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FUNDING AND ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China (42494884, 42449303), Key Special Project for Introduced Talents Team of Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) (GML20190609). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. We also thank Kejing Fang for his contributions to the Figure.

AUTHOR CONTRIBUTIONS

Lina Lyu: Conceptualization, Visualization, and Original draft. Si Zhang: Conceptualization, Reviewing and Editing, and Funding acquisition. All authors contributed to and approved the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.