Proceedings of ICBioMed 2024 Workshop: Computational Proteomics in Drug Discovery and Development from Medicinal Plants
DOI: 10.54254/2753-8818/71/2024.LA18908

The Impact of Microplastic Bioaccumulation on Marine Ecosystems

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Abstract. Microplastics, resulting from the decomposition of human-produced plastic waste, were first discovered in the ocean and have significantly disrupted marine ecosystems, causing widespread biological and ecological issues. These problems are severe, and no comprehensive solution has been developed to date. To address these challenges, studying the bioaccumulation process of microplastics and their impact on marine ecosystems is essential for developing effective solutions. This paper reviews recent research on marine microplastics, focusing on their sources, bioaccumulation mechanisms, ecological impacts, and future research directions. The results show that the bioaccumulation of microplastics has a significant negative impact on marine ecosystems and human health. Microplastics not only cause physical pollution but are also toxic, threatening marine biodiversity and potentially harming humans through the food chain. Future research should focus on improving the detection, identification, and degradation of microplastics in real-world environmental conditions, as well as developing standardized methodologies for their analysis.

Keywords: Microplastics, Bioaccumulation, Marine.

1. Introduction

Since its invention, plastic has become an indispensable material in daily life, but its persistence and improper disposal have caused significant environmental challenges, especially in marine ecosystems. A large portion of plastic waste is discharged into water bodies. In 2016, approximately 19 to 23 million metric tons of plastic waste made its way into the oceans. In 2010, 192 coastal nations collectively generated 275 million metric tons of plastic waste, of which between 4.8 and 12.7 million tons were deposited into the oceans. Without improvements to waste management infrastructure, it is projected that by 2025, the cumulative plastic waste entering the oceans could increase tenfold [1-2]. Under the influence of sunlight, wind, waves, and ocean currents, plastic fragments with very small particle sizes are generated, which are the microplastics we often refer to today.

Microplastics are defined as plastic fragments smaller than 5 mm in diameter, serving as significant contributors to environmental pollution. Their sizes range from just a few microns up to several millimeters. These particles consist of irregularly shaped plastic fragments, often imperceptible to the naked eye, and are metaphorically referred to as "PM2.5 of the ocean" [3]. The distribution of microplastics in seawater is related to the environmental conditions of pollution sources, including circulation, wind, terrain and other external conditions, and its own properties, including size, density and shape and other characteristics [4]. Bioaccumulation refers to the continuous intake of extremely

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low concentrations of pollutants from the environment, leading to high concentrations that can cause toxicity to other organisms or even humans [5]. Bioaccumulation is classified as bio-proliferation, food chain enrichmation, and enrichmation in a specific organism.

At present, as one of the four new pollutants widely concerned internationally [6], microplastics have become a hot spot for scholars. There have been many studies such as XiaoZhi Lim's article [7] and S Chatterjee, S Sharma's related research on marine microplastics [8]. The analysis in shows that microplastics in the ocean will threaten biodiversity, human health and the ecological balance of the whole ocean. These microplastics are not only directly toxic to marine organisms, but also easily eaten by marine organisms, enter marine organisms, affect the feeding of marine organisms, and eventually enrich along the food chain, causing very serious harm to the entire marine ecosystem. Research has shown that microplastics can infiltrate the human body via the food chain, leading to permanent harm to sensitive marine ecosystems, including coral reefs, wetlands, and deep-sea habitats [9]. Thus, microplastic pollution poses both an environmental issue and a significant threat to public health.

Immediate action is needed to tackle the environmental and health hazards caused by microplastic pollution. This paper examines recent research on the accumulation of microplastics in marine life and its wider effects on marine ecosystems, with the goal of identifying knowledge gaps and suggesting future research directions to combat microplastic pollution.

2. Methodology

A comprehensive search was conducted in databases such as Google Scholar, Baidu Academic, and CNKI, focusing on research articles related to microplastics, marine ecosystems, and bioaccumulation. Keywords including "microplastics," "marine pollution," "ecosystem hazards," and "prevention and control" were used. Studies unrelated to marine ecosystems, or lacking experimental data, were excluded. While microplastic research in non-ocean environments was not included, studies on freshwater species like zebrafish were considered due to their physiological similarities to marine organisms. Citation frequency and journal reputation were factored in to assess the reliability and relevance of the selected literature.

3. Literature review

3.1. Theme classification

3.1.1. Primary sources of microplastics in the ocean

Research indicates that microplastics mainly stem from two categories: primary microplastics, which are directly produced through industrial processes, and secondary microplastics, formed when larger plastic materials break down due to physical and chemical factors. While most studies focus on the degradation of plastic waste in marine settings, the processes by which microplastics break down under different environmental conditions, such as variations in temperature and salinity, are still not well understood.

3.1.2. The bioaccumulation mechanism of microplastics in marine organisms

Bioaccumulation of microplastics occurs through direct absorption by algae and microorganisms, root uptake by higher plants, and ingestion by marine animals. Ocean currents transport microplastics into deep-sea sediments, where benthic organisms may ingest them, leading to further bioaccumulation through the food chain. Ocean currents will carry microplastics to the submarine canyons, and then transport them under the action of the bottom water. Finally, these small particles are deposited and accumulate to form a large amount of sediment. Seabed sediments are easily attached to microplastics, so benthic organisms will directly ingest microplastics when eating sediments, and due to the small size of microplastics, they may also be ingested by different types of organisms in the ocean. Because microplastics cannot be digested and difficult to be excreted from the body, these microplastics will accumulate and gradually enrich in higher organisms after being transmitted through the food chain. In

DOI: 10.54254/2753-8818/71/2024.LA18908

this process, some of the microplastics that enter the organism will be discharged, but many of them will remain in the organism and will be transferred between tissues, especially microplastics with small particle size. For example, LU et al. found that polystyrene particles with a particle size of 5 microns were distributed in the gills, liver and intestines of zebrafish in indoor exposure experiments of zebrafish, while particles with a particle size of 20 microns were only accumulated in the gills and intestines [10].

3.1.3. The impact of microplastics on marine ecosystems

Microplastics will affect marine life, pollutant enrichment and migration. At the physical level, after being ingested by organisms in the ocean, microplastics will make organisms feel full, affect the judgement of marine organisms for their own feeding needs, and affect their normal life activities and growth and development. At the physiological level, microplastics themselves are toxic, and microplastics can be directly affected through ingestion, inhalation and direct skin contact. Organisms are toxic, and their intake and accumulation will pose a great threat to marine wildlife [11]. At the ecological level, marine microplastic particles and their fragments can be used as substrates for the growth of bacteria, viruses and other microorganisms and generate attached biofilms on the surface, which is easier to be ingested by medium and deep organisms, and their stability and buoyancy effects can It can lead to the long-distance spread of toxic or pathogenic bacteria, which will expand its ecological risk to marine life [12]. And marine microplastics are imported into the ocean from various sources, and their degradation, fracture degree, sedimentation and biological ingestion and other destination routes are complex, which will harm fragile marine ecosystems [13].

3.1.4. Marine life and human health risks related to microplastics

(1)Plankton

Matthew Cole's experiments on multiple zooplankton groups show that 13 plankton groups able to ingest microplastics, which will damage the growth and health of zooplankton [14].

(2)Oyster

In the experiment in which the reproduction of oysters by Rossana Sussarellu was affected by polystyrene microplastics, it was found that microplastics could affect the ingestion of oysters and interrupt their reproduction through the microplastics exposure experiment of adult oysters, which has a great impact on their descendants [15].

(3)Humans

Studies have shown that microplastics will deliver toxic substances and germs to marine fish. Humans can eat fish contaminated with microplastics and contact with plastic particles, which will cause chronic diseases [16].

3.2. Evaluation of key research

Toxicological studies confirm that microplastics induce adverse effects, such as intestinal obstruction, oxidative stress, and reproductive inhibition, across various marine species [17]. The research of Setälä and others has deeply explored the mechanism of microplastics upward transfer through the food chain [18]. It was found that after zooplankton (such as radis pods and hairy) that pre-ingested microplastics was eaten by bran shrimp, microplastics accumulated significantly in the intestines of bran shrimp. This finding shows that the transfer of microplastics in the food chain not only affects the underlying organisms, but also may endanger higher-level predators through the bioaccumulation effect. In addition, intestinal obstruction and oxidative stress reactions caused by microplastics have also been confirmed in other marine fish toxicological experiments, which further shows its physiological and ecological threats to marine ecosystems.

3.3. Comparison of different methods

In the research of microplastic enrichmation, biological, physical and chemical methods have their own advantages and disadvantages. Biological methods, such as labeling microplastics, provide visual insights into ingestion pathways but often lack quantifiable data due to system complexity. Physical

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methods can measure particle size but fail to capture metabolic processes, while chemical methods, though precise, are costly and technically demanding. Combining these approaches will yield a more holistic understanding of microplastic accumulation.

3.4. Identification of trends and patterns

Recognize significant patterns, such as the rise in bioaccumulation of filtered microplastics and their effects on the marine food web, particularly on species like fish. Recent studies have highlighted the crucial role that filter-feeding shellfish and plankton play in the accumulation of microplastics. For example, the study found that in severely polluted sea areas, the concentration of microplastics in filter-eating shellfish such as muss is significantly higher than that of other organisms. At the same time, the intake of microplastics of these organisms increases with the concentration of plastic particles in the water body, which eventually leads to the accumulation of high concentrations of microplastics in predators (such as fish and birds) at the top of the food chain. This phenomenon is called the "food chain step-by-step amplification effect".

3.5. Discussion on inconsistency and research gaps

While microplastics have been detected in polar and deep-sea regions, bioaccumulation studies in these ecosystems remain scarce due to sampling challenges and technological limitations. Further research is needed to clarify microplastic transfer routes in these unique environments.

4. Results and analysis

4.1. Summary of the main findings

Studies have established that microplastics are widespread throughout the world's oceans, accumulating in marine species, especially in filter-feeders like mussels and plankton. These particles bioaccumulate through the food chain, presenting significant risks to higher trophic levels and human health. Bioaccumulation has been linked to adverse effects such as intestinal obstruction, oxidative stress, and reproductive disorders in marine organisms. While microplastics may also enter the human body through seafood consumption, the precise health risks require further investigation.

4.2. Critical analysis of advantages and disadvantages

Significant advancements have been made in microplastic detection, particularly in controlled laboratory settings, enabling more precise tracking of microplastic accumulation in organisms. However, laboratory conditions fail to replicate the complex environmental factors found in marine ecosystems, such as temperature and salinity fluctuations. Field studies offer a more holistic view of natural accumulation processes but are hindered by high uncertainty and low data reproducibility. Future research should integrate both methods to better understand microplastic bioaccumulation under real-world conditions.

4.3. Suggestions for future research

Upcoming studies should prioritize combining ecological risk assessments with toxicological evaluations to investigate the long-term effects of microplastics on marine ecosystems. In particular, efforts should be directed toward understanding the bioaccumulation in under-researched environments, such as deep-sea and polar ecosystems, where microplastic enrichment remains poorly understood. Establishing standardized protocols for microplastic detection and assessment across various ecosystems will also be essential to addressing global challenges.

5. Conclusion

This research systematically examines the bioaccumulation mechanisms of microplastics and their ecological implications, emphasizing the long-term magnification of microplastics within the marine

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food web. The analysis reveals the dual impact of microplastics on both marine ecosystems and human health, underscoring the critical need for more effective environmental management strategies.

To address these challenges, future research must focus on establishing standardized global protocols for monitoring microplastics and further exploring their toxicological effects across various ecosystems. Immediate measures are required to mitigate the environmental and health risks associated with microplastic pollution, including stronger regulatory frameworks for plastic waste management and improved pollution control mechanisms. Further investigation is warranted into the sources, distribution, degradation pathways, and toxicological impacts of microplastics, particularly in deep-sea and polar ecosystems where current research is limited. The development of unified monitoring and evaluation standards at a global scale will be essential to effectively combat the pervasive issue of microplastic pollution. Specifically, these standards should be developed by an international consortium involving regulatory agencies, academic institutions, and industry stakeholders. Collaborative efforts should focus on creating clear guidelines for sampling, detection, and data reporting to ensure consistency and comparability of research findings across different regions.

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