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Strategies for Monitoring and Reducing Microplastic Pollution in Oceans

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Abstract Microplastics have become an emerging pollutant in the global marine environment and have attracted widespread attention. Based on the research progress at home and abroad in the past five years, this study systematically reviews the source, distribution, ecological environment and health impact of marine microplastic pollution, and discusses monitoring and governance strategies. The study found that microplastic particles produced by the decomposition of plastic waste are widely present in the ocean, posing a potential threat to plankton, benthic organisms, and human health of microplastics ingested through the food chain. In response to this global threat, countries and international organizations have successively carried out microplastic monitoring projects, developed a series of monitoring technologies, and formulated policies and regulations to reduce plastic waste emissions. At the engineering and technical level, the exploration of recycling and new cleaning technologies has made continuous progress. At the same time, public participation and educational publicity have played an important role in the control of plastic pollution. Therefore, formulating comprehensive strategies, monitoring, controlling and reducing microplastic pollution has become a key issue in achieving sustainable development of the marine ecological environment.
Keywords Microplastics; Monitoring technology; Marine pollution; Ecological impact; Governance strategy

1 Introduction

Plastic products are widely used for their durability and low cost, but a large amount of waste plastics continue to accumulate in the environment and break into microplastics with a size of less than 5 mm. Research shows that around millions of tons of plastic waste enter the ocean every year around the world, with microplastic particles dominating in quantity (Thanigaivel et al., 2025). Microplastics have been widely detected in oceans from the equator to the poles and penetrate deep into the deepest part of the ocean, becoming a global environmental threat (Straffella et al., 2020). Due to its small size and difficulty in degradation, microplastics can spread over long distances and remain in the environment for a long time, posing potential harm to marine ecosystems and human health.

Microplastics in the ocean can be divided into two categories: primary microplastics and secondary microplastics. Primary microplastics refer to plastic particles that are small in size during production, such as cosmetic scrub particles, plastic microbeads in detergents and plastic particles raw materials, etc.; secondary microplastics are made of larger plastic waste being broken in the environment by physical, chemical and biological actions (Xiao et al., 2024). In the environment, these microplastics are usually fragmented, fibrous, film-like or granular, with different colors and can be mistaken for food and enter the organism.

Faced with the increasingly severe pollution of marine microplastics, this study sorts out the research results in this field in recent years, analyzes the distribution patterns and migration mechanisms of microplastics in the ocean, clarifies its impact path on marine ecosystems and human health, and summarizes and evaluates existing monitoring technologies and governance strategies. Through a comprehensive review analysis, we hope to provide readers with a systematic understanding of the problem of marine microplastic pollution. The significance of this study is to provide theoretical support and decision-making reference for the scientific governance of marine microplastic pollution, and to contribute academic wisdom and practical solutions to the protection of marine ecological environment and human health.

2 Monitoring Technology for Microplastic Pollution

2.1 Application of optical microscope and infrared spectroscopy in monitoring

When detecting microplastics in environmental samples in laboratories, the traditional and basic method is optical microscopy observation and counting. Researchers usually use screens or filter membranes to collect microplastic particles in environmental media, and then use stereomicroscopes or microphotography systems to identify and count particles larger than a certain size (such as 0.3 mm). Due to the complex composition of environmental samples, it is easy to misjudge some natural fibers as plastics by visual observation alone. To improve identification accuracy, modern monitoring widely combines Fourier transform infrared spectroscopy (FT-IR) or Raman spectroscopy to identify components of suspicious microplastic particles. Microinfrared spectroscopy can quickly identify the polymer species of particles through infrared absorption peak fingerprint characteristics, and is one of the common methods for environmental microplastic monitoring (Figure 1) (Renner et al., 2019; Böke et al., 2022). When analyzing estuary and offshore water samples, particles in two particle size segments, 11 μm~500 μm and 500 μm~5000 μm were first captured by sieve filtration, and then batch scanning and identification were used by infrared microscopy technology to successfully obtain the concentration, size distribution and polymer composition information of the microplastics in the sample. Infrared spectroscopy can detect plastic particles with particle sizes of tens of microns or even smaller (Othman et al., 2023; Lim et al., 2024), but it is still difficult for nanoplastics. In addition, combined with polarization microscopy, fluorescence staining and other methods can also help improve the sensitivity of microscopy detection.

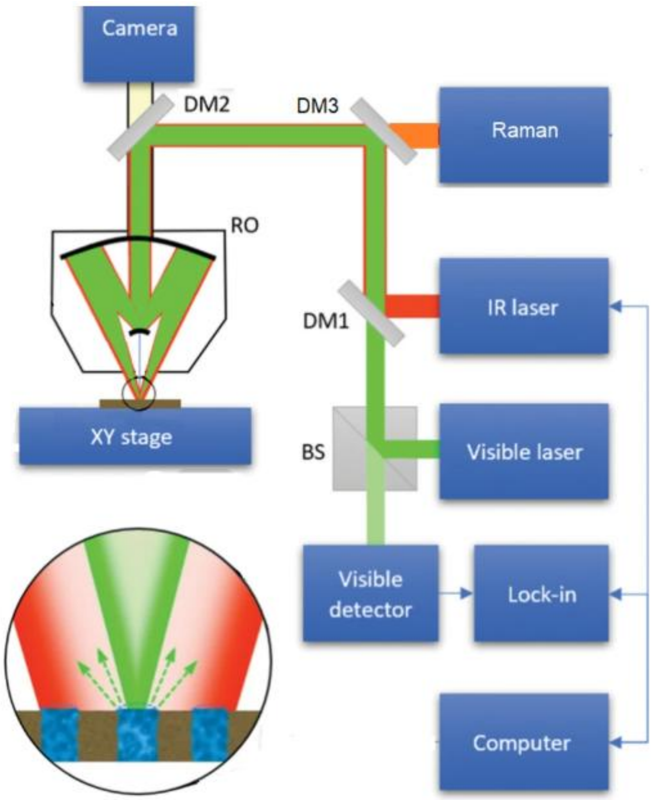

Figure 1 Schematic diagram of O-PTIR spectroscopy. A pulsed tunable IR laser is collinear with the visible detection laser, and the beams are focused via dichroic mirrors (DM1-3) on the sample surface through a reflective objective (RO). When IR absorption occurs, the photothermal response of the sample surface is monitored by the visible probe laser. The reflected light passes through a beam splitter (BS), is measured by a visible detector, and the IR signal is extracted while sweeping the wavelength of the IR laser source. Raman-shifted light is simultaneously diverted to the Raman spectrometer (Adopted from Böke et al., 2022)

2.2 The potential of environmental DNA technology in microplastic detection

Environmental DNA (eDNA) technology is a new environmental monitoring method developed in recent years. It refers to inferring the existence of species and environmental conditions by detecting free biological DNA fragments in environmental samples. Its potential application in microplastic pollution detection is mainly reflected in two aspects: indirect biological indicators, and changes in gene fragment abundance of specific marine organisms can reflect the existence and degree of microplastic pollution. It is conceived that by detecting changes in mussel DNA content in water samples, the effect of microplastics on mussel communities is indicated. Microbial community analysis shows that the surface of microplastics often attaches special microbial communities (so-called "plastic circles"). Through eDNA sequencing, the composition of bacteria and algae species adhered to the microplastics can be identified, thereby indirectly confirming the existence of microplastics in the environment (Ali et al., 2024). Although microplastics themselves do not contain DNA, they can act as a carrier to carry marine microorganisms, and analyzing these microbial eDNAs helps track the microplastic's environmental migration pathways and residence environments. For example, some attachment-resistant bacteria only reproduce on plastic surfaces. By detecting the DNA of such indicator bacteria, it is possible to quickly screen for plastic debris in seawater or sediments. Environmental DNA technology has the advantages of non-invasiveness and high sensitivity, and can directly detect DNA signals in the laboratory without the need for a large number of filtering samples.

2.3 European sea microplastic monitoring projects

Developed countries and international organizations have already carried out a number of large-scale programs and projects in marine microplastic monitoring. In Europe, the "Beihai Microplastic Monitoring Program" jointly developed by scientific research institutions from multiple countries is committed to establishing a systematic microplastic long-term monitoring network in the Beihai region. The plan unifies sampling and analysis methods, and regularly collects samples from seawater, beaches and organisms in the North Sea and adjacent Atlantic Ocean and Baltic Sea to monitor the changes in the abundance and distribution of microplastics over time. Europe has also adopted the Marine Strategic Framework Directive (MSFD) to require member countries to monitor offshore microplastic pollution and has developed detailed technical guidelines. For example, the German coast has set up an environmental sample library project with the support of the government, collecting unified specifications of biological samples such as mussels every year to analyze the changing trends of microplastic load in the body (Halbach et al., 2022). These measures provide a scientific basis for evaluating the effectiveness of governance measures. In the "North Sea" program, researchers found that there are on average about 4 plastic fragments per square meter of sand on the German coast of the North Sea, but there are large differences between locations (Walther et al., 2024). The project report also recommends that methods such as random sampling and vertical profile sampling be used to improve monitoring representativeness. In addition to government-led monitoring, Europe also encourages the public to participate in the "plastic detection" citizen science project and expand the monitoring scope through volunteer sampling.

3 Distribution and Migration Mechanism of Marine Microplastics

3.1 The influence of ocean current, wind and settlement on microplastic migration

The spatial distribution of marine microplastics is highly uneven, mainly driven by the joint force of marine dynamic processes and atmospheric processes. Ocean circulation is the main way to transport plastic debris from a long distance: ocean currents can carry microplastics from nearshore sources to the open ocean and gather in the circulation center to form a "garbage belt" (Wichmann and Delandmeter, 2019). Waves and tides can also affect the distribution of microplastics in vertical directions and near shorelines. Storm surges can push some of the floating plastic to the shore or bury them into nearshore deposits. The role of atmospheric wind power cannot be ignored. Some small-sized and low-density microplastics can be entrained into the atmosphere by aerosols generated by sea surface wind and waves, and then settle to the sea surface or land after long-distance transmission. Research points out that microplastics have been transported to remote alpine and polar regions through the atmosphere for a long distance. Sedimentation is the main mechanism of vertical migration of microplastics. Higher density of plastic particles or biologically attached weight-enhancing debris will gradually sink to the underlying seawater or even the seabed. Observations found that the number of microplastics on the surface of the ocean is much lower than the total input amount. It is speculated that a large number of microplastics settled to the seabed through agglomeration, biofooding and excretion, and become plastic reserves "hidden" in the deep-sea environment (Tsuchiya et al., 2023). At the same time, river flow into the sea and coastal hydrological processes (such as upstream and vortex) will also shape the regional microplastic distribution pattern.

3.2 Cumulative characteristics of sediments and marine organisms

Microplastics in the ocean not only float in water, but a large number of particles eventually deposit on the seabed or are ingested by biological organisms and enriched in the body. The study found that the surface microplastics on the ocean surface only account for a small part of the total, and a large amount of microplastics enter the marine sediment bank through settlement. Microplastic abundance in nearshore beaches and seabed sediments is often higher than adjacent water concentrations because microplastic density or particle size increases more easily and accumulates in a relatively stable deposition environment (Cau et al., 2024). In addition, the seabed topography and ocean currents also affect the sedimentary distribution. There may be less microplastics in strong current channels, while slow flow rates are prone to becoming microplastic enrichment centers. In addition to the inanimate environment, microplastics are also fed by a variety of marine organisms or transmitted through food networks and entered the organism. Filter or feeding methods such as zooplankton and shellfish make them a high-risk group for microplastic intake. The cumulative characteristics of microplastics in organisms vary with biological species and feeding properties. Filter-feeding invertebrates often accumulate fibers and debris, while particles and film-based plastics are common in the gastrointestinal tract of fish (Parolini et al., 2023).

Research also shows that there is a biological amplification phenomenon in marine food networks. Microplastics intake from low-trophic biological organisms can be transmitted to predators, and various types of plastic fragments are detected in top predators such as seabirds and sea beasts. These findings show that microplastics not only settle as environmental particles on the seabed, but can also move continuously along the food chain, affecting organisms of different ecological niches.

4 Effects of Microplastics on Marine Ecosystems

4.1 The hazards of microplastics to plankton and low-trophic organisms

Low-trophic organisms such as phytoplankton and zooplankton are the basis of marine food webs, but are susceptible to invasion and harm from environmental microplastics. Phytoplankton may be hindered from growth due to microplastic particles blocking light and adsorbing nutrients. Studies have found that exposure of polystyrene microbeads with higher concentrations can cause a decrease in photosynthesis rate and changes in community structure in some algae (Yu et al., 2020). Zooplankton, such as copepods, krill, etc., will consume microplastics similar to the size of food particles when filtered and fed. Some copepods are stimulated and blocked after ingesting microplastics, and no longer eat real algae, resulting in a decrease in the survival rate of individuals under high exposure. In addition, microplastics stay short but pass through high frequency in zooplankton, which can interfere with their intestinal microbiota and metabolic functions. For low-trophic benthic organisms such as filterfeeding shellfish, the harm of microplastics cannot be ignored. In field investigations, considerable amounts of microplastics were detected in mussels, oysters and other bodies. Some individuals had more than hundreds of them. These plastic particles could trigger stress responses and inflammation in the body. For example, after exposing Mediterranean mussels to high concentrations of polystyrene particles, their digestive gland tissues showed inflammation and increased cell damage markers, and their filter feeding rate and energy reserves decreased significantly (Trestrail et al., 2021). Microplastics can also accumulate in shellfish gill tissue, causing impaired respiratory function.

4.2 Synergistic effects of microplastics and heavy metals/organic pollutants

In addition to causing physical harm on its own, microplastics often have synergistic effects with other pollutants in the environment, aggravating the toxic effects on marine organisms. Due to its large specific surface area and strong hydrophobicity, plastic particles are prone to adsorbing hydrophobic organic pollutants and heavy metal ions in seawater. Microplastics can thus act as a "carrier" for these pollutants, concentrating them and carrying them into organisms (Wang et al., 2022). Studies have shown that when marine organisms ingest microplastics with pollutants, the toxic substances on the plastic can be desorbed and released under the media conditions of the biological digestive tract, causing composite pollution exposure. For example, an experiment exposed fish to clean microplastics, microplastics adsorbed with heavy metal cadmium and cadmium ion solutions, and found that the cumulative amount of cadmium and oxidative stress in the bodies of fish that were ingested at the same time were higher than those in the exposed group alone (Saikumar et al., 2024). This shows that the coexistence of microplastics and heavy metals can produce synergistic toxicity, causing organisms to withstand greater pressure. The interaction mechanism between microplastics and pollutants involves surface adsorption, complex bonding and carrier transport. Aging microplastics in the environment may lead to higher combined toxicity due to rough surfaces and increased oxygen-containing functional groups.

4.3 Investigation on the pollution of microplastics in the body of Mediterranean mussels

As a semi-enclosed sea area, the Mediterranean has dense population along the coast and frequent tourism and fishery activities, and its microplastic pollution situation has attracted much attention. Among them, investigations of filter-feeding shellfish such as mussels are often used as a classic case to indicate Mediterranean microplastic pollution. The study pointed out that the presence and type of microplastics in mussels is related to the degree of pollution in the collected sea areas, and the amount of microplastics contained in mussels near cities and ports is significantly higher than that in remote clean sea areas (Gedik and Eryaşar, 2020). In addition, the microplastic loads in the aquaculture mussels and wild mussels also differ slightly, which may be related to the water exchange conditions and bait source in the aquaculture area. Another survey on Mediterranean mussels further analyzed the distribution of microplastics in organisms. Through detection of mussel digestive glands, gills and other tissues, it was found that microplastics mainly gather in the digestive system, and a small amount can cross the epithelium and enter the gill tissue. This shows that most of the microplastics enter the digestive tract through feeding, and some of them will be excreted with the feces. Those that are not excreted may be embedded in the intestine or transferred to other tissues, causing continuous irritation and inflammation. The microplastic pollution in Mediterranean mussels has caused concerns about food safety, because mussels are seafood commonly consumed by local residents, and the daily shellfish consumed by people may bring a certain amount of microplastic into the human body (Gedik et al., 2022).

5 Potential Risks of Microplastics to Human Health

5.1 Food chain transmission and seafood safety hazards

Ocean microplastics are subtly entering human dining tables through the food chain, becoming a new food safety hazard. Microplastic particles have been detected in all seafood widely consumed by humans. Especially for the entire shellfish and small fish that are eaten, the human body cannot remove the digestive tract when ingested, and the microplastic accumulated in the body will directly enter the human digestive system. Research review shows that the average number of microplastic particles per gram of soft tissue sold on the market contains 0.2~0.3 microplastic particles; a typical seafood dieter may consume tens of thousands of microplastics from aquatic products every year. Although most of the microplastics can be excreted from the body through human feces, some small-sized particles may pass through the digestive tract mucosa and enter the blood circulation, and accumulate in the body (Marszałek et al., 2024). This has raised concerns about human health risks: the chemical components of microplastics themselves, their additives and adsorbed contaminants, may cause potential toxicity to the human body.

5.2 Test results of microplastics in drinking water and salt

In addition to seafood, microplastics may also enter the human body through daily dietary channels such as drinking water and salt. In recent years, investigations from many countries have reported microplastics detected in drinking water sources such as tap water, bottled water, and well water. For example, a study has sampled 11 brands of bottled water worldwide and found that 93% of the samples contain microplastic particles, with an average of more than 10 particles per liter of water. Although a 2019 report by the World Health Organization (WHO) believes that the current concentration of microplastics in drinking water is at a low risk to human health, it also emphasizes that due to limited evidence, further research on the long-term effects of smaller particles of microplastics and their pollutants. Salt is another food that is confirmed to contain microplastics. Testing of salt in many countries such as China, Europe, the United States and other countries shows that microplastics are detected, whether it is sea salt, lake salt or rock salt, among which sea salt content is the highest. A study on China's salt fields said that domestic sea salt contains an average of about 550 microplastic particles per kilogram, mainly fibers and fragments of 50~200 microns (Li et al., 2023). Microplastics of similar orders of magnitude are also detected in sea salt in South Korea and other countries.

5.3 Case analysis: research on microplastic exposure in the body of residents of coastal fishing villages in Asia

In order to understand the exposure of microplastics in populations, scholars have begun to directly detect microplastics in human samples. A representative study was a human microplastic exposure survey conducted in a coastal fishing village in Asia. The researchers selected a seaside village near Surabaya, Indonesia, which made a living by fishing, and recruited several adult resident volunteers who had long consumed local seafood to collect their feces samples for microplastic testing. It was found that microplastics were detected in more than half of the subjects' feces, ranging from about 3.3~14 micrograms per gram of feces. These particles are mainly common plastic polymers such as high-density polyethylene (HDPE), polypropylene, etc. On average, the HDPE microplastic concentration in the positive samples reached 9.2 μg/g, indicating that the microplastic load in this population cannot be ignored (Figure 2) (Luqman et al., 2021). At the same time, the researchers tested the main exposure sources in the fishing village environment, including fish, shellfish, water, salt and even toothpaste that residents consume daily. The results showed that microplastics were found in the sea fish and shellfish that the subjects often consumed, and microplastics were also present in drinking water and household salt samples. Even a certain toothpaste used by the subjects also contained plastic particles. This study is one of the first cases to directly confirm the presence of microplastics in humans, indicating that coastal high seafood diet populations are being exposed to environmental microplastics.

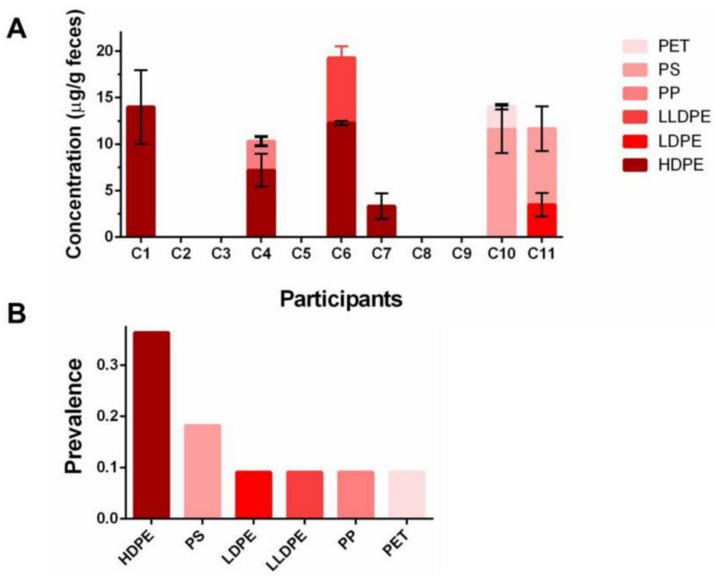

Figure 2 Concentration and prevalence of microplastics in stool samples collected from coastal populations of Kenjeran, Surabaya, Indonesia (Adopted from Luqman et al., 2021)

Image caption: (A) Various types of microplastics were detected in 6 out of 11 stool samples; (B) prevalence of different microplastic types in the studied population (Adopted from Luqman et al., 2021)

6 Policies and Regulations to Reduce Microplastic Pollution

6.1 The role of international organizations and multilateral agreements

As marine microplastic pollution is global and transboundary, governments and international organizations have begun to act in concert to seek to slow the plastic pollution crisis through multilateral agreements and cooperation mechanisms. Since 2014, the United Nations Environment Programme (UNEP) has held the "United Nations

Environment Assembly" to discuss marine garbage and microplastics issues, and unanimously passed a resolution at the Fifth Environmental Assembly in March 2022 to initiate the process of formulating a legally binding international treaty on ending plastic pollution. The resolution, supported by 175 Member States, is seen as a historic step in responding to global plastic pollution. At present, the "Intergovernmental Negotiation Committee on Plastic Pollution Control (INC)" is promoting treaty text consultations as planned, with topics covering the entire life cycle of plastics, including microplastic management, scientific research and information exchange. In addition to the United Nations framework, the G20, the G7 and others have also listed marine plastic waste as key issues and promoted members to take plastic reduction actions. At the regional level, the European Union has implemented a series of regulations under its Circular Economy Action Plan to prohibit specific single-use plastic products and limit intentionally added microplastics. In addition, the International Maritime Organization (IMO) adopted Annex V of the Anti-Pollution Convention (MARPOL) banned ships from dumping plastic waste into the ocean as early as 1988, which played a role in controlling the source of microplastics at sea.

6.2 Legislation and policy measures at the national level

Under the international framework, governments have also introduced national legislation and policies to reduce plastic pollution at the source and process, thereby reducing the possibility of microplastics entering the environment. Many countries have banned or restricted the production and use of certain single-use plastic products. From 2021, the EU will completely ban the sale of 10 common disposable plastic products such as disposable plastic tableware, cotton swabs, straws, etc., and require member countries to significantly reduce the use of plastic food containers. China has also banned the production and sales of daily chemical products containing plastic microbeads since 2020. In terms of waste management, many countries have strengthened plastic waste recycling and treatment measures (Wu and Chen, 2024). Germany, Japan and other countries have established a complete garbage classification and recycling system to enable a large amount of waste plastic to be recycled rather than leaking environments. In the "14th Five-Year Plan" plastic pollution control action plan, China proposed that by 2025, plastic waste recycling rate will significantly increase, and major cities will basically eliminate white pollution. Another important measure is to promote biodegradable plastics to replace traditional plastics in order to rapidly degrade and reduce the production of microplastics after use.

7 Governance Strategies at the Technical and Engineering Level

7.1 New model of waste recycling and recycling

In addition to policies and regulations, technology and engineering innovation play a key role in plastic pollution control, especially in the recycling of waste plastics, which can reduce the production of microplastics from the source. Promote the "circular economy" model: extend the service life of plastic products and improve the reuse rate. Improve recycling rate and recycling: improve the recycling rate and purity of waste plastics by improving the garbage classification system and introducing intelligent recycling equipment (Volk et al., 2021). Research and development of upgraded recycling technology: Research and development of new technologies such as chemical recycling and pyrolysis for traditional machinery recycling mixed or contaminated plastics that cannot be processed. Innovate a new model of community recycling: use the "Internet + Recycling" platform to recycle waste plastics on the door, or establish a community plastic exchange station to encourage residents to participate with points rewards, making recycling behavior more convenient and efficient (Rani et al., 2024).

7.2 Development of marine cleaning technology (drone, intercepting device)

For plastic waste and microplastic particles that have entered the marine environment, engineering and technicians are developing various marine cleaning technologies to actively remove pollutants from water bodies. One idea is large-scale centralized cleaning devices. For example, the "The Ocean Cleanup" project initiated by the Dutch non-profit organization designed a floating intercept device that stretches hundreds of meters to collect large areas of ocean surface plastic waste through ocean current drives. Since 2019, the team has deployed intercept networks in the Pacific “garbage belt” area and successfully captured multiple tons of floating plastic (Sainte-Rose et al., 2020). Although this method mainly targets macroscopic plastics, it can also block some large particles of microplastics. Another idea is to strengthen interception at the source of pollution, such as deploying intercept ships or fences at the mouth of rivers. There have been projects that have installed floating gates in some rivers in Southeast Asia to import river surface garbage into the collection cabin to prevent them from entering the sea (Wu et al., 2023). Meanwhile, small unmanned ships or robots are also used to fish for floating garbage in ports and nearshore waters. These robots are equipped with cameras and robotic arms, which can independently cruise and trap water surface garbage, and are highly flexible.

8 Public Participation and Educational Propaganda

8.1 The role of communities and NGOs in reducing plastic pollution

In addition to the government and scientific research community, community organizations and non-governmental organizations (NGOs) also play an indispensable role in the prevention and control of plastic pollution. Community-level actions are often intuitive and productive, with many coastal communities around the world conducting regular beach cleaning activities, with local residents, volunteers and environmental groups participating in cleaning up plastic waste from the beach. This not only directly reduces the plastic stock in the environment, but also enhances the public's awareness of environmental protection. Studies have shown that areas with continuous beach cleaning traditions have significantly lower plastic waste on the shore than unmanaged areas. NGOs often act as advocates and coordinators. For example, environmental organizations such as "Marine Guardian" have attracted the attention of the public and decision-makers to the microplastics issue through investigation reports and publicity, and promoted the introduction of relevant policies. In developing countries, some environmental organizations help communities establish simple recycling systems and train local personnel to process waste plastics into crafts or building materials, not only beautify the environment but also generate income.

8.2 Changes in consumer behavior and sustainable consumption patterns

The root cause of microplastic pollution lies in the way humans consume and dispose of plastic products. Therefore, guiding consumer behavior changes and building sustainable consumption models are regarded as one of the fundamental solutions. First, reducing unnecessary plastic consumption is the best contribution of every consumer. For example, bringing your own shopping bags instead of disposable plastic bags, carrying a water cup instead of bottled water, refusing to use plastic straws and tableware, etc. Secondly, choosing environmentally friendly packaging and biodegradable products is also a reflection of consumers' responsibility. Third, cultivate the habit of garbage sorting and correct disposal. Consumers classify waste plastics into recyclable barrels, which can improve recycling efficiency and prevent plastic from entering the environment.

In terms of education, environmental education should be strengthened, and the awareness of plastic reduction should be cultivated from children, and the truth about plastic pollution should be spread through the media and the green lifestyle should be promoted, so that the public can deeply understand that "everyone is a part of environmental protection."

8.3 The impact assessment of the “Plastic Free July” global campaign

"Plastic-free July" is a global charity event that originated in Australia, calling on people to avoid the use of disposable plastic products every July. Since its establishment in 2011, the number of participants in the "Plastic-free July" campaign has increased year by year, and has become an important platform for promoting public plastic reduction actions. According to statistics in 2022, about 140 million people from more than 190 countries participated in this activity that year. An independent study evaluated the actual plastic reduction effect of "No plastic July". The results show that households who have been participating in the exercise for a long time have reduced their plastic waste output by about 28% on average, and the cumulative reduction of plastic waste worldwide during the event is equivalent to 900 million kilograms. More importantly, many participants continued to maintain good habits after July, achieving a long-term shift in behavior.

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Conflict of Interest Disclosure

The authors confirm that the study was conducted without any commercial or financial relationships and could be interpreted as a potential conflict of interest.

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