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Analysis of the Current Situation of Marine Garbage and Microplastic Pollution in Typical Coastal Areas of Qingdao

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Abstract: Conducting research on the status and response to coastal marine debris and microplastic pollution is of significant scientific value and research importance for understanding the characteristics of coastal marine debris and microplastic pollution, as well as addressing and managing the harm of marine debris and microplastics to the coastal ecological environment. This study focused on investigating the status of coastal marine debris and microplastic pollution at two beaches in Qingdao. This study explored the types, sources, components, and spatiotemporal distribution of coastal marine debris and microplastics through field surveys, sample analysis, component identification, and mathematical statistics. Based on this, the study proposed suggestions for responses, such as strengthening public education and participation, implementing strict management and monitoring measures, and promoting technological innovation and international cooperation.

Keywords: Coastal marine garbage; Coastal microplastics; Pollution status

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1. Introduction

With the acceleration of industrialization and the rapid development of the social economy, plastic products have been widely used in daily life due to their lightness, durability, and low cost. However, the improper disposal of plastic waste has led to serious environmental problems, particularly marine debris, and microplastic pollution, which have become global environmental challenges. Microplastics, typically defined as plastic fragments smaller than 5 millimeters in diameter, have emerged as a new pollutant [1]. They affect marine ecosystems' health and may pose potential threats to human health through the food chain [2–3].

Qingdao's economic development is closely related to the ocean. It is an important port city in Shandong Province as it boasts abundant marine resources and beautiful coastlines. However, with the booming development of marine-related industries such as coastal tourism, shipping, and aquaculture, the accumulation

of marine debris on beaches has been increasing, with microplastic pollution being particularly prominent. These pollutants damage the natural landscape, cause severe harm to marine organisms, and even affect the sustainable development of fishery resources.

In recent years, the Qingdao municipal government has attached great importance to marine environmental protection and introduced a series of policies and measures to strengthen the detection and prevention of plastic waste and microplastic pollution in rivers, lakes, and seas. For example, the "Qingdao Action Plan for Further Strengthening Plastic Pollution Control" clearly proposes to enhance the source reduction, process control, and end-of-life disposal of plastic waste. It also encourages the research and development of key core technologies for recyclable and degradable materials. Despite these efforts, more detailed investigations are still needed regarding the specific pollution status of marine debris, especially microplastics, in typical coastal areas of Qingdao.

This study aims to systematically analyze the current status of marine debris and microplastic pollution in typical coastal areas of Qingdao, reveal the pollution's primary sources and distribution characteristics, and propose scientific and reasonable response strategies based on these findings. By employing comprehensive methods such as field investigations and sample collection analysis, the study aims to provide theoretical support and technical assistance for marine environmental protection in Qingdao and potentially a broader region, promoting sustainable use and development of aquatic resources.

2. Literature review

2.1. Research progress from a global perspective

Since the mid-20th century, with the acceleration of industrialization, plastic products have been widely used due to their durability and convenience. However, this has also led to much plastic waste entering the natural environment, especially marine ecosystems [4]. Microplastics (plastic fragments smaller than 5 millimeters) have recently become a hot international issue. Microplastics are not only found in surface seawater but can also settle on the seafloor and even appear in deep-sea sediments. Due to their difficulty in degrading, these tiny plastic particles cause long-term impacts on marine ecosystems [5].

Research worldwide indicates that microplastics have diverse sources, including disposable plastic products, industrial wastewater discharge, and enormous plastic waste breakdown under natural conditions. Once in the ocean, marine organisms quickly ingest microplastics, affecting their digestive systems and leading to malnutrition or even death. Moreover, microplastics can carry harmful substances such as heavy metals and persistent organic pollutants (POPs), causing more harm to organisms [6].

2.2. Sources of microplastics and the impact on ecosystems

Specifically, there are two main categories of microplastic sources: primary and secondary microplastics. Primary microplastics refer to tiny plastic particles that enter the environment as products or raw materials, such as microbeads in cosmetics and exfoliating particles in personal care products [7]. Secondary microplastics, on the other hand, are tiny fragments resulting from the breakdown of more oversized plastic items in the natural environment [8–9].

For ecosystems, the presence of microplastics affects marine organisms' health and may also be transmitted to humans through the food chain. Studies have shown that aquatic organisms like fish and shellfish may experience delayed growth and decreased reproductive abilities after ingesting microplastics. Additionally, microplastics can affect biological behaviors, such as altering foraging habits, thereby further disrupting the ecological balance [10–11].

2.3. Domestic and international governance measures and research trends

Governments and research institutions worldwide actively explore effective governance solutions when faced with the increasingly severe problem of marine microplastic pollution. For instance, some countries and regions have introduced regulations banning disposable plastic products and promoting using biodegradable materials as alternatives to traditional plastics [12]. Additionally, scientists are researching how to degrade microplastics through physical, chemical, or biological methods to mitigate their negative environmental impact [13–14].

Regarding technological approaches, researchers are attempting to develop new materials that can degrade more quickly in natural environments. Meanwhile, some projects focus on raising public awareness, reducing single-use plastic products, and promoting waste sorting and recycling. These efforts aim to reduce the generation of microplastics at the source and minimize their environmental harm through effective management measures [15–16].

2.4. Research and practice from the Chinese perspective

In China, research on marine microplastic pollution is gradually increasing. Researchers are not only focusing on the distribution characteristics of microplastics and their potential harm to ecosystems but also seeking appropriate management strategies and technological methods to reduce plastic pollution in the marine environment. Qingdao is responsible for marine environmental protection and is one of China's critical coastal cities. Qingdao has also strengthened its research efforts in this field in recent years, aiming to contribute wisdom and strength to solving this global challenge. For example, Qingdao has launched a series of monitoring projects, regularly collecting seawater samples and analyzing the content of microplastics while tracking their spatiotemporal variation trends. Pollution sources can be better understood through these data, providing a basis for developing targeted governance measures. Additionally, Qingdao actively participates in international cooperative projects, drawing on the successful experiences of other countries to jointly promote the development of marine environmental protection efforts [17–19].

Marine debris, especially microplastic pollution, has become an urgent environmental issue. Despite extensive research by scholars worldwide, many unknown areas still await exploration. Future studies need to focus more on the long-term ecological effects of microplastics, the effectiveness of management technologies and policies, and so on, to provide solid scientific support for marine environmental protection. Through continuous knowledge accumulation and technological advancements, this study aims to gradually alleviate or even solve this significant challenge threatening global ecological security.

3. Station layout, sample collection, experimental analysis, and data processing

3.1. Typical shoreline of Qingdao City

Located on the east coast of China, in the southeast of Shandong Province, Qingdao is a beautiful coastal city known for its magnificent coastline and rich tourist resources. Qingdao's coastline is more than 700 kilometers long, with many different styles of shore stalls; they are a good place for leisure and entertainment and an important tourist attraction. This paper will focus on two representative beach stalls — Shilaoren Beach and Qingdao's first bathing beach. The beach is located in the northeast of Qingdao, with a length of about 2.36 kilometers and an area of about 0.4 square kilometers. The east side of the beach is a marine erosion cliff monitoring the beach, which is in an arc to the southeast open bay, and there is no outflow river. The typical Cape Bay arc coast is formed due to the long-term shaping by the wave dynamics. Shilaoren Beach has flat terrain, fine sand, and a slope of about 2.4%, which makes it very suitable for tourists to walk and play [20]. Qingdao No. 1

Bathing Beach is another well-known beach stall in Huiquan Bay; the coastline is about 580 meters long and 40 meters wide. It was once known as one of the largest bathing resorts in Asia, surrounded by mountains on three sides and with beautiful scenery. The beach of Huiquan Bay Beach is also acceptable, and the slope is gentle, which is very suitable for beach recreation activities, such as sunbathing and beach volleyball [21].

3.2. Section layout of marine garbage on the shore

3.2.1. Layout rules

The principles of representativeness, uniform distribution, repeatability, ease of operation, and environmental protection should be followed to ensure the effectiveness and scientificity of the monitoring in the coastal area of Qingdao. In particular, at least two monitoring sections shall be arranged for beaches not exceeding 2 km in length. At least three monitoring sections shall be placed for shoals between 2 and 5 km in length. For beaches longer than 5 km, at least five monitoring sections shall be arranged, and these sections shall be evenly distributed in the monitoring area. In addition, when determining the location of the monitoring section, factors such as the distribution of coastal population, the division of Marine functional zones, and the types of coastal industries should be comprehensively considered. The monitoring points should be able to cover different kinds of sea areas to comprehensively reflect the status of Marine debris in the beach area.

3.2.2. Section layout

Based on the abovementioned principles, this study selected six typical coastal sections in Qingdao as monitoring points (**Table 1**). Among them, Shilaoren Beach (QD01–QD04) is located in a famous coastal scenic spot with dense tourist traffic. The four sections are arranged at different locations within the scenic area to assess the impact of tourism activities on marine garbage. Taiping Point Beach (QD05, QD06) is an essential landmark of Qingdao. Two monitoring sections are set up around this area to monitor the marine debris situation, especially environmental changes during the off-tourist season. Through these carefully chosen monitoring sites, this study can more accurately grasp the distribution and trends of marine garbage in Qingdao's coastal areas. This provides a scientific basis for subsequent environmental protection measures and enhances public awareness of marine environmental protection through regular data collection and analysis, thus promoting the effective implementation of relevant laws and regulations.

Table 1. Qingdao coastal marine debris section information

Monitoring area	Marine functional zoning	Section number	Length (m)	Area (m^2)
Shilaoren Beach	Tourism and recreation area, agriculture and fisheries area, reserve area	QD01	91	455
		QD02	86	430
		QD03	85	425
		QD04	61	305
Taiping Point Beach	Tourism and recreation area, port and shipping area, reserve area	QD05	48	240
		QD06	31	155

3.3. Microplastic monitoring station layout

To effectively monitor the microplastic pollution status in Qingdao's coastal areas, strategically establishing

monitoring stations on the selected beaches is essential. Considering factors such as beach length, coastal population distribution, marine functional zoning, and coastal industry types, this study will set up six microplastic monitoring stations at Shilaoren Beach and Taiping Point Beach. The specific information is shown in **Table 2**. Through this layout of stations, comprehensive monitoring of the microplastic pollution status in vital coastal areas of Qingdao can be achieved. This will provide reliable data support for formulating effective pollution control strategies and further promote public participation in marine environmental protection efforts.

Table 2. Coordinates of microplastic monitoring stations

Station name	Longitude (E)	Latitude (N)	Station name	Longitude (E)	Latitude (N)
QDW1	120.47086	36.09383	QDW4	120.45282	36.08224
QDW2	120.46475	36.09139	QDW5	120.33736	36.05670
QDW3	120.45927	36.08771	QDW6	120.36064	36.05094

3.4. Sampling method

To conduct a scientific and systematic survey of marine garbage on coastal beaches, this study will randomly select survey sections from the designated monitoring beaches and complete sample collection within 3 hours before and after the local low tide. The selected survey sections are set to be 5 meters wide and extend from the water's edge at the lowest tide line to the average high tide line or the boundary covered by vegetation. Marker poles will be inserted at the four corners of the survey section, connected by marking ropes to define the sampling area clearly. Similarly, two microplastic sampling stations will be established within each section to ensure the scientific rigor and standardization of microplastic sample collection in the selected marine garbage sections. One of these stations will serve as a parallel sample to verify the consistency and accuracy of the data. Sample collection should be conducted within 3 hours before and after the low tide.

3.5. Analysis and data statistics of marine garbage samples on the shoreline

3.5.1. Sample processing and analysis

Firstly, the coastal garbage fragments are cleaned, and then according to the "Technical Regulations for Monitoring and Assessment of Marine Garbage (Trial)", the collected samples are classified, measured, and recorded [22]. Sample classification and measurement methods include visual inspection, microscopic examination, and so on.

The source analysis of marine garbage samples adopts the statistical method of the Northwest Pacific Action Plan (NOWPAP) [23]. The sources are divided into five aspects: tourism/eating and other human coastal activities, shipping/fishing activities, smoking products, medical/sanitary products, and other waste.

3.5.2 Data processing

The density statistics of coastal garbage mainly include the density and mass density of coastal garbage, as shown in **Equation 1** [24].

$$D = \frac{n}{\sum_{i=1}^{k} w \times l_i} \quad (1)$$

Whereas D represents the density of coastal garbage, with units of ten thousand pieces/km² or kg/km²; n represents the total number or total weight of coastal garbage, with units of pieces or kg; l_i represents the length

of the i-th monitoring section, with units of km; *k* represents the number of monitoring sections; *w* represents the width of the monitoring section, with units of km.

4. Status of marine garbage and microplastic pollution on shoreline

4.1. Category analysis

According to the survey results of marine garbage on the Qingdao shoreline, the trash can be roughly divided into nine categories by material type: plastics, polystyrene foam, glass, paper, other artificial items, metals, wood products, fabrics, and rubber waste. According to quantity statistics, plastic waste accounts for a higher proportion (65.35%) of the marine garbage on the Qingdao shore, indicating the severity of plastic waste pollution in Qingdao. This is followed by glass waste (17.81%), polystyrene foam plastic waste (6.08%), other artificial items (5.96%), and paper (2.03%), with no rubber or fabric waste found.

The plastic waste on the Qingdao shoreline mainly consists of packaging bags, plastic bottles and caps, cigarette butts, and fishing gear. These items are numerous, and due to their durability and lightweight nature, they easily drift with the water flow and accumulate on the shoreline. In contrast, although glass, metal, wood products, and fabrics account for a small proportion of the total, their greater weight means they occupy a higher proportion in mass statistics. This highlights the importance of strengthening the management and recycling of plastic waste, which is widely used daily.

Regarding microplastic pollution, the investigation found that on the Qingdao shoreline, microplastics with particle sizes between 20–100 μm and 100–400 μm each account for 35%, followed by those between 400–700 μm accounting for 15%, those between 700–1000 μm accounting for 8%, and those between 1000–5000 μm being the least (6%); in terms of microplastic sediments, fibers have the highest proportion (53%), followed by fragments (25%), particles (18%), and films having the lowest proportion (4%).

4.2. Source analysis

The sources of marine garbage on the Qingdao Shilaoren beach are predominantly other waste materials (38.82%), followed by human coastal activities such as tourism and dining (38.49%) and smoking-related products (21.16%). The percentages for the other two categories are 0.68% and 0.86%, respectively, up to only 1.54%. In this area, the density of glass marine garbage is relatively high, which should raise concerns to prevent injuries from broken glass and enhance the recycling of glass waste.

On the Taipingjiao beach in Qingdao, the primary source of marine garbage is smoking-related products (41.22%), followed by human coastal activities such as tourism and dining (42.68%) and other waste materials (10.86%). The percentages for the other two categories are 3.47% and 1.77%, respectively, totaling only 5.24%. Given that smoking-related waste constitutes the highest proportion in this area, it is necessary to control smoking activities and establish designated smoking areas.

Table 3. Marine garbage section source data statistics

Garbage source	Garbage type	Proportion by number at Shilaoren	Proportion by number at Taipingjiao
Tourism/Dining and other human coastal activities	Plastic bottles, fast food containers, beverage cans, plastic bags, etc.	38.52	42.68
Medical/hygiene supplies	Discarded fishing nets and fragments, fishing lines, buoys, etc.	0.68	3.47
Other Waste	Cigarette butts, cigarette packs, lighters, etc.	38.82	10.86
Smoking equipment	Syringes, discarded medicine bottles, sanitary napkins, diapers, etc.	21.16	41.22
Shipping/fishing activities	Tires, lamps, window screens, wires, glass, etc.	0.86	1.77

The proportion of microplastic components in Qingdao Shoal mainly includes PT, RY, and PET, which are related to the discharge of urban domestic sewage. Research shows that the average washing of 5 kg of woven goods can release about 6 million fibers. Urban household laundry wastewater and textile industry water are imported into the sewage treatment plant through the sewage pipe and finally discharged into the ocean after treatment. Therefore, discharge from municipal sewage treatment plants is one of the primary sources of Marine microplastics [25–26].

4.3 Spatial and temporal distribution

The results of the temporal and spatial distribution analysis of marine garbage in Qingdao Shoal are presented in **Figure 1** and **Figure 2**. As illustrated, the quantity density of marine debris on the monitored beaches of Qingdao has exhibited a downward trend over the years, with minor fluctuations observed in 2012, 2016, and 2018, followed by a consistent decline after that. Mass density showed a gradual decrease accompanied by significant fluctuations during 2012, 2014, and 2018; notably, it reached its lowest level in history in 2017. Analyzing quantity and quality densities from historical monitoring data at Qingdao's beaches reveals that their trends are largely congruent, demonstrating an annual decline. From 2017 to 2024, Qingdao carried out several large-scale beach cleaning operations, such as the cleanup of the Shilaolao Bathing Beach, showing the importance of the government and all sectors of society to Marine environmental protection.

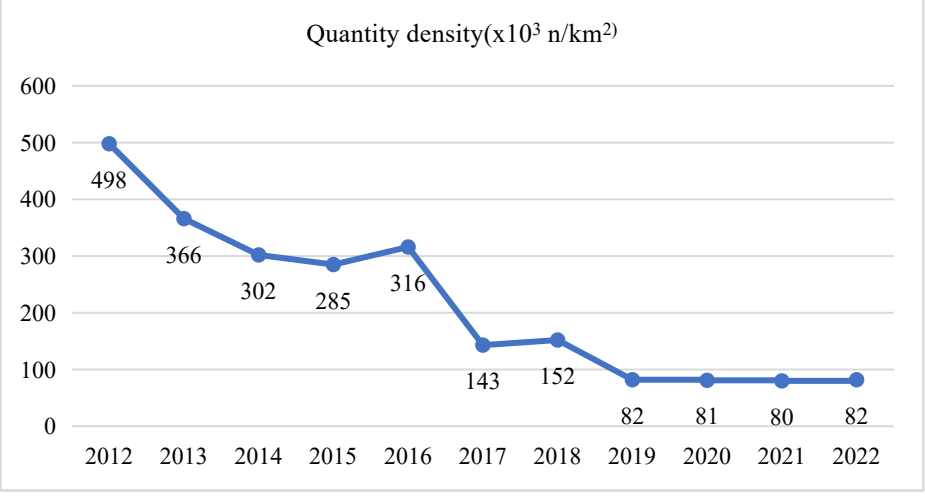

Figure 1. Changes in the amount of Marine garbage on the shore

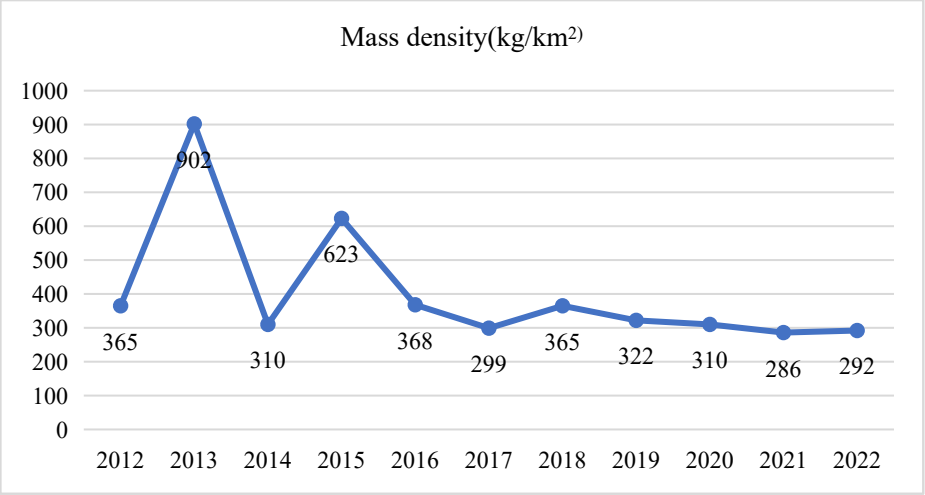

Figure 2. Quality change of Marine garbage on the shore

5. Suggestions for coping with marine garbage and microplastic pollution

5.1. Strengthen public education and participation

To effectively deal with the problem of marine garbage and microplastic pollution in the Qingdao coastal market, the top priority is to raise public awareness of environmental protection. Public responsibility and participation can be enhanced through various publicity and education activities, such as holding environmental talks in schools and communities, using social media platforms to spread ecological knowledge, and organizing regular voluntary beach cleaning activities. In addition, encouraging public participation in waste classification, reducing the use of single-use plastic products, and reducing the production of microplastics at source is a critical step in achieving sustainable marine environmental protection.

5.2. Implement strict management and monitoring measures

The Qingdao municipal government should strengthen garbage management in the area on the opposite bank, establish and improve the marine garbage monitoring network, regularly detect the level of microplastic pollution, and publish the monitoring results promptly. At the same time, special garbage collection facilities are set up to ensure the cleanliness of the beach area. The government can also introduce relevant policies to encourage enterprises to use environmentally friendly packaging materials and reduce the emission of plastic waste. Through legislative means, the illegal discharge of garbage is strictly punished to deter potential polluters and ensure the safety of the Marine ecological environment.

5.3. Promote scientific and technological innovation and international cooperation

To fundamentally solve the problem of microplastic pollution, Qingdao should actively introduce and develop new technologies, such as the research and development of biodegradable materials and the application of efficient microplastic capture equipment, to reduce the long-term impact of microplastics on the environment. In addition, strengthening cooperation and exchanges with the international community, sharing experience and technology in marine environmental protection, and participating in global environmental protection projects can not only improve their pollution control capabilities but also contribute to the formation of unified standards and norms to cope with this cross-border ecological challenge jointly.

Disclosure statement

The author declares no conflict of interest.

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