

# The Distribution and Characteristics of Microplastics in Coastal Beaches and Mangrove Wetlands



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**Abstract** Microplastics found in coastal environments can be transported to and accumulate in different coastal environmental media by diverse driving factors and pathways. Increasing numbers of studies indicate that microplastics accumulate in

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Defu He and Yongming Luo (eds.), *Microplastics in Terrestrial Environments - Emerging Contaminants and Major Challenges*,

Hdb Env Chem (2020) 95: 77–92, DOI 10.1007/698\_2020\_459,

© Springer Nature Switzerland AG 2020, Published online: 19 March 2020

coastal areas with highly intensive human activities. However, there are few discussions on the occurrence of microplastics in coastal sediments and coastal wetlands according to different land utilization patterns. In this chapter we investigate the distribution of shape, size, and abundance of microplastics in northern coastal beach sediments. We found that pellets, foams, fragments, flakes, films, fibers, and sponges occurred in beach sediments with different land utilization patterns. The abundances of microplastics were 344 particles  $\text{kg}^{-1}$  in tourist beaches, 1,226 particles  $\text{kg}^{-1}$  in beaches adjacent to mariculture areas, 98 particles  $\text{kg}^{-1}$  in beaches near fishing ports, and 1,302 particles  $\text{kg}^{-1}$  in undeveloped beaches. Foams were dominant in tourist beaches and beaches near fishing ports, while flakes dominated in beaches adjacent to mariculture areas and in undeveloped beaches. The differences are likely due to different anthropogenic influences in coastal zones. We then illustrate the characteristics and spatial distribution of microplastics in different mangrove sediments covering the main mangrove forest growing areas of south China. The abundance of microplastics was 1,302 particles  $\text{kg}^{-1}$ , and foams and fibers were the dominant shapes in mangrove sediments. The differences in distribution of microplastics in mangrove sediments are related to anthropocentric influences such as mariculture and fisheries and to the density of vegetation. Moreover, different potential sources of microplastic are contributors of microplastic pollution in coastal zones and need to be evaluated. They include land sources and offshore marine sources together with coastal atmospheric deposition. The results contribute to our understanding of microplastic pollution in coastal sediments with different coastal land utilization patterns, and they provide a reference for the management and control of microplastic pollution in coastal environments.

**Keywords** Characteristics, Coastal wetlands, Distribution, Microplastics, Sources

## 1 Introduction

Microplastics occur in coastal environments worldwide [1–3], especially in coastal zones with highly intensive human activities such as tourism [4, 5], mariculture [6, 7], and fishing and shipping ports [8, 9]. The spatial distributions of the abundance, composition, and size of microplastics show heterogeneity in coastal sediments due to the diversity of sources [10], variable biological and chemical effects [11, 12], complex hydrodynamics [13], and different geographical locations [9, 14]. However, few studies have focused on comparative differences in the occurrence of microplastics in coastal sediments under different coastal land utilization patterns worldwide.

There have been few studies of microplastic pollution in coastal wetland sediments. Mangroves are unique systems that play a valuable role in sequestering carbon in coastal wetlands worldwide [15]. They are capable of moderating wind

and waves, protecting embankments, promoting siltation, purifying the environment, and enhancing environmental conditions. They also provide important habitats for waterfowl, fishes, crabs, shrimps, and shellfish [16]. In recent years several studies have reported that mangrove ecosystems have been affected by microplastic pollution due to mariculture, sewage discharge, and other anthropogenic influences [12, 17]. Plastic debris retention and distribution in mangrove ecosystems caused by the density of vegetation (i.e., red mangrove or *Rhizophora mangle*) and tidal variation have been reported [18, 19]. The occurrence of microplastics in seven intertidal mangrove habitats in Singapore (collected from the top 3–4 cm at low tide, oxygenated zone) was initially investigated [17]. The abundance of microplastics was 12.0–62.7 particles  $\text{kg}^{-1}$ , and the majority of the microplastics were fibers with a diameter of  $<20 \mu\text{m}$ . The area of mangrove in China is 34,472 ha, accounts for about 0.4% of the global area, and is mainly distributed in Hainan, Guangdong, Guangxi, Fujian, Zhejiang, Hong Kong, and Taiwan [16, 20]. However, there have been few studies of microplastic pollution on the coast of Qinzhou Bay, Guangxi province, including the mangrove wetlands [7, 12].

Sources of microplastic pollution in the coastal environment are very complex [1]. They include land inputs such as river, sewage, and garbage dumping and marine inputs such as current transportation and shipping. The source analysis of microplastic pollution in coastal zones is regarded as an important research topic in revealing the spatial and temporal distribution of microplastics.

In this chapter we therefore introduce the characteristics and distribution in terms of shape, size, and abundance of microplastics in coastal beach sediments. The relationship between the occurrence of microplastics and intensive human activities in the coastal zone will be discussed. We will then illustrate the characteristics and spatial distribution of microplastics in different mangrove sediments, covering the main mangrove forest areas of China. Important factors and their relationships with the distribution and retention of microplastics in the mangrove sediments will be explored. Finally, different potential sources of microplastic pollution in coastal environments will be discussed. This will complement the data and provide a management reference of microplastic pollution in the coastal zone.

## 2 Distribution and Characteristics of Microplastics in Coastal Beaches

Intensive human activity has developed on the east coast of China, with development of mariculture, tourism, transportation, mining, salt harvesting, fishing, port construction, and land reclamation. The booming economy and population has resulted in the movement of large quantities of plastic wastes and microplastics into the coastal beaches and the waters. This section discusses the distribution of microplastics in beach sediments under different land utilization patterns along the Bohai Sea and Yellow Sea coastlines. There are tourist beaches, beaches adjacent to

mariculture areas, beaches near fishing ports, and undeveloped beaches. These are regarded as potential “hot spots” for microplastic accumulation.

## ***2.1 Distribution and Characteristics of Microplastics in Tourist Beaches***

Coastal tourist beaches are key areas of microplastic accumulation derived from anthropogenic activities [21]. Coastal tourism in China results in substantial pollution of beaches by plastics and microplastics, and descriptive statistics are shown in Table 1. The coefficient of variation (CV) of microplastic abundances of all sampling sites was 1.5. This implies that the abundance of microplastics in tourist beaches has high spatial variability. In this study the abundance of microplastics ranged from 3.3 to 2,456 particles  $\text{kg}^{-1}$  with an average of  $343.9 \pm 522.4$  (mean  $\pm$  S.D.) particles  $\text{kg}^{-1}$  (Table 1). This is comparable to the results of other studies. For example, Yu et al. investigated microplastics in bathing beaches on the north Bohai Sea, and the abundance was around 200–400 particles  $\text{kg}^{-1}$  [22]. Retama et al. investigated tourist beaches in Huatulco Bay on the Pacific coast of southern Mexico and found a range of microplastic abundance of 0–2,300 particles  $\text{kg}^{-1}$  [4].

The morphologies of microplastics in tourist beach sediments include foams, sponges, flakes, fragments, fibers, pellets, and films. The coefficients of variation of microplastic abundances of all shape types ranged from 1.1 to 3.3 (Table 1), showing that the abundance of different shapes in the tourist beaches was highly variable. The foams had the highest abundance,  $327.5 \pm 513.6$  particles  $\text{kg}^{-1}$ , accounting for 95.2%. Sponges ( $7.8 \pm 12.2$  particles  $\text{kg}^{-1}$  on average, accounting for 2.3%), flakes ( $4.1 \pm 13.5$  particles  $\text{kg}^{-1}$  on average, accounting for 1.2%), and fragments ( $2.4 \pm 2.6$  particles  $\text{kg}^{-1}$  on average, accounting for 0.7%) were much fewer than foams. Fibers ( $0.9 \pm 1.1$  particles  $\text{kg}^{-1}$  on average) and pellets ( $1.0 \pm 2.1$  particles  $\text{kg}^{-1}$  on average) accounted for only 0.3% of the total microplastics. Films were fewest at  $0.3 \pm 0.7$  particles  $\text{kg}^{-1}$ , accounting for 0.1%. Foams were common in the tourist beach sediments, and this may be explained as follows. First, a very large number of foam buoys and containers are used for fishing and seafood sales. Second, a high proportion of the foam items have been discarded because they are cheap and there is little incentive for recycling. About 5.8 million tonnes of waste polystyrene foam materials have been estimated to be produced globally every year, of which about 1.8 million tonnes are manufactured each year and only about 30% are recycled in China (<http://www.plas.hc360.com>). Third, the government does not control the disposal of these foam materials. Furthermore, foam materials readily break into smaller pieces, making them difficult to collect during beach cleaning events [23]. Finally, foam pieces in coastal waters can be easily transported by water currents and can easily accumulate on the beaches as a result of tidal action. Foams were found to account for 99% of plastics on coastal beaches in Korea

**Table 1** Range, average, and percentage of each microplastic type and size fraction in beaches under different land utilization patterns (unit: particles kg<sup>-1</sup>)

Land use	Pellets	Foams	Fragments	Flakes	Films	Fibers	Sponges	Total
Tourist beaches ( <i>N</i> = 24)	Range	0.0–8.2	0.0–9.8	0.0–65.1	0.0–3.3	0.0–3.6	0.0–40.2	3.3–2,455.6
	Average	327.5	2.4	4.1	0.3	0.9	7.8	343.9
	Percentage	95.2	0.7	1.2	0.1	0.3	2.3	100.0
Beaches adjacent to mariculture areas ( <i>N</i> = 10)	Range	0.0–4.95	0.0–7.8	0.0–10,664.0	0.0–3.6	0.0–136.1	0.0–33.89	1.3–10,689.3
	Average	0.8	3.4	1,071.1	0.9	14.3	3.7	1,226.2
	Percentage	0.1	0.3	87.4	0.1	1.2	0.3	100.0
Beaches near fishing ports ( <i>N</i> = 5)	Range	0.0–1.0	0.0–26.1	0.0–96.6	0.0–4.0	0.0–27.3	0.0–20.3	17.2–224.5
	Average	0.3	6.9	26.9	1.9	8.1	4.3	97.7
	Percentage	0.3	7.1	27.5	1.9	8.3	4.4	100.0
Undeveloped beaches ( <i>N</i> = 14)	Range	0.0–16.9	0.0–253.9	0.0–14,705.6	0.0–22.2	0.0–73.0	0.0–56.7	13.0–14,712.5
	Average	1.3	22.1	1,151.1	2.7	13.1	5.8	1,301.6
	Percentage	0.1	1.7	88.4	0.2	1.0	0.4	100.0

**Table 2** Percentage of each size fraction in beaches under different land utilization patterns (%)

	<1 mm	1–2 mm	2–3 mm	3–4 mm	4–5 mm
Tourist beaches	2.9	36.4	28.5	17.1	15.2
Beaches adjacent to mariculture areas	76.0	9.1	6.5	4.4	3.9
Beaches near fishing ports	3.8	14.3	25.4	25.3	31.2
Undeveloped beaches	77.0	8.7	6.5	4.6	3.3

[23]. However, other types of microplastics in the tourist beaches of the South China Sea include fibers, films, fragments, and granules [5, 24].

The majority of the microplastics found in this study were composed of particles within the size range 1–3 mm, accounting for 64.9% (Table 2). This is mainly due to the size fractionation of the foams which was dominated by 1–3 mm particles. The abundance of particles <1 mm was the lowest, accounting for only 2.9%. Overall, the proportion of the observed microplastics with a size range of 1–5 mm increased with decreasing plastic particle size.

## 2.2 *Distribution and Characteristics of Microplastics in Beaches Adjacent to Mariculture Areas*

The abundance of microplastics in beaches adjacent to mariculture areas ranged from 1.3 to 10,689 particles  $\text{kg}^{-1}$ , and the coefficient of variation (CV) of microplastic abundance was 2.7 showing very high spatial heterogeneity (Table 1). The average abundance of microplastics was  $1,226 \pm 3,336$  (mean  $\pm$  S.D.) particles  $\text{kg}^{-1}$ . Most sites showed abundances of microplastics of several tens or hundreds of particles  $\text{kg}^{-1}$ . The highest abundance of microplastics (10,689 particles  $\text{kg}^{-1}$ ) was found in an abandoned mariculture area (fish, shrimp, or crab) at Dongying, Shandong province, which was dominated by flakes (99.8%). The flakes were produced from the fragmentation of abandoned woven bags which were used for mariculture pools and bag dams in the coast. The lowest abundance of microplastics was found in a mariculture area at Yantai, Shandong province, with only 1.3 particles  $\text{kg}^{-1}$ , possibly attributable to the sediment texture. This sampling site was a small gravel beach with large plastic debris (>5 mm) but fewer microplastics. Furthermore, numerous sea cucumbers and abalones were cultured in this area, and a clean water environment would be required [25]. This suggests that the differences in microplastic contamination are likely also associated with different systems of coastal mariculture.

Flakes occurred in the highest percentage (87.4%) in the beaches adjacent to mariculture areas (Table 2). Foams were the second highest percentage (10.8%), while percentages of fibers (1.2%), sponges (0.3%), and fragments (0.3%) were much lower. Pellets and films were the lowest, both accounting for only 0.1%. This result differs from a report of foam accounting for 99% on coastal beaches in Korea [23]. The shape types of microplastics and their abundance in beaches adjacent to

mariculture areas differed greatly from other studies. In the Pearl River Estuary, there were large numbers of foams (>90%), fragments, and pellets, but no fibers, films, or sponges [26]. In beaches of the Hawaiian Islands of the United States, the common shape types were films and foams [23, 27].

The majority of the microplastics found in beaches adjacent to mariculture areas were composed of particles <1 mm which accounted for 76.0%. The abundance of the size fractions within 4–5 mm was lowest, accounting for only 3.9%. The proportion of the observed microplastics increased with decreasing particle size. Smaller size ranges of microplastics may have a more severe potential impact on marine biota because of their similar size range to food items of marine organisms and a high risk of ingestion [28, 29]. They may have potential impacts such as intestinal blockage, loss of nutrition, and perhaps mortality [30, 31]. In addition, smaller microplastics can act more as carriers of organic contaminants and potentially toxic metals due to their high surface area [32–35].

### ***2.3 Distribution and Characteristics of Microplastics in Beaches Near Fishing Ports***

The abundance of microplastics in beaches near fishing ports ranged from 17.2 to 224.5 particles  $\text{kg}^{-1}$  (Table 1). The average abundance of microplastics was  $97.7 \pm 88.7$  (mean  $\pm$  S.D.) particles  $\text{kg}^{-1}$ , lower than in tourist beaches and beaches adjacent to mariculture areas. Foams, sponges, flakes, fragments, fibers, pellets, and films occurred in beaches near fishing ports. Foams were dominant at these sampling sites, accounting for 50.5% ( $49.4 \pm 75.5$  particles  $\text{kg}^{-1}$ ), followed by flakes 27.5% ( $26.9 \pm 40.9$  particles  $\text{kg}^{-1}$ ). Films were lowest, accounting for 1.9% ( $1.9 \pm 1.8$  particles  $\text{kg}^{-1}$ ). The composition of shape types was similar to those in tourist beaches. The high percentage of foams in beaches near fishing ports is likely due to fishery activities [36].

The size fraction trend shows that the percentage of the observed microplastics decreased with decreasing particle size (Table 2). The percentage of the 4–5 mm size fraction was highest, accounting for 31.2%. The size fraction <1 mm had the lowest percentage, accounting for only 3.8%. This size distribution is different from that in tourist beaches and beaches adjacent to mariculture. However, the specific factors affecting the size distribution trends are difficult to identify. This is likely related to the length of time since the microplastics were released into the environment [37].

## **2.4 *Distribution and Characteristics of Microplastics in Undeveloped Beaches***

The undeveloped beaches (beaches which are not managed) exhibited an abundance range of 13.0–14,712 particles  $\text{kg}^{-1}$  with an average of  $1,302 \pm 3,875$  particles  $\text{kg}^{-1}$ . The abundance range and coefficient of variation (3.0) of microplastic abundance showed very high spatial heterogeneity (Table 1). The abundance of flakes was highest at  $1,151 \pm 3,906$  particles  $\text{kg}^{-1}$  accounting for approximately 88.4% of the microplastics. The total percentages of the remaining microplastic shapes accounted for only <10%. The average abundance and shape type composition of microplastics were similar to those at the beaches adjacent to mariculture. Clearly, the abundance and proportion of microplastics were related to coastal land utilization patterns. Large numbers of woven plastic bags have been used at undeveloped and mariculture beaches for coastal flood control, cultivation pools, or seawater transpiration pools. They are easily fragmented into small flakes within several months. They can be commonly observed at the coastal zone in Shandong province, especially near Laizhou Bay (Bohai Sea) [9].

The percentage of the observed microplastics found in undeveloped beaches showed a decreasing trend with increasing particle size (Table 2). The majority of the microplastics were composed of particles <1 mm, accounting for 77.0%. The percentage of 4–5 mm particles was lowest at 3.3%. Flakes contributed a large amount of microplastics <1 mm which were derived from abandoned plastic woven bags. These abandoned plastic woven bags may remain in the environment for a long time without local management. They readily fragment into microplastic pieces and are then released into the environment [37]. Thus, the local government needs to enhance the management and control of plastic woven bag wastes in the coastal zone.

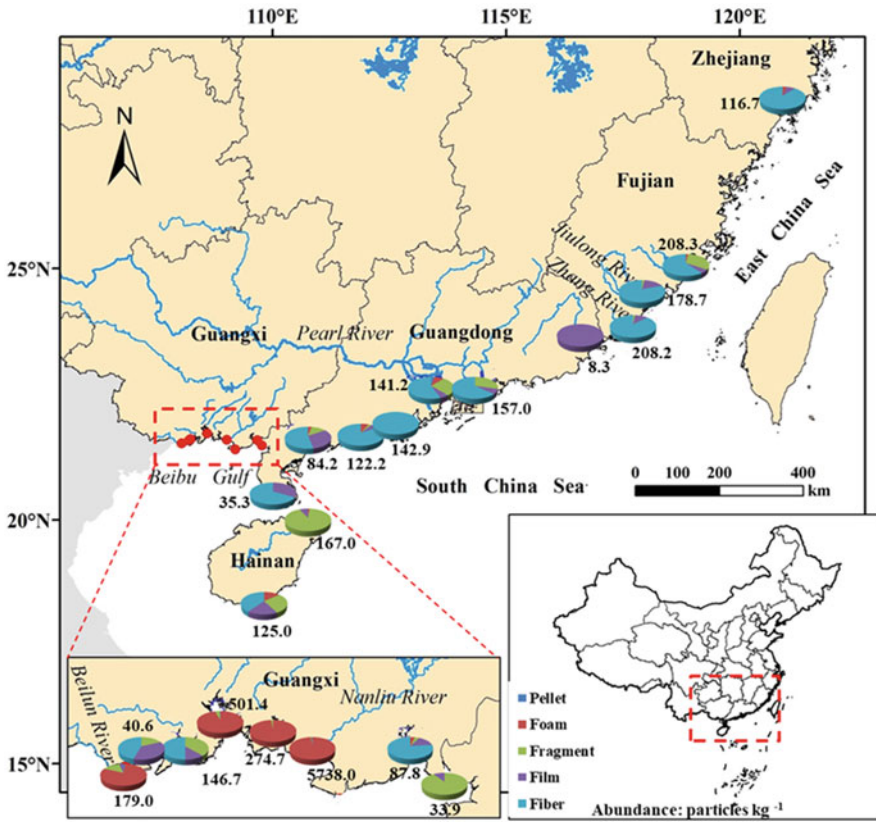
## **3 *Distribution and Characteristics of Microplastics in Coastal Mangrove Wetlands***

Mangrove ecosystems are important in the tropical and subtropical coastal zones of China and have been impacted by microplastic contamination. However, this problem has received little attention both in China and worldwide. Up to now, only three reports have been published on microplastic pollution in Chinese mangrove wetlands [7, 12, 38], and they have focused only on Qinzhou Bay in Guangxi province. There is a lack of research on the burden of microplastic pollution in different coastal mangrove ecosystems of mainland China. We compiled information about the occurrence of microplastics in response to the lack of data. The information compiled includes the abundance of different particle shapes, polymer types, and sources present in coastal mangrove sediments collected along the Chinese tropical and subtropical bays and islands.



### 3.1 Abundance and Spatial Distribution of Microplastics

The abundance of microplastics in mangrove sediments showed high spatial heterogeneity (Fig. 1). The mean microplastic abundance in the mangrove sediments shows that the declining order of mean abundance in sediments among the provinces was Guangxi province (875.3 particles kg<sup>-1</sup>), Fujian province (198.4 particles kg<sup>-1</sup>), Hainan province (146.0 particles kg<sup>-1</sup>), Zhejiang province (116.7 particles kg<sup>-1</sup>), and Guangdong province (98.7 particles kg<sup>-1</sup>). The abundance of microplastics in mangrove sediments ranged from 8.3 to 5,738 particles kg<sup>-1</sup>. The highest abundance was detected at Jinhaiwan mangrove tourist area which is affected by a fishery, mariculture, tourism, and local direct dumping [39], followed by GX4 (501.4 particles kg<sup>-1</sup>) and GX5 (274.7 particles kg<sup>-1</sup>), and the lowest abundance was found at site GD7 (8.3 particles kg<sup>-1</sup>). Microplastic abundances and shape types at most of the sites were much higher than in the contaminated sediments of the coastal mangrove in Singapore [17].



**Fig. 1** Spatial abundance distribution of microplastics with different shape types along the Chinese coastal mangrove sediments

### 3.2 Shapes, Sizes, and Abundances of Microplastics

Microplastics of shape types including fibers, films, fragments, foams, and pellets were found in the mangrove sediments. The foams, fibers, and fragments were the dominant shapes present. This may closely be related to the extensive coastal mariculture activities, shipping activities, reclamation, and inputs of effluent waters from wastewater treatment plants near the survey site [9, 12, 23, 24]. The shape composition of microplastics differed among the mangrove locations. Foam was the main type in Guangxi province with a percentage of 93.2% and mean abundance of 743.5 particles  $\text{kg}^{-1}$ . Offshore oyster mariculture was identified as a dominant source in Guangxi province. There was an oyster (*C. hongkongensis*) culture area of around 10,133 ha in Qinzhou, the largest oyster culture area in Guangxi province [40]. Foam plastic materials are widely used as floating rafts for oyster cultivation and fish farming [12]. A large amount of foam materials was discarded and remained on the coast due to poor management. They would be further broken into small pieces under the prevailing environmental conditions. Fibers were the most common type in Guangdong (71.1%, 70.2 particles  $\text{kg}^{-1}$ ), Fujian (75.9%, 150.5 particles  $\text{kg}^{-1}$ ), and Zhejiang (89.3%, 104.2 particles  $\text{kg}^{-1}$ ) provinces. Flakes were dominant in Hainan province (74.5%, 114.0 particles  $\text{kg}^{-1}$ ). The difference in the distribution of microplastic types may be related to the differences in microplastic types used and discharged locally.

Across all samples the highest abundance of microplastics was found in the smaller size microplastics (1–2 mm). However, the spectra of the size distribution of fibers, films, fragments, foams, and pellets were different. Most fibers (57.1%) comprised particles <1 mm, and the highest percentage was of 0.5–1 mm fibers at 36.3%. The percentages of films, fragments, and foams with a size range of 1–2 mm were highest in their respective particle size fractions (films, 28.6%; fragments, 25.0%; and foams, 48.7%). However, most pellets comprised particles of 4–5 mm. Fibers were the shape type with the smallest mean size ( $1.36 \pm 1.29$  mm) and might therefore be easily ingested by most of the local organisms [41, 42] and subsequently influence the behavior of the marine organisms [43, 44].

### 3.3 Contribution of Human Activities and Mangrove Vegetation to Microplastic Accumulation

The results demonstrate a close relationship between the abundance of microplastics and human activities. The highest abundances of microplastics (5,738 and 501.4 particles  $\text{kg}^{-1}$ , respectively) occurred in Jinhaiwan and Qinzhou bays, possibly due to highly intensive human activities such as tourism, harbor transportation, fisheries, and local direct dumping. Offshore fisheries and oyster cultivation were the dominant sources, with a very large oyster culture area and foam plastic materials used for cultivation in Qinzhou Bay [7, 12]. The microplastic abundance at the Yingluo

mangrove reserve with limited access limitation was lowest, with only 33.9 particles  $\text{kg}^{-1}$ .

The density of vegetation is an important factor affecting the distribution of microplastics in mangrove sediments. We found that microplastic abundance at site GX1 (309.0 particles  $\text{kg}^{-1}$ ) with dense vegetation (approximately 0.5 trees per  $\text{m}^2$ ) was about one order of magnitude higher than at site GX1 (49.0 particles  $\text{kg}^{-1}$ ) with sparse vegetation ( $\sim 0.25$  trees per  $\text{m}^2$ ) in the same mangrove system. This suggests that mangrove areas with dense vegetation intercept more microplastics or plastic debris [18, 45]. Li et al. [12] reported a similar observation in which microplastic abundances in sediments outside the mangroves were much higher than those in the sediments inside the mangroves.

## 4 Sources of Microplastics in the Coastal Environment

### 4.1 *Inland-Source Input*

Large-scale discharge of sewage and garbage dumping are the main land-source input sources of microplastics in the coastal environment. Some detergents, personal care products, and industrial raw materials contain large amounts of microplastic particles [46]. They are not easily separated or removed from the sewage due to their small particle size and are then discharged into the environment with the sewage. The results of Browne et al. [1] show that  $>1,900$  fibers may be released into the wastewater ( $>100$  particles  $\text{L}^{-1}$ ) in the daily cleaning process and there was one microplastic particle ( $<1$  mm) per liter of sewage from a sewage treatment plant. Moreover, river input is another important pathway for microplastic accumulation in the coastal environment. Zhao et al. [47] found that the abundances of microplastics floating on the surface of water bodies in the Yangtze River estuary and its adjacent waters were  $4,137 \pm 2,462$  and  $0.167 \pm 0.138$  particles  $\text{m}^{-3}$ , respectively. The abundance of microplastics decreased sharply after entering the offshore sea from the Yangtze River estuary, showing clear land-source input. In addition, tourism, salt fields, mariculture, port transportation, and fisheries in coastal zones likely also produce microplastic contamination (Fig. 2). For example, coastal dock pontoons (expanded polystyrene) and mariculture facilities in Asia, Australia, Panama, and the United States are broken into thousands of microplastic pieces after damage. This has become an important source of microplastic pollution in the local coastal zone [48].

### 4.2 *Offshore Marine-Source Input*

Plastic pollution caused by offshore operations and ship transportation, including fishing vessels and vessels transporting industrial goods, represents a marine source



**Fig. 2** Occurrence of plastic debris and microplastics on Chinese coastal beaches

of microplastics [49–51]. Microplastics may be produced by damage, dumping, or leakage during maritime transportation. On the other hand, there is a large area of millimeter-scale plastic waste enrichment. This has formed two “garbage belts” in the subtropical circulation areas of the North Pacific and North Atlantic [52, 53]. Garbage zones such as ocean vortex belts can also occur in coastal areas. They may cause microplastics to further migrate and be redistributed under the influence of ocean currents [54, 55].

### 4.3 Sources from the Coastal Atmosphere

Microplastics are present in the atmosphere and can be transported over long distances by atmospheric circulation [56]. Dris et al. [57] observed the presence of synthetic fibers, mixed fibers, natural polymers (artificial silk, cellulose acetate, etc.), and natural fibers (cotton, wool) from the atmosphere in Paris, France. We speculate that there are likely more microplastic types (not only fibers) in the atmosphere. These atmospheric microplastics may settle on land or be sent to the ocean through atmospheric transport. This may be an important source of microplastics in coastal environments.

We investigated the amount of microplastic sedimentation from air to land in Yantai city, Shandong province, East China. The amount of microplastic sedimentation showed seasonal differences. The daily deposition of different types of microplastics ranged from 0 to  $6.02 \times 10^2$  particles  $m^{-2}$  per day. The sedimentation flux of microplastics also varied seasonally, being high in spring, summer, and winter, and the range was from  $4.84 \times 10^2$  to  $6.24 \times 10^2$  particles  $m^{-2}$  per day. However, deposition was lower in autumn at only  $1.30 \times 10^2$  particles  $m^{-2}$  per day. In general, the amount of microplastic sedimentation from air to land reached  $1.46 \times 10^5$  particles  $m^{-2}$  per year, of which the amount of fibers was  $1.38 \times 10^5$  particles  $m^{-2}$  per year. Fragments, thin films, and foams were deposited at  $6.29 \times 10^3$ ,  $7.65 \times 10^2$ , and  $2.45 \times 10^2$  particles  $m^{-2}$  per year, respectively. The total amount of

microplastics obtained through atmospheric deposition in the local region each year can reach  $2.33 \times 10^{13}$  particles, approximately 0.9–1.4 tonnes (assuming that all microplastic types are fibers and estimated by the density of polyamide and polyester polymers which are widely used in the textile industry [58]). Dris et al. [58] estimated an amount of fiber settled in the atmosphere each year in Paris, France, with a 2,500 km<sup>2</sup> populated area, of about 3–10 tonnes. This indicates that microplastics (especially fibers) in the atmospheric environment are likely important sources of different microplastic types in coastal environment. However, atmospheric microplastic contamination has been little studied. Studies of contamination by atmospheric microplastics and its contribution to the land and ocean require further investigation.

## 5 Conclusions

Microplastic pollution occurs widely in different coastal beaches and wetlands and has complicated sources. Differences in the distribution of microplastics are closely related to the impact of human activities. Under the intervention of human activities, different patterns of land utilization are found in the coastal zone. This makes the distribution of microplastics in coastal zones regional and special. In the future the control and management of microplastic contamination in coastal wetland environments need to be implemented with regional specificity and accuracy.

**Acknowledgments** The authors gratefully acknowledge the financial support by the National Key Research and Development Program of China (Grant No. 2016YFC1402202), the Key Research Program of Frontier Sciences, CAS (Grant No. QYZDJ-SSW-DQC015), the National Natural Science Foundation of China (Grant No. 41771351), the External Cooperation Program of BIC, Chinese Academy of Sciences (Grant No. 133337KYSB20160003), and Sino-German initiatives WTZ China in the framework of the MEGAPOL consortium supported by BMBF (Contract No. 03F0786A). We appreciate the contributions of language polishing by Professor Peter Christie from Institute of Soil Science, Chinese Academy of Sciences, China.

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