Microplastics in the Sediments: From Rivers to Lakes Investigated in the Biggest Freshwater Lake (Poyang Lake) Basin and Yangtze River in China

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Abstract In recent years, microplastic (MP) pollution is increasingly becoming a new environmental problem of global concern. Rivers and lakes are important transport channels for MPs entering the ocean, and their contribution to MP pollution can't be ignored. In this chapter, the largest freshwater lake in China, the Poyang Lake, and its typical basin wetland areas are selected as the research areas. Wetland soils or sediment samples were collected; the types, particle size, abundance, distribution, and the main sources of MPs in these samples were investigated using the flotation separation and microscopic identification methods. The results show that foams (polystyrene), fibers (low-density polyethylene), debris, and films are found in the sediments of the typical wetlands; the debris-based MPs were the major and accounted for 50–70% of the total, followed by film MPs and fiber MPs, and foam MPs accounting for the lowest proportion. MPs with size less than 1 mm occupied the dominant percentage, accounting for more than 60% of the total MPs. The distribution of MPs in the sediments of the typical wetlands in the Poyang Lake is positively related to human activities; the differences of MP abundance among

different regions are influenced by human activities, hydrological conditions, river inputting, etc. The composition of MPs among different regions is closely related to the lifestyle of people in the region and the physical and chemical properties of MPs. This chapter can further supplement the basic data of the research on MP pollution in freshwater wetlands, such as rivers and lakes in China, and provide a basis for further research on MP pollution and its ecological impact.

Keywords Microplastics, Poyang Lake, Sediments, Typical Natural Reserve wetland, Yangtze River

1 Introduction

Microplastics (MPs) refer to plastic polymers with particle size less than 5 mm, which have been confirmed as emerging pollutants and have received increasing attention. Because of small particle sizes and low density, MPs in the environment can migrate under the action of external forces, such as wind, river, and ocean current, and can be used as carriers of organic pollutants and heavy metals. Moreover, MPs can be eaten by animals by mistake and are difficult to be excluded from the body, which will cause the physical damage to organisms, blockage of the digestive tract, or pseudo-satiety and then cause the decrease of the feeding efficiency, energy shortage, injury, or death of organisms. Over the past 10 years, more and more studies had demonstrated the types, abundance, distribution, sources, and biological effects of MPs in water surface and sediments in marine and coastal environments.

In this chapter, the typical wetland areas in the Poyang Lake were selected as the research areas, which mainly include the areas seriously affected by human production and life activities, the entrance of the five major rivers of the Poyang Lake, the National Nature Reserves, and the outflow areas of the Poyang Lake flowing into the Yangtze Rivers and other important wetland areas. The soils or sediment samples in the wetlands were collected as the research materials; the flotation separation methods and microscopic identification methods were used in order to investigate the types, particle size, abundance, distribution, influencing factors, and main sources of MPs in all sediment samples.

The results show that foams (polystyrene), fibers (low-density polyethylene), debris, and films are found in the sediments of the typical wetlands, such as Poyang Lake and Le'an River section, the entrance of the five major rivers of the Poyang Lake, the outflow areas of the estuary of the Poyang Lake and the Yangtze River section, and other important wetland areas. And the debris-based MPs were the most important and accounted for 50% to 70% of the total, followed by the film-based MPs and fiber-based MPs, and foam MPs accounted for the lowest proportion. According to the analysis results of the particle size of MPs, MPs with particle

size less than 1 mm occupied the dominant position, accounting for more than 60% of the total number.

The abundance of MPs was calculated by the dry weight of sediments. The average abundance of MPs in the sediments of the Poyang Lake wetland was 1,146.17 particles kg^{-1}. And the abundance of MPs in different regions shows spatial differences. The average abundance of MPs in the Poyang Lake and the Le'an River section was 1,799.56 particles kg^{-1}; and the average abundance of MPs in the entrance of the five major rivers of the Poyang Lake was 1,225.25 particles kg^{-1}; the average abundance of MPs in the National Nature Reserves was 82.33 particles kg^{-1}; and the average abundance of MPs in the outflow area of the Poyang Lake Estuary and Yangtze River section was 907.4 particles kg^{-1}. There were differences in the proportion, size, and abundance of MP particles in different study areas, but all of the samples were dominated by MPs less than 1 mm.

The surface morphology and attached materials of the MPs separated in the sediments of the Poyang Lake Basin were analyzed by scanning electron microscopy and energy dispersive spectroscopy. The results show that the surface of the MP samples in the environment is rough, with obvious weathering characteristics and some residues. There are impurities such as clay in the surface crack or attached Si, Fe, Mg, O, Al, Ca, and other elements. Therefore, the surface morphology and complexity of MPs that have existed in the environment for a long time will become carriers of persistent organic pollutants and toxic and harmful substances and form diffusion pollution through co-migration in the environment. In the future, more attention should be paid to the dynamic processes and ecological effects of MPs in the riparian environment.

The distribution of MPs in the sediments of the typical wetlands in the Poyang Lake is closely related to human activities and life activities; the differences of MP abundance among different regions are affected seriously by human activities, hydrological conditions, river inputting, etc. The composition of MPs among different regions is closely related to the lifestyle of people in the region and the physical and chemical properties of MPs.

2 Methodologies

2.1 Overview of the Study Area

Poyang Lake is the largest freshwater lake in China. It is located in the northern part of Jiangxi Province and is one of the three rivers and lakes in the middle and lower reaches of the Yangtze River. It is surrounded by mountains on three sides and lies between 28°22′–29°45′north latitude and 115°47′–116°45′ east longitude. Poyang Lake is the receptor for the inland source material in its basin, and it is also an important source of agricultural irrigation and industrial and domestic water in the basin. The Poyang Lake and the five major rivers (the Ganjiang River, the Fuhe River, the Xinjiang River, the Raohe River, and the Xiushui) constitute the Poyang

Lake water system, and the Ganjiang River has four branches named the north branch, the south branch, the west branch, and the middle branch. Consequently, the lake's hydrological conditions, sediment transport, and sedimentation are affected by inputs from these five major rivers. In recent years, due to the impact of the domestic garbage discharged by nearby residents, frequent waterway transportation, and poorly regulated fishing [1], the plastic pollution problem of the five major rivers in Poyang Lake has become serious. Therefore, it is of great benefit to comprehensively and accurately evaluate the distribution characteristics of MPs in the entrance section of the five major river systems in the Poyang Lake.

2.2 Sampling Methods and Sampling Sites

In this chapter, all sample were collected in different seasons from December of 2016 to July of 2018, the typical wetlands were selected as the study areas, such as the entrances of the five major rivers in the Poyang Lake Basin, the typical wetland of the National Nature Reserves in the Poyang Lake, the estuary of the Poyang Lake and the Yangtze River section, and other important wetland areas. Five-point sampling methods with an area of each 50×50 cm^2 were selected within each 10×10 m^2 standard sampling quadrat to investigate and collect the sediment samples, and samples were collected by retrieving about 5 cm depth of sediments and placing them into the sealed tin foil bags. Sampling was conducted during periods of steady water flow. All samples were transported back to the laboratory and timely pretreatment in the laboratory.

2.3 Separation and Identification of Microplastics

In the laboratory, extraction of plastic particles was achieved by density separation using a saturated NaCl (1.5 g cm^{-3}) solution as the density-controlled liquid [2]. The dry samples were transferred into a glass beaker for density separation, then the salt solution was added, and the sample was magnetically stirred for 2 min. After the sediments had settled, the supernatant was carefully poured through a sieve with 2 μm mesh size. The sediment samples were separated into the size fractions of 4.0–5.0, 3.0–4.0, 2.0–3.0, 1.0–2.0, and < 1.0 mm. Materials retained on the mesh were examined by the naked eye for potential MPs or under a stereomicroscope to select suspected MPs (0.002–5 mm in size).

At present, combinations of physical (e.g., microscopy) and chemical (e.g., spectroscopy) analyses are widely used [3]. The membrane and the material retained on the sieves were dried and observed under metallographic microscope (Shanghai Precision Instrument Company, China) to select plastic debris. All particles were photographed using a Nikon digital camera DXM1200F connected to the microscope. A desktop scanning microscope (S-3400N, Hitachi Electronics, Japan) with 5–3,000× magnification was used to observe the morphology of MPs.

2.4 Data Processing and Analysis

The individual numbers of MPs were counted by using Nano Measurer 1.2 software, and the particle sizes were measured along the longest side of the MPs. The infrared spectrum of the separated MP particles was analyzed by using an infrared spectrometer (Nicolet 6700). All sampling site maps were plotted by using ArcGIS 10.2 software; all experimental data were processed by using Origin 9.0 software. On the other hand, the PROC UNIVARIATE procedures were also used to test the normality of the data, and PROC TTEST procedure was used to test for homogeneity in the variances. Duncan's multiple-range test was used to perform multiple comparisons and evaluate whether the MP abundance significantly differed between different sites and seasons. The level of significance was set at $P < 0.05$. All statistical analyses were performed in SPSS v.20 [4].

3 Distribution Characteristics of Microplastics in the Sediments of the Le'an River Basin of the Poyang Lake Section

3.1 Overview of the Typical Areas Disturbed and Polluted by Artificial Activities in the Poyang Lake

This section focuses on the typical areas affected by the human activities. The Le'an River of the Poyang Lake is selected as the study area which is seriously affected by mining. The Le'an River is the main tributary of the Raohe River, one of the major five rivers of the Poyang Lake Basin. It originated in the southwest foot of Wulong Mountains in the northeast of Wuyuan County in Jiangxi Province; it is 279 km long and has a basin area of 8,456 km^2. The upstream of the Le'an River is mainly located in the area of Dexing City in Jiangxi Province, mainly flowing through residential areas. Garbage dumped in nearby residential areas is the major source of plastic pollution. The Dawu River is the main tributary of the Le'an River, with a total length of 14 km. It runs through the largest copper mine in Asia and the third in the world, the Dexing Copper Mine. In recent years, the Dawu River has become a typical area with extremely serious pollution due to the influence of mineral exploitation and garbage dumping. The downstream of the Le'an River is located in Poyang County of Jiangxi Province, and the environmental pollution problem is not optimistic, due to the influence of the nearby residents' domestic garbage, frequent shipping in the channel transportation, and disordered fishing. It has an important ecological significance to choose the Le'an River of the Poyang Lake as the study area.

3.2 Sampling Sites in the Le'an River of the Poyang Lake

In December 2016, nine typical sampling sites were set up from the upstream to the downstream of the Le'an River (S1, S2, S3, S7, S8, S9) and included other three sites (S4, S5, S6) located in the Dawuhe River of the tributary of the Le'an River in Dexing Mine Factory (Fig. 1). The first sampling site (S1) was located in the headstream of the Le'an River in Haikou Town in Wuyuan County of Jiangxi Province, the other two sites (S2 and S3) located in the middle stream of the Le'an River in Dexing City of Jiangxi Province, and the other three sites (S7, S8, and S9) located in the downstream of the Le'an River and Poyang Lake in Poyang City of Jiangxi Province. All samples were collected by five site sampling methods and transported back to the laboratory and timely pretreatment in the laboratory.

3.3 Type and Particle Size Distribution of Microplastics in the Le'an River of the Poyang Lake

MPs were separated from the sediment samples by flotation and identified by microscope. The results of microscopic identification show that there are four types of MPs in the Le'an River of the Poyang Lake, such as debris, foams, films, and fibers as shown in Fig. 2. The color of the debris MPs is mainly milky white, blue, and yellow, the shape of which is mostly flat debris with damaged border.

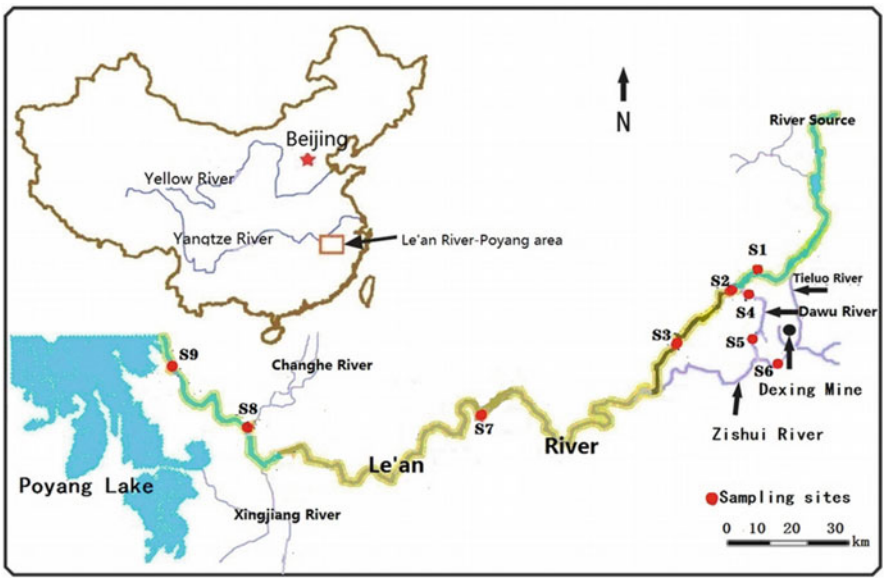

Fig. 1 Location of sampling sites in the Le'an River Basin of the Poyang Lake

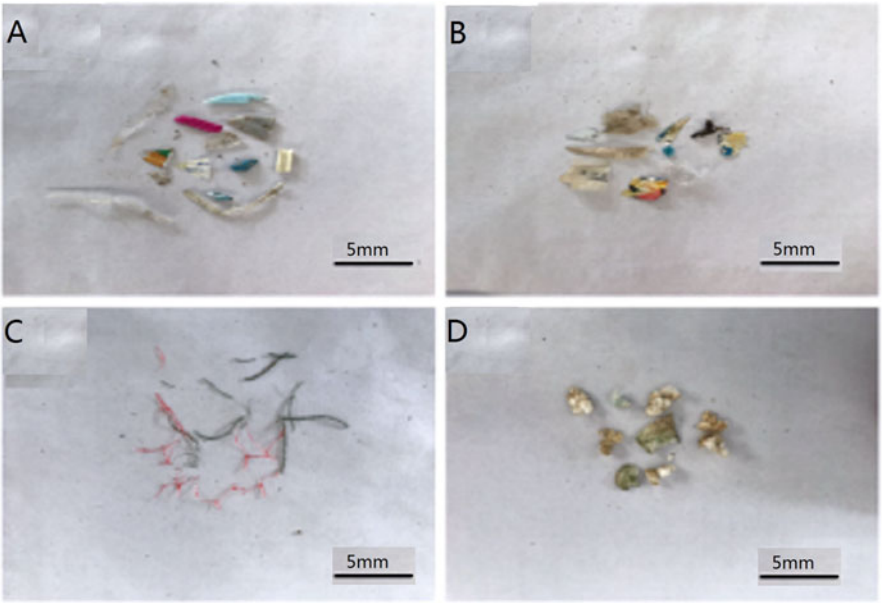

Fig. 2 Different MP samples in the sediments of the Le'an River Basin (unit: cm). (**a**) Debris MPs; (**b**) film MPs; (**c**) fiber MPs; (**d**) foam MPs

The color of film MPs is mainly milky white, red, and light blue; the shape of film MPs is mostly irregular curly. Fiber MPs are mainly blue in color and most of their shapes are curly. The color of foam MPs is mostly white, and their shape is mostly block or round.

At all the sampling sites, the proportion of debris MPs is the highest, accounting for 58.3% of the total, followed by foam MPs, accounting for 21.5%, and film MPs and fiber MPs accounting for 13.8% and 6.4%, respectively. The proportion of MPs is shown in Fig. 3.

The particle size distribution of MPs is shown in Fig. 4. MPs with the particle size <1 mm were the most abundant fraction in sediments, accounting for 62.4% of the total, and the abundance of MPs decreases with the increase of the particle size among 1–2 mm MPs, accounting for 18.7% of the total, and 2–3 mm, 3–4 mm, and 4–5 mm accounting for 8.7%, 6.9%, and 3.3%, respectively. The results of the particle size and the distribution are consistent with the results of Shandong coastal, Yangtze River Estuary, and Singapore mangrove area.

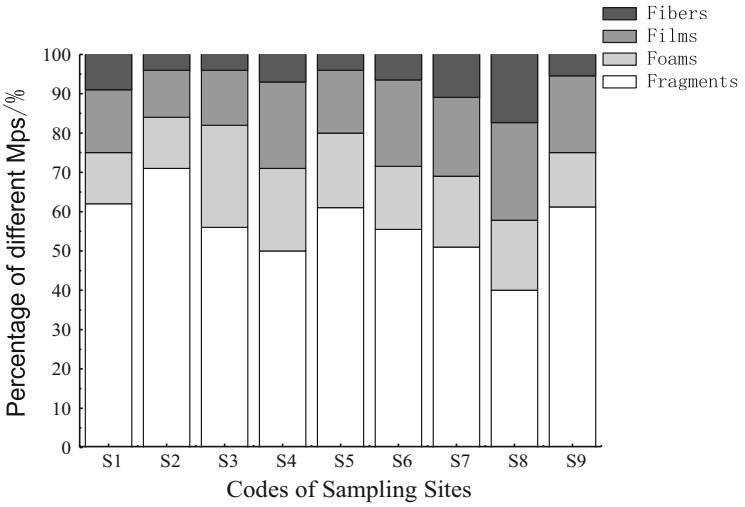

Fig. 3 Composition proportion of different forms of MPs in the Le'an River Basins

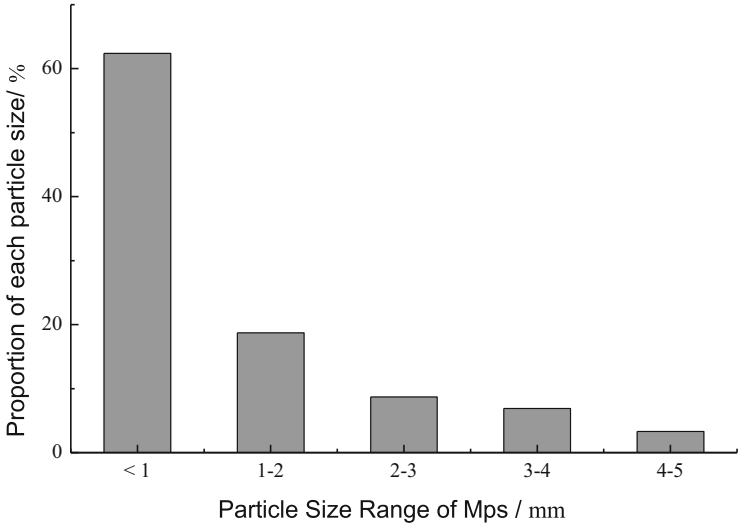

Fig. 4 Percentage chart of different sizes of MPs in the Le'an River Basins

3.4 Microplastics Abundance in the Le'an River of the Poyang Lake

This chapter carries out flotation separation methods of the sediments from the nine sampling sites in the Le'an River Basin. The average abundance value of MPs in the above nine sampling sites is 1,799.56 particles kg^{-1}. The abundance values of MPs

in different sampling sites are shown in Fig. 5. The results show that the average abundance value of MPs in the residential areas of Dexing Copper Mine (the S4 point) is 3,153 particles kg^{-1}, which is the highest in the whole study area of the Le'an River, the average value of MPs in the S5 point of Dexing middle school is 2,842 particles kg^{-1}, and the average value of MPs in the S6 point of the production area of Dexing Copper Mine is 2,619 particles kg^{-1}. The average value of MPs in the S1 point of the upstream of the Le'an River in Haikou Town is 842 particles kg^{-1}, which is the lowest in the whole study area of the Le'an River. At the same time, the nine sampling sites can be divided into three different regions including the upstreams of the Le'an River (S1, S2, and S3), the tributaries of the Le'an River (S4, S5, and S6 in the Dawu River), and the downstreams of the Le'an River (S7, S8, and S9). The average abundance value of MPs in the Dawu River is 2,871.33 particles kg^{-1}, and the values of MPs in the upstreams and downstreams of the Le'an River are 1,366.33 particles kg^{-1} and 1,121.33 particles kg^{-1}, respectively. The order of the average abundance values of MPs in the three areas were that the Dawu River, the downstreams of the Le'an River, the upstreams of the Le'an River, and the abundance values of MPs in the Dawu River are significantly higher than those in the downstreams and the upstreams of the Le'an River ($P < 0.05$). The main reason for this difference may be that the population density on both sides of the Dawu River is relatively concentrated and the domestic and industrial waste plastics are more than those of the upstream and downstream of the Le'an River, which leads to the increasing of the MP abundance. As a tributary of the Le'an River, Dawu River is the main accumulation area of the MPs because of its small surface water scouring effect. The abundance of MPs in the downstream of the Le'an River is significantly higher than that in the upstream ($P < 0.05$). The other reason may be that the MPs in

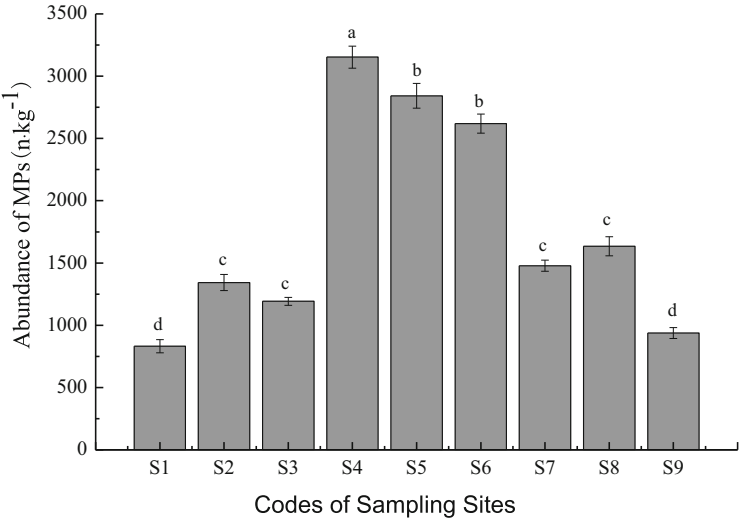

Fig. 5 Abundance value of MPs in the Le'an River Basin

Table 1 Comparison of the MP abundance in the Le'an River Basin and other reported areas

Study area	MP size	MP abundance	Regions
Mediterranean coastal beach (Venice Lagoon)	<5 mm	2,175 particles kg^{-1}	Noam et al. [5]
Halifax Port, Nova Scotia, Canada	<5 mm	500 particles kg^{-1}	Mathalon et al. [6]
Yangtze Estuary	<5 mm	4,137 particles kg^{-1}	Zhao et al. [7]
Belgian coastal beach	38 μm to 5 mm	120 particles kg^{-1}	Claessens [8]
Coastal beach of Shandong Province	0.025–5 mm	834 particles kg^{-1}	Zhou et al. [9]
The Le'an River of the Poyang Lake	0.025–5 mm	1,799.56 particles kg^{-1}	This study

the upstream of the Le'an River and Dawu River can be accumulated to the downstream of the Le'an River through the hydrodynamic exchange, which leads to the abundance of MPs in the area higher than those in the upstream of the Le'an River.

The results of this study are compared with those of domestic and foreign research areas, which are shown in Table 1. Noam et al. [5] found that MP abundance in Mediterranean coastal beaches (Venice lagoon) was as high as 2,175 particles kg^{-1}. Mathalon et al. [6] found that MP abundance in the Halifax Harbor, Nova Scotia, Canada, was 500 particles kg^{-1}. Zhao Shiye et al. [7] conducted a survey of MPs in the Yangtze River Estuary, and the results showed that MP abundance was as high as 4,137 particles kg^{-1}. Claessens et al. [8] took the sediment samples near the high water level in the intertidal zone on Belgian coastal beach. The results showed that MP abundance was 120 particles kg^{-1}. Zhou Qian et al. [9] surveyed the estuaries along the coast of Shandong Province. The results showed that MP abundance was 824 particles kg^{-1}. Compared with the abundance of MPs in the above regions, MP abundance in the Le'an River of the Poyang Lake was on the upper middle level.

3.5 Source Analysis of Microplastics in the Le'an River of the Poyang Lake

Based on the field investigation and the above research results, the source and abundance distribution of MPs in the Le'an River of the Poyang Lake are analyzed. The first important source is domestic waste plastic (such as plastic cases) and plastic toys discharged from surrounding residential areas, engineering plastic woven bags produced by flood control and dam filling, and fertilizer woven bags used in agricultural production. The second source is that the film plastic products produced by food packaging bags and agricultural products discharged from living areas are cracked. At the same time, the waste plastic bags produced by fishery activities in the study area are also one of the sources of film MPs in the Le'an River of the Poyang

Lake. Another important source is that aquaculture and fishing activities have led to the abandonment of some nets and fishing lines into the environment and then debris into the fine fibrous debris by long-term environmental effects. At the same time, the discharge of domestic water may also be the source of fiber MPs. Previous studies have shown that more than 2,900 fibers can be produced into the wastewater at a time in the daily laundry cleaning process, and the amount of fiber in wastewater can be up to more than 100 particles L^{-1} [10].The other source is that the disposable plastic box produced in human daily life and plastic foam floaters in fishing boats are made up of a large number of foam plastic particles, which are easily cracked into the environment and produce MPs. In addition, some foam plastic buoys used in aquaculture are also one of the important sources of the foam MPs.

4 Distribution Characteristics of Microplastics in the Sediments of the Five Major Rivers of the Poyang Lake

4.1 Overview of the Main Five Rivers of the Poyang Lake

The five major tributaries of the Poyang Lake are the Ganjiang River, the Fuhe River, the Xinjiang River, the Raohe River, and the Xiushui River. The Ganjiang River originated from Ganzhou of Jiangxi Province, flowing through Ganzhou City, Ji'an City, and Nanchang City, and was injected into the Poyang Lake in Wucheng Town in Yongxiu County of Jiujiang City. The Ganjiang River is also the longest river among the five major rivers of the Poyang Lake. The Fuhe River originated from Guangchang County and was injected into the Poyang Lake via QinglanHu Lake, which is the second largest river in the five major rivers of the Poyang Lake. The Xinjiang River originated from the junction of the two Provinces of Jiangsu Province and Zhejiang Province and was injected into the Poyang Lake through Ruihong Town of Yugan County in Jiangxi Province. The Raohe River is formed by the confluence of the two tributaries of the Le'an River and Changjiang River, which merge into the Poyang Lake through the intersection of Longkou Wharf in Lianhu Town of Poyang County in Jiangxi Province. The Xiushui River is the smallest tributary of the main five rivers of the Poyang Lake and is also transferred to the Poyang Lake by Wucheng Town in Yongxiu County of Jiujiang City. The main five rivers of the Poyang Lake gathered the most of the surface water in Jiangxi Province and eventually flowed into the Poyang Lake.

4.2 Sampling Sites in the Entrances of the Main Five Rivers of the Poyang Lake Basin

In November of 2017, eight representative sampling sites in the entrances of the five rivers, respectively, were also selected, and the sediment samples were collected. The position of each sample is shown in Fig. 6. They are mainly the estuary of the north branch of the Ganjiang River in Wucheng Town of Jiujiang City (S1), the estuary of the middle branch of the Ganjiang River in Zhugang Town of Xinjian County (S2), the estuary of the south branch of the Ganjiang River in Jiangjunzhou Farm of Nanchang County (S3), the estuary of the Xiushui River in Wucheng Town (S4), the estuary of the Fuhe River in Dutou Town of Nanchang County (S5), the

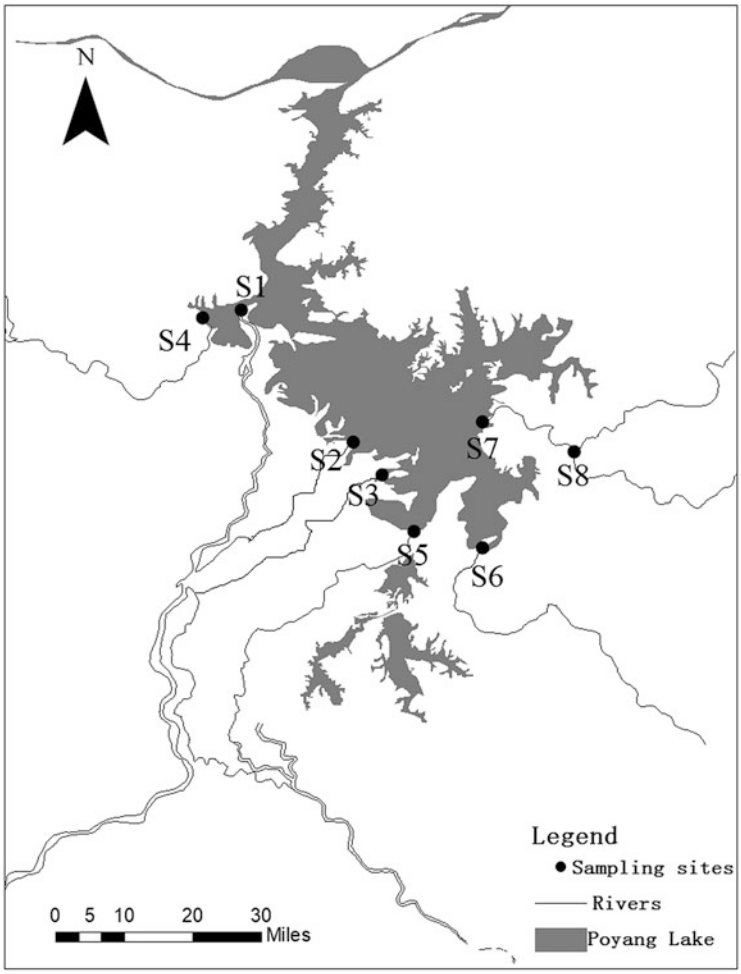

Fig. 6 Location of the sampling sites in the five major rivers of the Poyang Lake

estuary of the Xinjiang River in Ruihong Town of Yugan County (S6), the estuary of the Raohe River in Longkou Village of Poyang County (S7), and the estuary of the Le'an River in Yaogongdu of Poyang County (S8). All samples were also collected by five site sampling methods and transported back to the laboratory and timely pretreatment in the laboratory.

4.3 Shapes and Abundances of Microplastics in the Sediments of the Main Five Rivers of the Poyang Lake Basin

In this part, the shapes of MPs in the sediments of the main five rivers were identified by using the microscope, and the MP types of the five rivers are also mainly composed of debris, films, foams, and films in each point.

The composition of different forms of MPs is shown in Fig. 7. The debris MP particle size is relatively concentrated in the sediments, most of them were less than 1,000 μm, and the range of particle size was from 25 μm to 1,000 μm. But fibers, foams, and films had a wide range of particle size, and the ranges of the three types particle size were from 100 μm to 5,000 μm; the particle size is mostly concentrated in the range from 500 μm to 3,500 μm. The composition proportion of MPs in the sediments of different sites had both consistency and some differences.

The results of MP abundance in the eight sampling sites at the entrance of the major five rivers of the Poyang Lake are shown in Fig. 8. The abundance of MPs in the sediments of the north branch of the Ganjiang River (S2) is the highest, and the

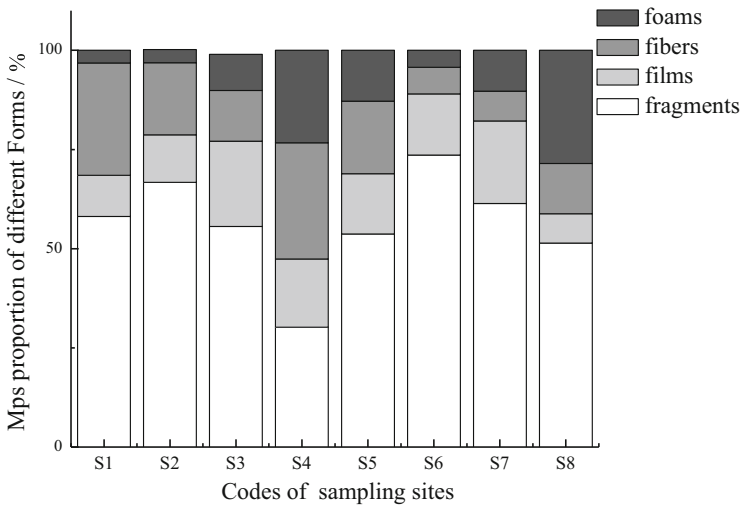

Fig. 7 Composition of MPs in the main five rivers of the Poyang Lake

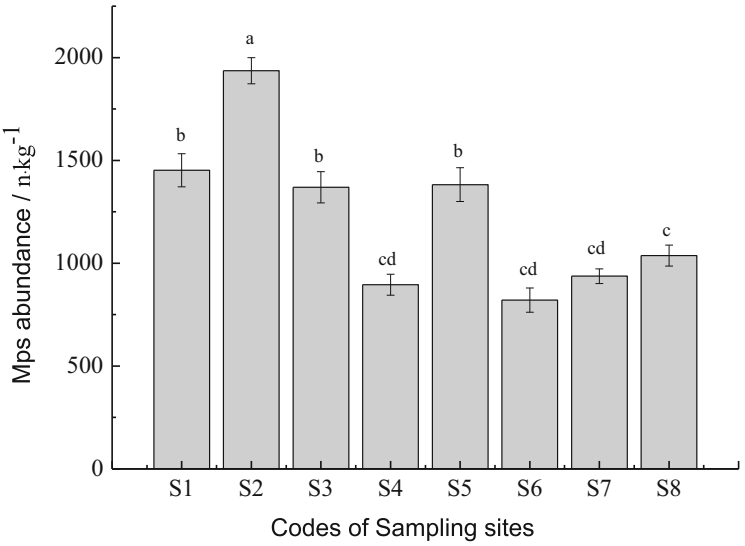

Fig. 8 MP abundance of plastic in each sampling site

value is 1,936 particles kg^{-1}, which is significantly higher than that of the entrances of other branches of the Ganjiang River (S1, S3, S5). The MP abundance in the sediments of the entrance in the Le'an River (S8) is 1,037 particles kg^{-1}, but there was no significant difference with the entrances of the Xiushui River (S4), the Xinjiang River (S6), and the Raohe River (S7).

4.4 Microplastics Polymer Components of the Main Five Rivers of the Poyang Lake Basin

The four types typical MPs of debris, films, foams, and films in the sediments of the main five rivers of the Poyang Lake Basin were selected for identification by infrared spectroscopy. One of the hard plastic debris of the infrared spectrum is shown in Fig. 9a, which shows that the composition is polyethylene. The white typical plastic woven bag debris infrared spectrum is shown in Fig. 9b, which shows that the main composition is polypropylene. The infrared spectrum of the white foam is shown in Fig. 9c; it shows the composition is polystyrene. The infrared spectrum of the red plastic bag films MPs is shown in Fig. 9d, which is mainly composed of polypropylene. The other kind of MPs is white plastic bag film, and the infrared spectrum is shown in Fig. 9e, which is mainly composed of polypropylene. The fishing line was selected as the fiber type and analyzed by spectroscopic analysis in Fig. 9f, which shows the MP composition is polyethylene. The polymer components of the MPs can also be found in the main five rivers of Poyang Lake in the study that have certain similarities and differences compared with other studies. Zhao et al. [7]

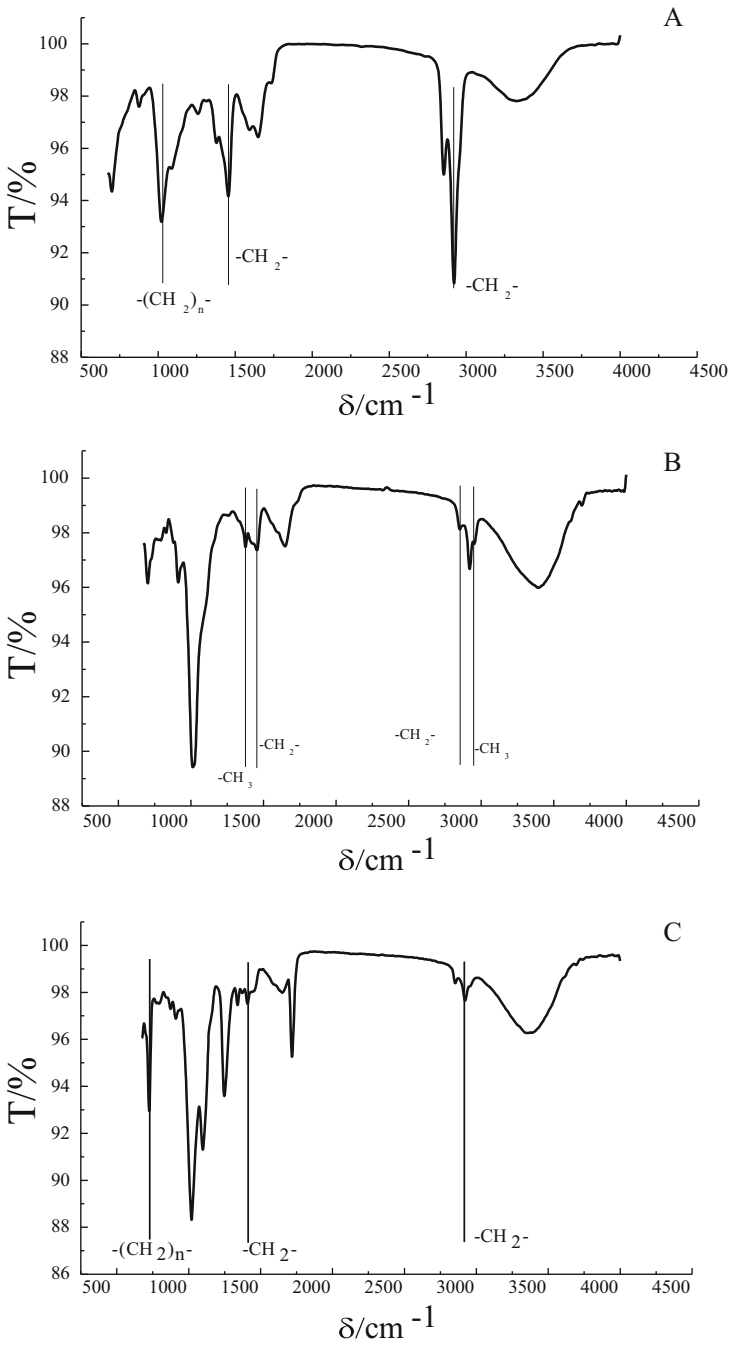

Fig. 9 FTIR spectrums of different MP samples in sediments. (**a**, **b**) Debris MPs; (**c**) film MPs; (**d**, **e**) fiber MPs; (**f**) foam MPs

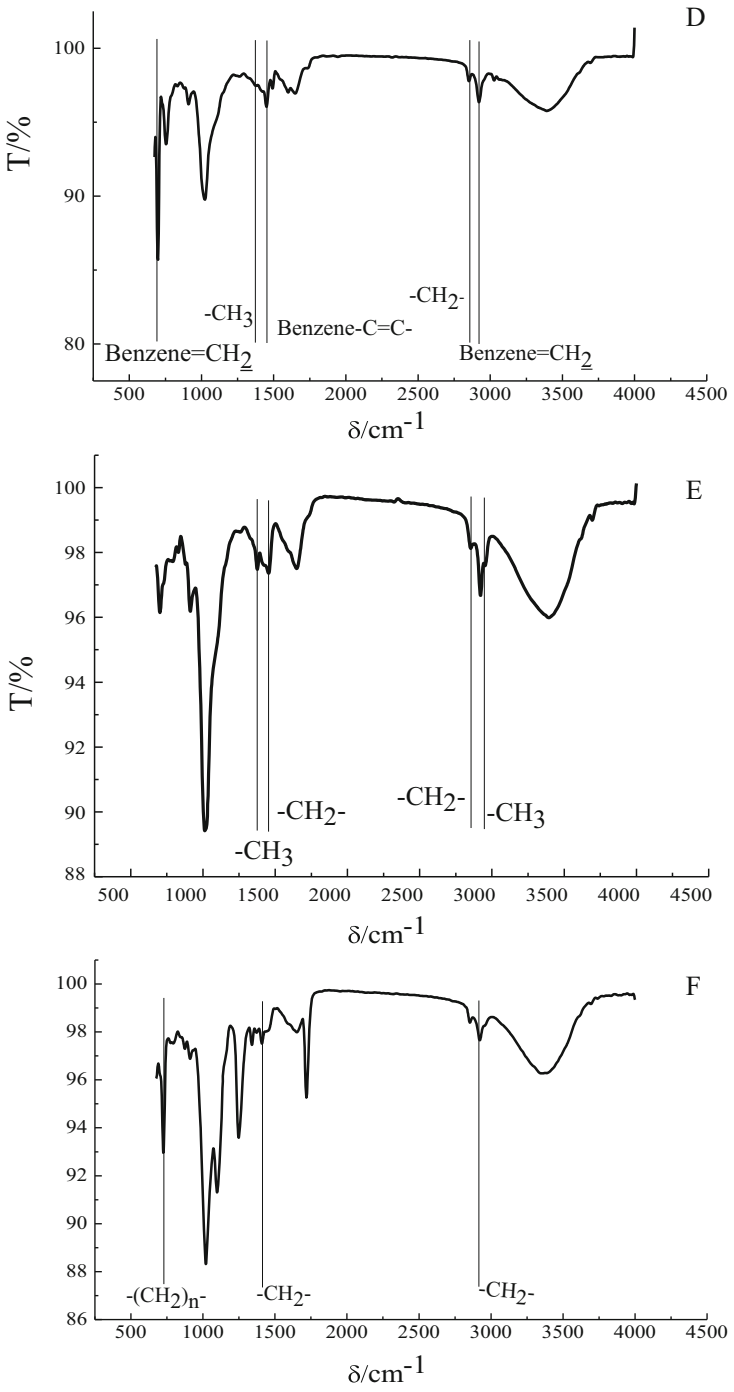

Fig. 9 (continued)

considered that the polymer composition of the MPs of the debris is polyethylene and polypropylene. The polymer components of the film are polyethylene, polypropylene, and polyphenylene, while the particles contain four polymer components of polyethylene, polypropylene, polyvinylchloride, and polytetrafluoroethylene.

The infrared spectrum of the typical MPs in the main five rivers of the Poyang Lake Basin was compared with the standard infrared spectrum of the corresponding polymer components, and the peaks of the infrared spectrum band of the MPs in the environment were found to be significantly more than the standard infrared spectrum, although the polymer components of the two are the same substance. For example, the peaks in the low-band region of the infrared spectrum of the debris MPs in the environment are significantly more than the standard, especially at the band of 750–1,500 cm^{-1}, and the infrared spectrum is significantly different in the environment, while the standard spectrum is flat at the band range with almost no significant fluctuations. Corcoran et al. [11] considered that the surface of MPs in the environment is oxidized to a certain extent, and there are many foreign substances, which further illustrate the complexity of the MP surface in the environment. At present, more and more researchers at home and abroad try to explore the effects of MPs on aquatic organisms. Koelmans [12] concluded that micropolystyrene has direct toxic effects on the cell and molecular levels of the marine mussels. Cole et al. [13] found that the intake of MPs by zooplankton can significantly change the feeding ability of phytoplankton, and the long-term exposure to polystyrene MPs will significantly reduce the reproductive rate of *Phytophthora*. But there is no significant effect on its survival.

4.5 Comparison of Microplastics Abundance of the Main Five Rivers in Poyang Lake Basin

The order of MP abundance values of the main five rivers in the Poyang Lake Basin are as follows: the Ganjiang River>the Fuhe River>the Raohe River>the Xiushui River>the Xinjiang River. There are many reasons for these differences. The first reason is that the runoff of the river has a certain influence on the MP abundance. The greater the runoff of the river, the more it flows through residential areas, and the more plastic waste is discharged into rivers. The Ganjiang River is the largest runoff river among the five rivers in the Poyang Lake Basin; its runoff reaches 70.2 billion m^3, which is far greater than the other four rivers. The MP abundance of the three tributaries is greater than that of other lakes. The second reason is that the amount of sand from the five rivers in the Poyang Lake Basin also affects the abundance of MPs. The most contribution of sediment transport in the Poyang Lake Basin is the Ganjiang River; its contribution rate of sediment transport is 40%, the Fuhe River and the Raohe River account for 20% respectively, the Xiushui River and the Xinjiang River account for 12% and 8% respectively.

4.6 Microplastics Types of the Main Five Rivers in the Poyang Lake Basin

The MP composition ratios of the north branch of the Ganjiang River, the middle branch of the Ganjiang River, and the south branch of the Ganjiang River have certain similarities. The proportion of debris and fibers are all the highest in the total MPs of the sediments in all branches of the Ganjiang River. The difference is that the proportion of foam MPs in the north branch of the Ganjiang River and the middle branch of the Ganjiang River is higher than that of film MPs, while the proportion of foam MPs in the south branch of the Ganjiang River is lower than that of films MPs. The reason may be due to the foam plastics in domestic waste into the entry of the main branches of the Ganjiang River into the Poyang Lake in Wucheng Town in Jiujiang City and the middle branch of the Ganjiang River into Zhugang Town in Xinjian County. In addition to the above reasons, there are also some fishing boats and shipping vessels in the main river basins of the Ganjiang River, and the plastic foam float in the hull also produces a certain amount of foam plastics in the environment. The composition of MPs in the estuary of the Xiushui River is relatively even, and the abundance values of MPs of debris, films, foams, and films account for 30.2%, 17.2%, 29.3%, and 23.3%, respectively. The reason may be that there is domestic sewage discharge around the sampling sites. Previous studies have shown that in the daily cleaning process, more than 2,900 fibers can be produced into the wastewater per cleaning. The amount of fibers per unit volume of discarded water can be more than 100 particles L^{-1}. Moreover, the abandoned fishing nets in the water are cracked to produce MPs. The proportion of MPs in the estuary of the Xinjiang River and the Raohe River is similar. The values are 73.6% and 61.4%, respectively, and the highest proportion of debris MPs, followed by the thin film MPs, with the smallest proportion of foams and films. The proportion of MPs in the estuary of the Le'an River is different from that of other sampling sites. The proportion of the film MPs is the lowest, accounting for only 7.4%, while the proportion of the fiber MPs is second only, accounting for 28.5%. The reason is similar to the estuary of the Xiushui River. There are a large number of abandoned fishing nets around the sampling sites, which produce a large number of fiber MPs after cracking. Therefore, the composition ratio of MPs in the environment is closely related to the production lifestyle around the plot.

5 Distribution Characteristics of Microplastics in the Sediments of Typical National Nature Reserves of the Poyang Lake

5.1 Overview of the Typical National Nature Reserves of the Poyang Lake Basin

In this section, the typical Nature Reserves of the Poyang Lake were focused on the Nanjishan National Nature Reserve and the Wucheng National Migratory Bird Reserve. The Nanjishan National Nature Reserve is located in the Xinjian County of Jiangxi Province. There are two small islands called Nanshan Island and Jishan Island, which are good hiding places and habitats for wintering migratory birds. The Wucheng National Migratory Bird Reserve is located in Wucheng Town of Yongxiu County in Jiujiang City of Jiangxi Province, where the main branch of the Ganjiang River and the Xiushui River merges into the intersection of the Poyang Lake. There are many kinds of rare birds such as cranes, mites, geese, ducks, and gulls in the two national reserves.

5.2 Samples Selection and Collection in the Typical Nature Reserve of the Poyang Lake

In December of 2018, the sediment samples were collected from the Nanjishan National Nature Reserve and Wucheng National Migratory Bird Nature Reserve. The five sampling sites included Nanshan (S1), Jishan (S2), Dahuchi (S3), Zhonghuchi (S4), and Banghu (S5) shown in Fig. 10. All samples were also collected by the five site sampling methods and transported back to the laboratory and timely pretreatment in the laboratory.

5.3 Morphological Characteristics and Composition of the Microplastics in the Typical Nature Reserve of the Poyang Lake

MPs were also separated from the sediment samples in the typical Nature Reserves by flotation and identified by microscope. The results of the microscopic identification show that there are also four different types of MPs, including debris, foams, fibers, and films, observed in the sample sediment. The separated debris MPs have blue and translucent colors, the shapes are flat, the edges are irregular, and there are signs of damage; the foam MPs are milky white, with no fixed shape; the fiber MPs are dark blue, with aging-like fishing line; the film MPs are more transparent, with

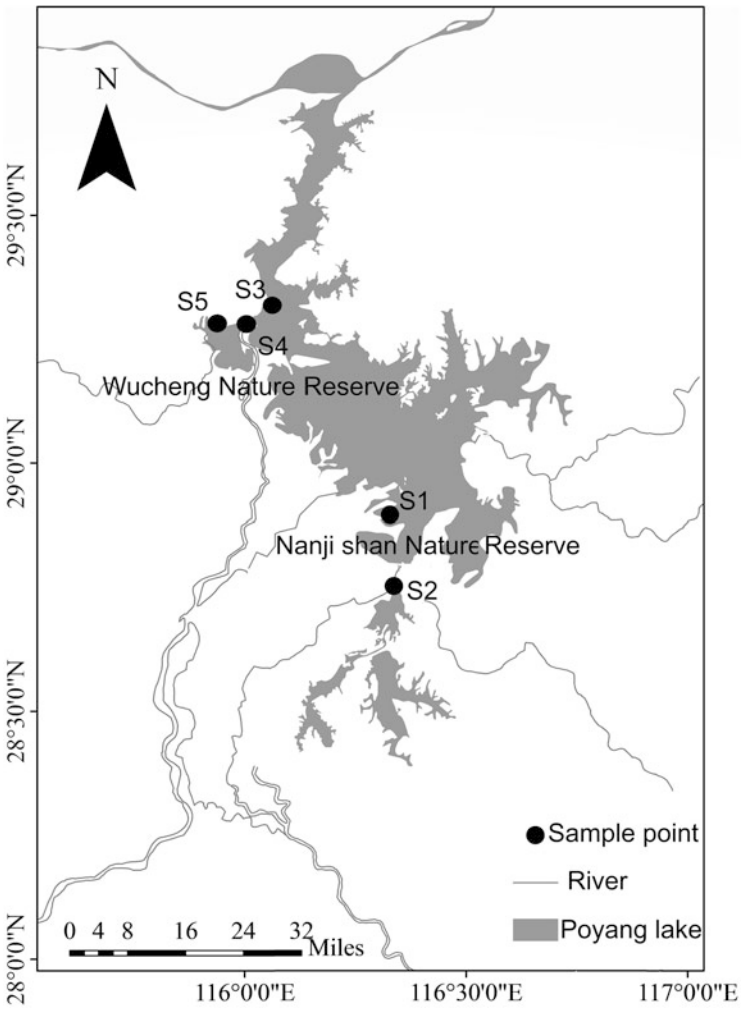

Fig. 10 Locations of sampling sites in the study area

muddy stains, also no fixed shape, and signs of damage to the surrounding edges. In the Nature Reserves, the color MPs have the highest detection rates, accounting for 61.2%. Plastics play an important role in human life, and dyeing of plastic products is an important means to improve the market competitiveness of the products. When humans use these plastic products, a large amount of plastic waste is discharged into the environment, and plastic waste left in the environment can be degraded into MPs for a long time. Colored plastic materials used in fishing lines and fishing nets in the study area may be an important source of these colored MPs. At the same time, domestic sewage discharged from the upper reaches of the Ganjiang River and food packaging waste left by human activities may also be potential sources of these

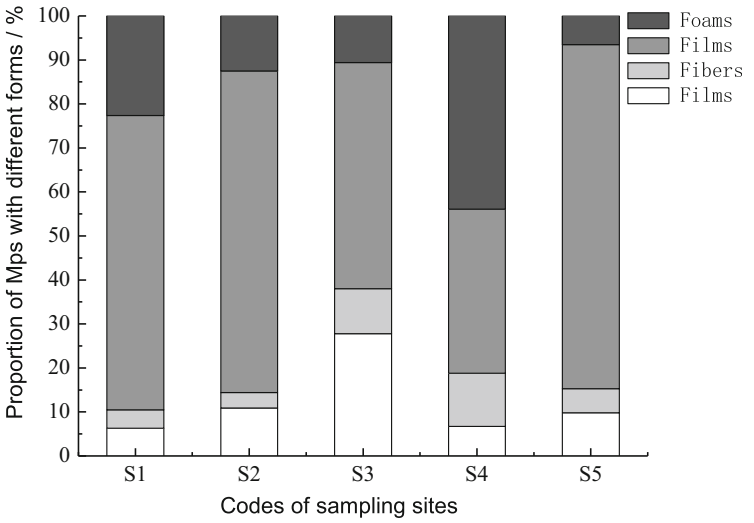

Fig. 11 Composition of microplastics in each sampling sites of the Nature Reserves

colored plastic particles. Although there are few studies on the detoxification of colored MPs by freshwater organisms, Shiber [14] in Hokkaido have shown that marine organisms have a higher probability of engulfing colored MPs than swallowing transparent MPs. Therefore, the research of colored MPs still needs to be further studied.

Among the four MPs isolated from the two National Nature Reserves of the Poyang Lake, the proportion of fiber MPs is more than half of all the samples and accounts for 53.9% (Fig. 11). A large part of the fiber MPs is derived from the degradation of fishing nets or fishing lines in fishing boats near the sampling sites. That is because the Nanjishan Nature Reserve and Wucheng Nature Reserve are both the National Nature Reserves and are less affected by human activities. In addition, household and industrial wastewater, waste slag emissions, surface runoff, agricultural production, and atmospheric deposition are also the potential sources of fiber MPs.

The types of MPs isolated in this study are compared with those of other scholars in China; there are five types of MPs in the tidal flat area of Bohai Sea which included debris MPs, fiber MPs, film MPs, granules, and foam MPs [9], while there is no particulate plastic in the Nature Reserves of the Poyang Lake. The reason for this difference is that there are a large number of transport vessels in the Bohai Sea area; the resin particles left in the transportation process are important reasons for the large number of particulate MPs in the Bohai Sea.

In some previous report, there were debris MPs, film MPs, and fiber MPs in Jiaojiang, Wujiang, and Minjiang, but no foams were mentioned, while debris, foams, and particles were found in the Pearl River beach, but no fibers and films were found [7]. The reasons for such differences are different from the study areas,

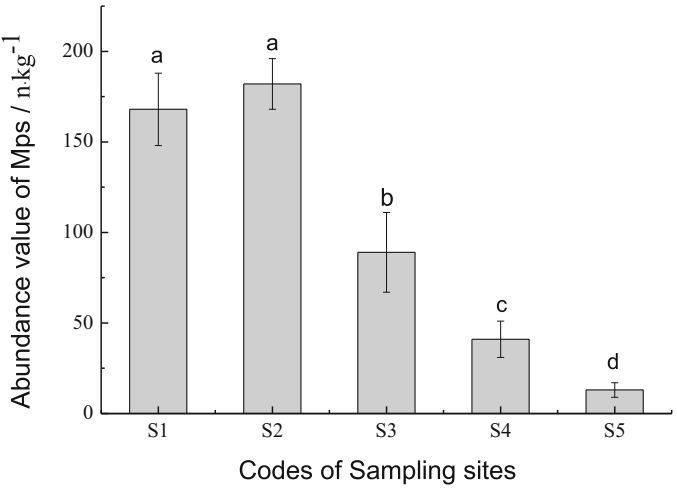

Fig. 12 MP abundance of plastic in each sampling site of the Nature Reserves

and there are differences in the classification basis. Zhao Shiye et al. [7] divided the granular MPs and resin particles into different types of MPs in the study of Jiaojiang, Wujiang, and Minjiang. Therefore, there is an urgent need to establish a systematic MPs classification standard.

5.4 Abundance of Microplastics in the Typical National Nature Reserves of the Poyang Lake

The abundances of MPs in the different five representative sampling sites in the National Nature Reserves were shown in Fig. 12. The results show that the range of the abundance values of MPs is from 13 to 182 particles kg^{-1} and the average abundance was 82.33 particles kg^{-1}. The highest abundance value of MPs is 182 particles kg^{-1} in the Jishan (S2) sampling sites of the Nature Reserves, followed by Nanshan (S1), which is 168.98 particles kg^{-1}, and then the MPs abundance values in the Dahuchi (S3) and Zhonghuchi (S4) were 89.67 particles kg^{-1} and 41 particles kg^{-1}, respectively. The lowest MP abundance value was 13 particles kg^{-1} in the Banghu sampling sites (S5).

5.5 Discussion of Microplastics Types in the Typical Nature Reserves of the Poyang Lake

There are similarities and differences in the proportion of MPs in the Nature Reserves. There is a certain similarity in the proportion of MPs in the Nanshan

(S1) and Jishan (S1) sampling sites. The proportion of fiber MPs is the highest in both sampling sites, accounting for 66.9% and 73.1%, respectively. But the difference among them is that the proportion of foam MPs is the second, accounting for 22.9% in the Nanshan, while the proportion of foam MPs is only 10.9%, and the proportion of debris MPs is 12.5% in Jishan. The reason may be that the intensity of human activities is higher in the Jishan than that in the Nanshan, and the domestic waste left into the environment by human activities made the debris MPs relatively higher in the region. The proportions of MPs in the Dahuchi (S3), the Zhonghuchi (S4), and the Banghu (S5) sampling sites accounted for 51.4%, 43.9%, and 78.2%, respectively. Among them, fiber MPs in the sampling site of Banghu (S5) accounted for a much higher proportion than other types of MPs. The reason may be that the Banghu is far away from human activities compared with the other two sampling sites, which makes the source of MPs in this area single, only MPs flowing from the upper reaches of the Ganjiang River and plastic waste left by fishing boats for fishing activities. In general, the proportion of fiber MPs is the highest MP type in the five sampling sites of the Nature Reserves, while the highest proportion of MPs in the Le'an River of the Poyang Lake section and the estuaries of the main five rivers of the Poyang Lake is debris MPs, the reason for this difference is that the Le'an River of the Poyang Lake section and the estuaries of the main five rivers are the areas with frequent human activities, and the degradation of domestic waste becomes an important part of the MP source in the region. Therefore, the composition ratio of MP in the environment is closely related to the production lifestyle around the plot.

5.6 Discussion of the Different Abundance of Microplastics in the Typical Nature Reserves of the Poyang Lake

In this part, the five sampling sites were divided into two regions according to the Nanjishan and Wucheng for significant difference analysis. It can be seen that the MP abundance of Nanshan and Jishan is significantly different from the MP abundances of the Dahuchi, Zhonghuchi, and Banghu sampling sites ($P < 0.05$). There are three main factors that cause this difference. The first is that the Nanjishan is the famous bird-viewing area in Jiangxi Province, with a large number of tourists visiting each year, and visitors will bring certain plastic garbage to the Nanjishan National Nature Reserve; the degradation of the plastic garbage discarded by tourists and nearby residents may be the source of MPs in sediments. The second is that there are fishery farming areas around the two sampling areas of the Nanshan and Jishan, and the fishing activities will also bring plastic waste, which remained in the environment. The third is that the surrounding areas of the Dahuchi, Zhonghuchi, and Banghu in the Wucheng National Nature Reserve are less affected by human activities, and only a small number of fishing boats are infested.

6 Distribution Characteristics of Microplastics in Sediments of the Estuary of the Poyang Lake and the Yangtze River

6.1 Overview of the Estuary of the Poyang Lake and Yangtze River

This section focuses on the key areas of the Poyang Lake that merge into the Yangtze River, and the estuary of the Poyang Lake into the Yangtze River section was selected as the research area. The sampling sites is located in Hukou County of Jiujiang City in Jiangxi Province, the left bank from the hillside Junction which is from the Dongsheng Dike and Puwan Village to the Meijiazhoutou; the right bank is from Wenchangfu to Jiujiang Shipyard, which is the key area for water from Poyang Lake into the Yangtze River and also the throat of Jiangxi Province and the outside shipping traffic. The estuary of the Poyang Lake and the Yangtze River is the only entrance to the Poyang Lake that enters the Yangtze River, which is affected by the flow of sediments of the Poyang Lake and Yangtze River; the relationship between the rivers and lakes is very complicated. Its river channel evolution directly affects the flood control and shipping safety of the Poyang Lake. In recent years, the economic development of the estuary of the Poyang Lake and the Yangtze River has developed rapidly, continuously increasing the development of fishery resources and more and more domestic garbage from industrial and agricultural sewage and towns.

6.2 Sampling Methods in the Intersection of the Poyang Lake and Yangtze River

In this part, the samples were collected in the Hukou County of Jiangxi Province in July of 2018. The five plots are Doushan (S1), Dukou (S2), Zheji (S3), Gaoshangzhou (S4), and Meijiazhou (S5) (Fig. 13). All samples were also collected by five site sampling methods and transported back to the laboratory and timely pretreatment in the laboratory.

6.3 The Distribution of Microplastics Types and Particle Size in the Estuary of the Poyang Lake and the Yangtze River

In this part, the forms of MPs in the sediments of the estuary of the Poyang Lake and the Yangtze River were also identified by using the microscope, and the main forms of MPs in sediments are mainly composed of debris, films, foams, and fibers in

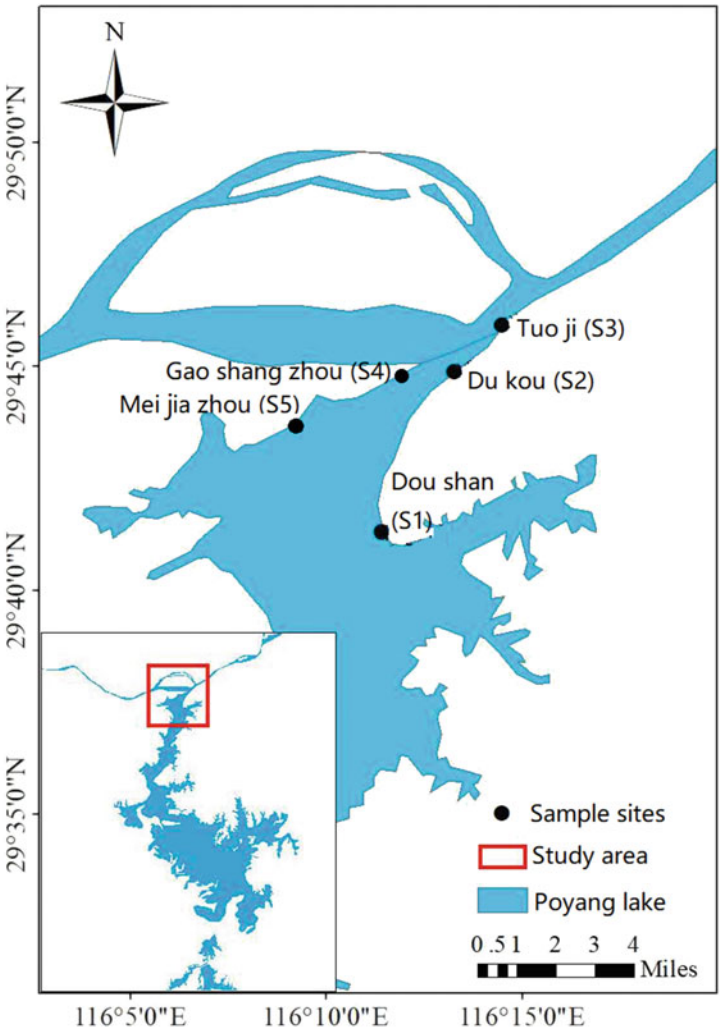

Fig. 13 Location of sampling sites in the estuary of the Poyang Lake and Yangtze River

different points. Debris MPs and film MPs accounted for the highest proportion, accounting for 50.8% and 25.1%, respectively. The main source of the debris MPs is the degradation of plastic products in daily life (such as polyethylene plastic bottles, plastic toys, etc.).

The main source of film MPs is the cracking of plastic products such as food packaging film and plastic film. The proportion of color in the study area is black (1%), transparent (23.87%), blue (13.09%), white (1.106%), red (10.60%), and other colors (2.6%), respectively. The debris MPs are mainly translucent, white, and black.

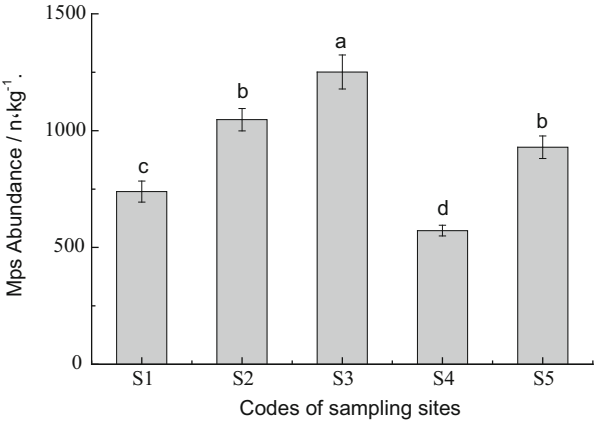

Fig. 14 MPs abundance value of plastic in each sampling site in the estuary of the Poyang Lake and the Yangtze River

The film MPs are mainly transparent and black, and the fiber MPs are mainly blue and red. The proportion of MP particle size is 0–1 mm (53.08%), 1–2 mm (27.60%), 2–3 mm (11.52%), 3–4 mm (4.72%), and 4–5 mm (3.08%). The whole trend of particle size distribution of MPs is as follows: with the decrease in the particle size of MPs, the number of MP particles in sediment samples increases, and about 80.68% of the MPs have a particle size of less than 1 mm.

6.4 Analysis of Microplastics Polymer Composition in the Estuary of the Poyang Lake and the Yangtze River

Four types of MPs were selected for Fourier transform infrared spectroscopy, and the results show that the main components are polyethylene (PE), polypropylene (PP), polystyrene (PC), and low-density polyethylene (LDPE), showing similar FTIR spectrums as shown in Fig. 9.

6.5 Microplastics Abundance in the Estuary of the Poyang Lake and the Yangtze River

MP flotation separation of the sediments in the estuary of the Poyang Lake and the Yangtze River was carried out, the abundance of the five sampling sites is shown in Fig. 14, MP abundance ranged from 572 to 1,251 particles kg^{-1}, and the average abundance value is 907.4 particles kg^{-1}. Among them, the MPs of Tuoji (S3) have the highest abundance of 1,251 particles kg^{-1}, the second highest is the Dukou (S2) with abundance of 1,047 particles kg^{-1}, Meijiazhou's (S5) MP abundance is 928.98 particles kg^{-1}, Doushan's (S1) MP abundance is 739 particles kg^{-1}, and the MPs of Gaoshangzhou (S4) have the lowest abundance of 572 particles kg^{-1}.

6.6 Analysis of Microplastics Abundance Difference in the Estuary of the Poyang Lake and the Yangtze River

The average abundance of MPs in this study area is lower than the average abundance of MPs in the entrances of the main five rivers of the Poyang Lake. The first reason may be that the waste plastic in the main five rivers has a wide range of sources. In addition to the waste plastic brought by the nearby residents' discharge and fishing activities, there are five plastic wastes discharged upstream of the river. Another reason is that the estuary of the Poyang Lake and the Yangtze River is the only entrance of the Poyang Lake which enters the Yangtze River, which affected by the Poyang Lake and the Yangtze River and sediments, the relationship of rivers and Lakes is very complicated, the river is highly fluid, causing the evacuation of MPs in the sediments. In addition, the MP abundance in the sediments of the estuary of the Poyang Lake and the Yangtze River is greater than the MP abundance of the Three Gorges Reservoir area (192.5 particles kg^{-1}); this may be because from July to August every year, the Yangtze River will be poured into Poyang Lake, and the MPs of the Yangtze River will be washed by waves to the banks of the Poyang Lake. Because of the discharge of plastic waste and domestic sewage in the Yangtze River Basin, plastic waste in the Yangtze River Estuary continues to gather. Compared with the estuary of the Poyang Lake and the Yangtze River and the Brazilian Goiana (18 particles kg^{-1}) [15], the Austrian Danube (0.3168 particles kg^{-1}) [7], and the British Tamar estuary (0.028 particles kg^{-1}) [16], the section of the estuary of the Poyang Lake and the Yangtze River is at a high level.

6.7 Analysis of Composition Differences of Microplastics Polymers in the Estuary of the Poyang Lake and the Yangtze River

The Fourier transform infrared spectrometer can measure the chemical bonds of the sample, while different chemical bonds can produce a unique spectrum, and the carbon-based polymer can be detected. The library of the Fourier transform infrared spectrometer can not only determine whether the sample is plastic but also determine its polymer type. In this chapter, MPs were selected for infrared spectroscopy analysis, and compared with the system's own library, the polymer components were identified. Debris plastics are mainly composed of polyethylene by infrared spectroscopy; the composition of thin film MPs is mainly polypropylene; the infrared spectrum of fiber MPs is mainly composed of polyethylene; the composition of foam MPs is mainly polystyrene. Comparing the infrared spectrum obtained in this study with the standard infrared spectrum of the corresponding polymer components, it is found that although the polymer components of the two are the same substance, the peaks in the infrared spectral band of the MPs in the environment are

significantly more than the peak of the band in the standard infrared spectrum, because the peaks of the debris in the environment are more complex in the band, and the standard spectrum is flat in this band, and there is almost no obvious peak.

7 Conclusions

The research areas of this chapter mainly included some typical areas disturbed and polluted by artificial activities, the entrance of the main five rivers of the Poyang Lake basins, two National Nature Reserves, and the outflow areas of the Poyang Lake flowing into the Yangtze River, and the research object is microplastics in the sediments of the wetland in the research areas. The composition and distribution characteristics of MPs were simultaneously identified by infrared spectrometer to determine the surface morphology and elemental composition of MPs in the chapter, the main sources of MPs are also analyzed and the pollution of MPs in the Poyang Lake Basins also evaluated. The main conclusions of the chapter are mainly as follows:

1. The average abundance of MPs in the sediments of the typical areas disturbed and polluted by artificial activities (the Le'an River Basin and Poyang Lake section) is 1,799.56 particles kg^{-1}. The MP abundance in the sediments of the middle and lower reaches of the Le'an River Basin is above-average level, compared with other areas. There are mainly four different forms of MPs including debris, foams, films, and fibers. Among the different MPs, debris have the highest abundance, accounting for 58.3% of the total, followed by foam, which accounted for 21.5%, while foams and fibers accounted for 13.8% and 6.4%, respectively. The Particle size of MPs in the area is mainly < 1 mm, accounting for 62.4% of the total. With the increase of the particle size of MPs, the number of MPs tends to decrease.
2. The MPs in the sediments of the main five rivers of the Poyang Lake are mainly composed of the four types, which included debris, films, foams, and fibers. The particle size of the MPs is relatively concentrated, and most of them is not exceeding 1,000 μm. Most microplastics particle size range is about from 25 to 1,000 μm. The particle size range of fibers, foams, and films is from 100 to 5,000 μm. The average abundance of MPs in the sediments from entrance of the five major river systems of the Poyang Lake was 1,225.25 particles kg^{-1}. The reason for the difference of MP abundance between samples is related to the runoff and sediment transport of the river. The main components of MPs in the study area are polyethylene (PE), polypropylene (PP), polystyrene (PC), and low-density polyethylene (LDPE).
3. The MPs in the sediments of the National Nature Reserve in the Poyang Lake are also mainly composed of four types: debris, films, foams, and fibers. The proportion of fiber in MPs samples is the most and account for about 53.9%. The average abundance of MPs in typical wetland of the National Nature Reserve is 82.33 particles kg^{-1}, which is the area with the lowest MP abundance value in the

whole research areas of the Poyang Lake. The main reason is that the impact of human activities in the National Nature Reserves after conservation is relatively slight. The MPs isolated from the sediments in the National Nature Reserves also have a complex surface characteristic, which is generally rough, porous, and cracked and has tears.

4. The MPs in the outflow areas of the Poyang Lake flowing into the Yangtze River are also mainly composed of four types: debris, films, foams, and fibers. The proportion of debris and films are 50.8% and 25.1%, respectively. The average abundance of MPs in the outflow areas of the Poyang Lake flowing into the Yangtze River is 907.4 particles kg^{-1}. The reason for the difference in the abundance of MPs is related to the runoff and sediment transport to the river. The main components of MPs are also polyethylene, polypropylene, and polystyrene, and the MP samples have the characteristics of rough surface, obvious weathering, and some residuals, and Si, Fe, Mg, O, Al, Ca, and other elements were observed on the surface of the MPs.
5. In this chapter, we comprehensively analyze the distribution characteristics of MPs in the different research areas and found that the distribution of MPs in the sediments of the Poyang Lake Basins is closely related to human activities. The order of the MPs abundance value of different regions is that the abundance of MPs in the sediments in the typical areas disturbed and polluted by artificial activities (The Le'an River of the Poyang Lake Section) > The entrance of the main five rivers of the Poyang Lake Basins>The outflow areas of the Poyang Lake flowing into the Yangtze River>The two National Nature Reserves in Poyang Lake. The reason for this difference is the combination of human activities, hydrological conditions, and river input impact; the difference in the proportion of MPs between different regions and the frequency of distribution is related to the local lifestyle, in addition to the physical and chemical properties of MPs.

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