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Microplastic abundance, distribution and composition in water, sediments, and wild fish from Poyang Lake, China

Wenke Yuan[a,c], Xiaoning Liu[a,b], Wenfeng Wang[a,c], Mingxiao Di[a,c], Jun Wang[a,b,*]

[a] Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China
[b] Sino-Africa Joint Research Center, Chinese Academy of Sciences, Wuhan 430074, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Microplastic pollution in global aquatic environments has aroused increasing concern in recent years. In this study, the occurrence of microplastics in multiple environmental compartments was investigated in Poyang Lake, the largest freshwater lake of China. The abundance of microplastics was respectively 5–34 items/L for surface waters, 54–506 items/kg for sediments, and 0–18 items per individual for wild crucians (*Carassius auratus*). The distribution of microplastics in Poyang Lake varied heterogeneously in space, with the highest abundance being observed in the middle region of the lake for surface waters and in the northern region for sediments. Anthropogenic and topographic factors were speculated to be the major factors affecting the abundance and distribution of microplastics. The majority of the detected microplastics were found with a size of < 0.5 mm, with fibrous and coloured being the predominant characteristics. Polypropylene (PP) and polyethylene (PE) were the major polymer types of the selected plastic particles, indicating that domestic sewage and fishing activities might be the main sources of microplastics in the lake. No significant correlation was observed between microplastic abundance in surface water and sediment samples. Our results demonstrated the wide occurrence of microplastics in water, sediment and biota of the Poyang Lake, which may assist in extending our knowledge regarding microplastics pollution in inland freshwater systems.

1. Introduction

In recent years, microplastics have been recognized as an emerging pollutant and have caused widespread concern around the world (Ogonowski et al., 2018; Revel et al., 2018). However, most studies regarding microplastic pollution have been focused on the marine ecosystems, which are considered as their final sink. It is estimated that most of the microplastic pollution in the marine environment comes from the terrestrial environment (Jambeck et al., 2015), while inland freshwaters are important pathways for microplastics to the oceans (Lebreton et al., 2017). However, studies regarding microplastics pollution in inland waters relatively insufficient, especially when compared with the marine environments. In inland areas, rivers and lakes are direct receivers of runoff from urban, industrial, and agricultural regions (Eriksen et al., 2013). Therefore, comprehensive monitoring programs for microplastics in freshwater environments are still highly encouraged.

Many sources can cause microplastic pollution in freshwater ecosystems, including discharged effluents from wastewater treatment plants (WWTP) (McCormick et al., 2014) and surface runoff (Frere et al., 2017). Previous studies found that microplastics were present in various freshwater systems, such as rivers, lakes, and estuaries (Eerkes-Medrano et al., 2015). Lakes may serve as the major sink of microplastics in freshwater ecosystems, since plastic debris could be continuously accumulating and preserved over a prolonged period of time. On the other hand, due to the higher reserves of microplastics, lakes could also become important sources of microplastics for the downstream watersheds. Moreover, owing to the resemblance of natural prey in size and/or colour, microplastics can be ingested mistakenly by aquatic organisms (Wright et al., 2013). Ample evidence has demonstrated ingestion of microplastics widely occurs for various aquatic organisms, such as fish (Sanchez et al., 2014), invertebrates (Hurley et al., 2017), and water fowl (Holland et al., 2016). Ingestion of microplastics may cause some negative effects to the aquatic organisms and even human beings by trophic transfer (Rochman et al., 2015).

China is the largest producer of plastic materials all over the world

* Corresponding author at: Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China.
E-mail address: wangjun@wbgcas.cn (J. Wang).

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(Jambeck et al., 2015). Extensive application of plastics leads to a considerable amount of plastic waste released into the environment, which has been a major source of microplastics. Previous studies have demonstrated the wide occurrence of microplastics pollution in some of China's important lakes, such as the Taihu Lake (Su et al., 2016), the Dongting Lake, and Hong Lake (Wang et al., 2018), and two remote lakes in Tibet plateau (Zhang et al., 2016). In view of the high diversity of freshwater ecosystems, the concentrations and distribution patterns of microplastics in different freshwater habitats are highly variable. In order to understand how microplastics were distributed in lakes and what factors would affect them, more in-depth investigations and studies are still needed.

As the largest freshwater lake in China, Poyang Lake was included in the list of International Important Wetlands in 1992 due to its important ecological position. Poyang Lake provides mankind with abundant freshwater and biological resources, and performs a vital function in the Yangtze River Basin. In this study, microplastic contamination in surface water and sediment of Poyang Lake was investigated. In addition, the presence of microplastics in the *C. auratus*, as an important fish species in Poyang Lake, was also examined. This study seeks to provide general information about the current status of microplastic pollution in the surface waters, sediments, and gastrointestinal tracts of wild crucians (*Carassius auratus*) of Poyang Lake. These data can be beneficial to the comprehensive evaluation of the original sources and potential risks of microplastics in Poyang Lake and provide guidance for formulating prevention and governance measures against microplastic contamination in the freshwater environment.

2. Materials and methods

2.1. Study areas

Poyang Lake is the largest freshwater lake in China, with a surface area varying seasonally from less than 1000 km^2 in the dry season to over 3000 km^2 in the rainy season. The area of the Poyang Lake watershed covers 162,225 km^2, accounting for 9% of the area of the Yangtze River Basin. The long term average runoff of the lake accounts for approximately 16% of the average annual runoff of the Yangtze River. In general, Poyang Lake can be divided into two parts. The northern part, as a waterway to the Yangtze River, has a length of 40 km and width of 3–5 km. The southern part is the main lake and has a length of 133 km and maximum width of 74 km (Liang et al., 2017). Five major tributaries (Xiu River, Gan River, Fu River, Xin River, and Rao River) are drain into Poyang Lake and exit through the narrow northern channel to the Yangtze River (Fig. 1).

2.2. Sample collection

All samples were obtained in November 2017, and a total of 21 sampling sites were distributed as evenly as possible in Poyang Lake (Fig. 1). These sampling points can be divided into three different geographic regions of Poyang Lake (Table S1). Points 1–6 were in the northern region of Poyang Lake and were surrounded by dense population. The connection between the northern and southern regions of the lake was designated the middle region and included points 7–10. The broad southern region, which contained points 11–21, is considered to suffer less influence by human activities than the other two regions due to its farther distance from urban areas (Fig. 1).

Before sampling, all tools and containers were cleaned with filtered pure water. Two replicates of 20 L of surface water were collected from each site (0–1 m in depth) with a steel sampler and filtered using a 50-μm stainless-steel sieve. The filtered residue from each site was washed with filtered pure water into the bottle as one sample. Similarly, approximately 500 g of sediment was collected twice from the boat using a Van Veen grab at the same site (0.25 m^2 sampling surface). The 1000 g of the sediment collected from each site was stored in an aluminium foil bag for transportation to the laboratory. Eleven fish were obtained from an aquatic product market in Duchang County, which was situated by the banks of the lake and near the fishing pier (Fig. 1). All 11 fish were adult female *C. auratus* that had just been captured from different regions of Poyang Lake, and they were frozen immediately before laboratory analysis. Plastic material was avoided throughout the whole sampling process.

2.3. Sample preparation

The preparation of surface water and sediment samples was performed with reference to previous freshwater studies (Di and Wang, 2018; Wang et al., 2017). Waters were incubated at room temperature with 10 mL 30% H_2O_2 overnight to degrade the organic matter. Then, the digested solution was diluted and filtered using a 0.45-μm gridded filter paper (GF/F, 47 mm Ø, Whatman). The filters were stored in covered glass dishes and were air dried for further analysis. Sediments were dried in an oven at 50 °C for 48 h. Microplastics were extracted from each sediment sample using a density separation method (details are described in the Supplementary materials).

The microplastics in the fish were extracted based on a methodology described in a previous study (Karami et al., 2017) with some modification. Each fish sample was weighed and measured prior to dissection. The dissection method was similar to one described in a previous study (Lusher et al., 2013), where the gastrointestinal tracts, including the oesophagus, stomach, and intestines, were removed from each individual using a fine scalpel and tweezers. The samples from each fish were placed in a conical flask and treated using 50 mL 10% potassium hydroxide (1:10 w/v), and then they were incubated for 48 h in a rocking bed of 40 °C at a speed of 100 rpm. The digestates that remained were incubated at room temperature with 10 mL 30% H_2O_2 overnight to degrade any remaining organic matter. At about eight o′clock in the next morning, the digested solutions were filtrated onto filters similar to the methods used for the water and sediment samples. All prepared samples on the filters were placed in covered glass dishes for further examination.

In the laboratory, a series of measures were taken to avoid potential background contamination. Nitrile gloves and a cotton lab gown were worn during the whole process. All of the solutions used in our study were filtered through a 0.45-μm filter before they were used. Tools and containers were thoroughly rinsed with filtered pure water and covered by aluminium foil after each step. Method blank tests were carried out in the laboratory. Twenty litres of purified water was filtered using a 0.45-μm gridded filter paper. The experiment was repeated three times and the filters were placed in a clean glass dish for microscopic examination.

2.4. Identification of microplastics

Microplastics on the filters were observed and photographed with a stereoscopic microscope (M165 FC, Leica, Germany). Microplastics were visually identified and measured according to their physical characteristics, following the method described in a previous study (Hidalgo-Ruz et al., 2012). The number, shape (fibre, film, pellet, fragment), colour (white, black, coloured, transparent), and size of the plastics were recorded. The size of the plastic particles was divided into five classifications: < 0.1 mm, 0.1–0.5 mm, 0.5–1 mm, 1–5 mm, and > 5 mm. Particles that were smaller than 50 μm were not included in this study due to the aperture limit of the sieves used.

In addition, Raman analyses were performed for further identification. A set of 100 representative particles (Table S5) were selected to obtain the spectrum using a micro-Raman spectrometer (ThermoFisher Scientific DXR2, USA) with an incident laser of 785 nm. The surface-enhanced of Raman scattering (SERS) was used in the Raman analyses. Plastic samples were polished and cleaned with alcohol, and silver slides were used to reduce fluorescence interference. The polymer types

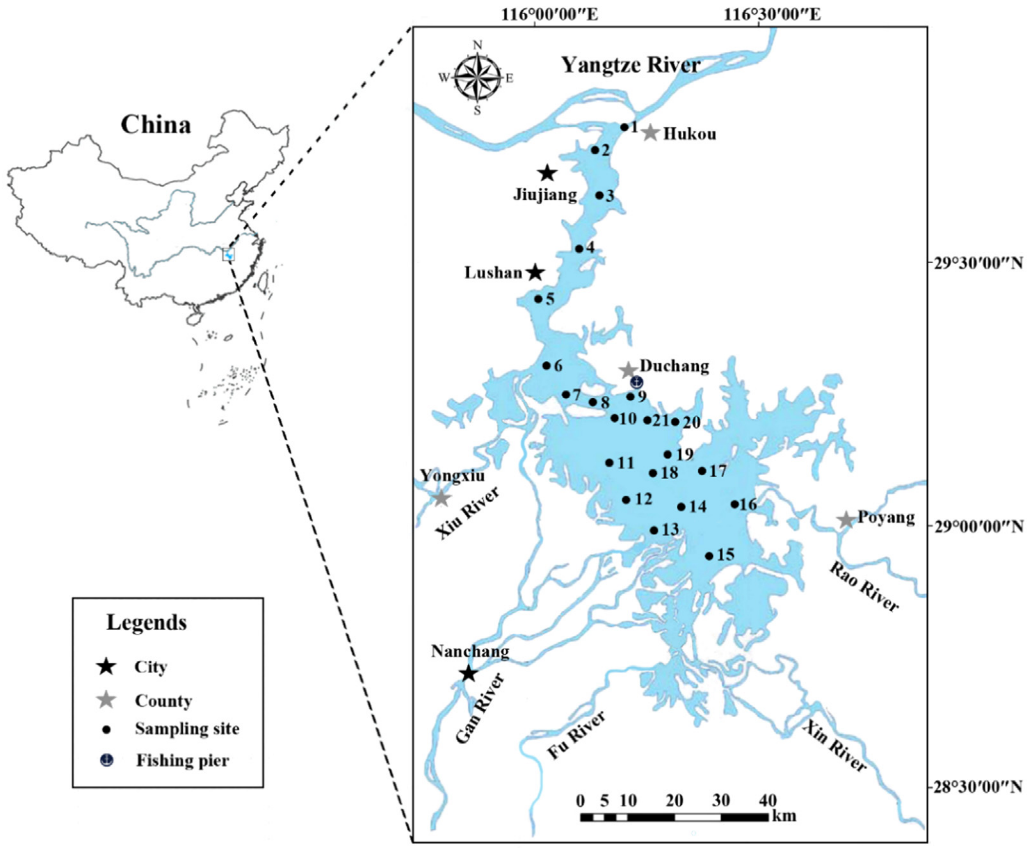

Fig. 1. Geographic position of sample sites and the distribution of cities and rivers around Poyang Lake.

of the resulting spectra were confirmed by comparison to the Raman polymer spectrum library. The visual identification data were corrected according to the Raman identification results before they were analysed.

2.5. Statistical analysis

The units of microplastic abundance for water, sediment, and fish samples were reported as the number of particles per litre, the number of particles per kilogram dry weight (dw) and the number of particles per individual, respectively. Means, standard deviations (S.D.), and median values were computed for each region. The correlation between microplastic concentrations of surface waters and sediments was tested with the Pearson correlation analysis. The difference between the abundances of the three different regions was analysed with the one-way analysis of variance ($p < 0.05$).

3. Results and discussion

3.1. Abundance of microplastics in waters and sediments

The number of microplastics detected in the blank samples was 0.38 ± 0.56 items, which indicated that the airborne contamination during the analysis process was negligible. Microplastics were present in all surface water and sediment samples with a range from 5 to 34 items/L and 54–506 items/kg dw, respectively (Table S2). The comparisons of the abundance of microplastics among different literatures must be performed with some caution, as considerable methodological differences exist in sampling, sample preparation and visual identification (Hidalgo-Ruz et al., 2012; Van Cauwenberghe et al., 2015; Wang and Wang, 2018). Worldwide freshwater studies that used similar units for quantifying microplastics were selected to compare with our study (Table S3), which showed that the Poyang Lake has a much heavier pollution load of microplastics than the Lake Chiusi, Italy (2.68–3.36 items/m^3) (Fischer et al., 2016), and is close to the Taihu Lake, China (3.4–25.8 items/L) (Su et al., 2016). Poyang Lake was considered to be subjected to various sources of contamination, including urban and industrial activities, fishing activities, and agriculture (Zhi et al., 2015). Poyang Lake basin is a famous land of fish and rice with developed agriculture, aquaculture and animal husbandry; thus, most counties surrounding Poyang Lake have a high-density rural population. A rural population of 26 million lived in Poyang Lake basin, and about 12 million tons of domestic wastewater was discharged annually. Though wastewater treatment plants can remove most of the microplastics from the municipal effluent (Carr et al., 2016; Talvitie et al., 2015), wastewater originating from the surrounding rural non-point sources might be discharged into the lake without treatment, contributing to a high abundance of plastics in a lake (Su et al., 2016). Moreover, there are more than ten thousand fishing vessels and 100 thousand people in the fishing population in the Poyang Lake district. The busy fishing activities may also be an important reason for the high level of microplastic pollution. Poor waste management practices, such as lack of necessary trash cans, illegal waste accumulation and waste burning phenomenon, were observed in the watershed. All of these contributors together may result in the higher microplastic abundance observed in Poyang Lake.

3.2. Spatial distribution of microplastics in waters and sediments

The distribution profiles of microplastics in the waters and sediments of Poyang Lake are presented in Fig. 2a and b, respectively. The abundances of microplastics detected in the three different regions of Poyang Lake are calculated in Table S2. For surface waters, the highest level of microplastics occurred in the middle region of the lake followed by the northern channel, while sites in the southern region of the lake

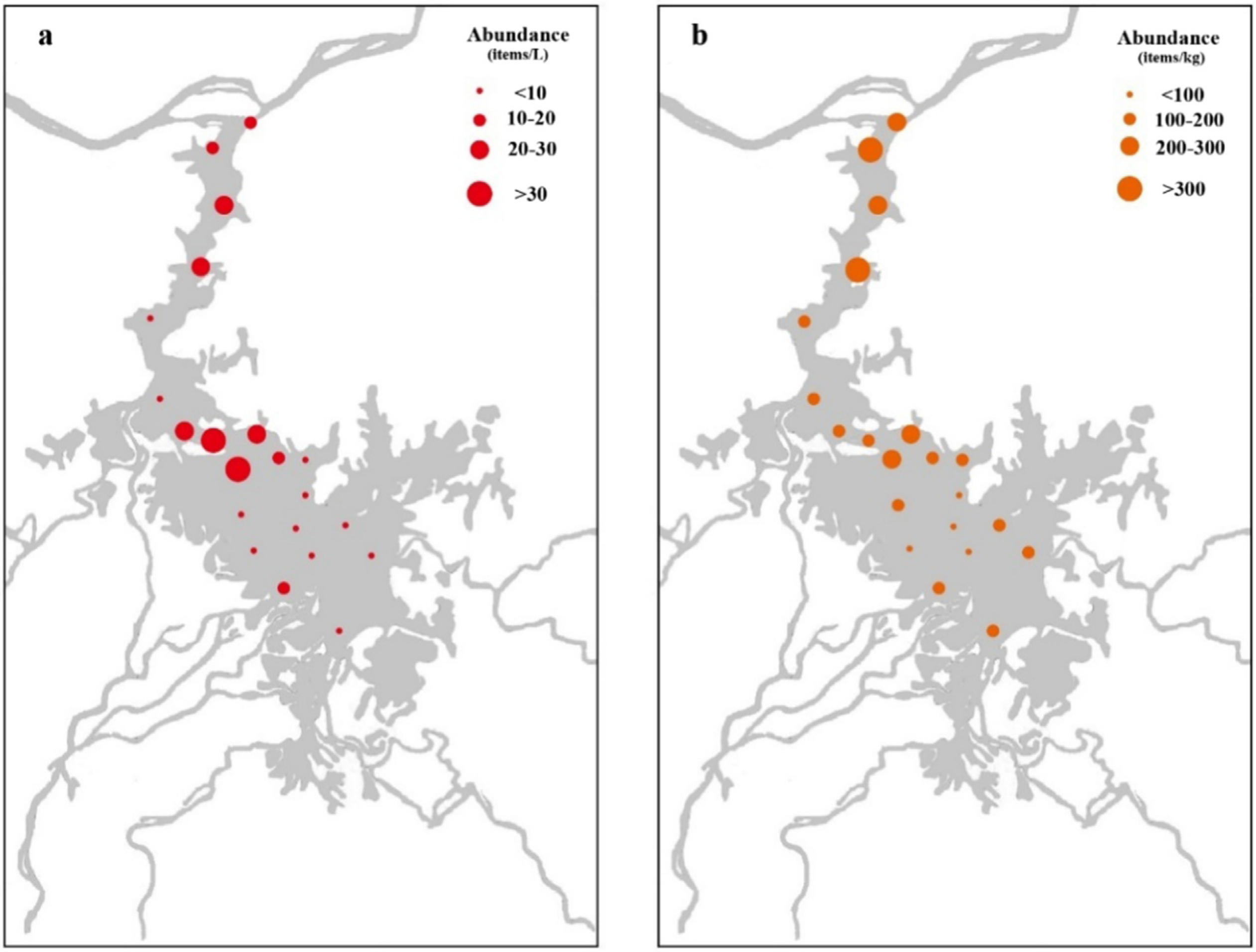

Fig. 2. Abundance and distribution of microplastics detected in surface waters (a) and sediments (b).

had the lowest microplastic pollution level. A remarkably higher abundance of microplastics (more than 30 items/L) was detected at site 8 (34 items/L) and site 10 (31 items/L). Both of these two sites were located in the middle region of Poyang Lake. The lowest abundance of microplastics was recorded at site 15 (5 items/L), the southernmost sampling location. The average microplastic concentration in surface waters of the middle region was approximately twice as much as that of the northern region and three times higher than that of the southern region ($p < 0.05$).

In the sediment samples, a high level of plastic debris items (more than 200 items/kg dw) is mainly located in the sediment samples of the northern region (sites 1–4) and middle region (site 9 and site 10), while all the sampling sites with an abundance less than 100 items/kg (site 12, 14, 18, 19) are located in the southern region (Fig. 2b). For sediments, the highest level of microplastics occurred in the northern region of the lake, followed by the middle region. The mean and median abundance of microplastics in the southern region was obviously lower than that in the other two regions ($p < 0.05$). No statistical difference was found between the northern region and the middle region ($p > 0.05$).

In addition, no significant correlation was observed between microplastic abundance in surface water and sediment samples ($p > 0.05$). This can be attributed to many complicated factors (e.g., water quality, water flow, and the characteristics of microplastics). The surface waters from the middle region of the lake suffered the most serious microplastic pollution, while the most polluted region for sediments was observed at the northern region of the lake. The similarity between microplastic abundance in waters and sediments was that the mean and median abundance of microplastics in the southern region of the lake was the lowest in both waters and sediments. Studies have shown that plastics in the sediments are more closely related to pollution sources than those in the waters (Su et al., 2016). However, spatial correlation between microplastic contamination in the surface waters and sediments still needs further studies in the future.

The distribution patterns of microplastics in waters and sediments might be influenced by many factors. First, anthropogenic activities are known as significant contributors to plastic pollution (Cole et al., 2011; Horton et al., 2017). The main human activities in this area include agriculture, fisheries, and industrial activities (Fig. 3). The southern region, with sporadic fishing villages that are scattered, is characterized with less anthropogenic pollution, while the northern and middle lake regions are adjacent to highly industrialized cities (Duchang, Lushan, Jiujiang, Hukou). There are 7 wastewater treatment plants around Poyang Lake, five of which are located in the northern region and two in the middle region. Huge amounts of sewage effluents from WWTPs and surface runoff from populated areas may bring plastics into the lake, contributing to higher microplastic abundance in these two (northern and middle) regions. Furthermore, the middle region is close to the largest fishing pier of the lake. Busy fishing activities may produce considerable quantities of plastic wastes from fishing tools (Stolte et al., 2015), thereby resulting in the aggravation of microplastic pollution in this region.

Moreover, previous studies have suggested that microplastic contamination levels can be influenced by geographical and topographic factors, such as lake size (Wang et al., 2017), shoreline morphology (Ballent et al., 2016), and even the presence of obstructing structures

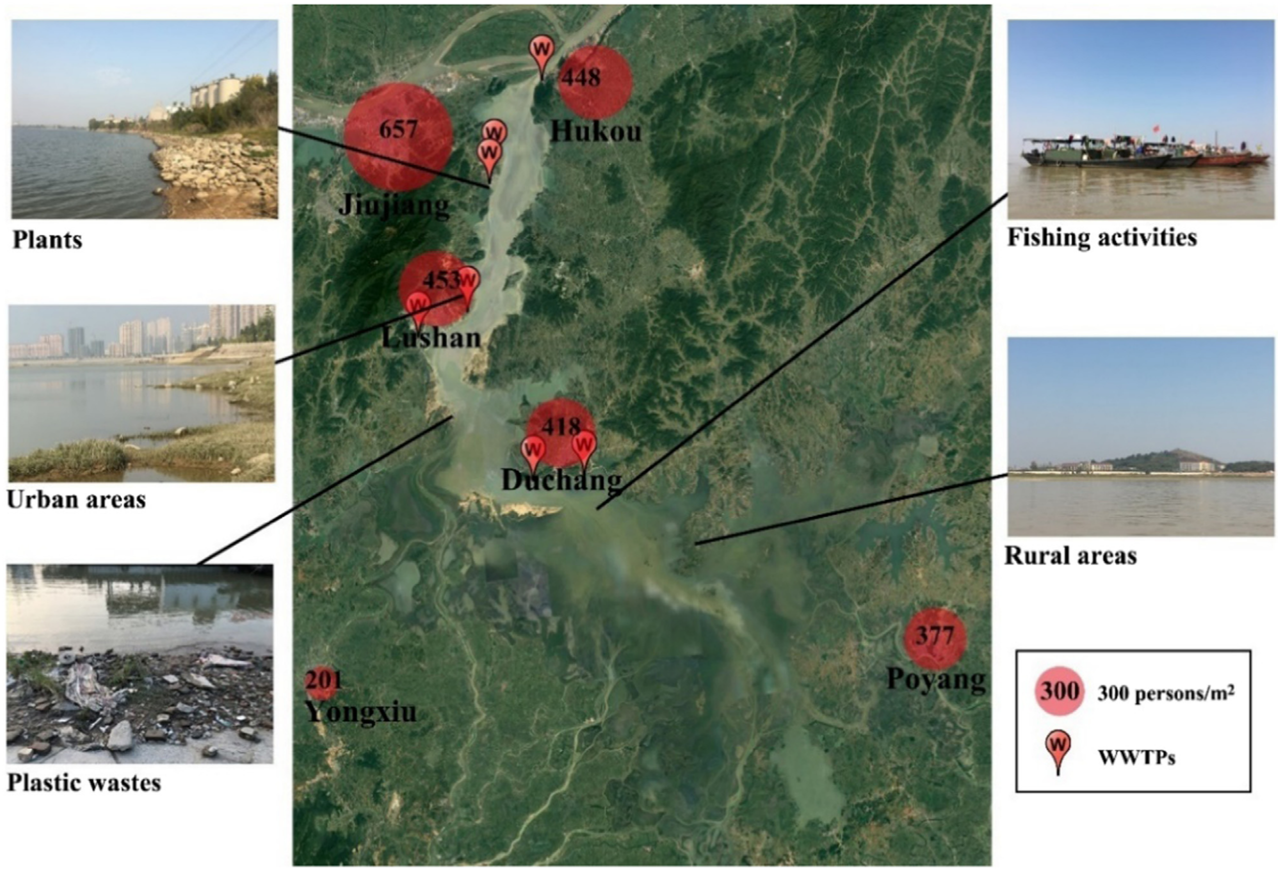

Fig. 3. Potential sources of microplastic pollution around Poyang Lake. The red circles and numbers on them refer to the population density (persons/m^2) of the main residential areas (Jiujiang, Lushan, Yongxiu, Poyang, Duchang, and Hukou).

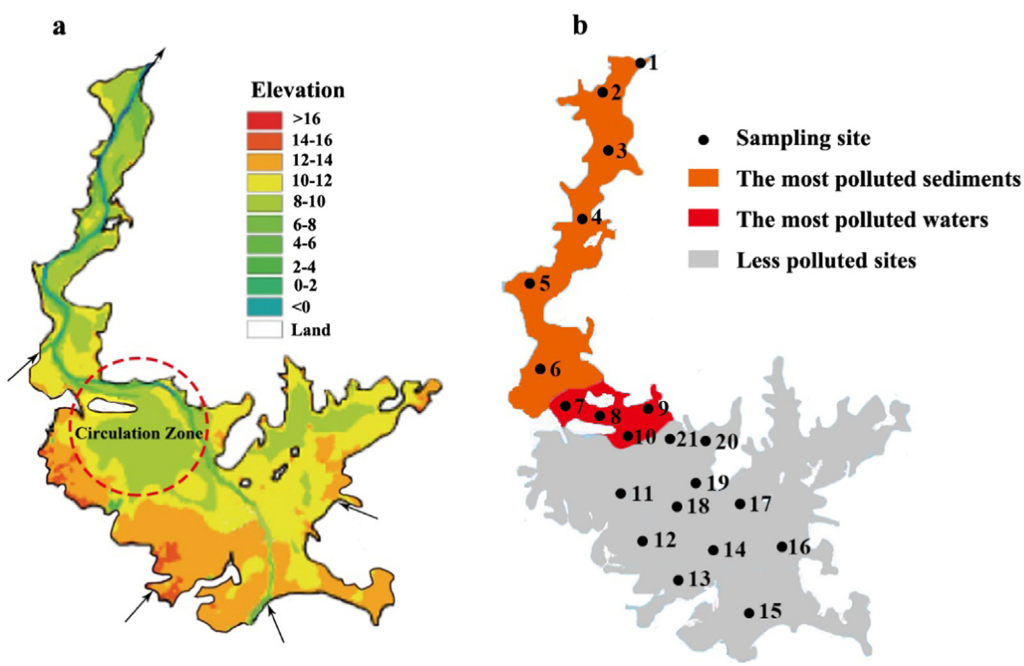

Fig. 4. Bed elevation (a) and microplastic pollution status (b) of Poyang Lake. The black arrows refer to the direction of water flow at the connection between the tributaries and the Poyang Lake.

like dams (Di and Wang, 2018). In this study, the wide area of the southern region may dilute the abundance of microplastics and reduce the impacts of land-based plastic debris, while the long narrow terrain of the northern channel could help to concentrate suspended particles. Changes in shoreline and elevation create a circulation zone in the middle region of the lake (Fig. 4), which can contribute to the comparatively high abundance of microplastics in this region. A similar phenomenon was found in another big lake of China, the Qinghai Lake (Xiong et al., 2018), and the authors also believed that the lake circulation could accumulate plastics from the surrounding areas. Additionally, previous study shown that the residence time of water in the northern and middle areas of Poyang Lake was about 10–20 days in the recession period (1st of October), while that in most southern areas was less than 10 days (Li et al., 2015). Therefore, the longer residence time of the lake water would allow larger plastics break into microplastics and continuously accumulating in the northern and middle areas.

The lake water flows northward into the Yangtze River with an annual average volume of 145 billion cubic meters, which may determine the eventual fate of microplastics in the water and sediment of Poyang Lake. Particularly in the sediments, the microplastic concentration has a tendency to increase gradually from south to north. To a certain extent, the distribution pattern of microplastics in Poyang Lake also agrees with the speculation that the high water discharge would shift plastic particles to the lower part of the watershed (Lima et al., 2014).

3.3. Morphological characteristics of microplastics in waters and sediments

Pictures of typical microplastic samples observed in this study were presented in Fig. S1. The microplastic size spectra shows that 0.1–0.5 mm was the dominant size classification in both water and sediment samples (Fig. 5a). Microplastics with a size less than 0.5 mm occupied 73.1% and 57.1% of plastic particles by number in the surface water and sediment samples from Poyang Lake, respectively. The dominance of small-sized plastics have been found in many freshwater studies, such as Laurentian Great Lakes, USA (Driedger et al., 2015), Lake Hovsgol, Mongolia (Free et al., 2014), and Taihu Lake, China (Su et al., 2016). Small-sized microplastics are mainly fragmented from larger plastic debris under the effect of mechanical forces and photochemical processes (Cooper and Corcoran, 2010; Zbyszewski et al., 2014). Small-sized plastic particles are considered to pose a more serious potential threat to aquatic organisms due to their greater surface area for possible adsorption of other pollutants (Devriese et al., 2017). Apart from that, the high percentage of small-sized microplastics in the present study also indicates a higher probability of mistaken ingestion events for aquatic organisms, since their fine size is similar to zooplankton (Cole et al., 2011).

The shapes of the observed particles were sorted into fibres, films, fragments, and pellets (Fig. 5b). Fibre particles were the most abundant shape of microplastics in both waters and sediments, accounting for 41.2% and 44.1%, respectively. The results were similar to previous freshwater studies in China, such as the Taihu Lake (48–84%) (Su et al., 2016), the Dongting Lake (41.9–91.9%), and the Hong Lake (44.2–83.9%) (Wang et al., 2018). It seems that the domestic sewage and fisheries were major contributors to the high abundance of fibres in Poyang Lake. Previous studies have showed that domestic sewage from washing machines contains a vast quantity of artificial and synthetic fibres (Napper and Thompson, 2016). Likewise, there are more than ten thousand fishing vessels and 100 thousand people in the fishing population in the Poyang Lake district. The busy fishing activities could produce a large amount of ageing fishing gears, such as fishing nets, lines and ropes, which can also contribute to the dominance of microplastic fibres. Films are mainly produced by the fragmentation of plastic carry bags (Nor and Obbard, 2014), which were the second most abundant type of microplastics in the water and sediment samples (33.5%), indicating their misuse in the lake. Interestingly, the percentage of films in surface waters was much bigger than that in the sediments. It is likely that the shape of the film could promote microplastics

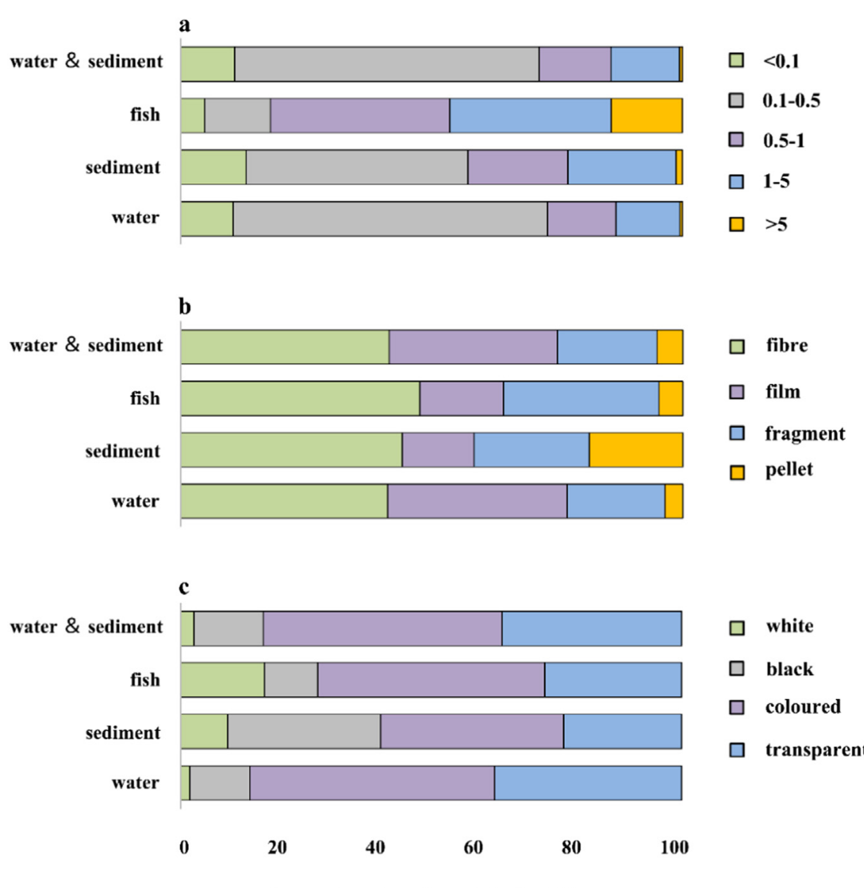

Fig. 5. Comparison of microplastics by the categories of shape (a), size (b), and colour (c) in different samples from Poyang Lake.

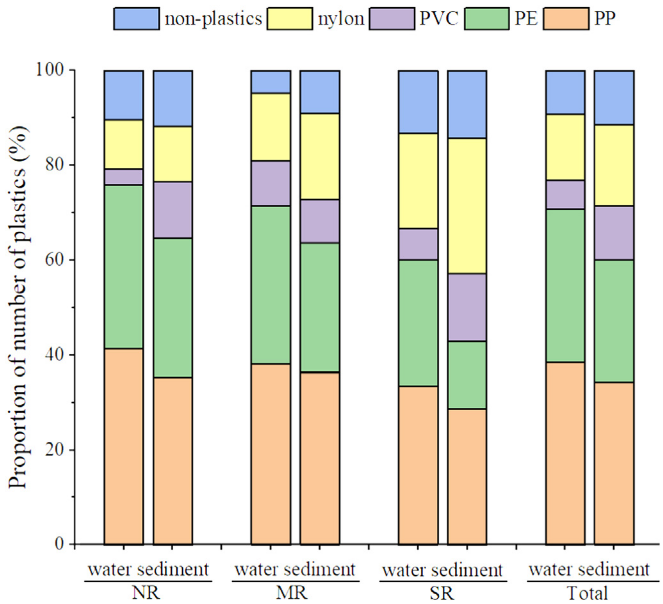

Fig. 6. Components of the selected particles from the northern region (NR), the middle region (MR) and the southern region (SR) of Poyang Lake.

to suspend in waters, rather than deposit in sediments. Fragments were mainly attributed to the breakdown of larger plastic products (Cole et al., 2011), accounting for 19.5% of the microplastics in waters and sediments. Pellets mainly originated from daily personal care products, such as cosmetics and cleaning medias (Napper et al., 2015), and were observed relatively low in proportion (5.2%).

The discussion on the colour must be cautious as colour is not permanent and bleaching processes may occur in the environment (Stolte et al., 2015). Therefore, the microplastics were grouped into four obvious colours (white, black, coloured, and transparent) in our study, instead of assessing other more controversial colours (e.g., blue, green, yellow, etc.). The results showed that majority of plastic items in Poyang Lake were coloured particles, accounting for 48.9% and 36.6% in waters and sediments, respectively (Fig. 4c). Abundant coloured particles have been found in many studies (Zhao et al., 2015). A great variety of coloured plastic products are widely used in modern life, and further, a large number of plastic wastes are produced with the consumption of these products. After splitting, these plastic wastes can ultimately result in coloured plastic particles. The second most frequent colour of particles was transparent, accounting for 35.9% of the total microplastics in number. In addition to bleaching of coloured plastics, the busy fishing industry of Poyang Lake may also be a significant contributor to these transparent microplastic fibres (Stolte et al., 2015). Although the different plastic particle characteristics can be used to speculate on plastic origins, knowledge of the original sources of microplastic pollution remains inadequate.

3.4. Microplastics in *C. auratus*

In this study, all of the fish samples were adult female *C. auratus*, and the basic information of these fishes was provided in Table S4. Ten of the eleven fish samples were observed to contain microplastics in their digestive system. A total of 84 plastic items were detected, with the abundance ranging from 0 to 18 items per individual (Table S4). Compared with other freshwater studies in China, our results were similar to that in Qinghai Lake (2–15 items per individual) (Xiong et al., 2018), and higher than the proportional value obtained from Xiangxi Bay of Three Gorges Reservoir (25.7%) (Zhang et al., 2017). The relatively higher microplastic abundance in *C. auratus* might be attributed to the high pollution level of microplastics in the surrounding environment. Additionally, the difference in species, feeding, living habits, and sampling positions may also result in the discrepancies (Sanchez et al., 2014; Silva-Cavalcanti et al., 2017).

Fibres were the most common particles observed in fishes, the same as what was found in waters and sediments (Fig. 5b). Coloured and transparent were the main colours of microplastics in the fish samples (Fig. 5c). These may be related to the microplastic abundance in their environment, since particles with these characteristics were also abundant in waters and sediments of Poyang Lake. Additionally, the proportion of white plastics observed in fish samples (16.7%) were much higher than that in waters (1.8%) and sediments (9.3%) (Fig. 5c). Aquatic organisms may feed on microplastics which most resemble their prey in colour and shape (Shaw and Day, 1994). Thus, there was high possibility that white microplastics could be mistaken to eat for plankton by *C. auratus*.

Different from what was found in waters and sediments, most of the microplastics in fish were larger than 0.5 mm, accounting for 82.1% in number (Fig. 5a). Plastic particles larger than 5 mm in fishes accounted for 14.3%, outclassing that which was found in surface waters (0.6%) and sediments (1.3%). Large-sized plastics have been frequently recorded in marine fishes (Romeo et al., 2015; Rummel et al., 2016), but rarely have been recorded in freshwater fishes (Jabeen et al., 2017). The deformability of large fibrous microplastics may cause them to be entangled with fish food items (e.g., worms and eggs) and therefore prone to be incidentally ingested by fish (Peters and Bratton, 2016). Besides, large-sized microplastics may be difficult to excrete out through the digestive system of fish.

Plastic particles collected from the gastrointestinal tracts of fish samples may be closely related to the contents of microplastics in lake waters. However, it is difficult to conduct more effective analysis due to the insufficient sample quantity. Poyang Lake is an important breeding, feeding, and fattening habitat for migratory fishes in the Yangtze River Basin. The *C. auratus* is the most common fish and one of the main food fish in the Poyang Lake watershed. Therefore, more in-depth investigations should focus on the potential risks of microplastics to organisms and human beings.

3.5. Identification of microplastics

The validation of plastic particles was identified by micro-Raman spectroscopy. Of the 100 selected particles, 89 were successfully identified as plastics. There are 4 polymer matrix composites of all microplastics: PP, PE, nylon, and polyvinylchloride (PVC) (Fig. S2). PP and PE were the main plastic types (37% and 30% of all particles, respectively), followed by nylon (15%) and PVC (8%). The remaining particles were non-plastics (10%) (Fig. 6). Densities and common uses of plastics that were identified in this study were showed in Table S6. As expected, the proportions of lower density microplastics (PP and PE) in waters (38.5% and 32.3%) were higher than those in sediments (34.3% and 25.7%), while the proportion of PVC (1.38–1.41 g/cm^3) in waters (6.2%) was much lower than that in sediments (11.4%). Of course, in addition to the density of plastics, the vertical distribution of microplastics is also driven by other factors, such as biofouling (Lobelle and Cunliffe, 2011), waves (Ballent et al., 2012), and the surface to volume ratio of debris (Zhao et al., 2015).

The results of polymer identification can help to trace the original source of plastic debris (Ballent et al., 2016). The proportion of PE and PP in the northern region (39.1% and 32.6%) were the highest among three different regions, followed by the middle region (37.5% and 31.3%). PP and PE have been widely used in industry and daily life (Table S6). Laundry wastewater from the northern and middle regions may be a significant source of nylon particles, since nylons are widely used in textiles, such as clothes and ropes. The sediment samples in the southern region have the highest ratio of nylon (28.6%) and PVC (14.3%). The extensive fisheries activities in the southern region may lead to large amounts of nylon particles, as they are the main component of fishing tools. In addition, the dominance of PE and PP was also seen previously within Dongting Lake and Hong Lake, China (Wang et al., 2018), indicating a similar microplastic pollution status in the freshwater lakes located in the middle reaches of the Yangtze River.

4. Conclusions

The present study shows that plastic particles not only accumulate in lake waters and sediments, but they can also be ingested by aquatic organisms like *C. auratus*, indicating that this emerging pollutant is ubiquitous in Poyang Lake. Compared to other studies of global freshwater lakes, Poyang Lake was observed to have higher levels and biological risks of microplastics. PP and PE were the major polymer types, and fishing activities and domestic sewage may be the major contributors of the microplastic abundance in Poyang Lake. In addition to human activities, the distribution pattern of microplastic contamination of Poyang Lake may be also affected by hydrodynamic and topographic conditions. Our results provide basic information on the status of microplastic pollution in Poyang Lake, which affects a population of approximately 10 million. The government should improve waste management facilities and optimize the process of wastewater treatment plants as soon as possible. We also suggest that the impacts and fate of microplastics in freshwater ecosystems need to be studied and assessed more accurately and effectively in the future, and the potential impacts on human beings resulting from the consumption of fishery products need to be watched closely.

Acknowledgments

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecoenv.2018.11.126

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