Environmental Pollution 225 (2017) 283–290

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Microplastics in sediments of the Changjiang Estuary, China☆

Guyu Peng [a], Bangshang Zhu [b], Dongqi Yang [a], Lei Su [a], Huahong Shi [a], Daoji Li [a, *]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, 200062 Shanghai, China
[b] Instrumental Analysis Center, Shanghai Jiao Tong University, 200240 Shanghai, China

ARTICLE INFO

Article history:
Received 16 August 2016
Received in revised form
28 October 2016
Accepted 23 December 2016
Available online 10 April 2017

Keywords:
Microplastic
Sediment
Changjiang estuary
μ-FT-IR
Marine pollution

ABSTRACT

Microplastics are plastics that measure less than 5 mm in diameter. They enter the marine environment as primary sources directly from industrial uses, as well as secondary sources resulting from the degradation of large plastic debris. To improve the knowledge of microplastic pollution in China, we investigated samples from 53 estuarine sediment locations collected with a box corer within the Changjiang Estuary. Microplastics (<5 mm) were extracted from sediments by density separation, after which they were observed under a microscope and categorized according to shape, color and size. Identification was carried out using Micro-Fourier-Transform Infrared Spectroscopy (μ-FT-IR).

The abundance of microplastics in the Changjiang Estuary was mapped. The mean concentration was 121 ± 9 items per kg of dry weight, varying from 20 to 340 items per kg of dry weight. It was found that the concentration of microplastics was the highest on the southeast coast of Shanghai. The distribution pattern of microplastics may be affected by the Changjiang diluted water in summer. All of the microplastics collected were categorized according to shape, color and size. Among which fiber (93%), transparent (42%) and small microplastics (<1 mm) (58%) were the most abundant types. No clear correlation between microplastics and the finer sediment fraction was found. Rayon, polyester, and acrylic were the most abundant types of microplastics identified, indicating that the main source of microplastics in the Changjiang Estuary was from washing clothes (the primary source). It is possible to compare microplastic abundance in this study with the results of other related studies using the same quantification method. The identification of microplastics raises the awareness of microplastic pollution from drainage systems. The prevalence of microplastic pollution calls for monitoring microplastics at a national scale on a regular basis.

1. Introduction

Plastics are everywhere in our daily lives, from clothes to food packages and from personal care products to electronics. In 2014, world plastic production reached 311 million tons (Plastics Europe, 2015). As the largest plastic producer in the world, China represents 26% of the world's total plastic production, followed by Europe. The plastics industry is the pillar of China's light industry (China Industry Research, 2015), making it not only the largest producer but also the largest consumer and import-export power (China Plastics Industry Editorial Office, 2015). However, despite of these positive aspects, the ineffective management of plastics waste will result in improper landfill and plastic accumulation in the ocean (Jambeck et al., 2015). A particular environmental concern in recent years is microplastics – plastics that measure less than 5 mm in diameter (Arthur et al., 2009).

Microplastics, also defined as microplastic marine debris in some studies, are plastics that measure less than 5 mm. Related studies in China are inconsistent with the mass production of plastics. Ingestion of microplastics by marine biota may have physical and toxicological effects (Law and Thompson, 2015). Microplastics have the potential for delivery of concentrated POPs, acting as a vector (Andrady, 2011; Setälä et al., 2014). Microplastics occur in size ranges that are similar to the sizes of many organisms from benthos and plankton communities. They can be ingested by marine biota and translocate in zooplankton tissues (Browne et al., 2008). They are present in all types of habitats, from populated urban beaches (Vianello et al., 2013) to deep-sea sediments (Van Cauwenberghe et al., 2013) and from commercial bivalves (Van Cauwenberghe and Janssen, 2014; Li et al., 2015) to abiotic environments (e.g., table salts) (Yang et al., 2015). Microplastics in

☆ This paper has been recommended for acceptance by Eddy Y. Zeng.

* Corresponding author.
E-mail address: daojili@sklec.ecnu.edu.cn (D. Li).

http://dx.doi.org/10.1016/j.envpol.2016.12.064
0269-7491/© 2016 Published by Elsevier Ltd.

sediments have been reported in many places in the world. Browne et al. (2008) studied spatial patterns of microplastics in the Tamar Estuary in the UK and found that more plastics accumulated at downwind sites. Classens et al. (2011) found that the microplastics concentration in sediment cores along Belgian coasts reflected the increase in global plastic production. The concentration of microplastics in sediments of the Lagoon of Venice (Vianello et al., 2013) significantly correlated with the metal pollution index. However, a study of Slovenian tourist beaches found that tourism did not affect the microplastic concentration (Laglbauer et al., 2014). Microplastics in Singapore mangroves might come from the degradation of macroplastics (Mohamed Nor and Obbard, 2014). In South Portuguese waters, Frias et al. (2016) identified rayon fibers as a vast majority of microplastics. Bakir et al. (2014) proposed a transport model of persistent organic pollutants (POPs) onto microplastics.

Shanghai, the most populated city in China, is located in the Changjiang Estuary, where the third largest river in the world empties into the East China Sea. Technological innovation and social development in China have put coastal waters under stress from pollution in the vicinity of the Changjiang Estuary. Throughout recent history, the estuary has suffered from extreme weather events as a result of climate change. To date, microplastics in China have been reported in Hong Kong beaches (Fok and Cheung, 2015), surface waters (Zhao et al., 2014), estuaries (Zhao et al., 2015), bivalves (Li et al., 2016) and lake sediments (Zhang et al., 2016). Given the potential threat of these materials to the health of marine creatures and human beings, quantifying the abundance of microplastics in China (the largest plastic producer and consumer) is an urgent need. Our investigation into the abundance and distribution of microplastics in the seafloor sediment samples of the Changjiang Estuary may lay the foundation for future studies.

2. Materials and methods

2.1. Sampling

All of the samples from 53 locations were collected using a box corer in September 2015 during a cruise along the Changjiang Estuarine system (Fig. 1). The Changjiang Estuary has an average tidal range of 2.5 m. It is divided into the North Branch and the South Branch by Chongming Island, and the South Branch is split into the North Channel and the South Channel by Hengsha Island and Changxing Island. Jiuduan Shoal in the South Channel further breaks the channel into the North Passage and the South passage. Depth information of the Changjiang Estuarine system is shown in Fig. 1, along with the simplified pattern of the Changjiang diluted water in summer, 2015. The Changjiang diluted water expands towards the northeast-north in summer (Zhu et al., 2003), after it leaves the Changjiang River mouth at around 122°30′E under the influence of the southerly monsoon (Wu et al., 2011). One of the largest sewage treatment plants in the world, Bailonggang sewage treatment plant (located in the southeast coast of Shanghai) was included in the sampling area. Samples were collected with precleaned bottles and taken from the upper 5–10 cm on the seafloor. All the HDPE sample bottles were rinsed with Milli Q water three times and carefully stored in boxes before coming onboard. These bottles were carefully stored at room temperature until analysis, when the samples were then taken out of the bottles using aluminum boxes and clean stainless steel spoons. There were three replicates for each sampling site.

2.2. Density separation

Microplastics in sediment samples were extracted using the same method used by Thompson et al. (2004) but with slight adjustments. The sediment samples were dried at 70 °C for 24 h to a constant weight and an aliquot of 100 g was taken from each site. The samples were then moved into a clean glass beaker. 30% H_2O_2 (hydrogen peroxide, Sinopharm, China) was added to degrade organic matter, such as diatoms. Samples were dried again at 70 °C for 24 h to achieve a constant weight. Because no visible plastics were observed in the sediment, in this study, no sieve was used before filtration. For floatation, sodium chloride (Sinopharm, China) was dissolved in Milli Q water to prepare a concentrated saline solution (1.2 g L^{-1}). The solution was then added to the beaker and manually stirred with a clean glass rod for 2 min. For filtration, the supernatant was settled for 24 h before it was poured through a Whatman GF/B (pre-dried at 50 °C) filter paper aided by a vacuum pump and then rinsed with Milli Q water. Finally, the filter paper was dried at 40 °C for 24 h before microscopic inspection.

2.3. Microscopic inspection

Microplastics were counted and photographed under a dissecting microscope (Leica M165 FC, Germany). When observing particles, the microscope moved in a "zigzag" pattern from left to right. Microplastic particles were visually identified and measured according to the following rules: 1) particles that cannot be torn apart by a tweezer; 2) particles that have distinguishable colors; and 3) particles that do not have organic structures (such as knots).

Microplastic particles were assessed by shape, color and size. Three shapes of microplastics were observed: fiber, fragment and pellet. Based on different colors, microplastics can be divided into six categories: blue, black, yellow, transparent, white and red. Note that in the blue category, deep blue, light blue, deep green and light green were counted. In the black category, transparent black, gray and white-striped black particles were counted. In the yellow category, orange and brown particles were counted. The transparent category consisted of colorless particles. The white category did not include transparent particles, but it did include silver particles. The red group included pink and purple particles. Plastic particles longer than 5 mm were mesoplastics which are not shown in our results. The size of large microplastics (LMP) is between 1 and 5 mm, and small microplastics (SMP) are shorter than 1 mm but longer than 1 μm (Vianello et al., 2013). Particles that are smaller than 1 μm are defined as nanoplastics in some studies (Andrady, 2011; Imhof et al., 2012), and they were not included in this study.

2.4. Grain size distribution

To test the relationship between grain size and microplastic abundance (Thompson et al., 2004; Vianello et al., 2013; Mohamed Nor and Obbard, 2014), the grain size distribution of 15 sites along the shoreline was tested by Coulter LS13 320.

2.5. μ-FT-IR analysis

Microplastics that were representative in each group were selected to test polymer types using a Micro Fourier Transform Infrared Spectrometer (Thermo Scientific Nicolet iN10, U.S.A). Transmittance mode was applied. Microplastic particles were placed onto a potassium bromide (KBr) surface. The detector spectral range was 675–4000 cm^{-1}, co-adding 16 scans at a resolution of 8 cm^{-1}. The aperture was set at 150–150 μm. The spectra were processed by OMNIC™ Picta™ software and compared with the OMNIC polymer spectra library.

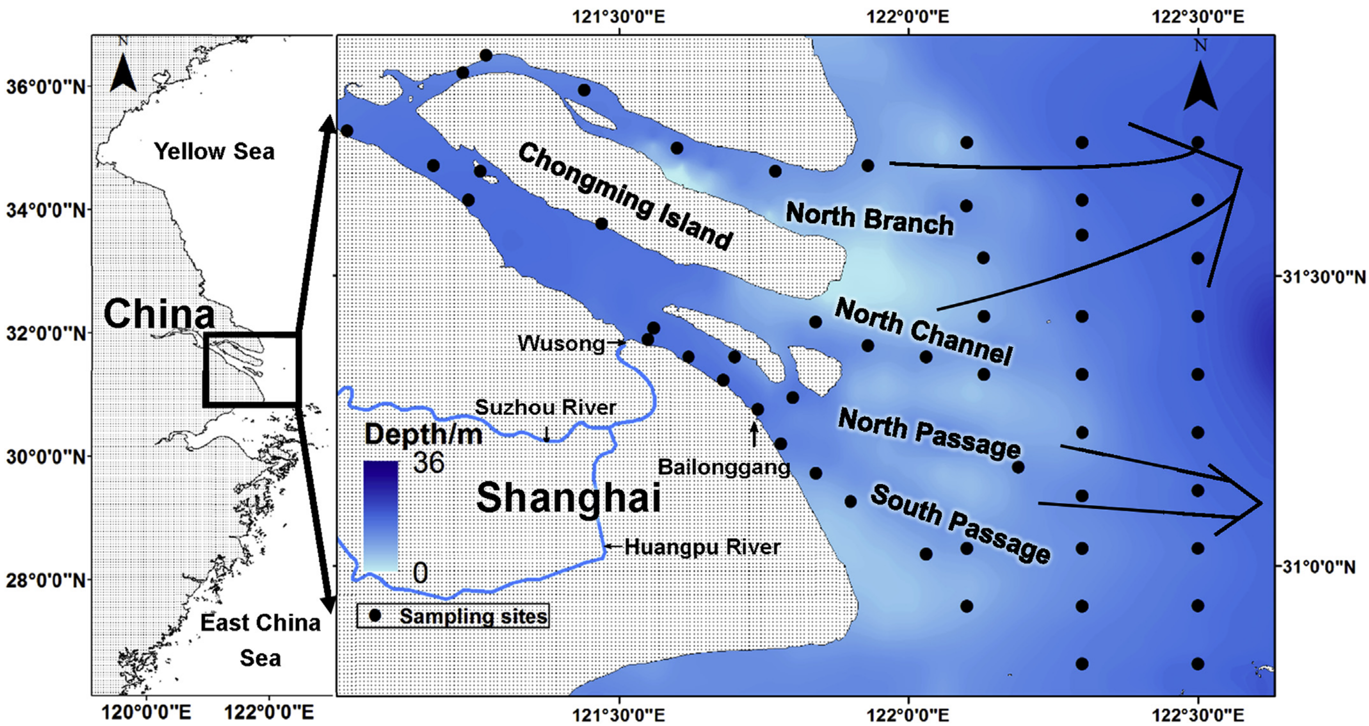

Fig. 1. Geographical location, 53 sampling sites and water depth (m) information of the Changjiang Estuary, with simplified spreading paths of the Changjiang diluted water in summer, 2015.

2.6. Mitigating contamination

All of the utensils were rinsed three times with Milli Q water and then dried before the experiments. All of the plastic equipment was replaced with non-plastics where possible. If this was not possible, they were rinsed three times with Milli Q water and inspected to ensure that no plastic fragments were generated. Lab coats and gloves were always worn in order to keep the process sterile during the experiments. Additionally, we avoided wearing polyester clothes at all times. The lab windows remained closed during experiments. Three procedural blanks were set to mitigate contamination from the environment.

2.7. Statistical analysis

All statistical analyses were conducted by IBM SPSS 22. The non-parametric Kruskal-Wallis H test was used to test multiple comparisons of the variance on the mean of multiple comparisons among sampling sites. If there was a significant difference, a pairwise Mann Whitney *U* test was performed (significance level, 0.05). Spearman's correlation was calculated to study the correlation between grain size and microplastic abundance.

3. Results

3.1. Abundance of microplastics in sediments

The number of microplastic particles found in sediment samples of 53 sampling sites of the Changjiang Estuary is presented in Fig. 2A (indicated by the size of the round circles). The abundance varied between 2.0 and 34.0 items per 100 g of dry weight sediment (i.e., 20–340 items per kg d.w.). The average microplastic concentration in each site was 12.1 ± 0.9 items per 100 g of dry weight (i.e. 121 ± 9 items per kg d.w.). According to various geographical features of the Changjiang Estuary, it can be further divided into four areas (Fig. 2). Area ORM (26 sites) included the sampling sites of the outer river mouth, (i.e., sites north of 122°E). The northeast part of the outer river mouth (i.e., the north part of Area ORM) of the Changjiang Estuary contained a higher abundance of microplastics. Area NB (11 sites) included the North Branch and part of the South Branch from Xuliujing to Wusong (refer to 2.1 sampling). Area NC (12 sites) included the Channel and part of the South Channel. Area NC focused on those sites from Wusong to the Bailonggang sewage treatment plant. They were subject to Huangpu River input and human waste input, which distinguished Area NC from Area ORM, NB and SP. Area SP (4 sites) included the South Passage. Discrepancies in the average abundances in the four areas were apparent (Kruskal-Wallis H test, $p < 0.05$). The average microplastic abundances in area ORM, NB, NC and SP are 11.8 ± 6.8, 8.9 ± 2.9, 16.9 ± 7.9 and 8.2 ± 3.4 items/100 g d.w., respectively. The microplastic abundance in area NC was significantly different from areas ORM, NB and SP (Fig. 2B, Mann-Whitney *U* test, $p < 0.05$).

3.2. Shape, color and size of microplastics

Features of microplastics in sediments of the Changjiang Estuary are shown in Fig. 3. Among all of the 570 microplastic particles, fiber was the most prevalent shape (93%). Only a small amount of microplastics were fragments (6%) and pellets (1%) (Fig. 3A). Transparent particles were the most abundant (42%), followed by blue and black particles, contributing 25% and 16%, respectively (Fig. 3B). Small microplastics particles (SMP) comprised the majority of microplastics (58%) compared to large microplastics (LMP), which agrees with many studies on microplastic distribution in sediments (Mohamed Nor and Obbard, 2014; Vianello et al., 2013) (Fig. 3C). Mesoplastics were not shown in the results because they only made up a small amount of the total plastic particles in the study. The average size of microplastics was 1174.5 ± 41.8 μm, ranging from 46.8 to 4968.7 μm. The size distribution of microplastics can be found in Fig. S1. In the procedural blanks, 1

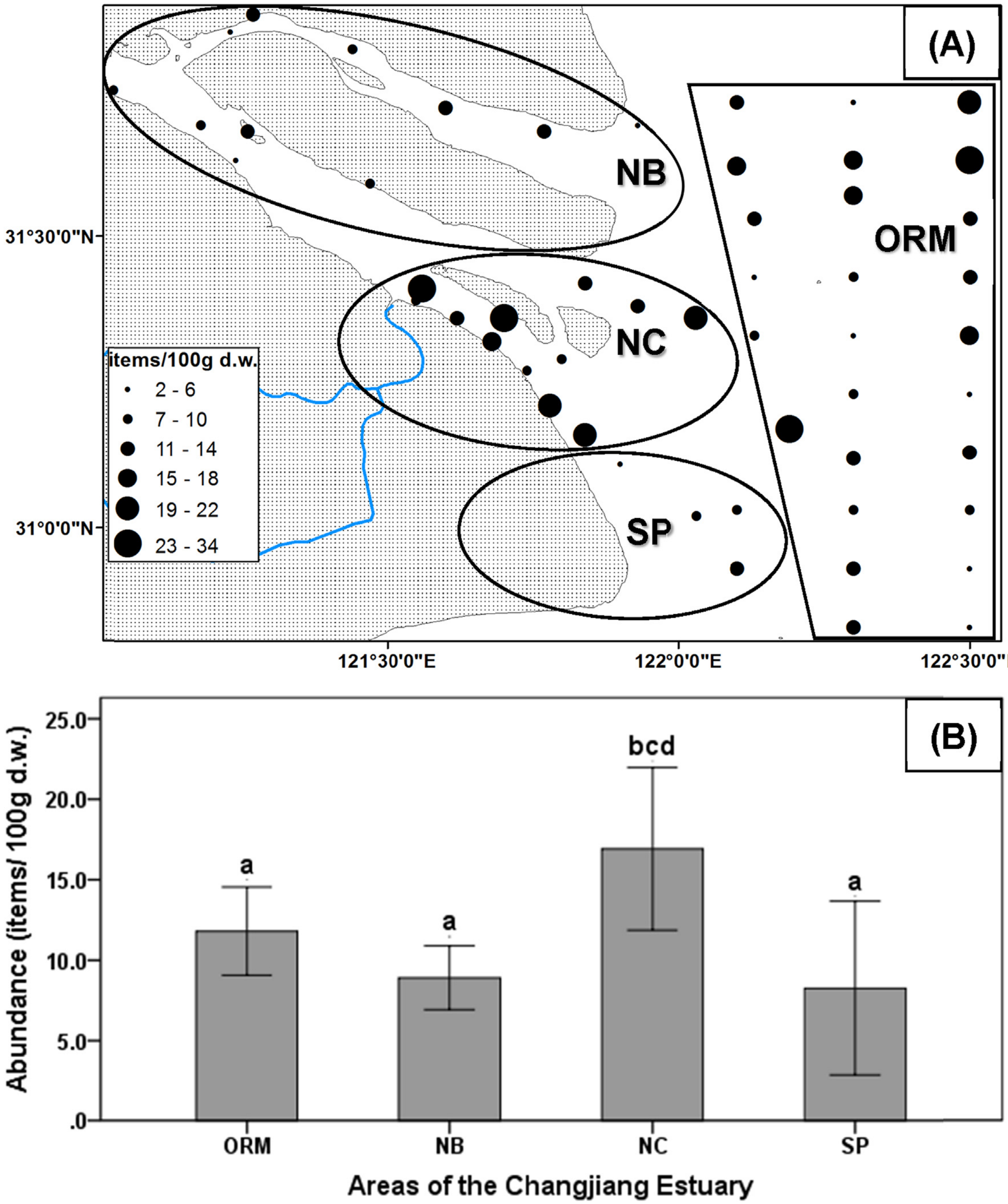

Fig. 2. (A) Microplastic abundance in sediments of the Changjiang Estuary and three areas of the Changjiang Estuary divided by geographical features. ORM: Outer River Mouth; NB: North Branch; NC: North Channel; SP: South Passage. (B) Microplastic abundance in four areas in the Changjiang Estuary. If two random groups have the same letter, they are not significantly different. Area NC had the maximum abundance and was significantly different from Area ORM, Area NB and Area SP (Mann Whitney *U* test, $p < 0.05$).

microplastic fiber was found. Nuelle (2013) found an order of magnitude of more microplastic contamination (33/39) in procedural blanks, raising awareness of contamination.

3.3. Grain size distribution and microplastic abundance

The fine grain size distribution showed no significant relationship with microplastic distribution (Spearman's correlation, $p = 0.13 > 0.05$). The same results appeared in previous studies (Thompson et al., 2004; Browne et al., 2010; Mohamed Nor and Obbard, 2014), but contrary results occurred in others (Vianello et al., 2013).

3.4. Identification of microplastics using μ-FT-IR

Selected groups of samples were examined using μ-FT-IR, and compared with libraries (i.e., Synthetic Fibers by Microscope, Hummel Polymer and Additives, and Cross Sections Wizard). Sixty-five particles were identified as microplastics. A total of six polymer types were identified (Fig. 4), which included rayon (RY), polyester (PES), acrylic (AC), polyethylene terephthalate (PET), poly (ethylene:propylene:diene), and polystyrene (PS). Only those spectra matches over 70% were enlisted in the result (for images of identified microplastics, see Fig. S2). In the procedural blanks, one polyethylene (LDPE) fiber was identified. Ninety-seven percent of

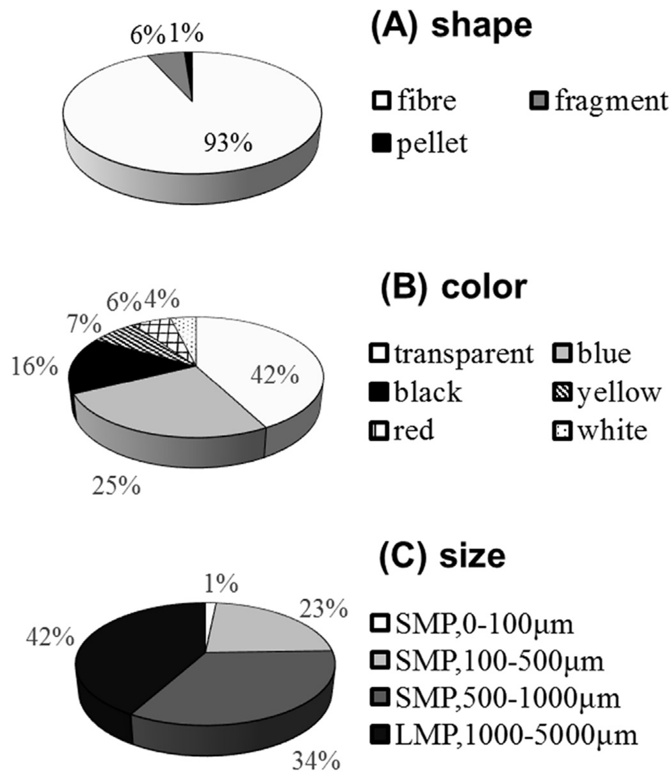

Fig. 3. Microplastic abundance in sediments of the Changjiang Estuary categorized by (A) shape, (B) color and (C) size. Fiber was the most prevalent shape (93%). Transparent, blue and black microplastics were the most abundant (83%). Microplastics less than 1000 μm were predominant (58%).

the total microplastics identified were the main components of clothes: rayon, polyester, acrylic and PET. The number of each polymer type and library used is shown in Table 1.

4. Discussion

4.1. Microplastic abundance and factors related to distribution

Microplastics were present in all 53 of the sampling sites of the Changjiang Estuary. The mapping of microplastics in Fig. 2 indicated that urban river input was the main factor for microplastics entering the sea. Microplastic concentration was the highest on the southeast coast of Shanghai near the Huangpu River and the Bailonggang sewage treatment plant. The lowest concentration was encountered in the outer part of the Changjiang Estuary. This pattern corresponds to many microplastics reports in sediments. Mohamed Nor and Obbard (2014) found that the lowest microplastic concentration was associated with low levels of human activities in Singapore mangroves. Vianello et al. (2013) found that micropollutants that are associated with human inputs have a high correlation with microplastics distribution, indicating that the source of microplastics was human activities. By comparing studies that used the same unit (items per kg of dry weight) for quantifying microplastics, the abundance in this study was of the same order of magnitude as studies in Belgian harbors (Claessens et al., 2011) and Slovenian beaches (Laglbauer et al., 2014). However, the abundance in an Italian subtidal zone (Vianello et al., 2013) was one order of magnitude more, while the abundance in a German beach (Dekiff et al., 2014) was two orders of magnitude less.

The distribution of microplastics may be affected by waves, tides, and water currents along the coast. The northeast part of the outer river mouth of the Changjiang Estuary generally contained a higher abundance of microplastics, as shown in Fig. 2A. The southerly monsoon drives the Changjiang diluted water northeastwards in the summer, thus determining the eventual fate of microplastics in water and sediments. Large quantities of the Changjiang diluted water, which carries solid waste and industrial waste in the vicinity of the Taihu Lake Watershed, pour into the East China Sea. Zhu et al. (2003) explained that due to the lower density of the Changjiang diluted water, it floats on the surface of the sea water once entering the East China Sea, after which the plume front is formed inside of it. Strong hydrological processes in the front area prevent dissolved organic matter (DOM), sediment and pollutants from transport toward the open water, thus making the front area highly polluted. Additionally, because of the abundant organic matter and nutrients brought by the Changjiang diluted water, the Changjiang Estuary is an ideal fishing ground (Li et al., 2004) and this area has a long history as a fishery. Fishing nets are mostly made from polyethylene and polyamide fibers.

A study in beaches of the East Frisian Islands (Liebezeit and Dubaish, 2012) found that fine-grained sediments generally contained higher microplastic levels. In this study, fine-grain size distribution showed no relationship with microplastic abundance. Because most plastics and microplastics tend to float on the water's surface due to their relatively low density, the same process of sedimentation is unlikely to occur in microplastics. Admittedly, sediment may be the source and sink of microplastics in estuaries and in the marine environment. Fragmentation of plastic waste which was discarded underwater will release microplastics. Sewage water that contains microplastic fibers and microbeads will enter coastal sediments as well. These processes make sediments the source of microplastics in the benthic food web. The existence of microplastics in the deep-sea sediments (Van Cauwenberghe et al., 2013) indicated that deep sea may be the sink of microplastics. Whether microplastics sink due to physical reasons (e.g., density) or biological reasons (e.g., marine snow) remains further research. In addition, the complexity of hydrological conditions in the Changjiang Estuary may explain part of the reason why grain size distribution showed no relationship with microplastic distribution. As the Changjiang Estuary is not a typical tide/wave/river-dominated estuary, advection, convection and turbulence, upwelling currents and vortex stretching complicate the interpretation of factors that impact microplastics distribution in the Changjiang Estuary.

In short, the Changjiang Estuary is subject to microplastic pollution under high urbanization and industrialization in addition to hydrodynamic and geographical conditions.

4.2. Extraction efficiency and standardization of procedure

The densities of identified polymers range from 0.92 to 1.50 g cm^{-3} (Table 1). Considering the density of a concentrated saline solution (1.2 g mL^{-1}) and the amount of samples extracted, the extraction technique was inexpensive and effective. The extraction technique adopted in this study was a common practice for microplastics and is recommended by MSFD (2013). Based on different samples, slight adjustments were always mentioned, but without specific details (Hidalgo-Ruz et al., 2012). In this study, biodegradation was added to the process. Preliminary experiments did not include the process of oxidation using hydrogen peroxide. The results showed a high density of diatoms (which interfered with microplastic inspection under microscope). Nuelle et al. (2014) found that biogenic material stored in 35% H_2O_2 solution for a week would be mostly dissolved or bleached. Oxidation should be applied where needed. The usage of heavy solution (e.g., zinc chloride ($ZnCl_2$, 1.5–1.7 g L^{-1}), sodium iodide (NaI,

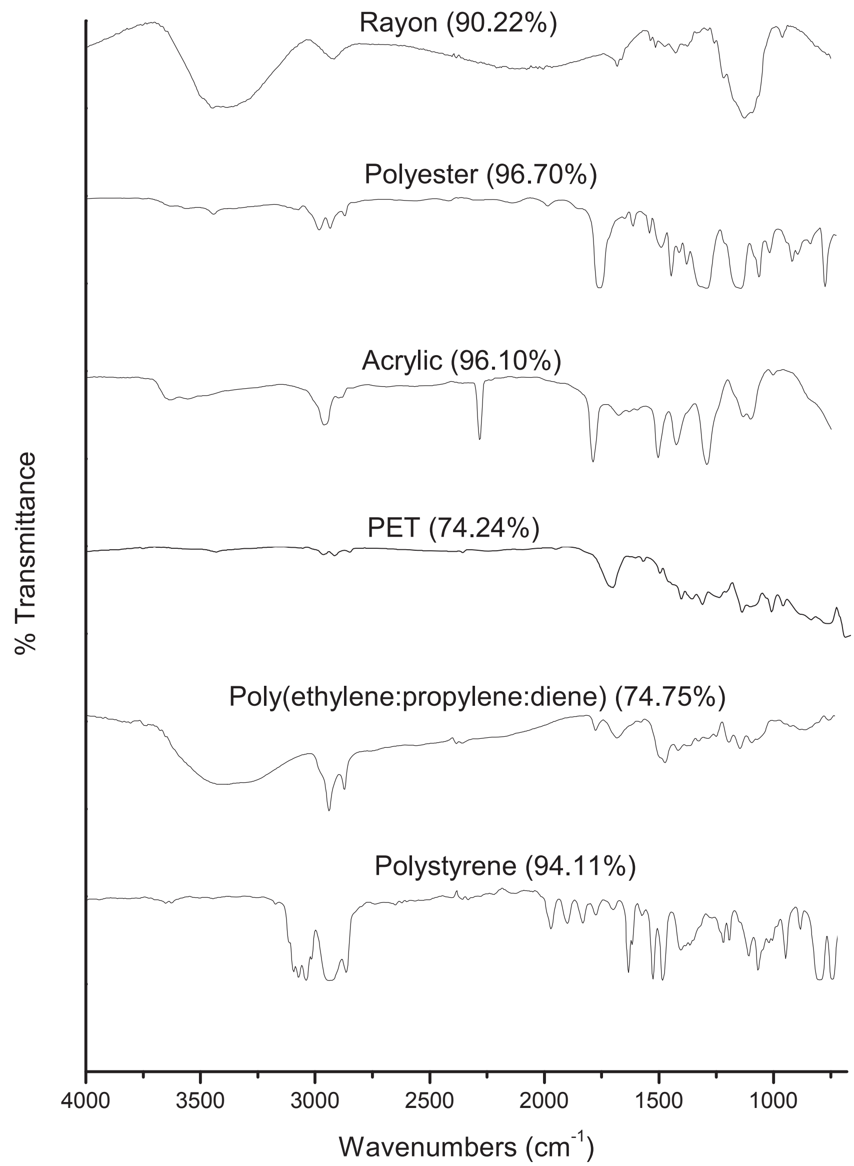

Fig. 4. Identification of microplastics in sediments of the Changjiang Estuary using μ-FT-IR. Spectra from top to bottom: a) Rayon (match 90.22%), b) Polyester (96.70%), c) Acrylic (96.10%), d) Polyethylene terephthalate (74.24%), e) Poly (ethylene:propylene:diene) (74.75%), and f) Polystyrene (94.11%).

1.6–1.8 g L^{-1}) and sodium polytungstate (3.0 g L^{-1}, Bolch, 1997) is ideal for separating denser polymers in some studies given that denser particles were successfully extracted (Zhao et al., 2014; Nuelle et al., 2014). Because $ZnCl_2$ is hazardous to water and sodium polytungstate has no reseller in China, sodium iodide will be the best choice if heavy solution is needed. A low-cost, two-step extraction technique for routinely monitoring microplastics developed by Nuelle et al. (2014), and a complete assessment technique by Claessens et al. (2013) improved the extraction rate; thus, this technique is being applied or further modified in some studies (NOAA, 2015; Van Cauwenberghe et al., 2013). With regard to the fast development of the plastics industry, standardized

Table 1
Relative abundance and density of identified microplastics.

Type of Polymers	Number	%	Library	Density (g cm^{-3})[a]
Rayon	41	63.1	Synthetic Fibers by Microscope	1.50
Polyester	12	18.5	Synthetic Fibers by Microscope& Hummel Polymer and Additives	1.37
Acrylic	9	13.9	Synthetic Fibers by Microscope	1.18
Poly (ethlene:propylene:diene)	1	1.5	Hummel Polymer and Additives	1.10
Polyethylene terephthalate	1	1.5	Cross sections Wizard	1.37
Polystyrene	1	1.5	Hummel Polymer and Additives	1.05
Total	65	100	/	/

[a] International Plastics Handbook.

methods for researching and monitoring microplastics should soon be developed in order to understand the source and fate of microplastics in China.

A potential source of contamination may be the air and the salt. Although methods to mitigate the contamination of microplastics were adopted, airborne contamination was untraceable. Identification results showed that the composition of airborne microplastics was different from that in sediments. A previous study on table salts (Yang et al., 2015) revealed that sodium chloride (the necessity of the extraction experiment) contained microplastics. To eliminate the contamination of microplastics from the time in which field samples are acquired until laboratory analysis and identification, it is always suggested to avoid using plastic equipment or wearing polyester clothing, to apply high-purity chemicals and to cover equipment with aluminum foil during experiments.

4.3. Source of microplastics in the Changjiang Estuary

Identification results showed the composition of microplastics in sediments of the Changjiang Estuary were mainly synthetic fibers, including rayon, polyester and acrylic (Table 1). Laundering clothes may be the source of microplastics entering the marine environment. Microplastics in the Changjiang Estuary are mostly primary microplastics. Large plastics are unlikely to degrade or fragment under high flow velocity. These results correspond to findings by Browne et al. (2011) that polyester and acrylic dominated microplastic fiber in sewage treatment plants and disposal sites. Because the majority of microplastic particles were smaller than 1 mm (58%, see Fig. 3C), most of the microplastics we chose to identify were visible to the eye aided by a hand-held magnifier. Therefore, not all microplastics were able to be identified by μ-FT-IR. Other methods have been deployed by some researchers (e.g., surface chemical mapping) (Vianello et al., 2013). As fiber and transparent particles were quite abundant, representative microplastics in each group were chosen to test polymer types. It was also a compromise between labor and cost. From this point of view, 65 microplastics represented most of the polymer types in our research. What's more, when comparing to the library, only those matches over 70% were selected to guarantee the accuracy of identification. Due to the weathering of microplastic surfaces and environmental degradation, even though samples are regarded as microplastics under microscope, they were not included in the identification results. It is important to combine microscopic and spectroscopic methods in order to obtain the knowledge of composition of microplastics, while improvement on the analytical process is urgently needed.

Note the presence and dominance of rayon. Rayon is a synthetic textile fiber made from cellulose (Jarmin, 1994). It is an inexpensive textile material and can be woven with other synthetic fibers. Two questions about rayon were raised. First, when the spectra of rayon particles was obtained, they were initially compared with the Hummel Polymers and Additives library and identified as cellophane. However, the prevalence of this fiber did not coincide with the decreasing production and consumption of cellophane. The bright varieties of these fibers' colors differentiate them from natural fibers. The Synthetic Fibers by Microscope library was applied to identify polymers, and significant matches were found (90.22%). Choices of libraries should be considered when comparing spectra in order to correct the identification results. Second, although rayon is a synthetic fiber, it is made from cellulose fibers, so technically, it is not plastic. However, because this material could not be distinguished from other microplastics during microscopic inspection and may just as likely to be ingested by marine creatures, considering the ecological effect on these marine living resources, rayon is included in the results. Remy et al. (2015) also found that viscose, a cellulose-based polymer, was present in the digestive tracts of nine dominant macrofauna species in the Mediterranean coastal zone. Identified dyes were known to indicate carcinogenic substances. Whether these synthetic non-plastic “microplastics” pose threat to marine biota remains uncertain and requires further toxicological experiments.

5. Conclusions & perspectives

The abundance of microplastics in sediments of the Changjiang Estuary was 20–340 items per kg of dry weight. The results indicated that the Changjiang Estuary was polluted by microplastics, both in sediments and in surface water (Zhao et al., 2014). Sites along the southeast coast of Shanghai had the maximum concentration, where the Bailonggang sewage treatment plant is located. Microplastic abundance in this area was much higher than that in the rest of the Changjiang Estuary. Rayon, polyester and acrylic and three other plastics were identified by micro-FT-IR, indicating that the main source of microplastics in sediments might be from washing clothes. So far, the abundance of microplastics in China has only been quantified on a small scale. In the future, microplastics should be quantified at a national scale. The use of microplastics/microbeads in personal care products and cosmetics (PCCPs) has been banned in some countries (UNEP, 2015) due to the potential harm of microplastics to zooplankton, fish and benthic fauna. Experiments on characterization and toxicology of microplastics in PCCPs are currently underway in order to provide evidence for proper legislation and regulations. Large amounts of small microplastics may transfer in tissues and through the planktonic food web, which should be the focus of future research.

Funding

This study was supported by National Key Research and Development project (2016YFC1402205), Ministry of Science and Technology of China Fundamental Project (2013FY112000) and National Natural Science Fund of China (41676190).

Acknowledgements

We would like to thank researchers in SKLEC for providing assistance with sampling, and we are especially thankful to Professor Zhang Weiguo and Yao Jun. Their hard work and contribution are of great significance to this research. We would like to thank Wu Hui for his advice and expertise. We are also grateful to our reviewers for their comments and language improvements on the research.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2016.12.064.

References

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605. http://dx.doi.org/10.1016/j.marpolbul.2011.05.030.

Arthur, C., Baker, J., Bamford, H. (Eds.), 2009. Sept 9–11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Bakir, A., Rowland, S.J., Thompson, R.C., 2014. Transport of persistent organic pollutants by microplastics in estuarine conditions. Estuarine. Coast. Shelf Sci. 140, 14–21. http://dx.doi.org/10.1016/j.ecss.2014.01.004.

Bolch, C.J.S., 1997. The use of sodium poly tungstate for the separation and concentration of living dinoflagellate cysts from marine sediments. Phycologia 36, 472–478. http://dx.doi.org/10.2216/i0031-8884-36-6-472.1.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested microscopic plastic translocates to the circulatory system of the Mussel,Mytilus edulis (L.). Environ. Sci. Technol. 42, 5026–5031. http://dx.doi.

org/10.1021/es800249a.
Browne, M.A., Galloway, T.S., Thompson, R.C., 2010. Spatial patterns of plastic debris along estuarine shorelines. Environ. Sci. Technol. 44, 3404–3409. http://dx.doi.org/10.1021/es903784e.
Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines woldwide: sources and sinks. Environ. Sci. Technol. 45, 9175–9179. http://dx.doi.org/10.1021/es201811s.
China Industry Research, 2015. Research on China plastics market current status and future trend. http://www.cir.cn/R_ShiYouHuaGong/1A/SuLiaoZhiPinShiChangQianJingFenXiYuCe.html.
China Plastics Industry Editorial Office, 2015. Progress of the World's plastics industry in 2013–2014. China Plast. Ind. 43, 1–40.
Claessens, M., Meester, S.D., Landuyt, L.V., Clerck, K.D., Janssen, C.R., 2011. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Mar. Pollut. Bull. 62, 2199–2204. http://dx.doi.org/10.1016/j.marpolbul.2011.06.030.
Claessens, M., Van Cauwenberghe, L., Vandegehuchte, M.B., Janssen, C.R., 2013. New techniques for the detection of microplastics in sediments and field collected organisms. Mar. Pollut. Bull. 70, 227–233. http://dx.doi.org/10.1016/j.marpolbul.2013.03.009.
Dekiff, J.H., Remy, D., Klasmeier, J., Fries, E., 2014. Occurrence and spatial distribution of microplastics in sediments from Norderney. Environ. Pollut. 186, 248–256. http://dx.doi.org/10.1016/j.envpol.2013.11.019.
Plastics Europe, 2015. Plastics – the Facts 2015, an Analysis of European Plastics Production, Demand and Waste Data. Plastics Europe, Brussels, Belgium.
Fok, L., Cheung, P.K., 2015. Hong Kong at the Pearl River Estuary: a hotspot of microplastic pollution. Mar. Pollut. Bull. 99, 112–118. http://dx.doi.org/10.1016/j.marpolbul.2015.07.050.
Frias, J.P.G.L., Gago, J., Otero, V., Sobral, P., 2016. Microplastics in coastal sediments from Southern Portuguese shelf waters. Mar. Environ. Res. 114, 24–30. http://dx.doi.org/10.1016/j.marenvres.2015.12.006.
Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ. Sci. Technol. 46, 3060–3075. http://dx.doi.org/10.1021/es2031505.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Marine pollution. Plastic waste inputs from land into the ocean. Science 347, 768–771. http://dx.doi.org/10.1126/science.1260352.
Jarmin, R.S., 1994. Learning by doing and competition in the early rayon industry. RAND J. Econ. 25, 441–454. http://www.jstor.org/stable/2555771.
Laglbauer, B.J.L., Franco-Santos, R.M., Andreu-Cazenave, M., Brunelli, L., Papadatou, M., Palatinus, A., Grego, M., Deprez, T., 2014. Macrodebris and microplastics from beaches in Slovenia. Mar. Pollut. Bull. 89, 356–366. http://dx.doi.org/10.1016/j.marpolbul.2014.09.036.
Law, K.L., Thompson, R.C., 2015. Microplastics in the seas. Science 345, 114–115. http://dx.doi.org/10.1126/science.1254065.
Li, J., Yang, D., Li, L., Jabeen, K., Shi, H., 2015. Microplastics in commercial bivalves from China. Environ. Pollut. 207, 190–195. http://dx.doi.org/10.1016/j.envpol.2015.09.018.
Li, J., Qu, X., Su, L., Zhang, W., Yang, D., Kolandhasamy, P., Li, D., Shi, H., 2016. Microplastics in mussels along the coastal waters of China. Environ. Pollut. 214, 177–184. http://dx.doi.org/10.1016/j.envpol.2016.04.012.
Liebezeit, G., Dubaish, F., 2012. Microplastics in beaches of the East frisian Islands spiekeroog and Kachelotplate. Bull. Environ. Contam. Toxicol. 89, 213–217. http://dx.doi.org/10.1007/s00128-012-0642-7.
Masura, J., et al., 2015. Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments. NOAA Technical Memorandum. NOS-OR&R-48.
Mohamed Nor, N.H., Obbard, J.P., 2014. Microplastics in Singapore's coastal mangrove ecosystems. Mar. Pollut. Bull. 79, 278–283. http://dx.doi.org/10.1016/j.marpolbul.2013.11.025.
MSFD Technical Subgroup on Marine Litter, 2013. Guidance on Monitoring of Marine Litter in European Seas. Publications Office of the European Union, Luxembourg. http://dx.doi.org/10.2788/99475.
Nuelle, M., Dekiff, J.H., Remy, D., Fries, E., 2014. A new analytical approach for monitoring microplastics in marine sediments. Environ. Pollut. 184, 161–169. http://dx.doi.org/10.1016/j.envpol.2013.07.027.
Remy, F., Collard, F., Gilbert, B., Compère, P., Eppe, G., Lepoint, G., 2015. When microplastic is not plastic: the ingestion of artificial cellulose fibers by macrofauna living in seagrass macrophytodetritus. Environ. Sci. Technol. 49, 11158–11166. http://dx.doi.org/10.1021/acs.est.5b02005.
Setälä, O., Fleming-Lehtinen, V., Lehtiniemi, M., 2014. Ingestion and transfer of microplastics in the planktonic food web. Environ. Pollut. 185, 77–83. http://dx.doi.org/10.1016/j.envpol.2013.10.013.
Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at sea: where is all the plastic? Science 304, 838. http://dx.doi.org/10.1126/science.1094559.
UNEP, 2015. Plastic in Cosmetics.
Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environ. Pollut. 193, 65–70. http://dx.doi.org/10.1016/j.envpol.2014.06.010.
Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R., 2013. Microplastic pollution in deep-sea sediments. Environ. Pollut. 182, 495–499. http://dx.doi.org/10.1016/j.envpol.2013.08.013.
Vianello, A., Boldrin, A., Guerriero, P., Moschino, V., Rella, R., Sturaro, A., Da Ros, L., 2013. Microplastic particles in sediments of Lagoon of Venice, Italy: first observations on occurrence, spatial patterns and identification. Estuarine, Coast. Shelf Sci. 130, 54–61. http://dx.doi.org/10.1016/j.ecss.2013.03.022.
Wu, H., Zhu, J., Shen, J., Wang, H., 2011. Tidal modulation on the Changjiang River plume in summer. J. Geophys. Res. Oceans 116, 192–197. http://dx.doi.org/10.1029/2011JC007209.
Yang, D., Shi, H., Li, L., Li, J., Jabeen, K., Kolandhasamy, P., 2015. Microplastic pollution in table salts from China. Environ. Sci. Technol. 49, 13622–13627. http://dx.doi.org/10.1021/acs.est.5b03163.
Zhang, K., Su, J., Xiong, X., Wu, X., Wu, C., Liu, J., 2016. Microplastic pollution of lakeshore sediments from remote lakes in Tibet plateau, China. Environ. Pollut. 219, 450–455.
Zhao, S., Zhu, L., Wang, T., Li, D., 2014. Suspended microplastics in the surface water of the Yangtze Estuary System, China: first observations on occurrence, distribution. Mar. Pollut. Bull. 86, 562–568. http://dx.doi.org/10.1016/j.marpolbul.2014.06.032.
Zhao, S., Zhu, L., Li, D., 2015. Microplastic in three urban estuaries, China. Environ. Pollut. 206, 597–604. http://dx.doi.org/10.1016/j.envpol.2015.08.027.
Zhu, J., Ding, P., Hu, D., 2003. Observation of the diluted water and plume front off the Changjiang River estuary during August 2000. Oceanol. Limnologia Sinica 34, 249–255.