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High levels of microplastic pollution in the sediments and benthic organisms of the South Yellow Sea, China

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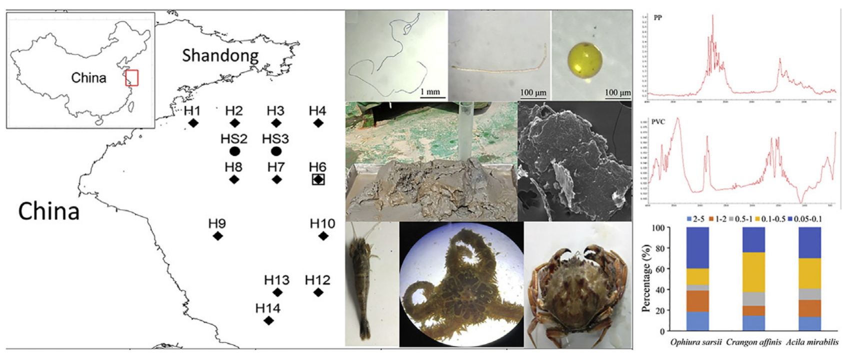
HIGHLIGHTS

- Microplastics in sediments and benthic organisms in South Yellow Sea were analyzed.
- Microplastic abundances decreased significantly with increase in sediment depth.
- Microplastic abundance was 560–4205 n/kg in sediment and 1.7–47.0 n/g in organisms.
- Fibers, transparent and small microplastics (<0.5 mm) were the most dominant types.
- Microplastic abundances were positively correlated with water depth.

GRAPHICAL ABSTRACT



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ABSTRACT

Microplastics, emerging contaminants in the ocean, are thought to sink and accumulate in sediments, and thus may pose a potential ecological risk to benthic communities. In this study, abundances and characteristics of microplastics in sediments and benthic organisms from the South Yellow Sea were investigated. First, we optimized the sediment sampling for microplastic analysis and found that the top layer (0–5 cm) had the highest abundance, and microplastic abundances decreased significantly with increase in sediment depth. The abundance of microplastics was 560–4205 n/kg dry weight in the surface sediments (the topmost 3 cm) of 14 sites and 1.7–47.0 n/g wet weight in the tissues of benthic organisms. Moreover, microplastic abundances in sediments and benthic organisms were both positively correlated with water depth. Fibers, transparent microplastics, and small microplastics (<0.5 mm) were the most dominant types in sediments and organisms. FTIR analysis showed that polypropylene (PP, 31%), polyester (PE, 24%), nylon (19%), and polystyrene (PS, 15%) were the most abundant polymers in sediments. The results of SEM showed rough surfaces and obvious cracks on the microplastics isolated from sediments. In addition, characteristics of microplastics in *Ophiura sarsii*, *Crangon affinis*, and *Acila mirabilis* were compared. Our results demonstrate that a comprehensive investigation of microplastics in sediments and benthic communities will help to fully understand the ecological risk of microplastic pollution.

1. Introduction

Since plastic was invented in 1907, the extensive use of plastic products has brought many conveniences to people's lives. Annual global

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plastic production is continuously rising, reaching 322 million tons in 2015 (PlasticsEurope, 2016). After being discarded, plastics are eventually transported to the ocean via river, wastewater from coastal cities, floods, and winds (Desforges et al., 2014; Hurley et al., 2018). It was estimated that >5 trillion plastic pieces weighing over 250,000 tons were floating at sea (Eriksen et al., 2014). These plastics finally break up into microplastics (defined as plastic particles <5 mm diameter) (Arthur et al., 2009), which have become the predominant form of marine plastic debris (Law and Thompson, 2014). Microplastics have been found throughout the world's ocean, including in estuaries, coastlines, seawater, sediments, and even remote areas (such as deep sea and polar regions) (Lusher et al., 2015; Isobe et al., 2017; Waller et al., 2017). By contrast, higher concentrations of microplastics are usually observed along the densely populated coastlines. For instance, microplastic concentrations in the surface seawater of the Yangtze Estuary (China) and southeastern coast of Korea were 500–10,200 n/m^3 and 210–15,560 n/m^3, respectively, (Zhao et al., 2014; Kang et al., 2015), while the highest concentration of microplastics in the Ross Sea (Antarctica) was 1.18 n/m^3 (Cincinelli et al., 2017). After entering the ocean, microplastics are covered with a biofilm or encapsulated into the feces of marine animals, becoming denser than seawater and sinking, accumulating in sediments (Lobelle and Cunliffe, 2011; Eriksen et al., 2014). Concentrations of 8000 and 6595 n/kg of microplastics have been found in sediment from Nova Scotia and Arctic Ocean, respectively (Mathalon and Hill, 2014; Bergmann et al., 2017). As the final destination of most marine microplastics, sediments have become the main focus of studies assessing microplastic pollution (Claessens et al., 2011; Reed et al., 2018).

Microplastics are very stable and have the ability to accumulate organic pollutants and heavy metals (Bakir et al., 2014; Brennecke et al., 2016). Moreover, microplastics could easily be ingested by zooplanktons (Desforges et al., 2015), mollusks (Kolandhasamy et al., 2018), and fish (Neves et al., 2015), which may pose serious ecological risks. Microplastics not only cause physical harm to marine organisms by uptake and ingestion but also provide a pathway for the transfer of organic pollutants and heavy metals to marine life (Bakir et al., 2016; Hodson et al., 2017). The accumulation of microplastics in sediments would greatly increase the possibility of microplastic ingestion in benthic organisms, and the abundance of microplastics in sediment alone could not reflect the quality of the living resources. A comprehensive analysis of microplastic pollution in sediments and benthic organisms may provide a good indication of environmental health (Santana et al., 2016).

China is considered to be the largest plastic producer and consumer in the world, accounting for 27.8% of the global plastic production (PlasticsEurope, 2016). Several studies have reported microplastic pollution in sediments of the Yangtze Estuary, South China Sea, Yellow Sea, and Bohai Sea (Peng et al., 2017; Qiu et al., 2015; Yu et al., 2016). However, data on microplastics in benthic organisms are almost completely nonexistent. Surprisingly, the above studies did not give a detailed description on the depth of sediments used for microplastic isolation, which may lead to a lack of comparability among these studies. For this reason, an optimized method for sediment sampling was thought to be necessary (Lusher et al., 2017). In this study, the South Yellow Sea was chosen as the target area. Core sediments, surface sediments, and benthic organisms were collected. First, we compared microplastic abundances in vertical sections of different sediment depth (0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm). Then, the abundances, shapes, sizes, and colors of microplastics in surface sediments (0–3 cm) and benthic organisms were analyzed. Furthermore, the components of microplastics in sediments were determined using Fourier transform infrared spectroscopy, and the surface morphologies were analyzed by scanning electron microscopy. This study will provide a basis for evaluating the ecological risks of microplastics in sediments from this sea area.

2. Materials and methods

2.1. Study area

The South Yellow Sea, located between Korean Peninsula and northern China, covers an area of 300,000 km^2, with an average depth of 40 m. The Yellow Sea is an important fishery and aquacultural area, which is adjacent to the developed urban areas of China. The water exchange between the South Yellow Sea and other seas is slow (at least 5 years, Park and Choi, 1993); thus, microplastics input from land accumulate in the sediments gradually. In this study, 17 sampling sites on four sections were designed (Fig. 1). Among them, core sediments were collected at sites HS1, HS2, and HS3, and benthic organisms were collected at sites HS1, H5, H6, and H11. The depths and geographical information for each sampling site is listed in Table S1.

2.2. Sample collection

During August 28–September 8, 2017, sediment was collected using a box corer (0.1 m^2) from 17 sites, and approximately 500 g of surface sediments (the topmost 3 cm) were obtained by a stainless-steel shovel. For core sediments, a plexiglass tube with an inner diameter of 6 cm was inserted vertically into the sediments, and sediments from layers of 0–5 cm, 5–10 cm, 10–15 cm, and 15–20 cm were collected separately. Surface and core sediments were stored in glass bottles and taken back to the laboratory for microplastic isolation. Replicate samples were obtained from each site to ensure accuracy of the sampling results. Benthic organisms were sampled by an Agassiz trawl with an inner diameter of 1.5 m at a vessel speed of 2 knots for 15 min. All the organisms were stored at −20 °C until further analysis.

2.3. Isolation of microplastics

In the laboratory, microplastics were extracted from sediments according to the methods of Claessens et al. (2013) with minor modification. Briefly, sediments (200 g) were dried at 60 °C overnight, and microplastics were floated by adding 400 mL of NaI solution (1.8 g/cm^3). After shaking for 10 min, the supernatant was centrifuged at 3000*g* for 5 min. Then, the NaI solution containing the microplastics were poured into steel sieves with diminishing pore sizes (2 mm, 1 mm, 0.5 mm, 0.1 mm, 0.05 mm) to separate the microplastics. The sieves were sequentially separated, and the contents of each sieve were carefully transferred into petri dishes by rinsing the sieves from the reverse side with filtered distilled water. To ensure that all plastic particles were isolated from the sediments, the processes of NaI-extraction and filtration were repeated three times. The collected organisms were then sorted and weighed. Then, the gastrointestinal tract and soft tissue were dissected from the fish (Nadal et al., 2016) and mollusks (Naji et al., 2018), respectively, for microplastic isolation. For small organisms (such as ophiuroids), the entire body was used for microplastic extraction. After weighing, these tissues or organisms were added into a mixture of 30% H_2O_2 and 65% HNO_3 (1:3, v/v) for two days to digest the tissues (Claessens et al., 2013). Microplastics were then isolated using the same procedure as sediments. Microplastics were separated by steel sieves with diminishing pore sizes and then dried in petri dishes with covers at 60 °C.

To avoid potential microplastic contamination, all liquids used were filtered with 0.45-μm membrane filters (Whatman, USA), and containers were rinsed with filtered water before reuse. All glass containers were covered by aluminum foil, and a cotton laboratory coat and nitrile gloves were worn. Moreover, the entire process of analysis and identification was conducted by one person in a closed room, and blank experiments were conducted to detect any ambient microplastic contamination (Cincinelli et al., 2017).