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Abundance and size of microplastics in a coastal sea: Comparison among bottom sediment, beach sediment, and surface water

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ABSTRACT

Microplastics have adverse effects on marine life. This study examined the abundance and size of microplastics as well as their polymer types in the surface water and the bottom and beach sediments of Hiroshima Bay. The fragmentation process and sinking factors of foamed polystyrene (FPS) microplastics were also examined. Serious FPS pollution spread out not only in the beach sediments but also in the bottom sediments. The average size of FPS particles in the bottom sediments was significantly smaller than that of beached FPS particles. Field emission scanning electron microscopy images suggest that large amounts of microsized or nanosized FPS fragments are likely to be generated from the margins of beached FPS microplastics. X-ray computed tomography images show that FPS microplastics from the bottom sediments had tunnel-like structures inside the particle. Based on these images, FPS microplastics in the bottom sediments were susceptible to biofouling and soil deposition.

1. Introduction

Annual plastics production has increased, reaching 322 million tons in 2015 (Plastics Europe, 2016). Some plastics slip through refuse dumps and enter the ocean. According to Jambeck et al. (2015), the mass of land-based plastic waste entering the ocean in 2010 is estimated at 4.8–12.7 million metric tons. Plastic waste entering the ocean will drift on the sea surface, wash ashore or sink to the sea bottom. In this process, plastic waste, especially on beaches, is exposed to UV radiation and fragmented into small pieces (Andrady, 2011). Fragments of 0.3–5 mm in size are called microplastics and their impact on the marine environment including the ecosystem has become a major concern. For example, microplastics absorb toxic compounds while drifting in the sea and then they are ingested by marine organisms (Hirai et al., 2011). Besseling et al. (2013) examined the effects of plastics on benthic organisms including the transfer of persistent organic pollutants (POPs), reporting a positive relationship between microplastic concentration in the sediment and both uptake of plastic particles and weight loss by the lugworm *Arenicola marina*. They also observed a reduction in feeding activity at a polystyrene (PS) dose of 7.4% dry weight. Lu et al. (2016) investigated the toxic effects of PS microplastics on the liver of zebrafish (*Danio rerio*) and reported a significant increase in the activity of superoxide dismutase and catalase, indicating induced oxidative stress.

Microplastic ingestion has been demonstrated in several marine organisms. Desforges et al. (2015) found the first evidence of microplastic ingestion by marine zooplankton in the Northeast Pacific Ocean and estimated that the consumption of microplastic-containing zooplankton will lead to the ingestion of 2–7 microplastic particles/day by individual juvenile salmon in coastal British Columbia. Neves et al. (2015) examined the digestive tract contents of 263 individuals from 26 species of commercial fish for the presence of microplastics. They found microplastics in 17 species, corresponding to 19.8% of the fish of which 32.7% had ingested more than one fiber or microplastic particle. Considering the more abundant ecosystem in coastal seas than in the open ocean, microplastics are more likely to enter the ecosystem in coastal seas than in the open ocean. To determine the extent of microplastic pollution in the coastal marine environment, it is necessary to understand the distribution of microplastics in the reservoirs of the coastal marine system, namely, the sea surface, water column, sea bottom, beaches and marine ecosystem. In addition, microplastic fluxes among the reservoirs should be estimated to assess and predict the adverse effects of microplastics on the ecosystem (Hardesty et al., 2017).

Understanding the abundance and size of microplastics in a coastal sea is a key factor in determining the spatial distribution and fluxes, because their behaviors in coastal seas will depend on their sizes. Isobe et al. (2014) investigated the quantity and size of microplastics and mesoplastics (approximately > 5 mm) in the surface water in a coastal sea by means of field surveys and a numerical particle-tracking model to interpret the size-dependent distribution of plastics and the possible

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transport process in the surface water. Recently, Hinata et al. (2017) revealed the size dependence of the residence times of beached plastics due to the size-dependent responses to turbulence generated by swash waves on the beach. Although the abundance of microplastics in the reservoirs of the coastal marine system has been investigated worldwide (e.g., Claessens et al., 2011; Lee et al., 2013; Vianello et al., 2013; Matsuguma et al., 2017; Tsang et al., 2017), these studies examined microplastic concentrations in only one or two reservoirs of the coastal marine system. In addition, the size of microplastics and its comparison among reservoirs have not been discussed in previous studies. Microplastic distribution in the reservoirs and microplastic fluxes between the reservoirs are still unknown.

This study examined the abundance and size of microplastics as well as their polymer types in the surface water and the bottom and beach sediments of Hiroshima Bay to infer the behaviors of microplastics in the region. Moreover, this study aimed to examine the shape characteristics, surface states and internal structures of FPS microplastics in the beach and bottom sediments by using digital microscopy, field emission scanning electron microscopy (FE-SEM) and X-ray computed tomography (X-ray CT) to deduce the sinking and fragmentation process of FPS microplastics. This study is the first step toward a comprehensive understanding of the behaviors of microplastics including the fragmentation process in the region.

2. Materials and methods

2.1. Study site

Hiroshima Prefecture is the leading center of oyster aquaculture in Japan by production quantity (Ministry of Agriculture, Forestry and Fisheries, 2016). There are 11,284 oyster aquaculture rafts in Hiroshima Bay (Fig. 1), covering about 2.2 km^2 (Ministry of Agriculture, Forestry and Fisheries, 2016). Foamed polystyrene (FPS) is often used for floats to keep the oyster aquaculture facilities on the sea surface. The specific gravity of FPS is 0.01–0.02 due to the inclusion of pores, which is much less than that of seawater. In the marine environment, FPS is likely to be transported by surface residual currents, Stokes drift and winds. The surface residual current in the study region flows southward from the head of Hiroshima Bay toward Suo-Oshima Island (Lee et al., 2001), and the bottom residual current returns to the bay head (Yanagi, 2008) mainly due to the inflow of freshwater from the mouth of the Ohta River (see Fig. 1). FPS floats without covers (i.e. protective surfaces) are directly exposed to the environment and easily break down into small spherules (Lee et al., 2013). Microplastics originating from FPS floats have been spread throughout the beaches of the bay by residual currents, Stokes drift and winds, causing serious pollution on the beaches (Fig. 2; Fujieda and Sasaki, 2005).

Fig. 1 shows an overview of the sampling sites. Sampling was performed at a total of 16 sites; beach and bottom sediments were collected at six sites, and surface water was collected at four sites. Considering the structure of the residual currents, the sampling sites were located from the upstream (bay head) to downstream (off the north coast of Suo-Oshima Island) of the surface residual current. The water depth at the sites ranged from 18 to 35 m. Straight beaches pointing in various directions were selected as sampling sites. Sampling of beach sediments and surface water was conducted in August and September 2016. Bottom sediment sampling was conducted in January and April 2017.

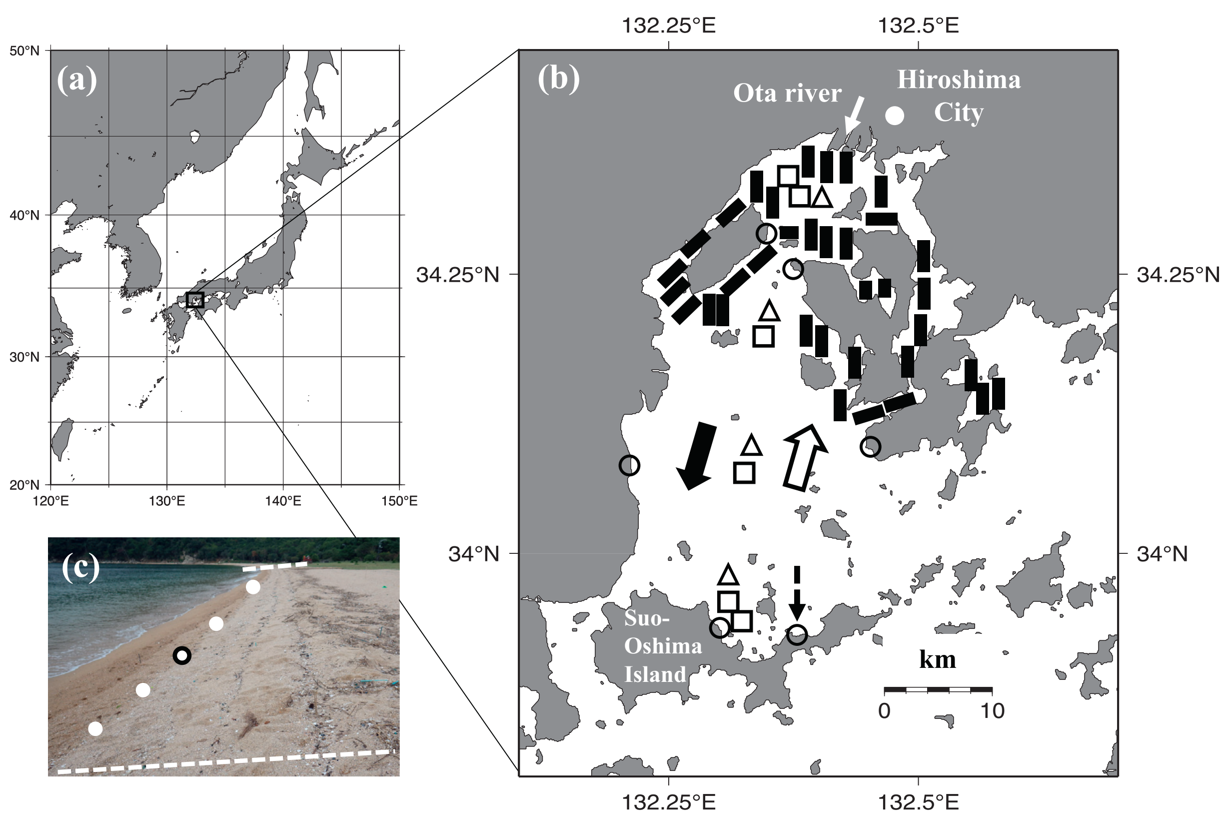

Fig. 1. Overview of sampling sites. (a) Location of Hiroshima Bay. (b) Enlarged map of Hiroshima Bay. White circles show the sampling sites for beach sediments and white triangles show the sampling sites for surface water. White squares show the sampling sites for bottom sediments. At the head of Hiroshima Bay, black rectangles show the positions of oyster aquaculture facilities, but the number or size of the rectangles may be different from that of the actual oyster aquaculture facilities. The black arrow and the white arrow show the direction of residual currents in the surface layer and bottom layer, respectively. The broken arrow represents the location of the beach in Fig. 2. (c) Sample collection on beaches; ends of the beach (dotted lines), center of the beach (outlined circle) and five sampling points per beach (outlined circle and white circles).