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Size distribution of stranded small plastic debris on the coast of Guangdong, South China☆

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ABSTRACT

Beach environments are known to be conducive to fragmentation of plastic debris, and highly fragmented plastic particles can interact with smaller organisms. Even through stranded plastic debris may not interact directly with marine organisms, backwash processes may transport this debris back to coastal waters, where it may affect a wide range of marine life at different trophic levels. This study analysed the size distribution of stranded plastic debris (<10 mm) collected from eight coastal beaches in Guangdong Province, China. Polystyrene (PS) foams and fragments smaller than 7 mm were increasingly abundant in the smaller size classes, whereas resin pellets remained in their production sizes (~3 mm). Microplastics (<5 mm) accounted for over 98% of the total plastic debris by abundance and 71% by weight, indicating that the plastic debris on these coastal beaches was highly fragmented and the majority of the plastic masses belonged to the microplastic size range. The observed size distributions of PS foams and fragments are believed to result from continued fragmentation. Previous studies found that the residence time of beached debris was less than one year on average, and no sign of plastic accumulation with depth in beach sediment was observed. Therefore, coastal beaches may represent a reservoir of highly fragmented and degraded microplastics that may be mobilised and returned to the sea during storm events. Further research on the dynamics and longevity of microplastics on beaches will help reveal the mass balance of microplastics on the shoreline and determine whether shorelines are sinks or sources of microplastics.

1. Introduction

Microplastics are often defined as plastic debris with a diameter of less than 5 mm (Arthur et al., 2009). Microplastic contamination has been reported in different natural environments, such as rivers (Mani et al., 2015), estuaries (Zhao et al., 2015), beaches (Fok and Cheung, 2015), the open ocean (Cózar et al., 2014) and the deep sea (Van Cauwenberghe et al., 2013). These small plastic fragments in the environment are potentially dangerous to wildlife because they can be ingested by a wide range of aquatic organisms (see review in Lusher, 2015), causing physical harm to lugworms (Wright et al., 2013) and disrupting physiological processes (Rochman, 2015) such as feeding and immunity (Browne et al., 2013) via the chemical pollutants adsorbed on the plastic surface. Nevertheless, the impacts of adsorbed contaminants on wildlife are less clear than physical impacts because a recent study showed that the exposure of these hydrophobic organic chemicals is actually more significant from natural prey than from consumed microplastics (Koelmans et al., 2016).

The particle size of ingested plastic debris is associated with the size of the affected organisms. Whereas plastic particles at the micron scale were ingested by zooplankton in laboratory conditions (Cole et al., 2013) and by commercial bivalves raised in a mussel farm (Van Cauwenberghe and Janssen, 2014), millimetre-scale particles have also been widely detected in fish (Lusher et al., 2013), seabirds (Codina-García et al., 2013) and sea turtles (Tourinho et al., 2010). The fragmentation of plastic debris in beach environment is believed to be much faster than in water (Gregory and Andrady, 2003) for two reasons. First, plastic degradation mainly occurs via solar UV-radiation-induced oxidation, the degradation rate can be accelerated by the high temperature and strong UV radiation on the beach surface compared to the sea surface (Andrady, 2015). Second, the chemical and mechanical

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breakdown of plastic debris is also promoted during saltation in the beach environment (Corcoran et al., 2009). These observations, together with the evidence showing that the average residence time of debris on the beach is often less than one year (Garrity and Levings, 1993; Kataoka et al., 2015), indicate that beaches may effectively represent a source of highly fragmented plastic debris to coastal waters and ultimately the open ocean, where it becomes available to wildlife.

Most studies on plastic debris accumulation at beaches have detected more plastic debris in the smaller than the larger size classes (Costa et al., 2010; Fok and Cheung, 2015). Studies that paid specific attention to the particle size distribution found that expanded polystyrene (EPS) was most abundant in sizes between 1 and 2 mm (Kim et al., 2015) and between 4 and 5 mm for all plastic debris (Martins and Sobral, 2011). However, this type of study has rarely been conducted in the tropics, where the beach surface temperature and UV intensity could be much higher.

Guangdong Province is situated on the southern coast of China and had a population of over one hundred million in 2014 (National Bureau of Statistics of China, http://data.stats.gov.cn/). The capital of Guangdong, Guangzhou, has a mean annual temperature of 26.7 °C. The hottest months are July and August, when the air temperature can increase to over 35 °C during the day. This coast is of particular interest to the study of marine plastic debris because it has a large coastal population but a relatively less mature waste management system; the input of plastic marine debris from the coastal areas of China was estimated at between 1.32 and 3.53 million metric tons, topping the other 191 coastal countries in the world (Jambeck et al., 2015). The Pearl River Estuary to the west of Hong Kong (Fig. 1) is another major source of plastic litter to the nearby coast (Fok and Cheung, 2015). Hence, the coast of Guangdong likely receives a high influx of debris, and the beached debris is also subject to an enhanced fragmentation rate. The trends in the size distribution of the plastic debris on Guangdong's coastal beaches are worth examining.

In this study, we aimed to reveal the abundance, weight and size distribution of plastic debris (0.315–10 mm) stranded on the coast of Guangdong Province in southern China. We also analysed the distribution of three individual categories of plastic debris, namely polystyrene (PS) foams, virgin plastic pellets, and fragments, as well as the sum of these three categories.

2. Materials and methods

2.1. Study area

Eight sandy beaches located on the coast of Guangdong Province were selected for this study (Fig. 1): (1) Shangchuan Island, (2) Chixi, (3) Gaolan Island, (4) Hengqin Island, (5) Qi'ao Island, (6) Dongchong, (7) Pinghai Bay and (8) Red Bay. The dimensions and directions of the beaches were reported in Table S1 in the Supplementary data.

2.2. Sample collection

To assess the original size distribution of plastic debris on each beach, samples were collected only from the section of the beach with minimal cleaning and maintenance services because some parts of the beaches are recreational, where the accumulation of debris is likely to be disturbed. Four random sampling locations were selected along a 30-m transect placed at the centre at each beach on the high tide line. The top 4 cm of sediment was removed using a metal shovel from a 0.25-m^2 quadrat in each of the sampling locations, resulting in four replicates per beach, and transferred to a graduated plastic bucket. Subsequently, seawater was added to the bucket, and the plastic debris was allowed to float upon gentle but thorough mixing between the seawater and the sediment. The supernatant was then filtered through a 0.315-mm stainless steel sieve. The above density separation and filtration processes were repeated until no visible plastic debris could be recovered from the sediment. All debris retained on the sieve was carefully transferred to a sealable plastic bag and stored at room temperature before further analysis. All samples were collected between July 21 and 25, 2015.

2.3. Sample processing and analysis

The samples were dried at 40 °C in an oven before they were sorted through a cascade of stainless steel sieves of 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 and 0.315 mm. Extra care was exercised in this process to avoid breaking any large debris into small pieces. It is worth noting that the size of the plastic particles in this paper refers to the longest dimension of the particles. In this sorting process, particles with high aspect ratios might fall into sieves of smaller mesh sizes than their longest dimensions. To address this problem, the sizes of all the plastic particles in each class were screened again using a scientific ruler and potentially misclassified particles were remeasured. Finally, the plastic debris was divided into ten size classes, namely 0.315–1.000, 1.001–2.000, 2.001–3.000, 3.001–4.000, 4.001–5.000, 5.001–6.000, 6.001–7.000, 7.001–8.000, 8.001–9.000 and 9.001–10.000 mm. For simplicity, integers will be used when the size classes are mentioned below. Plastic items larger than 10 mm were excluded from this study, which constituted 2% of the total sample size in terms of count.

In each size class, plastic debris was distinguished from non-plastic materials based on the physical and morphological characteristics of marine plastic debris described in Cheung et al. (2016). The plastic items were counted and weighed in three categories: PS foams, virgin resin pellets and fragments. For three PS samples in the smallest size class (0.315–1 mm) from Pinghai Bay, Gaolan Island and Dongchong, a particle sample divider (ELE Riffle Box, 6 mm, 12 slots) was used to reduce the volume of each of the samples to a quarter before being counted, weighed, and finally normalised to its original volume. In this study, plastic particles in the size classes between 0.315 and 5 mm are termed 'microplastics', and those between 5 and 10 mm are termed 'mesoplastics'.

2.4. Visual identification validation by ATR FTIR (Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy)

After the plastic debris was visually sorted by category, three random plastic particles from each category at each beach were used to verify their synthetic nature by FTIR. Infrared spectra between 4000 and 600 cm^{-1} were obtained using a PerkinElmer Frontier FTIR instrument (Llantrisant, UK), equipped with an ATR accessory. The sample spectra were compared with standard spectra in the NICODOM IR Polymer Library, and their polymer identities were accepted if the search score was over 0.7.

2.5. Data analysis

The mean (±SD) and median (±median absolute deviation (MAD)) abundances (items/m^2) and weights (g/m^2) of the microplastics and mesoplastics were calculated for the whole study area. The MAD is a non-parametric equivalent to the SD and is robust against outliers. In the main text, the abundances and weights are reported in unit area (per m^2) but are also reported in unit volume (per m^3) in the Supplementary data (Table S2) to allow comparisons between studies. The size distributions of the abundance and weight of the plastic debris were examined using bar plots. These

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