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Occurrence and distribution of microplastics at selected coastal sites along the southeastern United States

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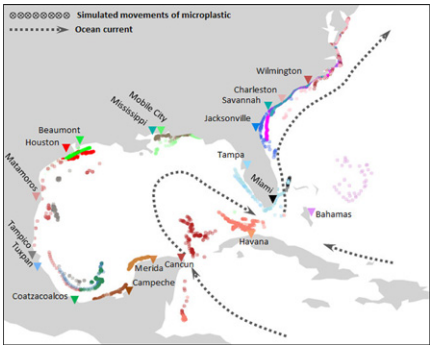
HIGHLIGHTS

- Microplastics were detected from sand samples in each of the sampled Southeastern NPS units, United States.
- Microplastic abundances among sites were highly variable.
- Polyethylene terephthalate (PET) was dominant in the composition of microplastics.
- About 68% of the fibers tested were composed of man-made cellulosic materials such as rayon.
- A Regional Ocean Modeling System model was successfully applied to predict the spatiotemporal distribution of particles.

GRAPHICAL ABSTRACT



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ABSTRACT

To investigate the occurrence and distribution of microplastics in the southeastern coastal region of the United States, we quantified the amount of microplastics in sand samples from multiple coastal sites and developed a predictive model to understand the drift of plastics via ocean currents. Sand samples from eighteen National Park Service (NPS) beaches in the Southeastern Region were collected and microplastics were isolated from each sample. Microplastic counts were compared among sites and local geography was used to make inferences about sources and modes of distribution. Samples were analyzed to identify the composition of particles using Fourier transform infrared spectroscopy (FTIR). To predict the spatiotemporal distribution and movements of particles via coastal currents, a Regional Ocean Modeling System (ROMS) was applied. Microplastics were detected in each of the sampled sites although abundance among sites was highly variable. Approximately half of the samples were dominated by thread-like and fibrous materials as opposed to beads and particles. Results of FTIR suggested that 24% consisted of polyethylene terephthalate (PET), while about 68% of the fibers tested were composed of man-made cellulosic materials such as rayon. Based on published studies examining sources of microplastics, the shape of the particles found here (mostly fibers) and the presence of PET, we infer the source of microplastics in coastal areas is mainly from urban areas, such as wastewater discharge, rather than breakdown of larger marine debris drifting in the ocean. Local geographic features, e.g., the nearness of sites to large

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rivers and urbanized areas, explain variance in amount of microplastics among sites. Additionally, the distribution of simulated particles is explained by ocean current patterns; computer simulations were correlated with field observations, reinforcing the idea that ocean currents can be a good predictor of the fate and distribution of microplastics at the sites sampled here.

1. Introduction

The total global production of plastics grew nearly 200 times in the last half century, from 1.5 million tons in 1950 to 269 million tons in 2015 (PlasticsEurope, 2016). A study shows that 4.8 to 12.7 million tons of plastic were discharged from land into the ocean in the year 2010 (Jambeck et al., 2015). Degradation processes of plastics are extremely slow; therefore, plastics can become and persist as an environmental hazard when they enter the marine environment. Plastic entanglement and ingestion by marine birds, mammals, fish, and reptiles resulting in injury and deaths are frequently reported (Clark et al., 2016; Wright et al., 2013). Additionally, the presence of plastic debris in the marine environment has economic repercussions for tourism and marine industries (GESAMP, 2015; UNEP, 2016).

Plastic debris found in the marine environment varies in size, from large to microscopic pieces. In recent years, there has been increasing environmental concern about 'microplastics'. Microplastics are generally defined as plastic particles (pieces, fibers, or beads) that are <5 mm in size. These small plastic particles are derived from the breakdown of large plastic debris, fabric and polymeric materials from clothes, and small manufactured pieces such as tiny plastic beads used as scrubbers in cosmetics (Browne et al., 2011; Cesa et al., 2017; Ladewig et al., 2015; Napper and Thompson, 2016). Because of their small size and low density, microplastics are considered readily bioavailable to organisms throughout the food-web (Andrady, 2011; Cole et al., 2011). Additionally, the relatively hydrophobic properties and large surface area make microplastics carriers sorbing persistent organic pollutants (POPs). Ingestion of microplastics may therefore transfer these POPs to aquatic organisms (Batel et al., 2016; Besseling et al., 2013). Noticeably, microplastics have been reported in marine waters worldwide and accumulate in depositional environments, including sandy beaches and marine sediments in remote and protected areas (Cozar et al., 2014; Lusher et al., 2015; Turra et al., 2014; Yu et al., 2016).

The relatively flat southeastern US coastal plain and seashore provide a variety of habitats for wildlife and are important resources for fishery and tourist industries across the region. However, data about the occurrence and distribution of microplastics across this area are relatively limited. Observations of large plastic debris in this area have been frequently reported (Viehman et al., 2011) and, this, along with the nearness to highly-urbanized areas of some sites, pointing to the value of this survey. To sample across this broad geographic region, US NPS units were utilized as test sites due to their accessibility and willingness of staff to provide samples. Additionally, despite protection from a variety of anthropogenic activities, these sites are prone to many of the same stressors as other coastal sites including the effects of marine debris. These sites also range widely in their distance from the immediate impacts of urbanized areas. Wastewater discharge is considered a primary source of plastic debris and microplastics in the marine environment (Browne et al., 2011; Cesa et al., 2017; Klein et al., 2015) and is generally associated with urban development. These features make the NPS units ideal sites for gaining an understanding of the large scale distribution of microplastics while providing these protected areas with valuable information about potential input of microplastics into their habitats.

The sites selected vary in broad geographical features (e.g. barrier islands, estuaries) and distance to developed areas. The effects of both these natural and anthropogenic factors are used to understand the occurrence and distribution of microplastics in this region. The two main objectives of this study are to: 1) quantify the amount of microplastic contamination at the selected coastal sites and 2) investigate the factors that influence this microplastic distribution.

2. Materials and methods

2.1. Field sampling collections

Eighteen coastal sites from sixteen National Parks Service units in the southeastern region were selected for this study. Sixteen sites are located from North Carolina to Texas and two sites are in the US Virgin Islands (Table 1, Fig. 1). Sampling locations within a park were selected by park staff based on where they had consistently observed large marine debris. All surface sand samples were collected by NPS staff using sampling kits provided by the research team. Each sampling kit included a written procedure with a visual illustration (see Box S1), a metal sampling ring, a small metal shovel, premade aluminum foil bags, a blank data sheet, and a box with return postage. Samples were collected at low tide along a 50-m transect between the high and low tide lines parallel with the shore close to the high tide line. To keep sample sizes consistent, a metal ring with a 25-cm diameter and 1.5-cm height (equivalent volume = 736 cm^3) was pressed into the top sand layer; material within the ring was carefully collected using the metal shovel and subsequently transferred into an aluminum foil bag. A total of 10 samples were collected from each site. The bags were carefully folded and packed, and shipped back to the laboratory at the Baruch Institute of Coastal Ecology & Forest Sciences at Georgetown, SC for processing. All sand samples were collected in 2013 between July and October.

2.2. Microplastic isolation and quantification

Sand samples were dried at 50 °C for at least 48 h upon receipt. Five dried samples from each site were randomly selected for microplastic quantification. A density separation method as described in Thompson et al. (2004) and Hidalgo-Ruz et al. (2012) was employed for isolating microplastics from the sand matrix. A 100 g sample of dried sand ($V \approx 60\ cm^3$) was mixed with a 250 mL saturated salt solution (NaCl with $\rho \approx 1.27$ g/mL) and manually stirred with a glass rod for 2 min in a shallow aluminum plate with a diameter of 35 cm. Results of our preliminary experiments indicated that the recovery of microplastics in a wide-open plate (i.e., larger surface area) with a thinner layer of sand was significantly higher than that of regular flasks containing a thicker layer of sand with the same amount of materials. After 2 h of settlement, the water solution above the sand layer was carefully transferred to a 500 mL beaker for an additional 1 h of settlement. The solution was then filtered through a 47 mm glass-fiber filter with 1.0 μm pore size (GF/B, Whatman, USA). The 500 mL beaker and all the transfer apparatus were washed with deionized water multiple times and all washing solutions were filtered through the same glass-fiber filter to minimize any sample loss due to adhesion of microplastics on the walls of the filter apparatus. Filters were air dried for 24 h and subsequently sealed individually in petri dishes for further quantitative and qualitative analyses. This isolation process was repeated three times for each sample to increase the recovery. A new glass fiber filter was used in the repeated isolation for a total of three filters for each sample. Our preliminary study demonstrated that a single isolation