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Microplastics in a wind farm area: A case study at the Rudong Offshore Wind Farm, Yellow Sea, China

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A B S T R A C T

Despite the rapid construction of offshore wind farms, the available information regarding the risks of this type of development in terms of emerging pollutants, particularly microplastics, is scarce. In this study, we quantified the level of microplastic pollution at an offshore wind farm in the Yellow Sea, China, in 2016. The abundance of microplastics was 0.330 ± 0.278 items/m^3 in the surface water and 2.58 ± 1.14 items/g (dry) in the sediment. To the best of our knowledge, the level of microplastic pollution in our study area was slightly higher than that in coastal areas around the world. The microplastics detected in the surface waters and sediments were mainly fibrous (75.3% and 68.7%, respectively) and consisted of some granules and films. The microplastics in the samples might originate from garments or ropes via wastewater discharge. The abundance of plastic in the water and sediment samples collected from the wind farm area was lower than that in the samples collected from outside the wind farm area. The anthropogenic hydrodynamic effect was the main factor affecting the local distribution of microplastics. The presence of a wind farm could increase the bed shear stress during ebb tide, disturbing the bed sediment, facilitating its initiation and transport, and ultimately increasing the ease of washing away the microplastics adhered to the sediment. This study will serve as a reference for further studies of the distribution and migration of microplastics in coastal zones subjected to similar marine utilization.

1. Introduction

Plastics, which are organic synthetic polymers, are widely used by humans around the world for their unique properties, including a high strength-to-weight ratio, bio-inertia, and affordability. The global annual production of plastic reportedly exceeds 300 million t (Plastics Europe), and approximately 10% of this amount will enter the ocean (Thompson, 2007). It has been estimated that 4.8–12.7 million t of plastic debris enter the marine environment every year, and this amount will probably increase by an order of magnitude before 2025 (Jambeck et al., 2015). Plastic can persist in the environment for hundreds to thousands of years (Collignon et al., 2012), potentially threatening marine environments and ecosystems. This type of environmental debris can be divided into macroplastics, megaplastics and microplastics according to size (Barnes et al., 2009). Millimeter-level and even micron-level plastic fragments, specifically plastics that are < 5 mm, are commonly classified as microplastics (Arthur et al., 2009; Galgani et al., 2013).

The sources of microplastics can be divided into two categories: primary and secondary. Primary microplastics directly enter the oceans as micro-sized particles, including synthetic fibers, cosmetics, medicine and raw materials used for plastic production (Åström, 2010; Browne et al., 2011; Fendall and Sewell, 2009; Lechner and Ramler, 2015). Secondary microplastics are mainly derived from the breakdown of large items of plastic litter through mechanical action, biodegradation, photodegradation, photooxidative degradation and other processes (Rochman et al., 2013; Zbyszewski et al., 2014). Due to their small size, microplastics can be ingested and transferred into the intestinal system, stomach, hepatopancreas and other tissues of the marine biota (Browne et al., 2010; Moos et al., 2012). Microplastic particles also adsorb various persistent organic pollutants (POPs) and heavy metals (Bejgarn et al., 2015; Goldstein et al., 2012; Kaposi et al., 2016). Microplastics and their composite pollutants are toxic to some marine life and can affect the growth, feeding, spawning and other physiological activities of organisms (Bejgarn et al., 2015; Goldstein et al., 2012; Kaposi et al., 2016). In addition, microplastics pose potential risks to humans

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through the consumption of marine and terrestrial food products and drinking water (Brennecke et al., 2015; Vethaak and Leslie, 2016). Therefore, studying microplastic pollution in the environment is an urgent issue.

Microplastics enter the marine environment via different pathways, including sewage river flow, discharge, currents, and wind (Auta et al., 2017; Ryan et al., 2009), and have been found in marine surface waters and sediments all over the world, particularly in coastal and estuarine areas associated with human activity (Cole et al., 2013; Fossi et al., 2012; Lusher et al., 2013; Moos et al., 2012). Coastal zones are subject to an increased risk of microplastic contamination due to their proximity to microplastic sources, and the abundance of microplastics in coastal sediments is higher than that in the deep sea (Imhof et al., 2013). Furthermore, costal zones constitute abundant biological resources and important ecosystems. Increases in human activity have intensified the risk of microplastic pollution in coastal zones (Mathalon and Hill, 2014).

In the context of clean energy development, offshore wind farms are rapidly being constructed in coastal zones around the world (Fig. S1). In fact, offshore wind farms are increasingly becoming an important type of marine utilization, particularly in China (Xia, 2017). The pollution status of emerging pollutants associated with anthropogenic activities in such areas is of great concern. Therefore, we investigated the microplastic pollution levels in the surface water and sediments of the Rudong Offshore Wind Farm area in Jiangsu, which includes fishery and reclamation sites among its various uses. The goal of this study was to assess the microplastic contamination, composition and distribution characteristics in the offshore wind farm area. We also explored the main factors affecting the content and distribution of microplastics in sediments from various aspects, including the sources and hydrodynamic characteristics. Our study will provide basical data for further investigations of microplastic pollution in the coastal areas of China, particularly those containing offshore wind farms, as well as a reference for studying the distribution and migration of microplastics in coastal regions subject to a similar type of marine utilization (involving artificial structures and aquaculture, among other uses).

2. Materials and methods

2.1. Research area and sampling sites

The study area is situated at the north wing of the Yangtze River Delta (Fig. 1). The sampling sites are mainly located in the subtidal zone and the offshore area of Rudong County in Jiangsu. Under the cover of the divergent tidal current field composed of the East China Sea tidal wave, the Yellow Sea rotating tidal wave and the radial sand ridge group, the tidal flat is wide and gentle. Tidal action is the main dynamic in the area, and the tide is regular and semidiurnal. The diurnal inequality trend is relatively obvious. Silt, fine sand and very fine sand account for the majority of the sediment, and the region's wind energy resources are abundant.

In September 2016, samples were collected from 12 locations mainly distributed in three areas: Wind Farm Phase I project (WF I) (sites F_1-F_3), Wind Farm Phase II project (WF II) (S_1-S_6) and outside of the wind farm (OWF) (sites O_1-O_3). Unfortunately, water samples were not collected at site F_3 because the net was lost. WF I entered into operation in 2009, whereas WF II started in June 2011 and entered into operation by the end of 2012. In addition to offshore wind farms, there are other types of human activities in the study area, including farming activities, which are common (Fig. 1).

To explore the factors influencing the distribution and migration of plastics, we also surveyed the hydrodynamic and geomorphological conditions in the wind farm area and a contrasting area (the mudflat outside the OWF) in August. We measured wave- and water-level data using an SBE 26plus Seagauge Wave and Tide Recorder at 4 Hz. Each site was equipped with an Acoustic Doppler velocimeter (ADV) configured to measure the current velocity and pressure at 16 Hz. The ADV probe was deployed 15 cm above the seabed, pointing downward. During the field observations, weather data were collected from a wave buoy near the study area.

2.2. Sample collection

Water and sediment samples were collected in September 2016. The total floating microplastics were collected using a neuston net with a 40 × 40-cm^2 opening and 333-μm mesh (Ryan et al., 2009). The net was towed along the surface layer at a nominal speed of 2.0 knots (1.95–2.95 knots) for approximately 30 min in each transect. We also used GPS to fix and record the location. The contents of the net were washed into a brown glass bottle and fixed in 2.5% formalin (Lattin et al., 2004). Approximately 3 kg of sediments was collected with a bottom grab and stored in an aluminum foil bag, with one sample for each site. To ensure the accuracy of the sampling results, we obtained parallel samples. All the water and sediment samples were preserved in a freezer until they were transported to the laboratory on the same day.

2.3. Isolation of microplastics

To avoid airborne contamination in the laboratory, the samples were immediately covered with aluminum foil if not in use, and blank groups were analyzed simultaneously to estimate the background contamination. The water samples were sieved through a 2-mm metal mesh sieve to avoid clogging the mesh with zooplankton. Plastic particles larger than 2 mm were sorted and counted directly in a visual manner (Song et al., 2014). The remaining water samples were digested with 35% H_2O_2 for three weeks to remove biogenic materials (Nuelle et al., 2014). Microplastics were extracted from the sediment samples through a two-step extraction procedure following the method described by Nuelle et al. (2014) and Wang et al. (2016) with some modifications. In the first extraction step, the air-induced overflow (AIO) method was used to pre-extract sediments by fluidization with a saturated NaCl solution. The second step employed the principle of the flotation of lower-density microplastics in a saturated NaI solution (Nuelle et al., 2014). Finally, the samples were filtered through a gridded mixed cellulose ester filter paper (50 mm, 1.0-μm pore size; Shanghai Xinya Corporation, China) using a vacuum. After drying naturally, the microplastics were counted under a dissecting microscope at up to 80× magnification.

2.4. Verification of microplastics

To identify the microplastics, representative plastic-like particles (20% of plastic-like particles in water and sediments) were selected and verified with a micro-Fourier transform infrared spectroscope for μ-FTIR (μ-FT-IR, Thermo Nicolet IS 50) at the State Key Laboratory for Mineral Deposits Research of Nanjing University following the method described by Yang et al. (2015). The specific detection methods used are provided in the supplementary materials. Each particle was then verified by comparing all the spectra against a database (HR Spectra IR Demo, Hummel Polymer and Additives, Polymer Laminate Films, Cross Sections Wizard and Aldrich Vapor Phase Sample Library).

The sediment grain size was analyzed in the laboratory using a Mastersizer 2000 laser particle-size analyzer. The organic content of the sediment samples was determined via spectrophotometric ignition loss analysis (Heiri et al., 2001), and the moisture content of the sediments was measured.

2.5. Statistical analyses

To assess the effect of hydrodynamics on the sediment bed, we calculated the bed shear stress from the combination of the waves and current (τ_{cw}) using the models described by Soulsby and Davies (1995):