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Plastic and other microfibers in sediments, macroinvertebrates and shorebirds from three intertidal wetlands of southern Europe and west Africa☆

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ABSTRACT

Microplastics are widespread in aquatic environments and can be ingested by a wide range of organisms. They can also be transferred along food webs. Estuaries and other tidal wetlands may be particularly prone to this type of pollution due to their particular hydrological characteristics and sewage input, but few studies have compared wetlands with different anthropogenic pressure. Furthermore, there is no information on microplastic transfer to secondary intertidal consumers such as shorebirds.

We analysed intertidal sediments, macroinvertebrates and shorebirds, from three important wetlands along the Eastern Atlantic (Tejo estuary, Portugal; Banc d'Arguin, Mauritania and Bijagós archipelago, Guinea-Bissau), in order to evaluate the prevalence and transfer of microplastics along the intertidal food web. We further investigated variables that could explain the distribution of microplastics within the intertidal areas of the Tejo estuary.

Microfibers were recorded in a large proportion of sediment samples (91%), macroinvertebrates (60%) and shorebird faeces (49%). μ-FTIR analysis indicated only 52% of these microfibers were composed of synthetic polymers (i.e. plastics). Microfiber concentrations were generally higher in the Tejo and lower in the Bijagós, with intermediate values for Banc d'Arguin, thus following a latitudinal gradient. Heavier anthropogenic pressure in the Tejo explains this pattern, but the relatively high concentrations in a pristine site like the Banc d'Arguin demonstrate the spread of pollution in the oceans. Similar microfiber concentrations in faeces of shorebirds with different foraging behaviour and similar composition of fibres collected from invertebrate and faeces suggest shorebirds mainly ingest microfibers through their prey, confirming microfiber transfer along intertidal food webs.

Within the Tejo estuary, concentration of microfibers in the sediment and bivalves were positively related with the percentage of fine sediments and with the population size of the closest township, suggesting that hydrodynamics and local domestic sewage are the main factors influencing the distribution of microfibers.

1. Introduction

Plastic pollution is an increasing problem affecting aquatic ecosystems. Plastic materials represent 60–80% of all human-made debris found in the oceans and can be found from the polar regions to the equator (Gregory and Ryan, 1997; Barnes et al., 2009), either floating at sea surface or accumulated on the seafloor and along

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shorelines (Galgani et al., 2000; Barnes and Milner, 2005; Thompson et al., 2009). Negative impacts of large plastic debris (hereafter referred as macroplastics) have been reported for a wide range of marine taxa, including birds, mammals, turtles, fishes and invertebrates, which can either ingest or become entangled in macroplastics (review in Derraik, 2002).

Microplastics, a term used to include all plastic debris smaller than 5 mm (Arthur et al., 2008), have only been identified as an environmental issue recently (Thompson et al., 2004). These smaller plastic particles can either enter the marine environment directly as granules used in the production of larger plastic products and abrasive scrubbers from cosmetic products (Fendall and Sewell, 2009; Thompson et al., 2009), or indirectly from the breakdown of larger plastic items (Browne et al., 2007; Thompson et al., 2009). Recent studies on microplastics have shown they are widespread in marine environments (e.g. Browne et al., 2011; Lusher et al., 2014) and, due to their small size, can be ingested by a wide range of organisms and transferred along the food webs through the ingestion of prey that previously consumed microplastics (e.g. Eriksson and Burton, 2003; Ivar do Sul and Costa, 2014).

There is still limited information as to the consequences of microplastic ingestion by animals. Laboratory experiments with invertebrates (mainly bivalves) evidenced that microplastic ingestion can reduce feeding rates (e.g. Wegner et al., 2012), cause inflammatory responses (von Moos et al., 2012) and reduce growth rates and fertility (Besseling et al., 2014; Sussarellu et al., 2016). Furthermore, the higher surface/volume ratio of smaller plastic debris makes them more susceptible to adsorb persistent organic pollutants, such as DDT, PCB, DDE, PAH and NP, from sea water (review in Ivar do Sul and Costa, 2014). These pollutants can become orders of magnitude more concentrated on the surface of plastic debris than in the surrounding sea water (Mato et al., 2001; Teuten et al., 2007), and be desorbed under the physiological conditions found in animal guts (Bakir et al., 2014), making microplastics a potentially important route for the transport of chemicals to top predators such as seabirds and large fish (Teuten et al., 2007, 2009).

Estuaries and other coastal wetlands are among the most productive ecosystems in the planet, harbouring important wildlife populations and providing various important ecosystem services (Barbier et al., 2011). This productivity and their typical location on the interface between oceans and rivers also attracts human settlement and economic development, often leading to conflicts between human activities and the conservation of natural values (Mee, 2012). Human populations living near estuaries and along their drainage basins produce large amounts of domestic sewage which is likely an important source of microplastic input into the environment (Browne et al., 2011). Additionally, low water velocity in estuary tidal areas may favour the accumulation of microplastics on tidal sediment beds (Browne et al., 2010).

Shorebird species (Aves: Charadrii) are key predators in estuarine areas, feeding on the abundant macroinvertebrate populations living in intertidal sediments (e.g. Piersma, 1987; van der Meer et al., 2001). Most species are strongly migratory breeding at high latitudes and gathering in large numbers in coastal wetlands during the winter. These birds are often used as bioindicators of the "health" of their wetland habitats (e.g. Piersma and Lindström, 2004; Zhang and Ma, 2011; Ogden et al., 2014) and since they forage on intertidal sediments for infaunal prey they are particularly susceptible to microplastic ingestion. Therefore, sampling shorebirds, their prey, and the sediments where they feed should provide a clear picture of the level of microplastic pollution in intertidal food webs.

In this study we analyse sediments, macroinvertebrates and shorebird faeces from three key coastal wetlands for migratory shorebirds in the Eastern Atlantic (Tejo estuary, Portugal; Banc d'Arguin, Mauritania; and Bijagós archipelago, Guinea-Bissau) in an effort to evaluate the prevalence of microplastic pollution in these three sites with disparate natural and anthropogenic characteristics. We also aim to infer whether this form of pollution is transferred along intertidal food webs up to the level of key predators such as shorebird, by comparing species that exhibit different foraging strategies that may influence their susceptibility to ingest microplastics. We further study the occurrence of microplastics at a smaller spatial scale, only in the Tejo estuary, to determine which environmental or anthropogenic variables may explain their distribution in intertidal areas.

2. Methods

2.1. Study areas

Field work took place in intertidal areas of three large coastal wetlands with international relevance for migratory shorebirds (Delany et al., 2009) located along the Eastern Atlantic coast. The Tejo estuary (38°46′ N, 9°01' W), in Portugal, is a large estuary with strong fluvial input. This area encompasses an intertidal area of roughly 97 km^2 mostly dominated by mudflats but with smaller areas of sandy sediments. The shoreline is strongly humanised, with roughly 3.5 million people living in the townships that surround the estuary (INE, 2016), and the Tejo drainage basin includes several other large urban areas (Costa, 1999). Until 2011, both domestic and industrial sewage were discharged into the estuary, after which all regional sewage was diverted to a pipeline that discharges offshore.

The Banc d' Arguin (19°56′ N, 16°35' W), in Mauritania, is an area of shallow coastal waters and vast tidal flats located off the tropical Saharan coast. Covering over 500 km^2, this area is a fossil estuary, currently receiving no freshwater inputs. It lies in a semi-desert area with reduced human presence, which is limited to roughly 1500 inhabitants spread over a few small fishing villages (Honkoop et al., 2008).

The Bijagós archipelago (11°15′ N, 16°05' W), in Guinea-Bissau, includes 88 islands and islets off the West African coast. A vast intertidal area of about 760 km^2 surrounds the islands, including sand and mudflats and wide areas of mangrove. The Bijagós are sparsely populated with a total of roughly 30000 inhabitants living in the islands (INEGB, 2016). However, the archipelago is located near the mouth of the Geba River whose drainage basin includes several urban areas in Guinea-Bissau, Senegal and Guinea, including the national capital of Bissau.

2.2. Large-scale sampling

In order to evaluate the level of microplastic pollution in the three studied wetlands we collected samples of intertidal sediment, macroinvertebrates and shorebird faeces at each site. Sampling took place between July 2013 and November 2015. Since sediment grain size can influence microplastic abundance (see below), sampling was restricted to areas of muddy and sandy-mud substrates (over 50% sediment < 63 μm; Folk, 1954) in order to make an unbiased comparison among different wetlands. Sediment was sampled at three sites in the Tejo estuary and two sites in each of the other two wetlands (see Table 1 for site list and sample sizes) by collecting 3 × 3 cm squares of sediment with a depth of 1 cm using a spatula. Macroinvertebrate sampling only took place in the Tejo estuary and Banc d'Arguin, on the same sites where sediment was sampled, resorting to a sampling corer (10 cm diameter x 15 cm depth) and sieving the sediment using 0.5–1 mm mesh-size sieves.