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Microplastic concentrations in beach sediments along the German Baltic coast

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ABSTRACT

The contamination with microplastic particles and fibres was evaluated on beaches along the German Baltic coast. Sediments were sampled near the Warnow and Oder/Peene estuaries, on Rügen island and along the Rostock coast to derive possible entry pathways. Seasonal variations were monitored along the Rostock coast from March to July 2014. After density separation in saline solution, floating particles were found to be dominated by sand grains. Water surface tension is shown to be sufficient to explain floatation of grains with sizes less than 1.5 mm. Selecting intensely coloured particles and fibres, we find lower limits of the microplastic concentrations of 0–7 particles/kg and 2–11 fibres/kg dry sediment. The largest microplastic contaminations are measured at the Peene outlet into the Baltic Sea and in the North Sea Jade Bay. City discharges, industrial production sites, fishing activity and tourism are the most likely sources for the highest microplastic concentrations.

1. Introduction

1.1. Definition and risks of marine microplastics

Over the past decade, microplastic detections have become a growing concern in the scientific community, with a wide range of concentrations between one and thousands of potential plastic particles per kg of dry sediment or per litre of seawater reported (see Tables 4.1 and 4.3 in Leslie et al., 2011, for an overview). Seawater sampling with varying mesh sizes indicates that number concentrations of microplastics are increasing with decreasing particle sizes (Norén, 2008). Size ranges of microplastics reported in sediment, seawater, and biota samples range from several micrometres (μm) to a few millimetres and depend heavily on the employed mesh width of zooplankton net and the sieve or filter pore size (see e.g. the discussion in Leslie et al., 2011, Chpt. 6). In the Venice lagoon, a systematic spectroscopic analysis of 20 sediment samples found more than 93% of microplastics with sizes <500 μm, of which 55% were <100 μm for a lower size limit of 32 μm (Vianello et al., 2013). Particles with sizes 5–25 μm are found in mussels grown for human consumption (Van Cauwenberghe and Janssen, 2014), while a size peak at 1.25–2.5 mm is observed in North Atlantic and Celtic seawater samples for a lower size limit of 250 μm (Lusher et al., 2015). These size scales found in sediment, seawater, and biota samples cover the size range from micro- to mesoplankton and therefore bare the risk to infiltrate the marine food web from the lowest trophic levels.

These numbers raise the concern that contamination levels might inadvertently affect the marine food chain from the smallest planktivores to the largest fish and marine mammal species. Today, the chemical fingerprints of microplastics are detected in the muscle and blubber tissue of large filter feeders such as basking sharks and fin whales (Fossi et al., 2012, 2014). Although health adverse effects are demonstrated on marine organisms in experimental settings Barnes et al. (2009) and von Moos et al. (2012), whether health and natural development are compromised at environmental particle and additive concentrations is presently not clear. As microplastics cannot easily be removed from the marine environment and plastics are highly persistent materials, the risk of health adverse effects to marine organisms on all scales increases with increasing microplastic concentrations. This risk might return to us as the top predator since microplastics are already shown to infiltrate the human food web (Van Cauwenberghe and Janssen, 2014). With increasing levels of microplastic concentrations (Morét-Ferguson et al., 2010), health-adverse effects to humans have to be anticipated with the long-term presence and exposure to microplastics. The European Union (EU) has acknowledged microplastics as a pollutant with potential health risks to marine

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species as well as humans, and requests the characterisation of "*trends in the amount, distribution and, where possible, composition of microparticles (in particular microplastics)*" (Criterion 10.1.3), including microplastics ingested by marine animals (Criterion 10.2.1), in Annex III of the Marine Strategy Framework Directive (MSFD). The fact that all layers of the marine food web are exposed to microplastics implies that understanding the amount and origin of microplastic pollutants is necessary to identify counteracting measures.

In the executive summary of the *International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris* (IRW), microplastics are defined as particles with sizes less than 5 mm (Arthur et al., 2009). No lower boundary is determined, although seawater samples are frequently limited to 333 μm by the mesh size of neuston nets. The minimum boundary of sediment samples is frequently lower when 50–100 μm sieves or 1–5 μm filters are used to collect particles (see also Dubaish and Liebezeit, 2013). Two kinds of marine microplastics are distinguished throughout the literature on the basis of their origin, and were also defined by the IRW (Arthur et al., 2009). *Primary microplastics* originate from spillage during plastic production or recycling, from sandblasting in shipyards and other abrasives, and from microcleansing particles in personal care products. All of these primary microplastics share the common property that they are *designed to be small* during their production process. *Secondary microplastics* comprise broken fragments of larger plastic pieces, including, but not limited to, marine litter, derelict fishing gear from industrial and recreational fishing, litter from landfills, painting flakes from ship hulls, synthetic fibres from laundry discharge, and foil fragments from packaging, industrial or agricultural sources. Given the large diversity of sources, the entry pathways of secondary microplastics and possible mitigation measures are particularly difficult to define.

Biodegradation of macroplastic litter entering the environment from land- or sea-based sources is extremely slow (Thompson et al., 2004, see also Andrady, 2011, for a review). As all rivers flow to the sea, the oceans provide the largest sink for undegraded synthetic polymers down to molecular sizes. With UV radiation, oxidation, mechanical or bacterial degradation times of several hundred years (Thompson et al., 2004), the current rate of increasing plastic production and the expected enrichment of the environment and oceans with both macro- and microplastics imply that contamination of the food chain will proceed, even if particle input could be stopped instantaneously. The contribution of fishing line fibres and the degradation timescale of synthetic net material are presently unknown. Synthetic clothing likely comprises a major fibre source especially in coastal waters. A single polyester fibre shirt released 1900 fibres in a single washing (Browne et al., 2011). In a comparative study between micro- and macroplastics, Van Cauwenberghe et al. (2013) estimate that microplastics contribute between 8% and 40% of the plastic weight in beach sediments at the Belgian coast. Both fibres and particles are found to significantly contribute to the microplastic concentrations, and the large variation in the spatial distribution and local weight concentration between micro- and macroplastic fractions implies that microplastics have to be monitored separately (Browne et al., 2010; Van Cauwenberghe et al., 2013; Dekiff et al., 2014).

1.2. Microplastic concentrations in seawater and sediment

Marine microplastics have evolved into one of the major marine pollution research fields over the past decade. Although more than one hundred studies are presently available on marine microplastic pollution (see Ivar do Sul and Costa, 2014 for a comprehensive review), spanning beaches, continental shelf areas, central ocean gyres, and harbours worldwide, the spatial coverage is limited by the few research centres where microplastics are investigated (see Fig. 2 in Ivar do Sul and Costa, 2014). The largest concentrations of microplastic particles and fibres are observed in coastal and harbour areas and near industrial production sites (e.g. Norén, 2008; Claessens et al., 2011; Desforges et al., 2014). Microplastics have been found in several estuarine environments, indicating rivers as one of the entry pathways of microplastics into the marine environment. Microplastic concentrations are reported for the UK Tamar estuary in Europe (Browne et al., 2010) and seasonal and spatial variations correlated with rain floods were derived for the Goiana estuary in Brazil (Lima et al., 2014), where the ingestion of nylon threads in estuarine fishes was found at all life stages (Possatto et al., 2011; Ramos et al., 2012; Dantas et al., 2012). River basins and mangrove systems are affected by microplastic contamination along the Singapore coastline (Nor and Obbard, 2014). Particularly large concentrations of microplastic particles are reported in enclosed bays with industrial activity, such as the Jade bay (Dubaish and Liebezeit, 2013). On a larger scale, the Baltic Sea provides only limited exchange with the North Sea during storm events and has to be considered a sink for microplastics. With discharges from the Oder, Neva, Vistula, Western Dvina, and Neman rivers and major industrial coastal cities (Szczecin, Copenhagen, Malmö, Stockholm, Helsinki, Gdansk, Saint Petersburg, Rostock, Lübeck, Kiel), the Baltic Sea represents one of the largest enclosed marine bay areas worldwide.

Despite this predestined location, only one microplastic study was conducted in the Baltic so far. In Baltic Sea coastal waters, Magnusson and Norén (2011) found average concentrations of 4 fibres/litre (F/l) and 32 anthropogenic debris particles/litre (P/l), as quoted in the WP3 GES-REG report (Ojaveer et al., 2013, p. 3, original study not in English). Several groups have addressed microplastic contamination in the North Sea. In seawater samples obtained in a Skagerak transect at the outlet of the Baltic into the North Sea, Norén and Naustvoll (2011) found blue particles with sizes 10–100 μm in 15 of 17 samples, and 102 microplastic spheres per litre of seawater are found in Stenungsund industrial harbour near a polyethylene production plant (Norén, 2008). The characteristic size range of 0.5–2 mm of these spheres is large for marine microplastics and covers the size range of prey for juvenile fish. Increasing evidence indicates that the vicinity of urban areas increases the concentration of microplastics in surface waters and in beach sediments. In excess of 1200 particles/l, by far the highest microplastic concentrations reported in the North Sea environment, are detected in seawater samples in the densely populated Jade Bay serving as a discharge site for industry and the Wilhelmshaven sewage treatment plant (Dubaish and Liebezeit, 2013).

In deep, soft sediments in the UK, microplastic particles and fibres are found in 23 out of 30 samples (Thompson et al., 2004), indicating that microplastics were efficiently transported from the water column to sediments over the past decades and are omnipresent in benthal environments today. As in seawater samples, a wide variety of concentrations of potential microplastic particles is reported in sediments. In remote locations, microplastic contaminations between 1 and 2 particles/kg dry sediment are found at the island of Norderney (Dekiff et al., 2014), while a maximum of 50,000 particles/kg is reported for the island of Kachelotplate (Liebezeit and Dubaish, 2012). However, Lorenz (2014) recently found between 34 and 74 particles/kg dry sediment in three off-shore locations on the wider Helgoland shelf and two beach sediment samples on the island of Sylt, and showed that a significant fraction of particles after extraction in dense saline solution are natural minerals when scrutinised with FTIR spectroscopy, rendering previous high number counts uncertain. Along the Belgian coast, microplastic concentrations in harbour sediment