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Review

The physical impacts of microplastics on marine organisms: A review

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ABSTRACT

Plastic debris at the micro-, and potentially also the nano-scale, are widespread in the environment. Microplastics have accumulated in oceans and sediments worldwide in recent years, with maximum concentrations reaching 100 000 particles m^3. Due to their small size, microplastics may be ingested by low trophic fauna, with uncertain consequences for the health of the organism. This review focuses on marine invertebrates and their susceptibility to the physical impacts of microplastic uptake. Some of the main points discussed are (1) an evaluation of the factors contributing to the bioavailability of microplastics including size and density; (2) an assessment of the relative susceptibility of different feeding guilds; (3) an overview of the factors most likely to influence the physical impacts of microplastics such as accumulation and translocation; and (4) the trophic transfer of microplastics. These findings are important in guiding future marine litter research and management strategies.

1. Introduction

In contemporary society, plastic has achieved a pivotal status, with extensive commercial, industrial, medicinal and municipal applications. Demand is considerable; annual plastic production has increased dramatically from 1.5 million tonnes in the 1950s to approximately 280 million tonnes in 2011 (PlasticsEurope, 2012). Through accidental release and indiscriminate discards, plastic waste has accumulated in the environment at an uncontrollable rate, where it is subjected to wind and river-driven transport, ultimately reaching the coast. Due to its lightweight, durable nature, plastic has become a prevalent, widespread element of marine litter (Moore, 2008; Thompson et al., 2009); the most commonly produced and therefore encountered polymers being polypropylene (PP), polyethylene (PE) and polyvinylchloride (PVC) composing 24%, 21% and 19% of global plastic production in 2007, respectively (Andrady, 2011). Recently, inconspicuous microscopic plastic particles, referred to here as 'microplastics', have been identified as a ubiquitous component of marine debris. Defined as less than 5 mm in size by the National Oceanic and Atmospheric Administration (NOAA), microplastics can be of primary (purposefully manufactured to be of microscopic size) or secondary (derived from the fragmentation of macroplastic items) origin. They have been accumulating in oceans worldwide over the last four decades (Carpenter et al., 1972), from low background levels to localized 'hotspots' (see Table 1). Present on beaches, in surface waters, throughout the water column and within the benthos (Lattin et al., 2004; Moore et al., 2001; Thompson et al., 2004), microplastics have pervaded even the most remote marine environments (e.g. Ivar do Sul et al., 2009).

Gyres are particular hotspots for microplastic accumulation. Recently a maximum concentration and mass of 32.76 particles m^3 and 250 mg m^3 respectively have been recorded in the North Pacific Subtropical Gyre (Goldstein et al., 2012). Industrial coastal areas have also been identified as microplastic hotspots; concentrations of approximately 100 000 plastic particles m^3 of seawater have been reported in a Swedish harbour area adjacent to a PE production plant (Noren and Naustvoll, 2010). Sediment from densely populated coastal areas can be heavily contaminated with microplastics. Browne et al. (2011) found microplastics on eighteen shores across six continents, with a tendency towards fibrous shapes. Maximum concentrations of 124 fibres l^{-1} were reported and a significant relationship between microplastic abundance and human population-density was found (Browne et al., 2011). Thus as the human population continues to increase, the prevalence of microplastics will also most probably increase. Previous studies have found a predominance of fibrous microplastics (see Claessens et al., 2011; Thompson et al., 2004). Despite a variety of forms from irregular fragments to spherules, it seems likely that fibrous microplastics are most abundant in the marine environment.

A temporal increase in the abundance of marine microplastics has been indicated. Recently, combined data from peer-reviewed literature, publicly available data and new data sets revealed

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Table 1
The spatial distribution and abundance of microplastics, as summarised from a selection of reports. Values are reported to the nearest integer.

Location	Maximum observed concentration	Reference
Coastal waters, Sweden	102 000 particles m^3	Noren and Naustvoll, 2010
Coastal Waters, California	3 particles m^3	Doyle et al., 2011
Coastal waters, New England	3 particles m^3	Carpenter et al., 1972
Open ocean, North West Atlantic	67 000 particles km^2	Colton et al., 1974
Northwest Mediterranean Sea	1 particle m^2	Collignon et al., 2012
Beach, Malta	>1000 particles m^2	Turner and Holmes, 2011
Beach, UK	8 particles kg^{-1}	Thompson et al., 2004
Estuarine sediment, UK	31 particles kg^{-1}	Thompson et al., 2004
Subtidal sediment, UK	86 particles kg^{-1}	Thompson et al., 2004
Subtidal sediment, Florida	214 particles l^{-1}	Graham and Thompson, 2009
Subtidal sediment, Maine	105 particles l^{-1}	Graham and Thompson, 2009
Harbour sediment, Sweden	50 particles l^{-1}	Norén, 2008
Industrial harbour sediment, Sweden	3320 particles l^{-1}	Norén, 2008
Industrial coast sediment, Sweden	340 l^{-1}	Norén, 2008
Ship-breaking yard sediment, India	89 mg kg^{-1*}	Reddy et al., 2006
Harbour sediment, Belgium	7 mg kg^{-1}	Claessens et al., 2011
Continental shelf sediment, Belgium	1 mg kg^{-1}	Claessens et al., 2011
Beach, Belgium	1 mg kg^{-1}	Claessens et al., 2011
Beach, Portugal	6 particles m^2	Martins and Sobral, 2011
Beach, East Frisian Islands, Germany	621 particles 10 g^{-1}	Liebezeit and Dubaish, 2012

* Including glass wool.

changes in the abundance and mass of microplastics in the North Pacific Subtropical Gyre. Abundance and mass increased by two orders of magnitude from a median of 0–0.116 particles m^3 and 0–0.086 mg m^3, respectively from 1972–87 to 1999–2010. This is believed to have been driven by a localised increase in microplastic abundance (Goldstein et al., 2012). Additionally, North Atlantic and North Sea surface samples collected by a Continuous Plankton Recorder (CPR, Sir Alister Hardy Foundation for Ocean Science), coincided with a growth in global plastic production (Thompson et al., 2004). Archived plastic samples from the west North Atlantic Ocean over the past 24 years have revealed a decrease in mean particle size from 10.66 mm in the 1990s to 5.05 mm in the 2000s. Sixty nine per cent of fragments were 2–6 mm (Morét-Ferguson et al., 2010), highlighting a prevalence of small plastic particles. Given the continual fragmentation of plastic items, particle concentrations are likely to increase with decreasing size.

The entanglement in and ingestion of macroplastic items is widely recognised in vertebrates. Over 250 marine species are believed to be impacted by plastic ingestion (Laist, 1997). The demise of higher organisms, typically vertebrates, is highly emotive and ultimately more conspicuous to observers. As a result, such instances are often subject to extensive scientific research and media coverage. Information regarding the biological impacts of microplastics on marine organisms, however, has received less attention and is only just emerging. A technical report considering the impacts of marine debris on biodiversity revealed that over 80% of reported incidents between organisms and marine debris was associated with plastic whilst 11% of all reported encounters are with microplastics (GEF, 2012). Since microplastics occupy the same size fraction as sediments and some planktonic organisms, they are potentially bioavailable to a wide range of organisms. Microplastics can be ingested by low trophic suspension, filter and deposit feeders, detritivores and planktivores (Browne et al., 2008; Graham and Thompson, 2009; Murray and Cowie, 2011; Thompson et al., 2004). Therefore, they may accumulate within organisms, resulting in physical harm, such as by internal abrasions and blockages. In addition to the potential physical impacts of ingested microplastics, toxicity could also arise from leaching constituent contaminants such as monomers and plastic additives, capable of causing carcinogenesis and endocrine disruption (see Oehlmann et al., 2009; Talsness et al., 2009). Furthermore, microplastics are liable to concentrate hydrophobic persistent organic pollutants (POPs), which have a greater affinity for the hydrophobic surface of plastic compared to seawater. Due to their large surface area to volume ratio, microplastics can become heavily contaminated – up to six orders of magnitude greater than ambient seawater – with waterborne POPs (Hirai et al., 2011; Mato et al., 2001). This presents a possible route of exposure to marine organisms, whereby bioaccumulation and biomagnification could occur through the food chain. The transfer of POPs to marine organisms via microplastic vectors is not considered in detail in this review (for examples see Teuten et al., 2009); however the pathways and uptake of microplastic particles are clearly of relevance to chemical transfer, as well as physical harm.

Given the growing evidence outlined above, this review – focussing on marine invertebrates – aims to: (1) summarise the factors contributing to the bioavailability of microplastics; (2) outline the susceptibility of different feeding guilds to microplastic ingestion; (3) determine the factors likely to influence the physical impacts of microplastics; and (4) discuss microplastic transfer through the food chain.

2. Factors affecting the bioavailability of microplastics

2.1. Size

A key factor contributing to the bioavailability of microplastics is their small size, making them available to lower trophic organisms. Many of these organisms exert limited selectivity between particles and capture anything of appropriate size (Moore, 2008). Alternatively, higher trophic planktivores could passively ingest microplastics during normal feeding behaviour or mistake particles for natural prey. Work by Fossi et al. (2012) investigated the impacts of microplastics on the Mediterranean fin whale *Balaenoptera physalus*, one of the largest filter feeders in the world. *B. physalus* can engulf approximately 70 000 L of water at one time, potentially risking microplastic ingestion both directly and indirectly from the water and plankton, respectively. Using phthalate contamination as a proxy for microplastic ingestion, the authors concluded that *B. physalus* could be consuming microplastics (Fossi et al., 2012).

2.2. Density

The density of the plastic particles will determine bioavailability in the water column; hence the type of plastic ingested