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Review

The plastic in microplastics: A review

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ABSTRACT

Microplastics [MPs], now a ubiquitous pollutant in the oceans, pose a serious potential threat to marine ecology and has justifiably encouraged focused biological and ecological research attention. But, their generation, fate, fragmentation and their propensity to sorb/release persistent organic pollutants (POPs) are determined by the characteristics of the polymers that constitutes them. Yet, physico-chemical characteristics of the polymers making up the MPs have not received detailed attention in published work. This review assesses the relevance of selected characteristics of plastics that composes the microplastics, to their role as a pollutant with potentially serious ecological impacts. Fragmentation leading to secondary microplastics is also discussed underlining the likelihood of a surface-ablation mechanism that can lead to preferential formation of smaller sized MPs.

Contents

1. Introduction

The presence of small fragments of plastics, generally referred to as 'microplastics', in the oceans (Anderson et al., 2016; Browne et al., 2011) estuaries (Browne et al., 2010, Lima et al., 2015, Zhao et al., 2014), bodies of freshwater (Free et al., 2014; Sanchez et al., 2014; Biginagwa et al., 2016) and even in the remote arctic ice (Zarfle and Matthies, 2010; Hubard et al., 2014) is now well established. These have been sampled from beaches (Retama et al., 2016; Liebezeit and Dubaish, 2012; Browne et al., 2011), surface water (Cózar et al., 2014; Law and Thompson, 2014), marine sediment (Kedzierski et al., 2016; Galgani et al., 2000; Van Cauwenberghe et al., 2015) as well as in the marine biota (Wesch et al., 2016; Desforges et al., 2015). They are a unique, potentially bio-accumulating pollutant in the marine ecosystem that compromises the ability of the already-stressed oceans to deliver critical ecosystem services that support life on land. Unlike with large plastic debris, MPs in the oceans cannot be cost-effectively detected,

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collected for recycling or other managed disposal. In coastal regions floating MP counts as high as 10^3–10^4 per m^3 are not uncommon and this lack of an effective removal mechanism is a particularly serious concern. Floating MPs invariably accumulate in the sediment and their impact on the benthic ecosystem is unknown.

Primary microplastics [MPs] are industrially manufactured as microbeads of different sizes and are used in personal care products (Fendall and Sewell, 2009) generally as exfoliants (Darling et al., 2015; Leslie, 2015), in sand-blasting media (Sundt et al., 2014) or as the larger virgin plastics pellets intended as raw materials for fabrication of products (Browne et al., 2011). These pellets enter the environment via 'leakage' during manufacture, transportation or use. For instance, in the EU (along with Sweden and Switzerland), ~4360 MT of microbeads were used in year 2012 {UNEP 2015} while in the US, the consumption is estimated at US ~2.5 mg of microbeads per user per day (Gouin et al., 2011). With the primary MPs, production volumes Barnes et al. (2009) are tractable and their use is beginning to be regulated (Rochman et al., 2015b). But, far more abundant in the oceans are the secondary MPs (Barnes et al., 2009) typically derived from fragmentation of larger plastic debris items either during use of products or due to weathering degradation of their litter. Input of these is far more difficult to estimate. Secondary MPs include textile fiber fragments invariably released during laundering of synthetic fabrics (Fendall and Sewell, 2009, Browne et al., 2011) and fragments of post-use agricultural mulch films left in the field (Kyrikou and Briassoulis, 2007). Weathering breakdown of plastic litter in the beach environment (Andrady, 2011),however, is the likely predominant source of secondary MPs (Hidalgo-Ruz et al., 2012). Though their volumes in the oceans are intractable, secondary MPs have very high spatial and temporal variability.

2. Plastics production

The global production of plastic resins in recent years is about 300 MMT annually. Given the remarkable societal benefits plastics provide Andrady and Neal, 2009) this figure will almost certainly continue to increase in the future. Nearly a half of the current production is in Asia while NAFTA and EU countries each account for about a 20% share. Plastic litter is more likely at locations of product fabrication and in urban centers of high population density. They are the more likely locations for high incidence of litter and where they are coastal or near rivers, more probable sources of marine litter.

Based on available data, (Fig. 1) the increase in global plastics production with population growth in recent years is non-linear suggesting that per-capita consumption of plastics is also on the increase. Most of the common plastics resin production is used in packaging with a relatively short lifetime and ends up routinely in litter as well as in municipal solid waste [MSW]. Plastics account for 10–15% by weight of MSW depending on the location. A small fraction of this waste, an estimated

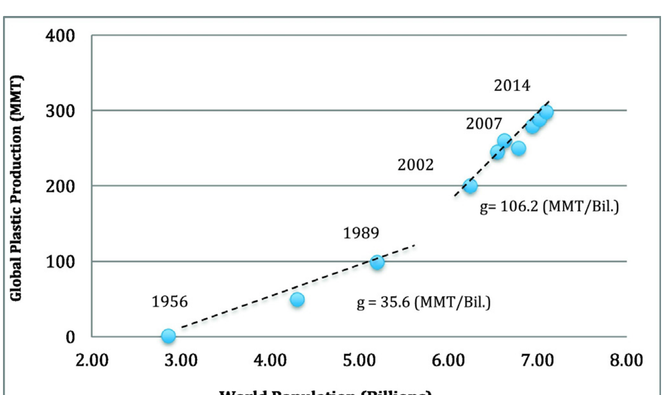

Fig. 1. The change in global production of plastics with the population, showing non-linear increase in production.

4.8–12.7 MMT/year invariably ends up in the oceans, assuming only about a 2% of waste plastics ends up as litter (Jambeck et al., 2015). The global production of PE and PP (the most common in marine MPs) grew at the rate of 8,7% per year (1950–2012) (Gourmelon, 2015), increasing the likely fraction that ends up as marine litter as well.

Incidence of MPs at different locations has been quantified using a variety of techniques and expressed in different units making the data difficult to compare (Hidalgo-Ruz, et al., 2012). In general there is a trend towards finding more MPs in coastal environments near population centers (Sul and Costa, 2014; Jambeck et al., 2015). Eriksen et al. (2014) estimates the load of floating plastics in the oceans to be 270,000 MT. The estimates exclude MPs that filter through the plankton nets used to gather the data the study was based on. Microplastics in oceans and their potential adverse impacts have been reviewed (Andrady, 2011; Browne et al., 2011; Cole et al., 2011; Barnes et al., 2009; Moore et al., 2008). While the weight fraction of MPs in plastic litter will be relatively small, they are able to interact with a very wide variety of marine organisms, ranging from zooplanktons (Ferreira et al., 2016) to fin whales (Fossi et al., 2016).

3. Consequences of MPs in the oceans

Over the recent years, concerns on plastic debris in oceans have expanded to include ingestion-related distress to organisms (Setälä et al., 2014; Neves et al., 2015; Jacobsen et al., 2010) in addition to the traditional issues of ghost fishing, entanglement and the ecological impact of rafter species (Gregory, 2009) discussed in 1980s and 1990s. These new concerns also center around the presence of low-molecular weight chemical species in the plastic that might be bioavailable to ingesting organisms and may present a toxic hazard to them; three categories of such compounds are known in plastics.

a) Persistent organic pollutants (POPs) present in seawater and sorbed very efficiently by MPs (Teuten et al., 2009; Endo et al., 2005; Engler, 2012). The equilibrium distribution coefficient K for common POPs in water-plastic systems ranges from 10^3 to 10^5 in favor of the plastic. This makes their ingestion a credible potential route by which sorbed POPs can enter the marine food web (Bakir et al., 2012). The potential toxic outcome from ingestion invariably depends on bioavailability of POPs, the body mass of ingesting organism, the concentration of the POPs 'cocktail' in the MP and their propensity to bioaccumulate in the organism. Even at non-lethal concentrations, MPs can alter key aspects of behavior (Ferreira, et al. 2016) such as reduction in predation in species such as *Goby* (Lobelle and Cunliffe, 2011) and result in adverse health outcomes (Rochman et al., 2016).
b) Additives are chemicals intentionally added to plastics during their manufacture or processing (Andrady, 2016). These include stabilizers, plasticizers or flame retardants. Plasticizers, for instance are used at relatively high concentrations (10–50%), added to ensure the functionality of the product, can be bioavailable to ingesting organisms (Oehlmann et al., 2009). MPs derived from compounded plastics may contain such additives.
c) Residual monomers in plastics. Common plastics found in marine MPs, polyethylenes [PE] and polypropylenes [PP] do not have any residual monomer. But, polystyrene [PS] also found in significant quantities in debris, can contain 0.1–0.6 wt% of styrene monomer and oligomers (Garrigós et al., 2004; Andrady, 2016).

The chemical-laden MPs, once ingested by small organisms, can move across trophic boundaries (Setälä et al., 2014; Farrell and Nelson, 2013) potentially affecting their predators at higher levels of the food pyramid. Finding MPs in commercial seafood species (Rochman et al., 2015a, 2015b; Van Cauwenberghe and Janssen, 2014; Li et al., 2015) provides the impetus needed to clarify both the exposure routes and bioavailability of POPs transferred via MPs.