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Review

Occurrence and effects of plastic additives on marine environments and organisms: A review

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HIGHLIGHTS

- PBDEs, phthalathes, nonylphenol, BPA and antioxidants are common plastic additives.
- Evidence for transfer and uptake of plastic additives by marine organisms.
- Plastic additives have negative effects on marine organisms.
- New research on microplastics should include their additives as a potential hazard.

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ABSTRACT

Plastics debris, especially microplastics, have been found worldwide in all marine compartments. Much research has been carried out on adsorbed pollutants on plastic pieces and hydrophobic organic compounds (HOC) associated with microplastics. However, only a few studies have focused on plastic additives. These chemicals are incorporated into plastics from which they can leach out as most of them are not chemically bound. As a consequence of plastic accumulation and fragmentation in oceans, plastic additives could represent an increasing ecotoxicological risk for marine organisms. The present work reviewed the main class of plastic additives identified in the literature, their occurrence in the marine environment, as well as their effects on and transfers to marine organisms. This work identified polybrominated diphenyl ethers (PBDE), phthalates, nonylphenols (NP), bisphenol A (BPA) and antioxidants as the most common plastic additives found in marine environments. Moreover, transfer of these plastic additives to marine organisms has been demonstrated both in laboratory and field studies. Upcoming research focusing on the toxicity of microplastics should include these plastic additives as potential hazards for marine organisms, and a greater focus on the transport and fate of plastic additives is now required considering that these chemicals may easily leach out from plastics.

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1. Introduction

Due to their numerous societal benefits, plastics hold an important place in human society (Andrady and Neal, 2009). Plastic, a man-made material, is inexpensive, strong, durable, lightweight and easy to produce (Thompson et al., 2009). As a consequence, plastic production has been increasing since the 1950s, and notably rose from 225 million tons in 2004 to 322 million tons in 2015, representing a 43% increase over the last decade (PlasticsEurope, 2016). However, this estimate does not take into account the proportion of synthetic fibers which are widely used in the textile and fishery industries (Dris et al., 2016) and there is an underestimation of 15%–20% depending on the year (Industrievereinigung Chemiefaser, 2013). Low estimates predicted that floating marine plastic weigh between 70,000 and 270,000 tons (Cózar et al., 2014; Eriksen et al., 2014; Van Sebille et al., 2015). Small pieces of plastics called microplastics (MP) account for a total of 51 trillion plastic debris (Van Sebille et al., 2015).

Microplastics have been defined as plastics particles smaller than 5 mm (Arthur et al., 2009). Growing attention has been accorded to microplastics during the last decade, since the publication by Thompson et al. (2004). Micro-sized plastic pieces originate from two distinct pathways: primary and secondary sources. Primary sources of MP correspond to (i) plastics that are directly manufactured at micrometric size, including plastic pellets (Barnes et al., 2009; Cole et al., 2011), (ii) MP from exfoliating cosmetics (Chang, 2015; Fendall and Sewell, 2009; Napper et al., 2015; Zitko and Hanlon, 1991) and (iii) clothing fibers found in wastewater treatment plants (Browne et al., 2011; Carr et al., 2016). Secondary MP results from the breakdown of larger pieces due to mechanical abrasion and photochemical oxidation in the environment (Andrady, 2011; Bouwmeester et al., 2015; Lambert and Wagner, 2016). MP can also degrade into smaller pieces called nanoplastics (Gigault et al., 2016; Koelmans et al., 2015; Lambert and Wagner, 2016).

Due to their small size, MP can be ingested by a wide range of marine organisms such as zooplankton, bivalves and worms (De Witte et al., 2014; Devriese et al., 2015; Graham and Thompson, 2009; Rochman et al., 2015; Sussarellu et al., 2016; Van Cauwenberghe and Janssen, 2014; Van Cauwenberghe et al., 2015) and by organisms from higher trophic levels such as fish (Boerger et al., 2010; Carpenter et al., 1972; Dantas et al., 2012; Foekema et al., 2013; Lusher et al., 2013; Neves et al., 2015; Possatto et al., 2011; Rochman et al., 2015) and marine mammals (Eriksson and Burton, 2003; Lusher et al., 2015). This ingestion of MPs can result in physical damage such as obstruction or internal abrasions (Wright et al., 2013). In addition to these physical threats, MP can potentially transfer chemicals adsorbed on their surface (Mato et al., 2001; Teuten et al., 2007, 2009) or plastic additives. However, less attention has been paid to the transfer of plastic additives to marine organisms in comparison with hydrophobic organic compounds (HOC), despite the fact that many additives have been recognized as hazardous (Lithner et al., 2011). Therefore, the transport and fate of plastic additives leaching out from plastic debris should definitely be carefully addressed in future field, laboratory and modelling works.

Plastics are made by polymerizing monomers and other substances (Lithner et al., 2011) including plastic additives. Plastic additives are chemical compounds, like plasticizers, which provide required properties to a plastic polymer or are incorporated to facilitate the manufacturing process (OECD, 2004). Moreover, some plastic additives are used as monomers, for example bisphenol A is the monomer of polycarbonate (PC) but also a stabilizer in other polymers. Plastic additives are mainly used as plasticizers, flame retardants, stabilizers, antioxidants and pigments. Phthalates, BPA, nonylphenols, and brominated flame retardants (BFR) are the most common additives recovered from the environment (Bergé et al., 2012; David et al., 2009; de Boer et al., 1998; de los Ríos et al., 2012; Mackintosh et al., 2004; Net et al., 2015; Xie et al., 2005, 2007) and represent a hazard to the environment and organisms (Lithner et al., 2011; Meeker et al., 2009; Oehlmann et al., 2009). These plastic additives are released into the marine environment by numerous pathways including industrial and municipal wastewater, atmospheric deposition, runoff and river transport resulting from application of sewage sludge in agriculture. In addition leaching of plastic additives from macro and microplastics is known to occur in the marine environment. Thus, the accumulation and degradation of plastic debris might represent another major input of these chemical compounds in oceans. As a consequence, more research is needed on the hazards of plastic additives associated with microplastics.

The aim of this review is to (i) list and describe the most predominant plastic additives used worldwide in the plastic industry, (ii) present an overview of the occurrence of plastics additives in the marine environment, and (iii) document the effects of plastic additives on marine organisms. Lastly, recommendations will be made in order to identify the polymer-additives pairs of major concern on which further research should focus.

2. Chemicals used as plastic additives

Multiple types and families of chemicals are mixed with polymers to produce plastics. The type of additive depends on the plastic polymer and the requirements of the final product (Table 1).