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(Nano)plastics in the environment – Sources, fates and effects

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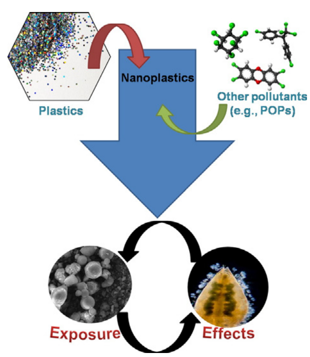
HIGHLIGHTS

- There has been a considerable increase of research on the fate o nanosized plastics.
- These can pose a significant threat to both the environment and human health.
- We reviewed their sources, fates and effects.
- We identified the key challenges researchers face in this field.
- Insights into the future of nanoplastics-related research are presented.

GRAPHICAL ABSTRACT



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ABSTRACT

There has been a considerable increase on research of the ecological consequences of microplastics released into the environment, but only a handful of works have focused on the nano-sized particles of polymer-based materials. Though their presence has been difficult to adequately ascertain, due to the inherent technical difficulties for isolating and quantifying them, there is an overall consensus that these are not only present in the environment – either directly released or as the result of weathering of larger fragments – but that they also pose a significant threat to the environment and human health, as well. The reduced size of these particulates (<1 μm) makes them susceptible of ingestion by organisms that are at the base of the food-chain. Moreover, the characteristic high surface area-to-volume ratio of nanoparticles may add to their potential hazardous effects, as other contaminants, such as persistent organic pollutants, could be adsorbed and undergo bioaccumulation and bioamplification phenomena.

In this review, we describe the most relevant sources of nanoplastics and offer some insights into their fate once released into the environment. Furthermore, we overview the most prominent effects of these small particulates, while identifying the key challenges scientists currently face in the research of nanoplastics in the environment. Lastly, we give a brief summary of the economic impacts of the pollution caused by plastic litter – a potential key source of nanoplastics – in the oceans, the most common destination of these contaminants.

Contents

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1. Introduction

Consisting of any wide range of synthetic and semi-synthetic organics, plastics are malleable materials that can be molded into solid objects of a multitude of shapes and sizes. The International Union of Pure and Applied Chemistry (IUPAC) defines plastics as a generic term used in the case of "polymeric material that may contain other substances to improve performance and/or reduce costs" (Vert et al., 2012). Typically synthetic, they are most commonly derived from petrochemicals and exhibit high molecular mass and plasticity. Due to their ease of manufacture, low cost, resistance to water, and chemical, temperature and light resistance, plastics are used in a wide range of products. Thus, in the modern world, they can be found in components ranging from stationary items to spaceships (Andrady and Neal, 2009), and the last comprehensive report on the global production of plastics showed it to exceed the 299 million tons mark in 2013 (EPRO et al., 2015). This success has proved versatile under many forms, namely, thermoplastics, natural polymers, modified natural polymers, and, more recently, driven by increasing environmental concerns, biodegradable plastics (Reddy et al., 2013; Shah et al., 2008). Consequently, this widespread use of plastics, as well as the resistance to degradation by many plastic materials, ultimately leads to their accumulation in the environment.

The recalcitrant nature of plastics and their ensuing accumulation, with deleterious ecotoxicological consequences, namely, in the aquatic environment, have been the focus of numerous recent works (Duis and Coors, 2016; Eerkes-Medrano et al., 2015; Fischer et al., 2015; Katsnelson, 2015; Rocha-Santos and Duarte, 2015), but these have focused solely on microplastics, particles generally considered to be <5 mm in diameter. Little attention has been paid to nanoplastics (<100 nm) (Koelmans et al., 2015a), which are of particular concern, as these are more likely to pass biological membranes and affect the functioning of cells, including blood cells and photosynthesis (Bergmann et al., 2015). Such particles have been reported to be ingested by zooplankton (Besseling et al., 2014), a process recently captured on video (http://tinyurl.com/oqeceon). Though the amount of plastic particles used far exceeded those expected in the environment, it certainly demonstrated that such processes are possible. Additionally, strong toxic substances have been demonstrated to be adsorbed by nanoplastics (Velzeboer et al., 2014), further underlining the relevance of these pollutants in aquifers and their subsequent consequences in the human food chain (Bouwmeester et al., 2015).

In the following sections, we characterize nanoplastics and describe their sources while also discussing their fate once in the environment(s). We also focus on the potential effects of these materials and identify the key challenges in the research of the environmental consequences of nanoplastics released into the environment. However, such consequences are not only of health, environmental and ecological nature, but also economic. Hence, we provide a brief summary of the economic impacts of the pollution caused by plastic litter – a potential key source of nanoplastics – in the oceans, the most common destination of these contaminants.

2. Nanoplastics and their sources

First and foremost, it is necessary to define what constitutes "nanoplastics". A clear definition of what "nanoplastics" are has not yet been provided (Koelmans et al., 2015a), and, consequently, the characterization of plastic particles has evolved over the past few years (Fig. 1), as more research into the implications of this environmental issue of increasing concern is conducted. Such classification has often been on the basis of the definitions used for non-polymer materials, thus implying that a plastic particle is said to be *nano* if it is <100 nm in at least two of its dimensions (Klaine et al., 2012). For the purpose of this review, however, we will consider the definition suggested by Hartmann et al. (Hartmann et al., 2015), as it consistently allows for a thorough categorization of all plastic particles. Thus, we'll consider as nanoplastics particles that are <1 μm in at least one of its dimensions.

As a man-made product, plastic sources are, mostly, on land. However, due to the fact that many plastic particulates can be found both in sewage sludge and treated effluents, these end up accumulating in aquatic systems (Leslie and Vethaak, 2014). Though existing wastewater treatment processes have been shown to effectively remove microplastics (Carr et al., 2016), this may not be the case for smaller particles, such as nanoplastics. Furthermore, it also depends of the processes used, as others have noted an inefficient removal of micro-sized plastics in wastewaters treatment plants (Browne et al., 2011). One of the main sources of polymeric micro- and nano-sized materials in aquatic systems have been suggested to be cosmetic and cleaning products, which are discharged in domestic wastewaters (Carr et al., 2016; Duis and Coors, 2016; Fendall and Sewell, 2009; Gregory, 1996; Zitko and Hanlon, 1991). However, these are hardly the sole sources of plastics in the environment. Additional sources include those of industrial origin, such as feedstocks used in the manufacturing of plastic products (Lechner et al., 2014; Sadri and Thompson, 2014) and from spillage of plastic resin powders or pellets used for airblasting (Claessens et al., 2011; Zbyszewski et al., 2014).

The breakdown of larger plastic items constitutes an additional source of micro- and nanoplastics (Eerkes-Medrano et al., 2015), whether taking place before entering the environment (Browne et al., 2011) as is the case of the fragmentation of synthetic fibers during the washing of clothes, or after, due to the wear-and-tear of the plastic items exposed to the elements (Tosin et al., 2012). This fragmentation process has been described by Shim and co-workers (Shim et al., 2014), who were able to produce micro- and nanoplastics from expanded polystyrene with an accelerated mechanical abrasion system, mimicking conditions found in beaches or river banks (Corcoran et al., 2009), where prolonged abrasion by sand particles may lead to the formation of these particulates. It should be noted that additional factors, such as UV radiation and microbiological activity, which can further accelerate the breakdown of larger plastics (Lambert et al., 2013), were not considered. In water, ship-generated litter or disposed off after recreational activities, as well as lost or carelessly handled in fishing fleets (plastic fishing gear) are also important sources of plastics in aquatic systems (Browne et al., 2007; Claessens et al., 2013; Desforges et al., 2014; EUCommision, 2011; Pruter, 1987; Ryan et al., 2009).

Additionally, these particulates may be transferred to the atmosphere *via* disintegration of agricultural polyethylene (PE) foils, drying of clothes and contaminated sewage sludge employed as fertilizer (Liebezeit and Liebezeit, 2014), or, as recently demonstrated, industrial activities, such as the thermal cutting of polystyrene foam, which has been shown to emit nanometer-sized polymer particles, in the range of ~20–220 nm (Zhang et al., 2012). The advent of 3D printing, now widely accessible for rapid prototyping and small-scale manufacturing,