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ScienceDirect

Current Opinion in
Environmental Science & Health

Micro- and nanoplastics in the environment: Research and policymaking

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Abstract

Initial reports on the presence of microplastics in the Ocean date from the 1970's. In spite of the noted potential risks these debris posed to both the environment and humans, the scientific community paid little attention to then raised alarms. Recently, however, there has been an increasing interest by both the general public and the scientific community in the contamination and pollution of the marine environment by micro- and nanoplastic particles.

Due to their physical and chemical characteristics, these pervasive contaminants can be found across the Globe and are distributed across the water column and have been shown to be ingested by numerous organisms. Although generally considered biochemically inert, such materials can adsorb other chemical substances, such as persistent organic pollutants (POPs), hence potentially leading to bioaccumulation and bioamplification phenomena.

However, despite this recognized harmfulness, and although microplastics are a recognized threat to the "Blue Economy", there are still multiple research gaps that should be adequately addressed, in order to obtain a realistic assessment of their prevalence in the environment. Additionally, despite the numerous national, regional and international regulatory instruments aiming at reducing the contamination by plastic litter, these appear to have been, so far, insufficient for reaching their proposed goal. Herein, the current gaps in micro- and neoplastic research and regulation are evaluated and some suggestions for overcoming such limitations are proposed.

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Current Opinion in Environmental Science & Health 2018, **1:**12–16

This review comes from a themed issue on **Micro and Nano-plastics**

Edited by **Dr. Teresa Rocha-Santos**

For a complete overview see the Issue and the Editorial

https://doi.org/10.1016/j.coesh.2017.11.002

Keywords

Microplastics, Nanoplastics, Environment, Pollution, Research, Policy.

Introduction

The term "plastic" designates a wide range of synthetic or semi-synthetic materials comprised of organic compounds highly malleable, that can hence be molded into a multitude of solid objects [1].

Owing to their versatility, plastics have almost limitless applications and can be found in toys, vehicles, clothing, construction materials, and electronics, as well as in numerous household items, including hygiene products. Nevertheless, the vast majority of plastics are used in packaging, which, in Europe alone, accounts for approximately 40% of the total annual plastic production [2]. In other words, most of the plastics produced annually – which surpassed the 320 million ton mark in 2016 [2] – are consigned for immediate discard. Hence, the increasing use of these materials, coupled to their imperviousness and high degree of resistance to chemical and thermal degradation, leads to their accumulation in the environment [3]. In spite of the increasing efforts and calls for the recycling of these ubiquitous materials [4], only a fraction of this plastic waste is recycled and most of it ends up in landfills [1]. However, some estimates point that, through the concerted or isolated actions of human activities and meteorological factors, ca. 10% of the total plastics produced enter the marine environment [5]. Upon entering these environments, plastic debris can disperse throughout the oceans and their presence and distribution, not only across the water column, but also in inhabited and remote locations on the planet, has been confirmed by numerous studies (e.g., [6–9]).

Micro- and nanoplastics and their impacts

Microplastics and nanoplastics are considered as particles ranging between 1 μm and 5 mm, and 1 nm to 1 μm, as defined by some authors [3,10]. Although some authors have suggested other categorizations (e.g., [11]), most, nonetheless, have not included the classification of nanoplastics [12,13].

These debris, whose presence was first reported in the 1970s [14,15], may enter the environment directly, and numerous sources of both micro- and nanoplastics have been described, such as [3]:

- Cosmetic and cleaning products, namely, toothpastes and exfoliating creams and scrubs;
- Industrial feedstocks used for the manufacture of plastic goods;
- Plastic resins used in airblasting;

- Textile fibers released during washing and/or drying cycles;
- 3D printing

Such particles are defined as primary microplastics and nanoplastics. Secondary micro- and nanoplastics result from the breakdown of larger plastic debris, due to exposure and animal and microbial activities, including plastic bags, bottles and fishing gear [16,17]. Although macro-sized debris account for the larger portion of plastic in the ocean by mass ($kg.km^{-2}$), estimates point that micro- and nanoplastics are the larger proportion by number ($items/km^{-2}$) [18].

The high occurrence of these materials has obvious aesthetic – with potential economic repercussions – and environmental consequences which are not confined to national boundaries and that exhibit multi-scalar and temporal mechanisms that remain unclear as to their fate and behavior in the environment [3]. In fact, determining the fate of micro- and nanoplastics in the Oceans is inherently difficult, not only due to their size and multitude of ways through which they occur in aquatic environments, but also due to the associated timescales required to ascertain the degradation of these materials [19]. All these limitations are further exacerbated by the current lack of standardized methods for sampling and analysis, as well as in data expression, unit normalization and an universal definition of micro-and nanoplastics [1,3,20].

Although the polymeric materials that make up micro- and nanoplastics found in the environment may be considered biochemically inert [21], these may be ingested by numerous organisms, as already demonstrated (e.g., [19,22]), and may result in their way up the food chain, ultimately affecting human health [23]. Additionally, plastics currently produced often include additives for improving the materials' properties. These include plasticizers, which soften the final product and coloring agents, as well UV-resistance and flame-retardation chemicals, characteristics that are of essential in transportation and electronics applications [18,24]. Most of these additives are of small molecular size and are not chemically bound to the polymeric materials, rendering them susceptible to leach into the surrounding environment [3]. Consequently, the ingestion of such particles may not only yield direct consequences, such as blockage, false satiety and energy expenditure for their egestion, but also other toxicological effects, due to the leakage of such contaminants, such as persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons [3,16]. However, it should also be noted that pure, unaltered plastic nanoplastics have been demonstrated to exert toxicological effects, such as the reduced fecundity observed in copepods exposed to 500 nm polystyrene particles [25] or the developmental effects noted in urchin embryos in the presence of 90 nm-sized polystyrene plastics [26].

All these highlight the potential hazards that micro- and nanoplastics pose to the environment and biota. Experimental data has evidenced the possible morphological, behavioral and reproductive consequences of exposure of numerous organisms to these particles (e.g., [10,19,22,27]). However, it should be noted that these experiments resort to amounts of particles that far exceed those found in the environment [1,28].

Hence, it becomes clear that more research focusing on the specific risks that these materials pose to the environment, biota and, ultimately, to human health, is required. Only then a thorough understanding of the underlying mechanisms of the associated ecotoxicological processes may be reached [29]. For this, some of the current pitfalls in micro- and nanoplastics related contamination and pollution should be addressed.

Research challenges

Despite the recognized risks that the ubiquity of these contaminants in the Oceans poses not only to the environment, including biota, but potentially also to human health, there are many challenges that research into the presence of micro- and nanoplastics that need to be addressed.

These challenges derive from the intrinsic difficulties in determining and identifying these small particles in environmental samples, due to their size and varied shape, color and degree of degradation. Hence, the efforts developed for assessing the presence of these particles have resulted in different methodologies and, currently, there are no standardized methodologies for their correct sampling and identification [30], although numerous workgroups have been established with the specific intent of developing such standardized methods (e.g., [18,31]). Alas, stemming from the different objectives of the studies, as well as from the distinct institutional contexts, these efforts have, so far, failed to provide a unified standardized protocol for the sampling of micro- and nanoplastics in the different environmental compartments, including biota [1], conspicuously highlighted by the simple reporting of the experimentally determined data, often expressed in different units of measurement and quantification [13]. For example, results are often expressed in weight particles per weight of sample, per volume of matrix or per sampling area, without additional information that allows the inter-conversion of data, thus compromising the direct comparison of generated information [32].