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Review

Is there any consistency between the microplastics found in the field and those used in laboratory experiments?☆

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ABSTRACT

The ubiquitous presence and persistency of microplastics (MPs) in aquatic environments are of particular concern since they represent an increasing threat to marine organisms and ecosystems. Great differences of concentrations and/or quantities in field samples have been observed depending on geographical location around the world. The main types reported have been polyethylene, polypropylene, and polystyrene. The presence of MPs in marine wildlife has been shown in many studies focusing on ingestion and accumulation in different tissues, whereas studies of the biological effects of MPs in the field are scarce. If the nature and abundance/concentrations of MPs have not been systematically determined in field samples, this is due to the fact that the identification of MPs from environmental samples requires mastery and execution of several steps and techniques. For this reason and due to differences in sampling techniques and sample preparation, it remains difficult to compare the published studies.

Most laboratory experiments have been performed with MP concentrations of a higher order of magnitude than those found in the field. Consequently, the ingestion and associated effects observed in exposed organisms have corresponded to great contaminant stress, which does not mimic the natural environment. Medium contaminations are produced with only one type of polymer of a precise sizes and homogenous shape whereas the MPs present in the field are known to be a mix of many types, sizes and shapes of plastic. Moreover, MPs originating in marine environments can be colonized by organisms and constitute the sorption support for many organic compounds present in environment that are not easily reproducible in laboratory. Determination of the mechanical and chemical effects of MPs on organisms is still a challenging area of research. Among the potential chemical effects it is necessary to differentiate those related to polymer properties from those due to the sorption/desorption of organic compounds.

1. Introduction

Plastics is a generic name encompassing most of the synthetic organic polymers exhibiting the property of plasticity. These products present many advantages: they are inexpensive, water and corrosion-resistant, chemically inert, easily molded, and they exhibit good thermal and electrical insulating properties. All these features explain why they are massively used in our daily lives. Since the mid-20th century, several million tons of plastics have been produced (Thompson et al., 2009) and in 2013, worldwide plastic production was estimated at 288 million tons (Free et al., 2014). Whilst the societal benefits of plastic are undeniably far-reaching (Andrady and Neal, 2009), this valuable commodity is nonetheless the subject of increasing environmental concern. Indeed, plastics present many disadvantages: being nonrenewable resources and sources of contamination by additive compounds; undergoing embrittlement at low temperatures and deformation under loads; going through a costly recycling process; being highly resistant to degradation, etc. It has been estimated that ten percent of the plastics produced end up in the ocean. Jambeck et al. (2015) recently made the approximate calculation that in 2010 alone, 4.8 to 12.7 million metric tons of plastic wastes entered the ocean and pointed out that a steady increase is to be expected in the coming

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years. After less than a century of existence, plastic debris already represent from 60 to 80% of marine litter depending on the locations investigated (Derraik, 2002). Once in the environment, macrodebris undergo mechanical (erosion, abrasion), chemical (photo-oxidation, temperature, corrosion) and biological (degradation by microorganisms) actions (Andrady, 2011; Costa et al., 2010; Zettler et al., 2013). These different degradation processes lead to their fragmentation into microplastics (MPs), which accumulate in the environment.

The term of MP was initially suggested by Thompson (Thompson et al., 2004). The size defining MPs varies according to authors with diameters of >1.6 μm (Ng and Obbard, 2006) and <1 mm (Browne et al., 2007, 2010; Claessens et al., 2011), <2 mm (Ryan et al., 2009), 2–6 mm (Derraik, 2002), <5 mm (Barnes et al., 2009), <10 mm (Graham and Thompson, 2009). Nowadays, most researchers agree with the definition of MPs proposed by Arthur et al. (2009) of MPs as particles in a size range of less than 5 mm. Those originating from the fragmentation of larger plastic items are defined as secondary MPs whereas primary MPs include all micro-sized particles entering the environment: such as fibers, industrial pellets and microbeads from cosmetics, for example (Andrady, 2011).

Whatever the definition of their size, MPs represent a very broad range of polymers. The most commonly used plastic materials are polyethylene (PE), PP, polyvinyl chloride (PVC), PS and polyethylene terephthalate (PET). They represent approximately 90% of the total world production (Andrady and Neal, 2009) and, as non-biodegradable polymers, they are expected to be among the most widely represented in sampled MPs. What happens to them in the environment will probably differ according to their chemical nature and physical properties. Being buoyant in water; PE and PP, float in seawater, mainly affect ocean surface and deposit ashore (Engler, 2012; Thompson et al., 2009) whereas PVC, which is denser than seawater, affects seabed, often next to the source (Engler, 2012). According to the most recent ten years of research, it appears that all natural habitats from pole to pole are affected by the presence of MPs (Wright et al., 2013).

The ubiquitous presence and persistency of MPs in aquatic environments are of particular concern since they represent an increasing threat to marine organisms and ecosystems. To evaluate this threat and the potential impacts of MPs on aquatic organisms, a number of laboratory experiments have been performed over recent years to mimic exposure (Nobre et al., 2015; Van Cauwenberghe et al., 2015). The global aim of this review is to compare the available literature data on MPs (size, form, quantity or concentration) having been sampled around the world with those having been employed in laboratory experiments. In this paper, we try to answer the following questions: i) Which MPs are found in the different environmental compartments (water, sediment, biota) of the marine ecosystems? ii) What are the laboratory conditions of exposure and putative ingestion of MPs by organisms, as well as their biological transfer and trophic transfer? iii) Are experimental laboratory exposures indeed consistent with this exposome? iv) Do the toxicity effects reported on a wide range of aquatic organisms actually reflect environmental reality?

2. Which MPs are found in the different environmental compartments?

2.1. MPs in marine waters

Due to their small size and capacity to float on the surface of seas and oceans, MPs are distributed in all marine ecosystems. At least 29 marine areas in the world have been investigated (detailed in Table 1).

Differences between sites are observed in MP concentrations and/or quantities. The Pacific Ocean is the most widely sampled area. When comparable, the measured concentrations in this ocean vary from almost 27,000 (Eriksen et al., 2013) to 448,000 (Goldstein et al., 2013) particles per km^2 and from 0.004 (Doyle et al., 2011) to 9200 (Desforges et al., 2014) particles per m^3. This uneven distribution is partially accounted for by the well-known zone of concentration in the North Pacific Central Gyre, where the large-scale presence of plastic debris has previously been highlighted. Indeed, several studies have shown that quantities and distributions of MPs are pronouncedly dependent on geophysical processes (wave, wind, water current; Goldstein et al., 2013; Wright et al., 2013). For example, the highest densities of MPs were detected in the Northeast Pacific Ocean under low-wind conditions (Goldstein et al., 2013). In the Atlantic Ocean, all reported plastic concentrations have been significantly lower than in Pacific areas with only 1500 particles per km^2 (Law et al., 2010) and 2.5 particles per m^3 (Lusher et al., 2014) in the most polluted zones. The Mediterranean Sea is another high spot of MP presence and a recent publication reported high levels of concentrations compared to the Atlantic Ocean (62,000 particles per km^2 for the lowest concentration; Collignon et al., 2014). Considerable research activity in the European zone has recently taken place since the Mediterranean Sea is a "closed sea" surrounded by urbanized areas, which may explain the high quantity of MPs (Cózar et al., 2015).

A reason other than geographic disparities for which it remains difficult to directly compare the reported MP concentrations/quantities is that the sampling techniques and analytical methodologies used in sample analysis are highly varied. For water samples, differences in sampling protocols lead to obvious difficulties of comparison between studies. Indeed, concentration data are usually expressed in terms of number of particles either by volume of filtered water (cubic meters) in the case of water pumping; or by area of waters covered (square meters) when using a trawl along a transect. The unit difference underlines the lack of standardized sampling methodology. Number of particles per km^2 implies that samples came mostly from water surfaces whereas particles per m^3 are likely to correspond to water column sampling. Given the wide range of polymer densities, these differences in sampling depth will surely affect results in terms of both concentration and polymer nature, even though Carson et al. (2011) have shown that in the water column, 95% of small plastic debris were concentrated in the top 15 cm. For example, the use of trawl enables MPs to be sampled on large surface areas. On the other hand, while pumped samples are more representative of MP distribution in the water column, this is only the case at a sampling point. Moreover, as seen in a few recent studies, depending on the protocol used the mesh aperture of nets can vary from around 330 μm (the most commonly used so far) to less than 50 μm (Hidalgo-Ruiz et al., 2012). As high volumes of sieved water lead to a rapid clog the lowest sizes of mesh aperture are less frequently employed. In addition, extraction and analysis of particles smaller than 330 μm is more challenging (Desforges et al., 2014).

Despite differences of MP concentrations/quantities, and even though the MP type was mentioned in only 6 studies out of 25, differences in MP types can be noticed are apparent, since PE and PP fragments have been found in sea water samples from America and Australia, while PE and PS have been observed in Europe.

2.2. MPs in sediment/sand samples

It is well-known that sediments are the long-term ultimate sink for of contaminants (Chapman and Wang, 2001). Table 2 illustrates some examples of MPs reported in the sediment compartment over the last 40 years.

As it is shown in Table 2, America, Asia and Europe are the most