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Review

Synthetic microfibers in the marine environment: A review on their occurrence in seawater and sediments

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ABSTRACT

The objective of this review is to summarize information on microfibers in seawater and sediments from available scientific information.

Microfibers were found in all reviewed documents. An heterogeneous approach is observed, with regard to sampling methodologies and units. Microfibers in sediments range from 1.4 to 40 items per 50 mL or 13.15 to 39.48 items per 250 g dry weight. In the case of water, microfibers values ranges from 0 to 450 items·m^{-3} or from 503 to 459,681 items·km^{-2}. Blue is the most common color in seawater and sediments, followed by transparent and black in the case of seawater, and black and colorful in sediments.

Related with polymer type, polypropylene is the most common in water and sediments, followed by polyethylene in water and polyester in water and sediments. Some polymers were described only in water samples: high-density polyethylene, low-density polyethylene and cellophane, whilst only rayon was reported in sediments.

1. Introduction

Plastics were first noticed in oceans in the 1970s (Buchanan, 1971; Carpenter and Smith, 1972) when plastic production was still far below current levels. Plastics are usually synthetic organic polymers of high molecular mass, most commonly derived from petrochemicals. Plastics are versatile materials that are inexpensive, lightweight, strong, durable, corrosion-resistant and can persist in the marine environment for a long time (see e.g. Tamara, 2015). The most commonly used polymers are polypropylene (PP), low-density polyethylene (LDPE), polyvinyl chloride (PVC), high-density polyethylene (HDPE), polystyrene (PS) and polyethylene terephthalate (PET), which together account for approximately 85% of the total plastic demand worldwide (Plastics Europe, 2016).

Related with fibers, textile manufacturing begins with fiber, which can be harvested from natural resources, manufactured from cellulosic materials or made from synthetic materials. As an example, viscose is made from natural sources (usually wood pulp) and rayon is a manufactured fiber which is neither natural nor artificial. Although it comes like viscose from cellulose, which occurs naturally in plants and also other materials, it has undergone several chemical processes before it is turned into its present form and it is called a semisynthetic fiber (see e.g. Ganster and Fink, 2009). It is called a regenerated cellulose fiber because it is made with cellulose fiber which is reformed or reconstructed. Synthetic fibers (like nylon) accounted for 61% of total fiber production in 2011 (Platzer, 2013).

A recent estimate suggested there could be between 7000 and 35,000 tons of plastic floating in the open ocean (Cózar et al., 2014). Another study estimated that more than five trillion pieces of plastic and > 250,000 tons are currently floating in the oceans (Eriksen et al., 2014). Microplastics are an emerging pollutant in the marine environment (Law and Thompson, 2014). Microplastics (MPs) are synthetic polymers measuring < 5 mm in diameter (Arthur et al., 2009) and are derived from a wide range of sources including synthetic fibers from clothing (Browne et al., 2011), polymer manufacturing and processing industries (Lechner and Ramler, 2015) and personal care products (Fendall and Sewell, 2009). Sources of MPs are known only generally as follows: they emerge from direct use of small particles (primary MPs) or from fragmentation of larger plastic debris (secondary MPs). Once in the sea, microplastics are transported around the globe by ocean currents, as direct consequence microplastics have been found in almost every marine habitat around the world (Cole et al., 2011).

Fibers are among the most prevalent types of microplastic debris observed in the natural environment (Browne et al., 2011). Microfibers (from hereinafter MFs) essentially are secondary MPs because they are mainly released by the use of synthetic polymers in garments, nets and other materials but not used directly in applications, as far as we know. These synthetic microfibers are typically manufactured from nylon,

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polyethylene terephthalate (PET), or polypropylene (PP).

There is a large amount of materials in our daily life that are made of fibers, either synthetic or natural (furniture, textile, etc.) (Engelhardt, 2016). The small size of MFs (below 5 mm in length but with a high relation length/radius) makes them available for interaction with marine biota in different trophic levels. As pointed out recently by Cole (2016) fibrous microplastics may pose an even greater threat than spherical particles for marine biota. An emerging issue in this field is nanoscopic and microscopic fibrous materials (e.g., asbestos fibrils, carbon nanotubes) that could result in carcinogenesis and fibrosis, whereas particles of the same material in particulate form are often benign (Cole, 2016).

Despite the fact that fibers are found in worldwide oceans, only until recently fibers and microfibers have been observed as an important issue in the marine environment (see e.g. Browne et al., 2011), but due to the high risk of airborne contamination during sampling and processing, in some studies (see e.g. Cózar et al., 2015; Suaria et al., 2016) fibers and microfibers are excluded. Even then, it is important to understand their distribution in the marine environment and their implications on marine habitats and marine biota. A recent study (Mizraji et al., 2017) highlighted that MFs have been reported as the major plastic form in the gut of diverse marine species, including vertebrates and invertebrates.

In this study we review for first time (as far as we know), the studies on fibers in seawater and marine sediments. Despite no many attention was pointed out in microfibers until very recently, they are distributed worldwide and actually are an emerging issue and many studies on ecotoxicology are carried out using fibers (see e.g. Cole, 2016).

The objectives of this review are: (1) to summarize the properties, nomenclature and discuss the sources of MFs to the marine environment; (2) to evaluate the sampling methodologies and identification methods by which MFs are detected in the marine environment; (3) and to ascertain spatial and temporal trends of MFs abundance from worldwide studies in oceans and seas.

2. Review of available literature

We conducted an extensive literature review using the ISI Web of Knowledge, Web of Science and Scopus databases. Based on the search parameters: microplastic, fiber and marine environment a total of 100 original publications were retrieved, dating back to 1960 until 2017.

Among all publications we selected those who follow our aim. The majority of paper researches (87%) were published from 2015 onwards (see Fig. 1). In addition to peer-reviewed papers, conference proceedings, posters and dissertations were also included in this review.

The information that was gathered from these publications included: i) the extraction technique, ii) microfibers abundance and distribution, iii) polymer color, and in case of microfiber polymer identification iv) type of polymer.

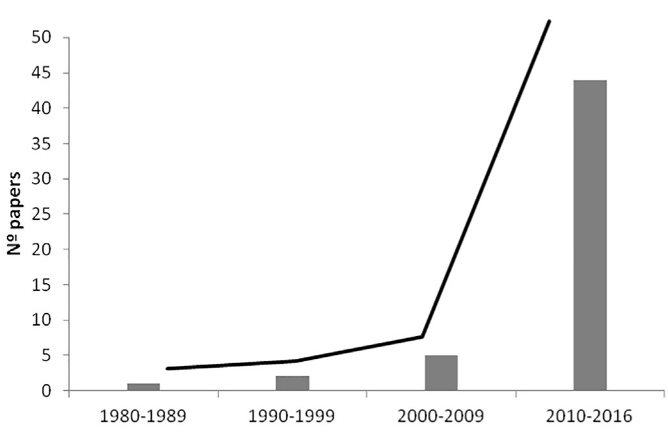

Fig. 1. Number of publications related to microfibers in the marine environment since 1976.

3. Sampling methodologies

The sampling methodologies of microplastics are different according to the environmental compartment studied; seawater or sediments.

3.1. Seawater

After the bibliographic review, a total of 43 articles related to abundance of plastic fibers in seawater were found (surface, sub-surface and water column). Twenty eight articles (~67%) focus on the sea surface. In this case, fibers were collected with manta trawls or other types of neustonic nets (Doyle et al., 2011; Morét-Ferguson et al., 2010) whose mesh size ranged between 330 and 500 μm, being 333 μm the most common net (Rios et al., 2010). Other authors used 150 μm plankton nets (Day et al., 1989). The trawl time fluctuate from 10–20 min (Kang et al., 2015; Lusher et al., 2015), to 60 and 90 min, (Enders et al., 2015; Eriksen et al., 2013; Faure et al., 2015). The trawl speed was around 3 knots (Gallagher et al., 2016; Lima et al., 2014). Other instruments, such as the continuous plankton recorder (CPR) were also used (Thompson et al., 2004). Only Dubaish and Liebezeit (2013), collected surface samples with PE bottles at 20 cm of depth. In all cases samples were filtered after collection. The mesh size varies between 80 μm (Nel and Froneman, 2015) and 500 μm (Amélineau et al., 2016), being the most common 300 μm (see Table 1).

For the sub-surface water sampling, eight articles focused on waters between 1 and 6 m depth (Table 1). Different types of pumps were used for collecting water. The most common is the continuous intake system located on the forward starboard side of the vessels, generally at 3 to 6 m depth (Lusher et al., 2014, 2015). This system collected and filtered the particles by a steel sieve with 250–300 μm of mesh size (Desforges et al., 2014; Enders et al., 2015). Setälä et al. (2016) employed other impeller pump at 0.5 m of depth, with a mesh size smaller (100 and 300 μm), around 2 m^3 was filtered. These authors and Cole et al. (2014) used the manta trawl (200 or 333 μm) to evaluate the fibers in this compartment.

Only Song et al. (2014, 2015) studied microplastic pollution in the surface microlayer (first 400 μm) in the southern coast of Korea. They collected samples by hand with a sieve. All plastics adhered to the sieve by surface tension were kept.

The laboratory processing of samples prior to the visual sorting, and polymer identification when possible, involves usually three steps: density separation, filtration and sieving as described by Hidalgo-Ruz et al. (2012) in their review. The density separation technique is based on the differences in density between plastic and sediment particles. This consists in the use of hypersaline solutions (normally NaCl or $ZnCl_{2,}$) to separate MPs by density differences. Typical densities for sand or other sediments are ~2.7 g cm^{-3}.

3.2. Sediments

In the present review, only nine articles determined plastic fibers in surface marine sediments. The most used sampling methodologies (in three papers) are box corer and mega corer dredges (see Table 2). These devices main advantage, in comparison with other dredges, is that the sediments deformation is minimal, allowing stratification sampling and an accurate reconstruction of the chronology.

Once the dredge was on board, the box was removed and the first layer of sediments was obtained (~0–5 cm). Afterwards the samples were homogenized and distributed in suitable containers and immediately frozen at −20 °C until further analysis (Strand and Tairova, 2016; Vianello et al., 2013; Woodall et al., 2014).