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Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins[☆]

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ABSTRACT

Microplastic and microfiber pollution has been documented in all major ocean basins. Microfibers are one of the most common microparticle pollutants along shorelines. Over 9 million tons of fibers are produced annually; 60% are synthetic and ~25% are non-synthetic. Non-synthetic and semi-synthetic microfibers are infrequently documented and not typically included in marine environment impact analyses, resulting in underestimation of a potentially pervasive and harmful pollutant. We present the most extensive worldwide microparticle distribution dataset using 1-liter grab samples ($n = 1393$). Our citizen scientist driven study shows a global microparticle average of 11.8 ± 24.0 particles L^{-1} (mean ± SD), approximately three orders of magnitude higher than global model predictions. Open ocean samples showed consistently higher densities than coastal samples, with the highest concentrations found in the polar oceans ($n = 51$), confirming previous empirical and theoretical studies. Particles were predominantly microfibers (91%) and 0.1–1.5 mm in length (77%), a smaller size than those captured in the majority of surface studies. Using µFT-IR we determined the material types of 113 pieces; 57% were classified as synthetic, 12% as semi-synthetic, and 31% as non-synthetic. Samples were taken globally, including from coastal environments and understudied ocean regions. Some of these sites are emerging as areas of concentrated floating plastic and anthropogenic debris, influenced by distant waste mismanagement and/or deposition of airborne particles. Incorporation of smaller-sized microfibers in oceanographic models, which has been lacking, will help us to better understand the movement and transformation of synthetic, semi-synthetic and non-synthetic microparticles in regional seas and ocean basins.

1. Introduction

Plastic is a major pollutant throughout the world. It is one of the most prolific materials manufactured globally, with over 322 million tons produced annually with the majority of the production going to single-use packaging (PlasticsEurope, 2016). The disposable nature of this plastic type generates a high volume of packaging that continuously enters the waste stream. Plastics are cheap, lightweight, and durable—characteristics that have made it an ever more attractive packaging material and led to its high volume in solid waste streams. Plastics are now a common and persistent pollutant. Most waste management infrastructure worldwide does not match disposal needs, with an estimated 4.8 to 12.7 million tons of coastal plastic waste entering the ocean each year (Jambeck et al., 2015). Rivers are also a global vector for plastic and are estimated to transport between 1.15 and 2.41 million tons of plastic waste into the ocean annually (Lebreton et al., 2017). Consequently, between 5.95 and 15.11 million tons of plastic enter the ocean via coastal land and inland rivers (Lebreton et al., 2017).

Plastic waste estimates are often based on mesoplastic (5 mm - 2.5 cm) and macroplastic (2.5 cm - 1 m) lengths. Larger plastic has long been the focus of public concern, mostly due to its visibility and documented negative interaction with animals (Gall and Thompson, 2015; Zettler et al., 2017). However, plastics also enter the ocean as microplastic (particles less than < 5 mm in size) through storm drains, run-off, wastewater treatment plant outfall pipes, tire wear, and atmospheric deposition, among other sources

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(Arthur et al., 2009; Auta et al., 2017; Browne et al., 2011; Dris et al., 2017; Galgani et al., 2015; Verschoor et al., 2014). Microplastics are categorized as either primary, meaning manufactured to be less than 5 mm, or secondary, which are plastics that are less than 5 mm as the result of the fragmentation of a larger plastic piece (Andrady, 2011; Cole et al., 2011). The relative significance of the two microplastic types are not well studied (Boucher and Friot, 2017), but the majority of particles in surface water appear to be microfibers, a threadlike particle with a length between 100 μm and 5 mm and a width of approximately 1.5 orders of magnitude shorter (Barrows et al., 2017), suggesting secondary microplastics are predominant (Browne et al., 2011; Carr, 2017; Mason et al., 2016).

Of the 9 million tons of fibers produced globally in 2016, cotton accounted for 30%, wool, silk and other natural fibers accounted for another 10%, and the remainder was synthetic (Carr, 2017). Non-synthetic and semi-synthetic (e.g. rayon) fibers have infrequently been reported in surface water studies. The few cases where they have been noted have been predominately in ingestion studies (Lusher et al., 2013; Remy et al., 2015; Rochman et al., 2015; Zhao et al., 2016). The majority of non-synthetic fiber textiles are treated with a similar cocktail of dyes and chemicals as synthetic textiles and can accumulate chemicals from the ambient water (O'Neill et al., 1999; Remy et al., 2015). These non-synthetic and semi-synthetic microfibers and their additives or dyes may interact negatively with biota in aquatic environments similar to plastic microfibers, but ingestion, chemical leaching and degradation rates in marine environments is poorly understood (Remy et al., 2015). It is possible that, like 'biodegradable' plastic, non-synthetic microfibers may not break down as readily as expected in the open ocean environment (Bagheri et al., 2017).

The majority of microplastic field sampling uses a trawl net. This allows for a large volume of water to be sampled, but will miss many of the particles that can pass through the most commonly used 333 μm mesh. This includes an unknown proportion of microfibers which can be many millimeters long, but typically have a diameter smaller than most mesh used in trawl nets. The estimated 15 to 51 trillion plastic particles weighing between 93 and 236 thousand tons floating in the ocean is based on trawl net data (van Sebille et al., 2015). A recent study showed that trawl net studies could be undersampling particle density by approximately three orders of magnitude (Barrows et al., 2017). This study employed grab sampling, a technique used to sample a limited volume of surface water for microplastic research (Barrows et al., 2017; Miller et al., 2017). Grab samples collect smaller sized particles as well as a greater range of microplastic shapes than a trawl net.

Understanding the concentrations of microfibers and microplastics is integral to analyzing their potential environmental impact. The last decade of microplastic research has brought attention to the issue and helped decrease knowledge gaps in a new field (Barrows et al., 2017). Under-reporting of microplastic delays our understanding how the shape and size of microplastics influence their location, important factors for recognizing pollution hot spots and areas of increased biological impacts. Models predicting accumulation at the poles (Isobe et al., 2017; Wilcox et al., 2015) have noted areas of high particle concentrations; this is matched by empirical studies (Bergmann and Klages, 2012; Cózar et al., 2017) but is still lacking for many areas in the Southern Oceans.

Unfortunately, research can be expensive, challenging, time consuming and often seasonally driven, especially at sea. Researchers are increasingly engaging with citizen scientists to help with large scale data collection (Hoellein et al., 2015; McKinley et al., 2016), with numerous projects focusing on marine plastic pollution (Zettler et al., 2017). To date, wide geographic research into plastics and microplastics in the environment has relied heavily on citizen scientist initiatives (Hidalgo-Ruz and Thiel, 2013; Zettler et al., 2017). Using citizen scientists not only allows for wider data collection, but raises awareness outside of the research community and increases engagement with environmental issues (UNEP, 2011; Zettler et al., 2017). Citizen science can also lead to positive changes in policy outcomes, and can be a rigorous process of scientific data collection to help solve global problems (Cigliano et al., 2015; McKinley et al., 2016).

In this study, we use the term 'microparticle' to include both microplastics, microfibers and anthropogenic litter of undetermined material type in the size range of 5 mm–100 μm. This work started with a focus on microplastics but was expanded to microparticles when it became clear that other types of materials were a significant component of our samples. The term 'synthetic microfiber' indicates fibers manufactured from petrochemicals, chemically synthesized or from semi-synthetic cellulosic material (e.g. rayon), and the term 'non-synthetic microfiber' refers to fibers made from natural materials and not chemically synthesized, such as cotton or wool. For this study microfibers that appear to be a blend of synthetic and non-synthetic materials are included with the synthetic microfibers.

This study is the most extensive dataset on microparticle contamination in global coastal marine environments. Over five years, we covered a wide geographic distribution and this study is the first to show extensive grab sampling data. The aim is to better understand the global distribution, concentration and type of surface microparticles in the marine environment. This was completed by implementing a citizen science field protocol focused on high quality assurance, sufficient data collection, ease of use and accessibility. Using opportunistic collection of 1-liter grab samples by citizen scientists, we focused on understudied and often remote ocean regions, including coastlines and the open ocean.

2. Materials and methods

2.1. Experimental design

One-liter grab samples were collected from marine surface waters following protocols outlined by Barrows et al. (2017). Sample bottles were triple-rinsed with tap water, sealed, and then triple-rinsed *in situ*. Samples were collected up-current of the citizen scientist and sample bottles were capped underwater immediately following sample collection to reduce air contamination. In the instance the water could not be reached from the sampling platform, a bucket was used to collect surface water; the bottle, cap and bucket were triple-rinsed before sample water was collected. While the citizen scientist stood downwind, sample water was poured into the sample jar until overflowing and capped immediately. Samples were closed tightly, packed and mailed to a laboratory in Stonington, Maine for analysis by trained professionals. 1628 samples were collected by citizen scientists and processed by three professional scientists from 2013 to 2017. The citizen scientists had a wide range of both scientific expertise (from no previous training to professional scientists), and field experience (basic outdoor competency to professional outdoor athletes). For a citizen scientist to participate in the project, they were required to take an online test to confirm they understood and could follow our sampling procedures.

Citizen scientists collected samples from a diversity of sampling platforms (including wading, and from small and large watercraft) and sampling locations (rocky and sandy shorelines, offshore, estuaries, remote and urban). They were asked to record standard field sampling data about the sampling site and time. Citizen scientists recorded data in a smart phone app, as well as on a hard copy data sheet. As a measure of quality assurance, collectors