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Invited Commentary

# Determining Global Distribution of Microplastics by Combining Citizen Science and In-Depth Case Studies

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## EDITOR'S NOTE:

This is 1 of 15 invited commentaries in the series "Current Understanding of Risks Posed by Microplastics in the Environment." Each peer-reviewed commentary reflects the views and knowledge of international experts in this field and, collectively, inform our current understanding of microplastics fate and effects in the aquatic environment.

## ABSTRACT

Microplastics (<5 mm) are contaminants of emerging global concern. They have received considerable attention in scientific research, resulting in an increased awareness of the issue among politicians and the general public. However, there has been significant variation in sampling and extraction procedures used to quantify microplastics levels. The difference in extraction procedures can especially impact study outcomes, making it difficult, and sometimes impossible, to directly compare results among studies. To address this, we recently developed a standard operating procedure (SOP) for sampling microplastics on beaches. We are now assessing regional and global variations in beach microplastics using this standardized approach for 2 research projects. Our first project involves the general public through citizen science. Participants collect sand samples from beaches using a basic protocol, and we subsequently extract and quantify microplastics in a central laboratory using the SOP. Presently, we have 80+ samples from around the world and expect this number to further increase. Second, we are conducting 2, in-depth, regional case studies: one along the Dutch coast (close to major rivers, a known source of microplastic input into marine systems), and the other on the Lesser Antilles in the Caribbean (in the proximity to a hotspot of plastics in the North Atlantic Ocean). In both projects, we use our new SOP to determine regional variation in microplastics, including differences in physicochemical characteristics such as size, shape, and polymer type. Our research will provide, for the first time, a systematic comparison on levels of microplastics on beaches at both a regional and global scale. *Integr Environ Assess Manag* 2017;13:536–541. © 2017 SETAC

**Keywords:** Beach sediment   Citizen science   Distribution   Microplastics   Physicochemical characteristics

## INTRODUCTION

There is mounting concern over the amount of plastic in our environment. It has been estimated that over 8 million tons of plastic waste enters the marine environment each year (Jambeck et al. 2015). One important subgroup of plastic contamination are small pieces of plastic, termed "microplastics" (<5 mm), which are now ubiquitous in the environment (Andrady 2011; Cole et al. 2011; Eerkes-Medrano et al. 2015; Nizzetto et al. 2016). Because of an increase in scientific attention and significant public interest in the issue, "concerns about the potential impact of microplastics in the marine environment has gathered momentum during the past few years" (UNEP 2014). This, in turn, has put pressure on decision makers and politicians to respond to the issue (UNEP 2014). To move the field forward, it is imperative that we have a clear understanding of the levels of microplastics in the environment.

At this point, however, there are significant differences in how different scientists across the world sample, extract, and quantify microplastics (Hidalgo-Ruz et al. 2012; Shim and Thomposon 2015; Van Cauwenberghe et al. 2015). For example, we recently showed that there is a significant amount of variation in both sampling and extraction protocols from beach sand (Besley et al. 2017). In addition, there is a lack of consistency in the reporting of results. For example, whereas the majority of studies reported the number of particles per weight of sediment sample (e.g., particles/kg sand [dry weight]; 9 studies), some studies reported the number of particles per unit area (e.g., particles/$m^2$; 7 studies) (Table 1) and others as the weight of microplastics per weight of sediment (e.g., mg

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Table 1. Variation in the presentation of results of microplastics in peer-reviewed publications[a]

| Reporting variable | Nr of studies[b] |
|---|---|
| Unit of expression | |
| Number of particles/sample | 2 |
| Number of particles/dry weight | 9 |
| Number of particles/$m^2$ | 7 |
| Wt (mg) of particles/dry wt sediment | 1 |
| Wt (mg) of particles/$m^2$ | 2 |
| Other | 1 |
| Multiple units | 2 |
| Not reported | 2 |
| Description of physicochemical characteristics of samples | |
| Polymer type | 6 |
| Shape of particles | 10 |
| Size of particles | 6 |
| Color of particles | 1 |
| Multiple parameters | 3 |
| None | 2 |

[a]Based on literature review; $n = 22$ peer-reviewed studies.
[b]In some articles, multiple units of expression or descriptions were reported, therefore the number of studies exceeds 22.

plastics/kg sand) or area (mg plastic/$m^2$) (Table 1). Moreover, the description of the physicochemical characteristics of microplastics also showed significant variation across studies, with the shape of the sample (10 studies), the type of polymer (6 studies), and the size ranges of the particles (6 studies) most commonly reported (Table 1). These variations in sampling, extracting and reporting of outcomes makes it difficult, if not impossible, to directly compare loads of microplastics across studies (Hidalgo-Ruz et al. 2012; Shim and Thomposon 2015; Van Cauwenberghe et al. 2015).

Because of this variation, there are difficulties describing spatial and temporal distribution of microplastics at a local, regional, and subsequently global scale. To address this, and to allow us to investigate these distributions, we have developed a standard operating procedure (SOP) which we will use in subsequent projects (Besley et al. 2017). This SOP was developed based on a detailed literature review to highlight major differences in both sampling and extraction procedures. Next, we conducted a case study (Meijendel, the Netherlands) to determine the influence of variation in sampling and extraction procedures on microplastic quantification (Besley et al. 2017). In our work, as described in detail in Besley et al. (2017), we found that the location of collection of sand on a beach (e.g., sampling at the high tide line or in intertidal zone) had marginal influence on the outcomes. Sampling depth was found to be of importance, and samples should be conducted in the top 5 cm (Besley et al. 2017). Importantly, we demonstrated that the variation in extraction procedures did cause a significant impact on outcomes (Besley et al. 2017). Specifically, the variation in sample drying time, settling time for the sand-salt solutions, and the number of repeat extractions need standardization to ensure comparability (Besley et al. 2017). For example, on average only 30.2% of microplastics were recovered after 1 extraction of beach sediment relative to 5 extractions. This increased to an average of 83.0% after 3 extractions (Besley et al. 2017). Using this newly developed SOP affords us the opportunity for systematically determining regional and global variations in beach microplastic levels.

In this short communication, we will highlight our efforts in determining levels of microplastics at the local and global level using this new protocol. The first goal of our research is to involve the general public through citizen science in the collection of samples on beaches around the world, thereby enhancing the societal awareness on this issue. We focus on microplastic levels on beaches because these locations are easy to access and are a potential direct link to sources of microplastics in the marine environment. Additionally, the second goal of our research is to further strengthen our understanding on the geographic variation in microplastic loads. Therefore, we are conducting 2 in-depth case studies, one in the Netherlands and the other on the Lesser Antilles in the Caribbean. These case studies are focused on regional variation in microplastic levels with a focus on determining the linkage with potential microplastic sources.

## CITIZEN SCIENCE TO DETERMINE GLOBAL VARIATION IN MICROPLASTICS

Citizen science can be a powerful tool in research and at the same time serve as an outreach mechanism to inform and involve the general public on scientific progress (Bonney et al. 2009; Silvertown 2009). Recently, a citizen science project on beach microplastics was conducted in Chile, in which school children across the nation participated in collecting and extracting samples (Hidalgo-Ruz and Thiel 2013). The majority of experimental steps were conducted by the participating children, including sieving and collection of the samples. Samples were sent to a central laboratory for re-evaluation (Hidalgo-Ruz and Thiel 2013). Although the project is very valuable, there were some limitations. First, the size range was between 1–10 mm, discarding smaller pieces of plastic. Second, extraction, which we demonstrated being the most important variable when standardizing across studies, was done by the schoolchildren and only involved sieving (Hidalgo-Ruz and Thiel 2013).

We started a citizen science project in the summer of 2015. Importantly, there are indications that there is a lower accuracy of the collected data in citizen science (Dickinson et al. 2010). For example, a study on lady beetles involving citizen science in the United Kingdom and United States resulted in an overestimation of species richness (Gardiner et al. 2012). To minimize the impact of individuals, we requested participants to return small quantities of sand from a beach. Our previous results indicated that the collection of samples has minimal influence on the outcome of the results (Besley et al. 2017), thereby limiting the influence of participating individuals on the overall outcomes. Importantly, sample extractions are conducted in a centralized laboratory using a standardize protocol, as the differences in extraction protocols are the main source of variation in outcomes among studies (Besley et al. 2017). Participants were recruited over social media (Facebook and project blog, https://lucmicroplastic.wordpress.com), as well as general and personal emails within our institutes to request participation. To collect the samples, the following materials are needed:

- A camera or smartphone to take a picture of the sampling locations
- A smartphone with a GPS app (if possible)
- A metal spoon
- Six Ziploc bags (provided by us, all standard for each sample collected)

A sampling protocol is provided online (https://lucmicroplastic.wordpress.com/collection-instruction/). In short, participants are requested to sample a 40 m stretch of beach at the high tide line. First, a picture is taken from the sampling location, and the GPS coordinates are noted. If no smartphone with GPS app is available, participants can also provide us with the coordinates afterwards (e.g., by using Google maps). Next, over the 40 m stretch, 5 replicate samples are taken from the top 5 cm, 1 per 10 m (0 m, ~10 m, ~20 m, ~30 m, and ~40 m). To ensure only the top 5 cm were sampled, participants were requested not to sample deeper than the second joint of their little finger. Finally, participants return the samples to a central laboratory at Leiden University (the Netherlands), where extraction is conducted using the SOP developed by Besley et al. (2017). Locations are mapped and published on the aforementioned project blog. These maps may increase public engagement during the process of sampling collection when compared to tabular representations.

At present, we have collected samples on 42 beaches, with 5 replicate samples per beach, and have another 39 for which we expect to receive samples (Figure 1). In addition, from several locations we have replicate samples, including several locations along the Dutch coast, allowing for further validation of our protocol. The distribution of these samples is not uniform around the world. We have a relatively large number of samples from Europe, the Caribbean, and the East coast of North America. We are currently focusing our efforts in increasing the number of samples from Africa, South America, and parts of Asia, including India, while expanding our sample collection from the other locations. Ultimately, this work will result in the first detailed study on levels of microplastics on beaches across different continents.

## IN-DEPTH CASE STUDIES

In addition to the citizen science project, 2 in-depth case studies are being performed at different locations. The locations of the 2 case studies are related to different potential sources of microplastics. To determine the influence of proximity to river discharge on the distribution of microplastics, we are conducting sampling at regular intervals along the Dutch coast, away from the main discharge areas of the Rhine and Western-Scheldt rivers (Figure 2). The site of our second case study is in relative close proximity to a hotspot of plastics in the subtropical North Atlantic Ocean (Law et al. 2010; Eriksen et al. 2014). This research is conducted on 4 islands of the Lesser Antilles: St. Martin (both the Dutch and French side), St. Eustatius, Anguilla, and St. Berthélemy (Figure 3). Sample locations include the windward and leeward sides of the Island (the prevailing winds are predominantly easterly (ranging from east-north easterly to east-south easterly in the region), as

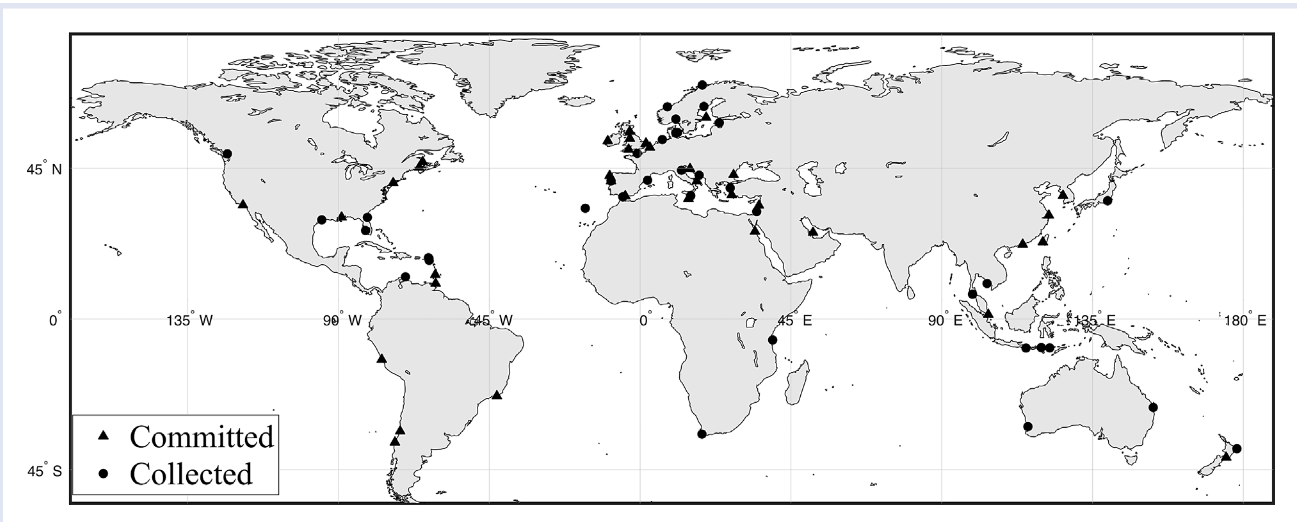


Figure 1. Locations for which samples have been (collected) or will be (committed) collected for a citizen science project on microplastics loads on beaches.

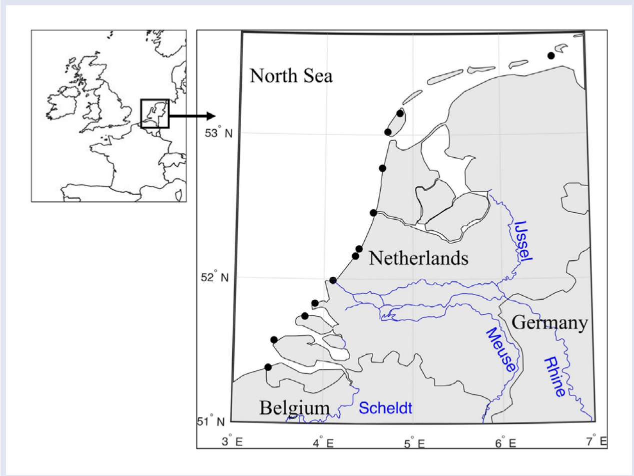


Figure 2. Locations of beach sand collection in the Netherlands for in-depth case study on microplastics loads.

these might influence the occurrence of plastics (de Scisciolo et al. 2016).

Next to the difference in distribution, we will also focus on differences in physicochemical characteristics. Microplastics enter the environment from 2 main sources. First, some microplastics are intentionally added to cosmetic and household products. These are commonly referred to as primary microplastics and end up in aquatic systems after usage (Browne et al. 2011; Rochman et al. 2015; van Wezel et al. 2016). A second source of microplastics results from the UV exposure of larger pieces of plastic in the marine environment, which increases the brittleness of plastic and drives fragmentation into smaller sizes (Andrady 2011). These are commonly referred to as secondary microplastics and can potentially be as small as a few nanometers (Andrady 2011; Cole et al. 2011). Consequently, there is a large range of variation in physicochemical characteristics of microplastics: they exist in different shapes (e.g., fibers, microbeads, fragments) (Cole et al. 2011; Wright et al. 2013; Ivar do Sul and Costa 2014; Naidoo et al. 2015), size ranges from nano- to mm-range (Cole et al. 2011; Wright et al. 2013; Ivar do Sul and Costa 2014; ter Halle et al. 2016), and different chemical constituents with different densities, including polyethylene, polypropylene, polyvinylchloride, and polystyrene (Browne et al. 2010; Andrady 2011; Engler 2012).

Five replicate samples at each sampling location were collected over a 100 m stretch using a randomized number generator. Sampling was conducted using a sampling quadrat of $50 \times 50$ cm ($0.25\,m^2$). Five metallic rulers were placed in the quadrat (in each of the corners and in the center), and approximately 250 g of sand from the top 5 cm was collected using a metallic spoon in the 4 corners of the sampling quadrat, as well as the center. Next, the sand was sieved using a 5 mm metallic sieve and stored in a plastic Ziploc bag. Between sampling, the materials were rinsed using seawater. Samples were transported back to a laboratory in the Netherlands or at St. Eustatius, dried, and kept at room temperature until extraction. Next, samples were extracted using the SOP developed by our group (Besley et al. 2017). Data will be reported as number of particles per kg of dry weight sand. The physicochemical characteristics of the samples will be determined, including the shape, size, and type of polymer (using Raman spectrometry as described in Horton et al. [2017]).

These 2 in-depth case studies will allow us to make direct comparison within and across regions, including key

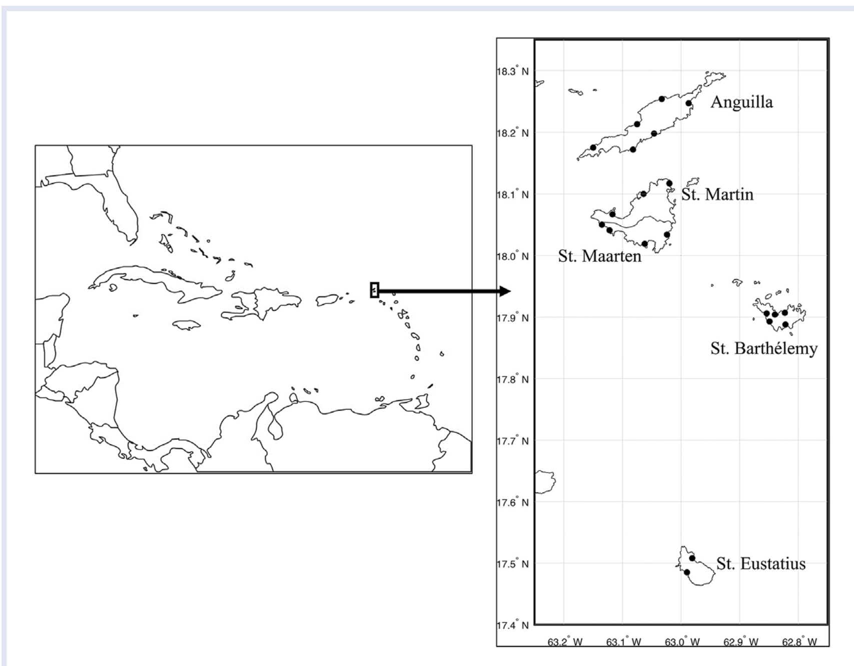


Figure 3. Locations of beach sand collection on 4 islands on the Lesser Antilles in the Caribbean for in-depth case study on microplastics loads.

physicochemical characteristics. In addition, the results can be compared to the outcomes with the results of the citizen science project, further validating our citizen science approach.

## FUTURE OUTLOOK

Using citizen science, we are investigating the variation in distribution of microplastics on beaches around the world. We use 2 approaches (in-depth regional case studies carried out by scientists and a citizen-science project at global scale), making use of a recently developed SOP to standardize sampling and extraction of microplastics from beach sediment (Besley et al. 2017). We aim to produce a foundational study on which systematically begins the work of measuring microplastics on different continents. Although our data may be used as input for circulation models in future work, at present we are focusing on collection and analysis of levels.

An important novel aspect of our project is the inclusion of citizen science. Citizen science can be a powerful tool to employ in environmental research, as large amounts of data can be collected while engaging the general public at the same time (Dickinson et al. 2010; Busch et al. 2016). The interaction with citizens assisting in data collection is growing as a cost-effective way to deploy continuous large scale environmental monitoring. A common application of citizen science is the investigation of population trends of species of organisms (Dickinson et al. 2010). Kullenberg and Kasperowski (2016) indicated that the largest impact of citizen science is in research on biology, conservation, and ecology, where citizen science is mainly used as a methodology of collecting and classifying data. Following this line, the citizen science component in our microplastic research has additional benefits of media visibility. To ensure continued involvement, participants in the citizen science project can follow the progress of the project via a blog, which includes information on the research, pictures of participants, and mapped sampling locations.

To conclude, our systematic data collection involving both in-depth case studies as well as citizen science, will address important questions on the distribution of microplastics across beaches over the world, while simultaneously raising public awareness and active participation on this issue.

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*Data availability*—Data are available by contacting corresponding author Thijs Bosker (t.bosker@luc.leidenuniv.nl).

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