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A large-scale investigation of microplastic contamination: Abundance and characteristics of microplastics in European beach sediment

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ABSTRACT

Here we present the large-scale distribution of microplastic contamination in beach sediment across Europe. Sediment samples were collected from 23 locations across 13 countries by citizen scientists, and analysed using a standard operating procedure. We found significant variability in the concentrations of microplastics, ranging from 72 ± 24 to 1512 ± 187 microplastics per kg of dry sediment, with high variability within sampling locations. Three hotspots of microplastic accumulation (> 700 microplastics per kg of dry sediment) were found. There was limited variability in the physico-chemical characteristics of the plastics across sampling locations. The majority of the microplastics were fibrous, < 1 mm in size, and blue/black in colour. In addition, using Raman spectrometry we identified particles as polyester, polyethylene, and polypropylene. Our research is the first large spatial-scale analysis of microplastics on European beaches giving insights into the nature and extent of the microplastic challenge.

1. Introduction

Since the first commercial manufacture of plastics in the 1940s, plastic production and consumption have increased rapidly (Cole et al., 2011), with approximately 322 million tonnes (Mt) of plastic produced in 2015 (PlasticsEurope, 2016). Approximately 5 to 13 Mt of plastic waste entered the ocean in 2010 (Jambeck et al., 2015), where it will persist and accumulate (Barnes et al., 2009). One subgroup of plastic that has raised particular concern are microplastics (MPs), commonly defined as pieces of plastic smaller than 5 mm (Thompson, 2004; Arthur et al., 2009; Cole et al., 2011). MPs are now ubiquitous in the marine environment (Eriksen et al., 2014): their presence has been recorded near densely-populated areas, remote regions, and in different types of marine environments, such as beaches (e.g. Besley et al., 2017), estuaries (e.g. Leslie et al., 2013), surface water (e.g. Lusher et al., 2015) and deep sea sediment (e.g. Van Cauwenberghe et al., 2015).

A distinction is commonly made between primary and secondary MPs. Primary MPs are manufactured to be of microscopic size and are often purposefully added to products (Derraik, 2002; Napper et al., 2015) or can be used as raw material in industry. These MPs likely enter the environment via wastewater treatment plants and industrial drainage systems (Derraik, 2002; Napper et al., 2015). Secondary MPs are the result of the gradual weathering or abrasion of larger plastics, mainly through prolonged exposure to solar UV radiation resulting in photo-degradation, or mechanical abrasion (Barnes et al., 2009; Andrady, 2011; GESAMP, 2015). Weathering is particularly evident on beaches, where temperatures and oxygen concentrations are higher than in water (Andrady, 2011; GESAMP, 2015).

As fragmentation and weathering decreases the size of plastics, their potential to be ingested by marine biota increases (Browne et al., 2008). The bioavailability of MPs in the marine environment has been demonstrated in different studies. MPs have been found in mussels (Santana et al., 2016), demersal and pelagic fish species (Bellas et al., 2016; Rummel et al., 2016), worms and seabirds (Cole et al., 2013). The direct effects of MP ingestion include reduced feeding, blocking of the intestinal tract leading to starvation and impaired bodily functioning, and translocation to the circulatory system (Browne et al., 2008; Cole et al., 2013; Wright et al., 2013). Furthermore, a limited number of studies have demonstrated trophic transfer of MPs, raising concerns about the possible negative impact of MPs on the health of marine food webs and humans (Farrell and Nelson, 2013; Setälä et al., 2014; Van Cauwenberghe and Janssen, 2014; Rochman et al., 2015).

Numerous studies have quantified the abundance of MPs in marine sediment in locations in Europe and other continents. There is a wide

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range in concentrations of MPs recorded in Europe: from 1 MP/kg dry weight (d.w.) (Frère et al., 2017), to over 2000 MP/kg d.w. (Vianello et al., 2013; Popa et al., 2014; Leslie et al., 2017). Part of this variation can be attributed to the different methodologies employed for extraction, as well as different size definitions of MPs (Cole et al., 2011; Besley et al., 2017). For example, there were differences in the way in which samples were obtained, how the MPs were separated from the sediment, and how MPs were subsequently identified across the literature (Besley et al., 2017). Additionally, the identification of MPs can be performed using different instruments with varying degrees of accuracy (Song et al., 2015; Käppler et al., 2016; Qiu et al., 2016). These differences can limit the comparability of the reported abundances, making it difficult to gain an understanding of the broader spatial distribution of MP abundance (Cole et al., 2011; Besley et al., 2017).

Besley et al. (2017) investigated the major sources of variation in sampling and extraction procedures. The main source of variation resulted from the extraction procedure, and not the sampling technique. Based on these outcomes we developed a citizen science project where samples were collected by non-professional volunteers (Bosker et al., 2017). Recently, researchers have begun to realise the value of these volunteers regarding the significant resources that they can provide in terms of labour, skills, and even finance (Silvertown, 2009). Citizen science is particularly valuable to large-scale projects that require extensive data collection (Silvertown, 2009; Dickinson et al., 2010). There are a variety of ways citizen scientists can participate in research, ranging from sample collection (as in the current study), to helping analysing and processing data (Kobori et al., 2016). In return, the citizen scientist actively contributes to increasing the scientific understanding of microplastics, a topic which has received considerable public attention and many feel concerned about. Citizen scientists have participated in previous research on marine litter, but Hidalgo-Ruz and Thiel (2015) noted that in the current literature on marine litter, citizen science studies do not tend to focus on MPs. This is because advanced techniques are needed to adequately identify small MPs (Hidalgo-Ruz and Thiel, 2013; Zettler et al., 2017). Therefore, the two studies in which citizen scientists participated in the quantification of MP contamination had to use a lower size limit of 1 mm (Hidalgo-Ruz and Thiel, 2013; Davis and Murphy, 2015). In the current study, the citizen scientists followed a protocol to collect bulk sediment samples and then to send them to our laboratory. This allowed for smaller MPs to be properly identified and for the continent-wide, spatial distribution of MPs to be examined with increased accuracy. The aim of this study was first to quantify MP contamination of European beach sediment, allowing examination of MP distributions, and secondly to characterise MPs in terms of their physical properties and polymer type.

2. Methodology

2.1. Sampling, extraction and identification procedure

2.1.1. Sample collection

Five samples per beach were collected between June 2015 and January 2017. Beach sediment was collected from 23 different locations across 13 different countries (Table S1). Samples from Israel and Turkey were also included, because they adjoin the Mediterranean Sea, which is a specific area of interest due to possible trapping of MPs. Participation in sample collection for this study was volunteer-based, with recruiting predominantly via social media. Within Leiden University, participants were also recruited via personal emails. The participants were provided with 6 re-sealable plastic bags and a link to the sampling instructions. The only other materials needed to obtain the samples were a metal spoon and a smartphone to take a picture of the sampling location, and note the GPS coordinates. For details on the sample collection protocol see: www.lucmicroplastic.wordpress.com. Participants were first asked to look for the high tide line, described as the line of deposition, take a picture and note the GPS coordinates if possible. Five replicate samples were obtained from a 40 m stretch of beach at the high tide line. Every 10 m, approximated by 10 large steps, a zip-lock bag was filled with roughly 100 g of sand of the top 5 cm of the beach using the metal spoon.

2.1.2. Extraction

All samples were sent by mail or transported in person back to Leiden University for extraction. A standardised, density separation method of extraction was used to extract the MPs from the sediment (Besley et al., 2017). A total of 100 g of the sediment was weighed, put into a glass dish and dried for 48 h at 60 °C. The dried sediment was sieved through a 5-mm sieve. Next, a 250 mL flask was filled with 50 g of dry sediment and 200 mL of a fully-saturated, filtered salt solution (358.9 g of NaCl in 1 L of demineralized water; water density of 9043 kg/m^3 at 20 °C). Finally, it was sealed with Parafilm. If < 50 g of sand was provided by the participants all of the available sediment was used, and the final abundance was adjusted accordingly. The mixture was then stirred at 900 RPM for 2 min, after which it was left to settle. After a minimum of 8 h, approximately 75–100 mL of the supernatant was poured off the surface and filtered through a vacuum pump covered with 47 mm Millipore, 0.45 µm filter paper (Fisher Scientific, the Netherlands). The filter paper was transferred to a covered petri dish to avoid contamination and left to dry at room temperature. This extraction process was repeated three times for each sample to increase the recovery rate (Besley et al., 2017).

2.1.3. Visual identification

The filter papers were examined under a stereo-microscope (Motic Classmag 41, Motic, Germany); at up to 40 × magnification and MPs counted. This process allowed for quantification of MPs in the range of 0.3–5 mm (NOAA, 2015). This was done systematically by dividing the filter paper up into four quarts with the top clearly marked. The approximate location on the filter paper, the colour and shape (fibre, film or particle) were noted for all MPs. Colours were then grouped in the categories 'blue/black' and 'red', as these were the most abundant, with all other colours grouped within the category 'other'. The visual identification was partially guided by a set of rules reported by Hidalgo-Ruz et al. (2012). They mention three important characteristics of MPs: i) there should be no cells or organic structures visible, ii) fibres should be equally thick throughout their entire length, and iii) they should exhibit clear and homogenous colour throughout. However, there are exceptions to these rules. For example, biofouling and bleaching can change the colour and apparent thickness of a fibre (Marine and Environmental Research Institute, 2015). Therefore, the identification was additionally guided by a visual comparison to pictures of MPs from other publications (Leslie et al., 2013), and the observed colour (perceived as bright or unusual, as depicted in Dekiff et al. (2014).

For every sampling location, 10 MPs were selected randomly to measure the length of the MPs (DinoCapture software, version 2.0, Dino-Lite Europe, the Netherlands). The fibres were measured by tracing their length (mean length ± standard error [mm]). For particles and films, the largest cross-section was measured. Only in 2.6% of measurements did the fibre length exceed 5 mm (due to coiling it is difficult to visually ensure that fibres are below 5 mm); for transparency they were included in the analysis.

2.1.4. Contamination

To avoid contamination, all equipment used during the extraction process was rinsed with distilled water before usage. All Petri dishes for storage of samples were wiped (Kimberly Clark cellulose wipe, Fisher Scientific, the Netherlands). During the extraction process, all equipment and vessels were covered when they were not in use. Additionally, the complete extraction process for one sampling location was repeated without beach sediment to quantify the procedural contamination. An analysis using a procedural blank was performed, finding an average of 3 MPs per 5 replicates, or less than one MP per replicate. The maximum