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Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification

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ABSTRACT

Sewage effluent input and population were chosen as predictors of microplastic presence in sediments at four sites in the River Thames basin (UK). Large microplastic particles (1 mm–4 mm) were extracted using a stepwise approach to include visual extraction, flotation and identification using Raman spectroscopy. Microplastics were found at all four sites. One site had significantly higher numbers of microplastics than other sites, average 66 particles 100 g^{-1}, 91% of which were fragments. This site was downstream of a storm drain outfall receiving urban runoff; many of the fragments at this site were determined to be derived of thermoplastic road-surface marking paints. At the remaining three sites, fibres were the dominant particle type. The most common polymers identified included polypropylene, polyester and polyarylsulphone. This study describes two major new findings: presence of microplastic particles in a UK freshwater system and identification of road marking paints as a source of microplastics.

Capsule: This study is the first to quantify microplastics of any size in river sediments in the UK and links their presence to terrestrial sources including sewage and road marking paints.

1. Introduction

Since the 1960s plastics have become widely manufactured and used, with global production of plastics reaching 311 million tonnes in 2014, 59 million tonnes of which were produced in Europe (PlasticsEurope, 2016). However, only 17.9 million tonnes were recycled or used in energy recovery processes in Europe in 2014 (PlasticsEurope, 2016). Their inherent durability and longevity which make plastics such a favourable commercial material are also the characteristics that allow them to persist in the environment (Barnes et al., 2009). Degradation of large plastic items can be a very slow process therefore plastics may persist in the environment over long timescales (Andrady, 2011; Hidalgo-Ruz et al., 2012), even in the range of hundreds of years (Barnes et al., 2009). However, despite the wide-ranging use and disposal of plastic products and the recognised abundance of plastic litter worldwide, the importance of understanding the fate and impacts of these plastics within the environment has only recently started to be addressed.

Microplastics, plastic particles <5 mm in size, are a specific concern given their small scale and potential for widespread environmental dispersal. The first reports of synthetic fibres and pellets as marine environmental contaminants emerged in the early 1970s (Buchanan, 1971; Carpenter and Smith, 1972), however direct research into this field was not pursued until the last decade (Thompson et al., 2004). Since 2004, many studies have investigated the presence and effects of marine microplastic debris (Arthur and Baker, 2011; Faure et al., 2012; Law et al., 2014; Lusher et al., 2015; Van Cauwenberghe and Janssen, 2014). The majority of plastic debris found in the marine environment (70–80%) has land-based sources and rivers are considered an important medium for transfer of this debris (Arthur and Baker, 2011; Bowmer and Kershaw, 2010; Hirai et al., 2011; Jambeck et al., 2015; Sadri and Thompson, 2014; Wagner et al., 2014; Zbyszewski and Corcoran, 2011; Zbyszewski et al., 2014). Comparatively few studies have actually been published on microplastics in freshwater or terrestrial environments, although this field of research is growing with a number of papers recently published on microplastics in freshwater systems (Corcoran et al., 2015; Klein et al., 2015; Lechner et al., 2014; Sanchez et al., 2014; Zbyszewski and Corcoran, 2011; Zbyszewski et al., 2014), with the greatest proportion of microplastic debris in freshwater environments being observed near to industrialised areas (Dubaish and Liebezeit, 2013; Eriksen et al., 2013; Sadri and Thompson, 2014; Zbyszewski and Corcoran, 2011).

Microplastics fall into 2 categories: primary and secondary. Primary microplastics are those which were manufactured with the intention of them being of a micro scale, for example those used in cosmetics or exfoliating scrubs (such as glitter and 'microbeads') or virgin pellets used in the plastic production industry. Secondary microplastics are those that have formed as a result of macroplastic degradation, for example breakdown of in situ litter (Andrady, 2011; Barnes et al., 2009; Rillig,

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2012; Shah et al., 2008) or the washing of artificial fabrics in the laundry, which can lead to the loss of up to 1900 fibres into wastewater per wash (Browne et al., 2011). Within these categories, microplastics are categorised into 2 size brackets: 'large microplastic particles' (LMPP, 1 mm–5 mm) and 'small microplastic particles' (SMPP, <1 mm). Over time, LMPPs may become SMPPs or even nanoplastics, due to degradation within the environment (Andrady, 2011; Koelmans et al., 2015; Lambert and Wagner, 2016).

Sources of microplastic particles to the environment are numerous and varied. Sewage treatment works (STWs) are a critical link in the microplastic transport and distribution web given that many plastic particles including microbeads and synthetic fibres will enter these STWs. If not physically filtered out within the plant itself then they will be discharged to rivers via effluent or incorporated into sludge (Habib et al., 1996; Zubris and Richards, 2005). Sludge may in turn be applied to agricultural land (DEFRA, 2012), leading to direct terrestrial implications, in addition to potential for runoff into watercourses. STW outfalls discharge directly into rivers representing a point source discharge of particles to freshwater environments. Thus, sewage outfalls have been recognised as a likely significant source of microplastic pollution to the oceans (Arthur and Baker, 2011; Browne et al., 2011). Additional sources include degradation of macroplastic debris such as sanitary waste from sewage treatment overflows, plastic packaging, particle runoff from roads in the form of tyre wear particles or parts of vehicles and runoff from land containing degraded litter (Andrady, 2011; Eriksen et al., 2013; Galgani et al., 2015; Hidalgo-Ruz et al., 2012). Another source was recently recognised in the form of polymer composite paints. Due to the low polymer composition of paints, these are likely to be more brittle than pure polymers and therefore break down quickly into smaller particles in the environment (Imhof et al., 2016; Song et al., 2014; Takahashi et al., 2012).

The aim of this study was to investigate the presence, abundance and types of microplastics within tributaries of the River Thames basin (UK). This study investigated the link between two expected and related drivers of microplastic input, sewage effluent input and population density, with the presence of microplastics in river sediments. The River Thames catchment in the UK was selected as the location for our survey as it is the UK's second longest river and the river basin supports many large urban areas, receiving effluent from a population of over 13 million (Bengtson Nash et al., 2006; National Statistics, 2002). Although likely acting as a source of microplastics to the marine environment, the Thames also has the capability to act as a sink for some plastic particles due to flow dynamics: in the Thames estuary (and other estuaries), water near the riverbed has a tendency to flow landward, meaning that some of the debris entering the river may be retained within estuarine sediments (Board, 1973). Sediment was our selected medium for analysis given that microplastics can accumulate in sediments at an order of magnitude higher than in the water column (Hoellein et al., 2016). This indicates the potential for rivers to act as a sink for environmental microplastics. Studies of macroplastic in the Thames have shown there to be an abundance of litter being transported down the Thames (Morritt et al., 2014). To our knowledge, however, with the exception of estuaries this is the first study investigating microplastics in the Thames catchment or indeed any freshwater system in the UK.

2. Materials and methods

2.1. Sampling site selection and sample collection

Sampling sites within the Thames river basin were selected based on two variables; average % effluent present in the river as estimated using the Low Flows 2000 (LF2000) WQX (Water Quality eXtension) model (Williams et al., 2009) and population equivalent density as calculated using population within the catchment area (of known area) served by the upstream sewage treatment works (Pottinger et al., 2013; Williams et al., 2009). Selected sites comprised three tributaries of the Thames: the River Leach, the River Lambourn and The Cut (two sites). These rivers are regularly monitored for a range of water quality and biological characteristics as part of the ongoing Thames Initiative project and are therefore well characterised (Bowes et al., 2014). Four sampling sites were selected to represent scenarios ranging from low sewage input and population equivalent density, Leach (SU228996) and Lambourn (SU429721) through an intermediate site, The Cut site 1 (SU859704, upstream of an effluent outfall) to a site with high sewage input and population equivalent density, The Cut site 2 (SU855732, downstream of an effluent outfall) (Figs. 1 and 2). Samples were collected between 28th August and 3rd September 2014 to correspond with seasonal low flow conditions. At each site four sediment samples were collected at 1 m intervals along a 3 m transect running parallel to the bank at 1 m distance, therefore giving four replicate samples per site. The sediment surface was sampled in all cases to approximately 10 cm depth using a stainless steel scoop, collected to fill a 1 L glass Kilner jar, ensuring that minimal excess water was retained.

2.2. Sample processing

The sediments were processed in three steps in order to find and separate microplastic particles: 1) visual inspection of whole sample, 2) flotation and 3) further visual inspection of unfloated material. This three-step process was designed to remove microplastic particles with maximum thoroughness and efficiency, without the need for custom-made equipment (Claessens et al., 2013; Imhof et al., 2012), based on the assumption that each step would not in itself be sufficient to recover all microplastics. To determine whether any of the three steps could be eliminated from future analyses to further streamline the process, the effectiveness of each step for microplastic removal was compared, based on percentage removal of total microplastic particles. As methodological limitations prevent accurate determination of small microplastic particles <1 mm, before undertaking the steps to extract microplastics particles the 1 L sediment samples were each wet-sieved to retain two size fractions, 1–2 mm and 2–4 mm. These sizes were selected for analysis as indicators of the types and likely sources of microplastics present in this environment while remaining visible and easily quantifiable. Two fractions were specified in order to differentiate between abundances of microplastics of different sizes. Both size fractions from each site were carefully rinsed into individual clean containers and oven-dried at 80 °C. This temperature is below the melting point of all common polymers and wouldn't be expected to alter the inherent particle shape considered for the analysis (Kalpakjian and Schmid, 2008). Once dry, samples were weighed and total dry weight calculated, then covered to prevent airborne contamination and stored for sorting and analysis.

2.2.1. Extraction step 1: visual inspection of sieved sediments

The first sorting step was a visual inspection of the entire sample using a binocular light microscope at 6× magnification (Wild Heerbrugg, Switzerland, with Photonic PL2000 cold light source), in order to determine to what extent this step could remove all microplastics and potentially eliminate the necessity for flotation in future analyses. For each sample, all sediment from the 2–4 mm fraction was inspected for 15 min and the 1–2 mm fraction for 25 min (subsample of 40 g where the total 1–2 mm size fraction exceeded this). These time frames were found to be sufficient based on the time taken to manually skim through sediment of this size and remove visible microplastic particles from surrounding organic and inorganic matter. In order to be selected, all particles sorted from sediment were required to conform to the following criteria as outlined by Nor and Obbard (2014): no visible cellular or organic structures, particles/fibres are not segmented and if fibres, were equally thick throughout their entire length and should not be tapered at the end. Two additional criteria were specified by Nor and Obbard, however these were considered unsuitable as they would have led to dismissal of likely plastics (homogenously coloured and not shiny) (Nor and Obbard, 2014). Furthermore, based on initial observations

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