Marine Pollution Bulletin xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Microplastic pollution in the Northeast Atlantic Ocean: Validated and opportunistic sampling

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Plastic
Fibres
Sub-surface
Neuston
Continuous monitoring

ABSTRACT

Levels of marine debris, including microplastics, are largely un-documented in the Northeast Atlantic Ocean. Broad scale monitoring efforts are required to understand the distribution, abundance and ecological implications of microplastic pollution. A method of continuous sampling was developed to be conducted in conjunction with a wide range of vessel operations to maximise vessel time. Transects covering a total of 12,700 km were sampled through continuous monitoring of open ocean sub-surface water resulting in 470 samples. Items classified as potential plastics were identified in 94% of samples. A total of 2315 particles were identified, 89% were less than 5 mm in length classifying them as microplastics. Average plastic abundance in the Northeast Atlantic was calculated as 2.46 particles m^{-3}. This is the first report to demonstrate the ubiquitous nature of microplastic pollution in the Northeast Atlantic Ocean and to present a potential method for standardised monitoring of microplastic pollution.

1. Introduction

Pollution of the marine environment is a global phenomenon, and plastic debris presents an increased threat to ecosystems and marine organisms due to its durability and persistence. Most plastics are discarded within a year of their production (Hopewell et al., 2009), making them the most abundant type of marine debris (UNEP, 2009). It has been estimated that plastic materials make up to 60–80% of marine litter (Gregory and Ryan, 1997) and even though some plastic waste is recycled, up to 10% of plastics produced (by mass) is estimated to end up in the oceans where they can accumulate (Barnes et al., 2009).

Worldwide plastic production was estimated at 280 million tonnes in 2011 (PlasticsEurope, 2012), suggesting that 28 million tonnes will find its way into the marine environment every year. Accumulation of plastic litter in marine and coastal environments has been reported at the sea surface (Barnes et al., 2009), on shorelines (Barnes and Milner, 2005) and the seafloor (Galgani et al., 2000). However, data on worldwide distribution are incomplete. Many reports of plastic debris have focused on larger items, known as macroplastics, and reviews have commented on the impacts and effects of their presence in the marine environment (e.g. Derraik, 2002).

Monitoring programs for macroplastics in the marine environment estimate plastics by direct observations: ship and aerial based, the use of ROVs on the seabed, and trawl and net surveys (Galgani et al., 2013). A few studies have assessed the temporal trends in marine debris and plastic abundance (for example directed, shoreline monitoring efforts include monthly and annual sampling on strandlines, beaches (Tourinho and Fillmann, 2011), surface waters (Day and Shaw, 1987) and the seafloor (Galgani et al., 2000)). Temporal trends including yearly and seasonal increases have been observed (Tourinho and Fillmann, 2011), which suggests that yearly monitoring efforts might not be sufficient to understand the temporal trends in debris accumulation, and monthly or seasonal sampling might be more appropriate to monitor long-term changes. Indicator species have also been employed to monitor plastic debris. Data on plastic ingestion by Northern fulmars (*Fulmaris glacialis*) from the Netherlands began in the 1980s and levels of ingested plastic are used as proxies of plastic accumulation in the North Sea and European coastlines, for the OSPAR Ecological Quality Objective on marine litter (Van Franeker et al., 2011). Monitoring marine plastic debris is difficult, expensive and time consuming. Furthermore, time series of data are required to address changes in abundances of marine litter including variations in spatial and temporal distribution.

Once plastics reach the marine environment, they fragment into smaller and smaller pieces following a number of mechanical, chemical and biological processes (Andrady, 2011). Microplastics are small items of plastic, generally less than 5 mm in length,

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http://dx.doi.org/10.1016/j.marpolbul.2014.08.023
0025-326X/

although size dimensions of microplastic classification can vary between research areas and research groups (Arthur et al., 2009). Microplastics come from a number of marine- and land-based sources which can be classified into two groups: primary (abrasive scrubbers, cosmetics, pre-production pellets, powder for air-blasting) and secondary microplastics (fragments and fibres of larger plastic items) (Hidalgo-Ruz et al., 2012). Irrespective of their origins, once in the marine environment, microplastics will persist and accumulate because of their durable qualities which make them a desirable user product. Accumulation and the fate of microplastics are of particular concern as they are impossible to remove from the environment.

Studies from the past four decades have identified microplastics in almost every habitat around the globe (Ivar do Sul and Costa, 2014). Microplastic distribution is expected to be driven by prevailing environmental conditions, including surface circulation and winds. Wind-induced mixing of surface waters vertically distributes plastics. For example, modelling has suggested that higher wind speeds result in the capture of fewer plastics (Kukulka et al., 2012). This is in addition to plastic density which can govern microplastics' position in the water column (Murray and Cowie, 2011). Microplastics have been found suspended in the water column (e.g. Lattin et al., 2004), surface waters (e.g. Moore et al., 2001; Morét-Ferguson et al., 2010), coastal waters (e.g. Ng and Obbard, 2006), rivers (Sadri and Thompson, 2014), estuaries (e.g. Browne et al., 2010) and in sediments (e.g. Browne et al., 2011). To date most research has focused on accumulation of microplastics in surface waters of ocean gyres, specifically in the North Pacific (Goldstein et al., 2013). There have been some attempts at monitoring the spatial and temporal trends of microplastics (e.g. in the Pacific, Shaw and Day, 1994). Despite the rapid increase in plastic production, there have been no observed trends in plastic concentration (Law et al., 2010); however, the spatial and temporal dynamics of microplastics are poorly assessed due to a lack of data on their at sea occurrence.

With the exception of data from the Continuous Plankton Recorder collected in the Northeast Atlantic (Thompson et al., 2004), to the authors knowledge there are no reported cases of microplastics in the Irish marine and coastal environment, and there are currently no published or widely established monitoring methods for microplastics in European exclusive economic zones. Methodology used to monitor microplastics varies (Hidalgo-Ruz et al., 2012) including quantitative plankton tows and sediment samples, which are sometimes standardised across monitoring schemes. However, the methodology changes with vessel, research group and weather. There are currently no methods developed to enable large spatial scale assessment of microplastic abundance which are relatively inexpensive, easy to collect, and simple to use despite often unavoidable and adverse weather conditions.

An understanding of microplastic distribution and abundance at broad spatial scales is required to inform policy makers and governmental organisations on the fate of microplastics in the marine environment. Such assessment is therefore of legislative relevance within Europe's Marine Strategy Framework Directive (MSFD, 2008/56/EC) which requires the development of monitoring schemes for marine litter. A key attribute of the MSFD is to determine the ecological harm caused by microplastics (Galgani et al., 2013). Effects of larger, easily visible, macroplastics interacting with marine organisms, such as entanglement and ingestion (Derraik, 2002), often overshadow the presence of microplastics (Arthur et al., 2009). There is much less known about microplastics, and their fate in the marine environment is poorly understood. The interaction of organisms with microplastics is a widely discussed topic. Studies have identified microplastics in the stomachs of wild caught species (e.g. Lusher et al., 2013). Uptake could be via normal ventilation processes (Watts et al., 2014), direct ingestion of microplastics (e.g. Thompson et al., 2004; Besseling et al., 2013) or through trophic transfer (e.g. Eriksson and Burton, 2003). Laboratory studies have begun exploring the possible negative effects of microplastic ingestion (e.g. Besseling et al., 2013). Furthermore, if microplastics are taken up by organisms, there is a potential for any chemicals associated with the plastics to transfer and pose a toxic risk to individuals (e.g. Bakir et al., 2014).

It is important to establish the origins, trajectory, and fate of microplastics in the environment in order to mitigate future effects. Once microplastics have been identified, and standardised field methods developed, results can be fed into international monitoring strategies to map microplastic distribution worldwide.

In this study a new sampling method was developed and trialled with the aim of establishing a protocol suitable for continuous underway sampling of sub-surface microplastics in the marine environment. Generalised linear models were produced to understand what factors could be influencing microplastic distribution.

2. Materials and methods

2.1. Method development

This method was designed to create a simple, replicable monitoring system that could be integrated into already existing research surveys without impinging on the primary aims or operations of existing surveys. Samples were collected alongside research cruises on the R.V. *Celtic Explorer* during surveys for the collection of oceanographic, acoustic and biological data within the Irish marine environment. By creating a validated method of sample collection that would not delay or interfere with vessel operations, we were able to optimise a protocol that could be conducted 24 h a day with no need to slow the research vessel or adjust its operating procedures.

2.2. Sample collection

Samples were collected during several research cruises onboard the R.V. *Celtic Explorer* during 2013 (Table 1). The nature of the sample collection meant there was no control over the vessel speeds and length of each transect. Vessel speeds ranged between 0 (stationary) and 10 knots (surveying). A constant sample duration was maintained by calculating the flow rate and time required to filter a known volume of water (as described below).

Seawater was collected from a continuous intake located on the forward starboard side of the vessel, at 3 m depth covered with primary gauze (1 mm) to remove larger items of debris. Under MARPOL regulations the grey water (treated sewage) outlet on the vessel is on the forward port side and released on average every 4 h. It does not affect the water collected, as grey water is released on the opposite side of the vessel and behind the intake Seawater was pumped aboard using a Desmi DPV 6/6 B pump (Netherlands) at 1.5 kW power, 50 Hz with a flow rate of 6.3 m^3 per hour (0.75 bar vacuum). It is a vertical multistage centrifugal sealed pump with an optimum pressure of 2 bar and optimum capacity of 23.6 l s^{-1}. Pressure is regulated by a pressure regulator valve, and can be adjusted by hand. Seawater is passed under pressure through stainless steel and food grade PVC pipes to the laboratory. Samples were collected using a hose connected directly to the seawater system. A marine grade stainless steel 250 μm sieve, in a simple frame fitted with a lid, was used to filter suspended particulate matter from a known volume of water. Calculation of the flow rate made it possible to determine the period of time required to filter a known volume of water and 2000 l was chosen as a standard. This method is similar to the independently developed protocol of Desforges et al. (2014).

Please cite this article in press as: Lusher, A.L., et al. Microplastic pollution in the Northeast Atlantic Ocean: Validated and opportunistic sampling. Mar. Pollut. Bull. (2014), http://dx.doi.org/10.1016/j.marpolbul.2014.08.023