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Abundance and composition of near surface microplastics and plastic debris in the Stockholm Archipelago, Baltic Sea

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ABSTRACT

We collected plastic debris in the Stockholm Archipelago using a manta trawl, and additionally along a transect in the Baltic Sea from the island of Gotland to Stockholm in a citizen science study. The samples were concentrated by filtration and organic material was digested using hydrogen peroxide. Suspected plastic material was isolated by visual sorting and 59 of these were selected to be characterized with Fourier transform infrared spectroscopy. Polypropylene and polyethylene were the most abundant plastics identified among the samples (53% and 24% respectively). We found nearly ten times higher abundance of plastics near central Stockholm than in offshore areas (4.2×10^5 plastics km^{-2} compared to 4.7×10^4 plastics km^{-2}). The abundance of plastic debris near Stockholm was similar to urban areas in California, USA, and the overall abundance in the Stockholm Archipelago was similar to plastic abundance reported in the northwestern Mediterranean Sea.

1. Introduction

Worldwide plastic production has increased from 5 million tons in 1950 to 322 million tons in 2015 (PlasticsEurope, 2016), and plastic debris is now ubiquitous in aquatic environments (Barnes et al., 2009). Many sources contribute to the burden of plastic pollution in marine waters. Major inputs of plastic litter from land-based sources are known to come from densely populated or industrialized areas (Gregory, 1991; Jambeck et al., 2015; Pruter, 1987), with landfills and tourism being important contributors (UNEP, 2005). Furthermore it has been shown that the effluent water of wastewater treatment plants (WWTPs) contain plastic, mainly in the form of synthetic fibers from clothing (Browne et al., 2011; Magnusson and Norén, 2014) and play a critical role in the fate and transport of microfibers in the environment (Napper and Thompson, 2016). Sea-based sources of marine litter include ships and vessels, offshore oil and gas platforms and aquaculture installations (UNEP, 2005).

Plastic litter in the environment is usually classified into different size fractions. Plastic particles exceeding 5 mm in diameter are called macroplastic (Moore, 2008). Particles < 5 mm in diameter are called microplastics and can be further distinguished between primary microplastic particles that are produced in that size range, and secondary microplastic particles formed by fragmentation of larger plastic debris (Cole et al., 2011; Derraik, 2002; Moore, 2008; Ryan et al., 2009).

Floating plastic debris in the marine environment can be degraded by reactions initiated by UV-radiation, hydrolysis and microorganisms (Gewert et al., 2015). However, in general plastic is highly durable and tends to accumulate in the environment (Barnes et al., 2009). The buoyancy of plastic debris depends on the composition, density and shape of the plastic particle, among other factors (Derraik, 2002). Plastic used in common consumer items can be buoyant or prone to sinking (Morét-Ferguson et al., 2010), but the majority of plastic debris is buoyant (Derraik, 2002). Biofilms formed on plastic particles may further modify the density of plastics making initially buoyant particles heavier and more prone to sinking (Cozar et al., 2014; Fazey and Ryan, 2016; Gorokhova, 2015; Ye and Andrady, 1991) but also more attractive for ingestion by animals such as zooplankton (Nerland et al., 2014).

Microplastics have recently become a cause for concern as ingestion has been observed in a wide range of taxa spanning from zooplankton to mammals (Browne et al., 2008; Cole et al., 2013; Derraik, 2002; Laist, 1987; Murray and Cowie, 2011; Setälä et al., 2016b, 2014; Thompson, 2004; Van Cauwenberghe et al., 2015; Wright et al., 2013). Although the effects of this exposure are not yet well understood (GESAMP, 2015), the hazard posed by microplastics has inspired initiatives aimed at reduction of plastic litter in marine environments (Moore, 2008; Storrier and McGlashan, 2006), and plastic in the global oceans was recently identified as a potential planetary boundary threat (Jahnke et al., 2017).

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The European Union's Marine Strategy Framework Directive (European Commission, 2008) sets the conditions required for European member states to achieve “good environmental status” by the end of 2020. Descriptor 10 of the directive, marine litter, states that good environmental status can only be reached when "the properties and quantities of marine litter do not cause harm to the coastal and marine environment". To reach good environmental status and to monitor future changes in the environment, it is imperative to assess the current abundance and characteristics of plastic debris in European marine waters. Although some European countries already have initiated monitoring campaigns, their efforts have mainly focused on microplastics in sediments (Claessens et al., 2011; Imhof et al., 2013; Van Cauwenberghe et al., 2013; Vianello et al., 2013) or on beaches (Ryan et al., 2009) and relatively little information regarding floating plastic debris exists from European waters.

The Baltic Sea is a semi-enclosed intracontinental sea of about 4.2×10^5 km^2 that is particularly vulnerable to pollution because of restricted water exchange with the North Sea (Feistel et al., 2008). Consequently, the Baltic Sea has often been referred to as the most polluted sea globally (HELCOM, 2010). The Swedish capital, Stockholm, is one of the largest urban areas in the Baltic Sea drainage basin, with about 900,000 inhabitants in the city and a population of about 2 million in the urbanized area (Statistics Sweden, 2016). The city of Stockholm lies within the Stockholm Archipelago, which comprises about 30,000 islands and small islets (Eriksson et al., 2004). The Archipelago is one of the top tourist destinations in Sweden with about 1,400,000 visitors in 2011 (Stockholm Visitors Board, 2011). This area is the most popular location for summer homes in Sweden (Marjavaara, 2007). In addition to being a tourist attraction and vacation area, the Stockholm Archipelago is the largest receiver of treated sewage in Sweden (Rosenberg and Diaz, 1993) and has intense ship traffic (Engqvist and Andrejev, 2003; HELCOM AIS, 2017).

Although the Baltic Sea is one of the most thoroughly studied seas in the world (Feistel et al., 2008), there are only a few studies reporting on the concentration and spatial distribution of microplastics in the Baltic Sea (Gorokhova, 2015; Magnusson, 2014; Magnusson et al., 2016; Magnusson and Norén, 2011; Norén, 2007; Norén et al., 2014, 2015; Setälä et al., 2016a; Talvitie et al., 2015). But the applied methods, i.e. samples depth, mesh size, sampling area etc. vary broadly. Some of the studies focus on specific point sources of plastic debris, which is not representative for the Baltic Sea. Hence, our knowledge regarding the distribution, abundance and composition of floating marine plastic debris in the Baltic is still limited.

In this paper we report the concentrations and compositions of floating plastic debris collected with two different types of trawls in the Stockholm Archipelago and the open Baltic Sea. Twenty-one samples were collected with a manta trawl towed behind a boat, and cover an anthropogenic disturbance gradient spanning from highly urbanized coastal areas, including harbors and a WWTP, to remote areas in the outer Stockholm Archipelago. We also report on plastics collected in four additional samples using custom-built trawls that were towed behind stand-up paddleboards by two citizen scientist outdoor adventurers who were seeking to raise awareness of pollution of the Baltic Sea by plastics.

2. Materials and methods

2.1. Sampling and study area

Our primary sampling campaign included 21 surface water samples and was conducted on the 24th (samples 1–4) and 25th (samples 5–9) of June and 7th (samples 10–12), 9th (samples 13–17) and 11th (samples 18–21) of July 2014 in the Stockholm Archipelago (Sweden). We collected samples in areas close to Stockholm city (samples 10–12), Nynäshamn (a larger commercial harbor) (samples 18–20), Trosa (a town with high leisure boat activity) (sample 21) and Himmerfjärdsverket (sample 17), a wastewater treatment plant south of Stockholm which handles the wastewater of approximately 350,000 people (SYVAB, 2016). These areas were chosen because they are potentially important sources for plastic pollution to the marine environment and represent different types of activities. Hence, the concentration of plastics was expected to be high relative to more remote areas of the Stockholm Archipelago that were also sampled.

After our primary sampling campaign, in the summer of 2014, we were contacted by two Swedish adventurers who were planning to attempt to cross the Baltic Sea from Visby on the Swedish island of Gotland to Stockholm on standup paddleboards. The adventurers volunteered to collect surface water samples during their 210 km open water crossing to raise public awareness of plastic pollution in the Baltic Sea. We designed special lightweight trawls that could be deployed on the water surface behind the paddleboards with an 80 µm net with a round opening of 10 cm in diameter. The trawls were tested in a flume experiment in the laboratory to optimize the distance between the paddleboard and the trawl to achieve efficient sampling. Prior to their trip the adventurers received several of the custom trawls and were trained in sampling techniques and sample handling. They collected four samples from their paddleboards during their 10-day unaccompanied crossing, which occurred between the 4th and 14th of June 2015. These samples were sent to our laboratory and were separated and analyzed using the same technique as the samples collected during our primary sampling campaign.

2.2. Sampling method

Samples for the primary study were collected using a manta trawl (obtained from Marcus Eriksen, 5 Gyres institute) towed outside of the wake zone approximately 35 m behind a research vessel, harbored at the Askö Research Station in the southern Stockholm Archipelago. The 61×16 cm rectangular opening of the manta trawl was connected to a 4 m long net with a standard mesh size of 335 µm and a 30×10 cm^2 collecting bag (c.f. Hidalgo-Ruz et al., 2012; Zampoukas et al., 2010).

During sampling, the boat was traveling at a speed of 2–3 knots and its position was logged using a Garmin GPSMAP 78 GPS device (Garmin, USA). The duration of sample collection varied between 12 and 60 min (Table 1 in Supporting information) due to different surrounding factors (e.g. intense boat traffic). After each sampling event, the whole net was rinsed thoroughly with seawater from the outside starting from the opening towards the collecting bag to ensure that all the plastic debris would be collected. Then the collecting bag was deployed and rinsed with about 6–10 L of seawater and the collected samples were stored in 12 L hard plastic containers. On land, the water volume of each sample was reduced by filtering the sample through a 110 µm mesh. Then the mesh was rinsed with tap water and the sample was collected in a smaller 0.5 L container of hard plastic. The total of 21 samples were stored at 4 °C in darkness to minimize algal growth until analysis.

2.3. Separation methods

Several steps were conducted to separate the plastic particles from the biological matrix and water, using a method based on that described by Mason et al. (2016a) (Fig. 1). To avoid contamination of the samples with airborne fibers and other material, the separation was conducted under a fume hood. First larger pieces of biological material, including e.g. leaves, bugs, larger algae, wood, were picked out of the samples with tweezers and were carefully rinsed with water, which was collected back into the container to avoid loss of microplastics. Larger plastic debris was picked out and rinsed in the same way, but instead of discarding it, we counted and stored the plastic for further analysis. Then the samples were stored in the dark until denser particles had settled at the bottom of the container. Afterwards, the supernatant was filtered using a vacuum pump through a glass fiber filter (GF/F;