BASELINE

Low abundance of floating marine debris in the northern Baltic Sea

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Abstract

We determined the spatial and seasonal distribution of Floating Marine Debris (FMD) by visual ship surveys across the northern Baltic Sea between Finland and Sweden. FMD density was comparatively low, and we found the highest debris density close to major port cities. The seasonal variation in debris density was not pronounced although we observed more FMD items during the summer surveys. Plastic bags were the most common identifiable litter items, and we also found other consumer items (plastic bottles and cups). Styrofoam items suggest fishing or aquaculture activities as potential sea-based sources of FMD. These are the first data on FMD density in the Baltic Sea, and they are substantially lower than those reported for other coastal waters, which may be due to (i) lower human population densities, and (ii) higher environmental awareness in the Scandinavian countries.

Keywords: visual ship based surveys, plastics, pollution, single-use items, public marine transport, ferry surveys

The Baltic Sea is one of the world's largest brackish water systems and under strong anthropogenic influence. The high degree of industrialization of the Baltic coasts, intense ship traffic, extensive nutrient runoff, contamination by anthropogenic hazardous substances, and excessive extraction of living and non-living resources are major environmental stressors that make the Baltic Sea one of the most impacted marine ecosystems (Reusch et al., 2018). Accordingly, the environmental status of the Baltic Sea has declined continuously over recent decades in many respects (Ojaveer and Eero, 2011).

As in most other regions of the world's oceans the pollution of the environment by anthropogenic marine debris (primarily plastics) has become evident also in the Baltic Sea. An extensive large-scale study involving citizen scientists has demonstrated the pollution of beaches in the southern Baltic Sea by anthropogenic debris (Honorato-Zimmer et al., 2019). Routine samples taken within the ICES International Bottom Trawl Survey have shown noticeable marine litter quantities of 5 items km^{-2} on the seafloor of the southern Baltic Sea, which were, however, still lower than on the seafloor of the southern North Sea (17 items km^{-2}) (Kammann et al., 2018). Moreover, a constantly growing number of studies from various regions of the Baltic Sea are revealing contamination of the water column, sediments, and marine organisms by microplastics (Gewert et al., 2017; Graca et al., 2017; Rummel et al., 2016).

The Baltic Sea catchment area has a population density of approximately 30 to 50 habitants per km^2, with a total population size of over 85 million (BSEP87-HELCOM), and anthropogenic marine debris enters the sea from diverse sources along the urbanized coasts, including tourism, industries, and riverine input but also from shipping and fishing (Hengstmann et al., 2017; Schernewski et al., 2018; Stolte et al., 2015). Accumulation of pollutants in the semi-enclosed Baltic Sea is promoted by the restricted exchange of water masses with adjacent marine regions (i.e. the North Sea – Witt and Matthäus, 2001) similar to the situation in the Mediterranean, which is one of the most heavily polluted marine regions of the world with regard to marine debris (Cincinelli et al., 2019; Cózar et al., 2015).

Extensive environmental observation programs have documented the pollution of enclosed seas such as the Mediterranean or the Black Sea, making use of intense public marine transport by ferries, which allows for an opportunistic cost-effective quantification of floating marine debris (FMD) in offshore areas (Arcangeli et al., 2018; Campana et al., 2018). FMD is of concern as it potentially impacts numerous species from various compartments of the marine ecosystem, including pelagic organisms and marine mammals, reptiles and seabirds, with well documented harmful effects on the biota (Roman et al., 2019; Thiel et al., 2018). FMD items that lose buoyancy, e.g. as a consequence of dense overgrowth by fouling organisms, constitute a continuous flux of marine debris to sensitive seafloor habitats (Fazey and Ryan, 2016; Ye and Andrady, 1991). Moreover, FMD may transport associated organisms over extensive distances thereby facilitating the spread of non-indigenous species (Carlton et al., 2017).

Although many harbors of the Baltic Sea are connected by intense ferry traffic, opportunistic monitoring programs for FMD, as those conducted in the Mediterranean, do not seem to exist in this region, and information on the quantities, composition and dynamics of FMD in the Baltic Sea is as yet entirely missing. This information is, however, essential for a comprehensive evaluation of the pollution status of the Baltic Sea, as well as to identify sources of marine debris and to monitor future trends. Here, we report the first data on FMD from the northern Baltic Sea collected during seasonal ferry transects between the Finnish city of Turku and the Swedish capital of Stockholm.

FMD was quantified on a total of eight seasonal ferry voyages from aboard MS Galaxy (Silja Line) along a fixed route, connecting Turku in the east with the Åland Archipelago and Stockholm in the west (Figure 1). Each cruise covered four marine regions from east (Turku) to west (Stockholm): the Archipelago Sea, the Åland Archipelago, the Åland Sea, and the Stockholm Archipelago. Two spring cruises were conducted in April 2012 and May 2013, three summer cruises in July and August 2012, and three autumn cruises in October and November 2012. Observations were performed from one side of the ship, the port side close to the bow, and at the lowest outdoor deck situated 11 m above the sea surface. During the cruises, two to three dedicated observers recorded all FMD items passing the ship. The GPS was connected to a laptop that automatically recorded the fixed ferry route. When a debris item was encountered its GPS position was marked as a waypoint along with specifications of the item, such as type and distance from the ship. We also roughly estimated the size of the items and separated them into three groups, namely 0 to 10 cm, 10 to 30 cm, and 30 to 70 cm. The three size categories were pooled when calculating the density.

Afterwards, the length of each voyage was calculated from the GPS tracks and sub-divided into 5 km transects. We chose a transect width of 50 m because of the gradually diminishing probability of reliably capturing objects farther away from the vessel. Accordingly, FMD densities (items km^{-2}) were calculated as the number of items recorded along the 5 km transects within the transect width of 50 m. All observations were made under conditions of good visibility and calm sea state, in a range of speed between 8 knots in the archipelagoes and 20 knots in the more open sea regions.

In total, we conducted eight ship surveys, one less in spring due to logistical problems. Since FMD in spring was surveyed during two subsequent years, 2012 and 2013, the data were combined for the analysis of a seasonal pattern in FMD densities. For each cruise, the transect length of 5 km resulted in 16 replicate transects for the Archipelago Sea, 17 transects for the Åland Archipelago, and 9 transects for the Sea of Åland. In the Stockholm Archipelago, 18 replicate transects were surveyed during the summer cruises, but only 9 during the autumn cruises because of limited daylight hours in autumn. Each of the surveyed 5 km transects was considered an independent replicate.

The FMD densities were tested separately for seasonal and regional variation by a generalized linear mixed model implemented by SAS 9.4 procedure Glimmix (Littell et al. 2006), where the cruise identity was treated as a random factor. Negative binomial distribution was used for the error variation. Good model fit was confirmed with the generalized chi-square divided by the degrees of freedom being close to one. We conducted the analyses separately because the two-way statistical models fitted poorly our data.

A total of twenty-seven FMD items were counted during the eight ferry cruises (Figure 1). Twenty-six items (96 %) were identified as plastics, comprising four styrofoam items (22 %), five plastic bags (18 %), three plastic beverage containers (bottles and cups – 11 %, 1 and 2 respectively), and twelve unspecified plastic items (44 %). A single non-plastic item (4 %) was recorded, which consisted of paper.

We found FMD items ranging in size from 5 to 70 cm. Four items were found in the size class from 0-10 cm, sixteen from 10-30 cm, and seven from 30-70 cm. The smaller items were on average (± SD) observed closer to the vessel, namely size classes of 0-10 cm at 10.0 ± 7.7 m (range of distance, minimum = 3 m, maximum = 20 m) whereas size classes of 10-30 cm and 30-70 cm, were observed further away at 31.0 ± 11.9 m (minimum = 12 m, maximum 50 m) and 32.6 ± 10.0 m (minimum = 18 m, maximum 40 m), respectively.

The FMD density did not vary significantly among the seasons ($F_{3, 3.9} = 0.91$, $p = 0.47$) but tended to be higher in summer than in autumn (Figure 2A). The overall average (± SE) FMD density in the survey region was 0.2 ± 0.1 items km^{-2}.

The density of FMD varied among the 5 km transects from zero to 11.9 items km^{-2}. Most items were observed in the vicinity of land or large islands. In six out of eight cruises, no FMD was encountered in the Åland Sea, whereas the highest density was observed in July 2012 in the Stockholm Archipelago. However, FMD densities did not significantly vary among the four sea regions ($F_{3, 618} = 1$, $p = 0.39$, Figure 2B).

Abundance of FMD in the northern Baltic Sea was very low. Average densities of < 1 item km^{-2} have been reported in recent times only from very few marine regions. Ryan et al. (2014) counted on average between 0.03 and 0.58 FMD items km^{-2} in the African sector of the Southern Ocean. Accordingly, the authors classified the Southern Ocean as the least polluted marine region with regard to FMD. Densities of FMD in the northern Baltic Sea were about two orders of magnitude lower than in the adjacent North Sea (~ 30 items km^{-2} – Gutow et al., 2018; Thiel et al., 2011), suggesting only very limited import of FMD from the North Sea into the Baltic basin. This can be explained by the predominance of surface currents from the Baltic to the North Sea (Leppäranta and Myrberg, 2009). Substantially higher densities of FMD have been reported from the Mediterranean, which is, similar to the Baltic Sea, a semi-enclosed basin with limited water exchange with the open ocean. In the Mediterranean, FMD densities varied between 2-5 items km^{-2} (Arcangeli et al., 2018; Campana et al., 2018) and about 250 items km^{-2} (Zeri et al., 2018), whereas in the Atlantic Ocean average densities of FMD of about 0.8 items km^{-2} and 1.7 items km^{-2} were counted around the Azores and throughout the S Atlantic, respectively (Barnes et al., 2018; Chambault et al., 2018). Similarly high abundances of FMD (1-240 items km^{-2}) as in the Mediterranean were counted in the fjord system of southern Chile (SE Pacific) with highest densities in the semi-enclosed inner parts of the fjords (Hinojosa and Thiel, 2009) and declining FMD densities towards offshore waters (Thiel et al., 2003). Highest densities of FMD of 40-2440 items km^{-2} were observed off the Mexican Pacific coast (Díaz-Torres et al., 2017).

Out of all FMD seen, 25% were small sized and observed relatively close to the ship. A lower detectability of small FMD items at larger distance from the ship has also been observed by Ryan (2013) and may lead to a slight underestimation of the overall FMD densities, especially of small items. We found that FMD in the northern Baltic Sea was composed almost exclusively (96 %) of plastic items (including styrofoam). Similarly high contributions of plastics have been observed among FMD in the Southern Ocean (Ryan et al., 2014), in the Mediterranean (Palatinus et al., 2019; Suaria and Aliani, 2014) and the Black Sea (Suaria et al., 2015), whereas in other regions the share of plastics was substantially lower. For example, in the North Sea 70 % of the total FMD consisted of plastics (Gutow et al., 2018; Thiel et al., 2011), whereas the contribution of plastics in the Mediterranean varied between 65 and 95 % (Campana et al., 2018; Suaria and Aliani, 2014) and was above 80 % in coastal waters of the SE Pacific (Hinojosa and Thiel, 2009; Thiel et al., 2003).

The share of plastics was mostly lower in other marine habitats of the Baltic Sea. Densities of beach debris in the southern Baltic Sea have been found to vary significantly between sampling sites and among seasons (Hengstmann et al., 2017; Schernewski et al., 2018), suggesting complex dynamics of supply and deposition of debris. There, the contribution of plastics ranged between 30 and 91 % (Balčiūnas and Blažauskas, 2014; Honorato-Zimmer et al., 2019; Schernewski et al., 2018; Urban-Malinga et al., 2018). Similarly, the contribution of plastics to marine litter on the seafloor of the southern Baltic Sea was 67 % (Kammann et al., 2018). The high contribution of plastics of 96 % to the total amount of FMD in the northern Baltic Sea can be explained by the buoyancy and long persistence of plastics at the sea surface. On beaches and on the seafloor, the share of other materials, such as metal, glass and ceramics, was much higher (Kammann et al., 2018). These items do not float and, therefore, disappear quickly from the sea surface, resulting in a corresponding increase in the proportion of floating plastics among the remaining floating material. Moreover, the general sea surface circulation pattern of the Baltic Sea (Leppäranta and Myrberg, 2009) suggests that buoyant debris is transported from the southern Baltic Sea to the north.

The most common FMD types were objects made of styrofoam, plastic bags, and plastic beverage containers, including bottles and cups. Styrofoam is often used as floating device in aquaculture and fisheries but it can also originate from land because it is excessively used in the building sector as insulation material (Aditya et al., 2017). Plastic beverage containers have constituted a conspicuous fraction of debris on beaches of Poland already in the 1990s (Jóźwiak, 2005). That study suggested emissions to come primarily from land-based sources as the amount of plastic beverage containers on beaches correlated with the development of tourism but also with the overall increasing use of these items by the Polish society. Beverage containers were not particularly abundant on beaches of the southern Baltic Sea (Hengstmann et al., 2017), indicating again qualitative and quantitative differences in marine debris between the northern and the southern Baltic Sea. Also beverage containers such as plastic bottles are highly buoyant and have the chance to move offshore from land-based source areas (Ryan et al., 2015). The considerable share of plastic bags among FMD in the northern Baltic Sea also suggests emissions primarily from land. Accordingly, plastic bags are being banned in many countries of the world and the EU parliament recently agreed to ban single-use plastics (including e.g. straws, cutlery, plates) by 2021 in order to reduce their excessive use and discharge into the environment (Xanthos and Walker, 2017).

Densities of FMD were slightly (though not significantly) elevated during summer while it decreased towards autumn. Previous studies identified recreational activities and tourism as important sources of marine debris in the Baltic Sea (Balčiūnas and Blažauskas, 2014; Hengstmann et al., 2017; Honorato-Zimmer et al., 2019). This may lead to elevated amounts of marine debris during summer, with lower amounts in autumn/winter similar as shown for the Mediterranean Sea (Arcangeli et al., 2018; Campana et al., 2018). However, just as in our study on FMD, the seasonality in the overall debris accumulation on various beaches of the Baltic Sea was low (Balčiūnas and Blažauskas, 2014; Schernewski et al., 2018).

The northern Baltic Sea is relatively clean with regard to FMD. A likely explanation is the low human population density in this region (e.g. < 10 inhabitants km^{-2} in Finland and Sweden versus > 500 inhabitants km^{-2} in Poland, Germany and Denmark, BSEP87-HELCOM), which mainly consists of sparsely inhabited archipelagos, where the input of debris into the sea may be low. Additionally, international actions to combat the input of litter from land- and sea-based sources into the sea may have led to low FMD densities in some regions of the Baltic Sea (see e.g. the HELCOM Regional Action Plan for Marine Litter 2015). Overall, FMD densities were low despite intense ferry traffic and the potential of FMD to become transported via sea surface currents from south to north.

The pollution by anthropogenic marine debris seems to differ between regions of the Baltic Sea. The observed low FMD densities suggest a declining pollution gradient from south to north as beaches in the southern Baltic Sea showed debris densities that were well in the range of beaches in substantially polluted marine regions (Honorato-Zimmer et al., 2019; Jang et al., 2018; Ourmieres et al., 2018). Contrary to the Mediterranean, marine debris apparently has not accumulated massively in the semi-enclosed basin of the Baltic Sea (Beer et al., 2018). However, a conclusive regional comparison is currently not possible due to low data availability. The use of the intense public ferry traffic may provide a valuable opportunity for cost-effective monitoring of FMD in various regions of the Baltic Sea to achieve a more complete estimation of the pollution status of the sensitive Baltic ecosystem. Clearly, more investigations on a larger spatial scale, considering all marine compartments from beaches down to the seafloor, are needed to comprehensively evaluate the litter pollution of the Baltic Sea and to understand the processes that shape the distribution of anthropogenic marine debris within the Baltic Sea basin.

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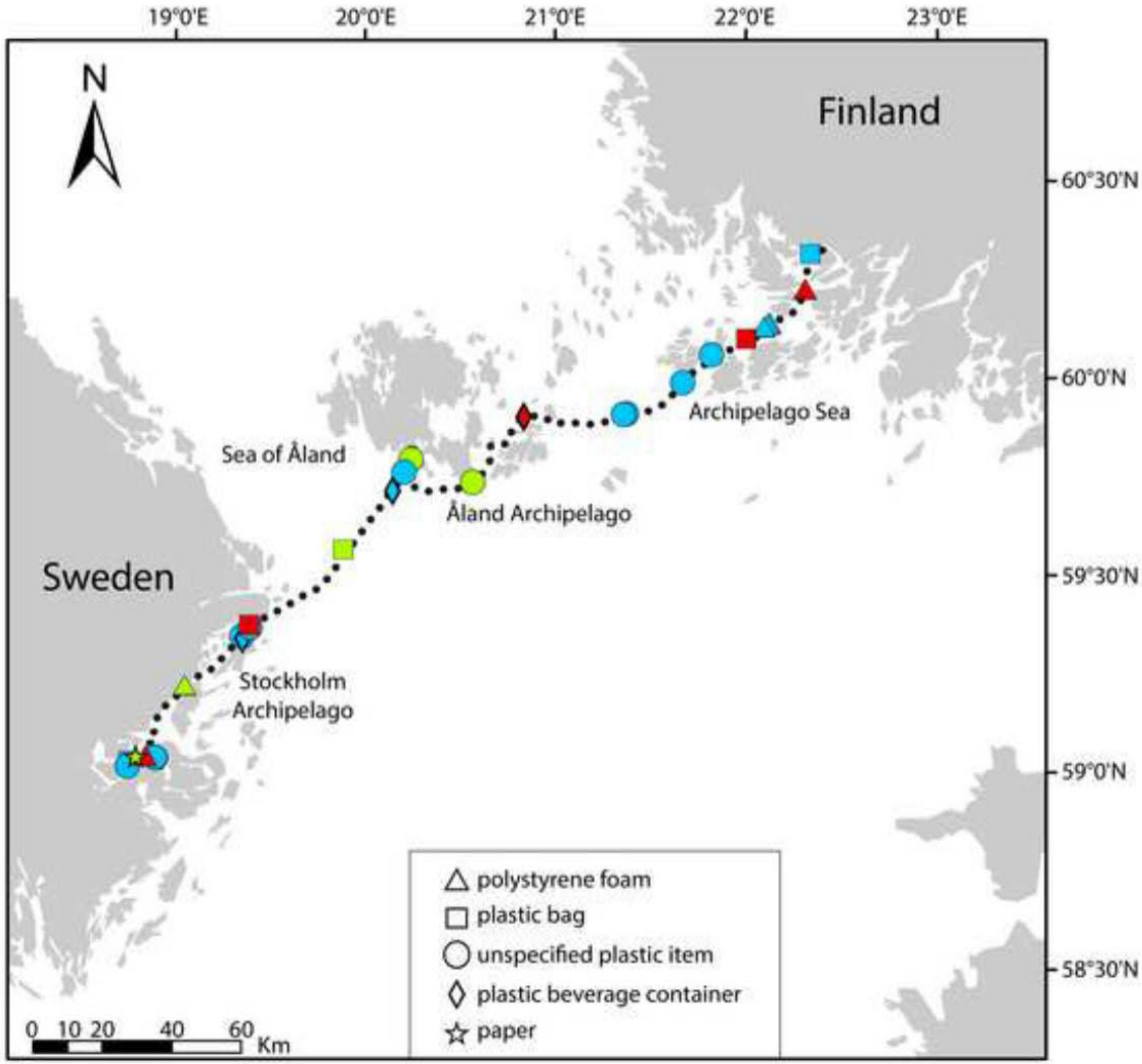
Figure 1. Map of study area in the northern Baltic Sea. Dotted Line shows the ship route, symbols indicate the type and location of floating marine debris (FMD); n = 27 FMD items. Colors indicate the sampling season: green – spring 2012 and 2013, blue – summer 2012, red – autumn 2012.

Figure 2. Average (± SE) seasonal density of floating marine debris in the northern Baltic Sea among (A) seasons and (B) sea regions during the study period of 2012 to 2013. Numbers in parentheses represent number of surveys (first number) and number of transects (second number).

Figure1


19°0'E
20°0'E
21°0'E
22°0'E
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N
Finland
60°30'N
60°0'N
59°30'N
59°0'N
58°30'N
Sweden
Sea of Åland
Åland Archipelago
Archipelago Sea
Stockholm Archipelago
polystyrene foam
plastic bag
unspecified plastic item
plastic beverage container
paper
0 10 20 40 60 Km

Figure2

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