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Anthropogenic fibres in the Baltic Sea water column: Field data, laboratory and numerical testing of their motion

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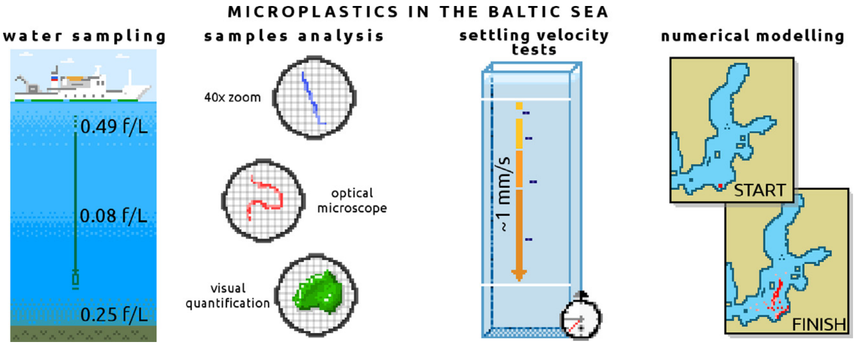
HIGHLIGHTS

- A "selective" strategy is proposed: different types of MPs request different models.
- Fibres are the prevailing type of MPs in the Baltic Sea water column.
- Fibres behaviour in the sea: flow with currents, slow sinking, and delayed settling
- Sinking velocity and re-suspension threshold determine distribution of fibres in the sea.

GRAPHICAL ABSTRACT



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ABSTRACT

Distribution of microplastics particles (MPs) in the water column is investigated on the base of 95 water samples collected from various depths in the Baltic Sea Proper in 2015–2016. Fibres are the prevalent type of MPs: 7% of the samples contained small films; about 40% had (presumably) paint flakes, while 63% contained coloured fibres in concentrations from 0.07 to 2.6 items per litre. Near-surface and near-bottom layers (defined as one tenth of the local depth) have 3–5 times larger fibre concentrations than intermediate layers. Laboratory tests demonstrated that sinking behaviour of a small and flexible fibre can be complicated, with 4-fold difference in sinking velocity for various random fibres' curvature during its free fall. Numerical tests on transport of fibres in the Baltic Sea Proper were performed using HIROMB reanalysis data (2007) for the horizontal velocity field and laboratory order-of-magnitude estimates for the sinking velocity of fibres. The model takes into account (i) motion of fibres together with currents, (ii) their very slow sinking, and (iii) their low re-suspension threshold. Sensitivity of the final distribution of fibres to variations of those parameters is examined. These experiments are the first step towards modelling of transport of fibres in marine environment and they seem to reproduce the main features of fibres distribution quite well.

1. Introduction

Presence of plastic pollution is an emerging worldwide threat to the health of marine ecosystems. Small (<5 mm) fragments of artificial polymer objects are commonly termed as "microplastics" (Bergmann

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Abbreviations

MPs	microplastics
DW	dry weight
	HIROMB High Resolution Operational Model for the Baltic
	GESAMP The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
R/V	research vessel
ANS	"Akademik Nikolay Strakhov"
PSh	"Professor Shtokman"
	MARBLE Microplastics Research in BaLtic marine Environment
CMEMS	The Copernicus Marine Environment Monitoring Service
	BAL MFC Baltic Sea Marine Forecasting
SMHI	Swedish Meteorological and Hydrological Institute
HIRLAM	High Resolution Local Area Modelling

Variables

ρ_{fibre}	mean density of the fibre (kg/m^3)
ρ_{water}	mean density of the marine water (kg/m^3)
w_s	vertical settling velocity
ΔT	time step
A_h	coefficient of horizontal turbulent diffusivity of the particles

et al., 2015). Such objects have started to appear in the ocean since 1970th (Bergmann et al., 2015); they were first properly reported in 2000s (Derraik, 2002), and are nowadays found as far as in the Arctic (Lusher et al., 2015) and Antarctic waters (Ivar do Sul et al., 2011). The microplastics (MPs) high surface-to-volume ratio (Teuten et al., 2007) makes them effective collectors of various toxins dissolved in marine waters, which imposes danger to all the levels of the food chain (Cole et al., 2011). The stated problems are generating considerable attention in terms of sources, transport mechanisms, and accumulation areas of MPs (Kershaw, 2015; Law et al., 2010).

Numerical modelling is the most cost-effective instrument used to understand the transport and fate of various pollutants in marine environment. Marine plastics in general and MPs in particular are shown to have various densities, shapes and sizes, which makes simulation of their transport quite a challenging problem. Transport of *floating litter* in the ocean has been modelled successfully at a time scale of years (e.g., Maximenko et al., 2012; Van Sebille et al., 2015; Liubartseva et al., 2016; Lebreton et al., 2012), and this selective methodology allowed for an important general conclusion: floating plastics get accumulated in surface convergence zones in the ocean or certain coastal areas. The *MPs* has been modelled in (Critchell and Lambrechts, 2016; Ballent et al., 2013; Carson et al., 2013) with ultra-high space resolution at the time scale of days, and the results showed importance of the source location, turbulence coefficient, and polymers density for a determination of the MPs fate in the coastal zone. Studies (Chubarenko, 2016; Chubarenko and Bagaeva, 2016; Chubarenko and Stepanova, 2017) indicated that denser MPs migrates mainly in the sea coastal zone under the influence of surface waves. For non-buoyant MPs it was shown that particle shape strongly defines the character of the particle settling (Ballent et al., 2013; Khatmullina and Isachenko, 2016; Kowalski et al., 2016). In particular, elongated particles exhibited such a relation between settling velocity and size which was by far different from that known for natural (isometric) particles (Isachenko et al., 2016a, 2016b; Khatmullina and Isachenko, 2016). Thus, for a particular type of plastics, different *physical mechanisms* are of importance, and different time and length scales are of interest: for dense particles, the key parameters are the settling velocity and the near-bottom current velocity magnitude, while, say, for the buoyant particles/pieces - the surface currents direction, windage, and turbulence. Such a "selective" philosophy is quite a common practice at the beginning of investigation of any kind of a complex object, and in modelling as well. Although representing a simplified approach with several limitations, this method could give a valuable insight necessary for development of a more comprehensive model.

Almost every report on MPs research in marine environment shows presence of very small (length ~0.5–5 cm, diameters ~10–50 μm) fibres of anthropogenic origin: in bottom sediments (e.g., Mathalon and Hill, 2014), water body (e.g., Dubaish and Liebezeit, 2013; Lattin et al., 2004; Thompson et al., 2004), at water surface (e.g., Doyle et al., 2011), on beaches and coastlines (e.g., Browne et al., 2011), in the deepest oceanic depressions (e.g., Woodall et al., 2014), and in the Arctic ice (Obbard et al., 2014). Some studies (Browne et al., 2011) showed strong correlation between wastewater disposal areas and textile polymer fibres concentration. A recent study (Woodall et al., 2014) suggested that the deep-sea sediments are the main 'sink' or accumulation zone of the fibres in the ocean. The review paper (Ivar do Sul and Costa, 2014) reported that in the Atlantic Ocean fibres appeared in much higher concentrations in the sediments than in the water samples. A paper of (Desforges et al., 2014) represented the elevated concentrations of submerged MPs fibres in areas close to land-based sources. In the Baltic Sea, fibres are considered to be a more threatening pollutant than larger particles, especially for invertebrate communities (Setälä et al., 2016), however their sources and concentrations are poorly known. In coastal seawater, (Stolte et al., 2015) reported that off Warnemünde the concentration of fibres varied from 0.1 to 20 fibres per litre (55 μm mesh size); our measurements (this study) show fibre concentrations in coastal and open waters in the range from 0 to 2.7 fibres per litre.

In this paper an attempt is made to simulate with a basin-scale numerical model the transport of fibres, accounting for just their basic transport properties. Our original measurement data on concentrations of fibres in the Baltic Sea serve as a basis for the analysis and modelling.

2. Methods

2.1. Water sampling in the Baltic Sea proper

With the goal to investigate the presence and distribution of MPs in general and artificial fibres in particular, 95 water samples from various depths, near-surface and near-bottom layers in the water body were collected during six cruises in the Baltic Sea Proper, see Table S1 in Supplementary material for the list and Fig. 1 for the map.

Water samples were collected using standard technique of sampling by means of the 10-litre or 30-litre Niskin bottles. In the cruises of r/v NORD, water samples were taken in the coastal waters from the lowest horizon possible at locations where water depth ranges from 6 to 21 m. The 10-litre Niskin sampling bottle (0.8 m long) was attached to the rope with an anchor and lowered vertically, so that the distance between the anchor and the lower part of the bottle was about 0.7 m. This way, water samples were collected from the depths of 0.7–1.5 m above the bottom. During the ANS ("Akademik Nikolay Strakhov") cruises the same procedure was carried out with the exception that the distance between the anchor and the lower part of the bottle was around 2 m. Surface samples were collected with the black plastic (*polyethylene*) bucket. During the cruises of "Professor Shtokman" PSh-131 and PSh-132, water samples were collected using Multi Water Sampler SlimLine 12 at different depths. Samples from the r/v NORD were transported to the laboratory and filtered there using 174 μm filters. In the other cruises, water was filtered through the square (7 × 7 cm) filters (174 μm) immediately on-board.