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Preliminary approach to ecological risk assessment of microplastics in selected coastal regions of Baltic Sea

Keywords

risk characterisation, microplastics, density separation, microscopic observations

Abstract

The aim of the study is to provide a primary understanding of the risk of microplastics (MPs) pollution in selected coastal regions of the Baltic Sea waters. This chapter presents preliminary data on the presence of MPs in superficial layers of seawater and sediments of the Puck Bay and Gulf of Gdansk. The environmental risk assessment has been performed for microplastics of the order of size from 0.3 to 5 mm. The detected fragments of microplastics and synthetic textile fibres are present in amounts that do not pose a significant threat to the marine ecosystem. However, microplastics contamination is projected to continue to increase in the region of the Baltic Sea, so it is necessary to monitor and take precautionary actions to minimise concentrations of microplastics in these environments.

1. Introduction

The natural environment, including the marine environment, is exposed to continuous pressure from human activities. It is well known that to register any changes undergoing in the environment it is necessary to monitor specific elements corresponding to the anthropogenic pressure (Zalewska & Zdanowska, 2017). Plastics have permeated nearly all economic sectors and are commonly used in a wide range of everyday items. Ubiquitous high plastics consumption is responsible for the global environmental pollution. The negative effects of plastics on the environment and human health and the problems associated with their resistance to degradation have significantly increased over past decades. These issues have received attention from major scientific research centres, regulatory bodies around the world, and popular science reports.

Plastics are the most common type of marine debris, constituting between 60% and 80% of all marine debris and over 90% of all floating particles (Setäläa et al., 2014). Special attention is given to very small pieces of plastic, often undetectable to the naked eye, which are referred to as microplastics.

The first term of *microplastics* (MPs) was proposed by Arthur et al. (2009) and included small pieces of synthetic polymer particles smaller than 5 mm in their longest dimension fall.

Over the years, not only the upper but also the lower dimension limit of MPs became systematized. Further terms such as mini-microplastics (MMP) and nanoplastics (NP) have been defined in scientific literature. Mini-microplastics comprise small pieces of plastic debris from 1 μm to 1 mm and nanoplastics have particles smaller than 1μm (Cole et al., 2011; Crawford & Quinn, 2017; Zeng, 2018; Frias & Nash, 2019).

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From a practical point of view, the lower bound of MPs size is frequently described by the number 333 µm which corresponds to the mesh size of a typical neuston net commonly used to catch various types of pollutants, including MPs in aquatic environments (Arthur et al., 2009; Crawford & Quinn, 2016).

MPs are commonly divided into primary and secondary MPs.

Primary MPs are intentionally produced for use in various industry products. For example, microbeads are used in personal care products (scrubs), or in medical applications (delivery systems of drugs). In addition, huge amount-plastics fibre come from synthetic clothing and rope.

Primary MPs present in personal care products and synthetic clothes will ultimately enter wastewater treatment systems. Although removal efficiency in wastewater treatment plants (WWTPs) is high, a certain number of particles can still remain in the effluents. Many of primary MPs are small enough to pass through wastewater treatment processes and get discharged into aquatic environment (Auta et al., 2017; Cristaldi et al., 2020).

It has been estimated that 15–31% of all microplastic in the ocean could originate from primary sources (Boucher & Friot, 2017).

Secondary MPs result from the fragmentation of larger plastic debris, either during use or while destruction in the environment. Fragmentation can take place through photodegradation by UV-light, hydrolysis in the presence of water, (thermal) oxidation, physical abrasion in sediments and soils but also by waves, and biological degradation by organisms (Horton et al., 2017; Adam et al., 2021).

Pollution by microplastics in aquatic ecosystems represents a significant global issue due to their worldwide detection and their negative ecotoxicological effects on biota (Anbumani & Kakkar, 2018; Ugwu et al., 2021). Despite the awareness of the MPs ubiquity and persistence in the marine environment, the impact on environment and risk assessment are still not uniformly defined. There is a lack of uniformity in testing methods, resulting in variability in field and laboratory bioassay results. In order to be able to make reliable measurements of the amount of microplastics in water, it is necessary to standardize the measurement methods. Without it, it is difficult to determine how much microplastic is in the environment, where it comes from and what impact it has on biota (Sa et al., 2018; Ruijter et al., 2020).

Microplastics are of special concern because they can be ingested by a variety of marine organisms, and possibly be also transferred along the food chain. The potential toxicity of microplastics is basically due to the additives and monomers they include (Thomson et al., 2007).

It is likely that the transfer of microplastics in marine food webs has a similar mechanism to that of many other harmful substances such as hazardous chemicals.

As part of sustainable development goal 14, the United Nations, has called for the prevention and significant reduction of marine pollution of all kinds, in particular from land-based activities (United Nations, 2017).

Risk assessment (RA) combines an exposure assessment and a hazard assessment to determine whether any given substance is present in the environment at concentrations known to exert negative effects on organisms living, thus posing a risk (Burns & Boxal, 2018; Adam et al., 2021).

The current studies on the risk assessment of MPs in the aquatic environment suggest that the in situ concentrations are on average several orders of magnitude lower than the concentrations where effects are expected to occur (Everaet et al., 2020).

Currently available data is often difficult to use for quantification of the environmental risk assessment of MPS in the marine environment because particles have a wide size range, have variable shapes, represent different polymers, concentrations of particles are reported in different units. In addition to this, MPs can either be primary or secondary, which impacts the surface shape and properties, and impacts the leaching rate of contaminants to the environment (Koelmans et al., 2017).

Taking into consideration the attempts to quantify in situ concentrations of MPs in the past two decades, it can observed that microplastics are ubiquitous and can present at very high concentrations in areas such as enclosed seas harbours, lagoons, narrow straits and coastal waters. This relatively high concentration of MPs is leading to concerns on their environmental risk to local populations and communities (Everaet et al., 2020).

The Baltic Sea is a shallow and semi closed brackish sea. It is connected to the Atlantic Ocean through the narrow Danish straits. Possibility to renew all the water itself takes decades. This facilitates accumulation of pollutants in the Baltic Sea because only 2–3% of the contaminants entering can flow out through the North Sea. The coastal countries around the Baltic Sea are highly industrialized which led to increasing accumulation of plastic pollutants from agricultural, industrial, tourism industries and wastewater run-off (HELCOM, 2018).

In an ecotoxicological study of Baltic fish conducted between 1987 and 2015, stability of plastic concentrations in their digestive tracts was observed despite an increase in microplastic contamination of the Baltic Sea (Beer et al., 2018). Considering the doubts previously expressed by the research community about the discrepancy of the study results, caution should be exercised in drawing such definitive conclusions. It is of vital importance to obtain more data on the accumulation and effects of MPs in Baltic Sea organisms.

One of the most polluted zones along the Baltic coast is the Gulf of Gdansk, receiving the discharge of the wastewaters from the two big Polish cities of Gdansk and Gdynia, and from the Vistula River. The Gulf of Gdansk is surrounded by a heavily populated region and agricultural lands. Typically, plastics less dense than seawater such as common consumer plastics polyethylene and polypropylene, tend to float on the sea surface whereas denser plastic types are suspended in the water column or sink to the seafloor (Pinja et al., 2017).

Although the plastic particles of different polymer types could be heavier or lighter than water and might be able to sink or float over its surface, many of them sink to the sea floor. This is encouraged by lack a permanent system of currents and tides in the Baltic Sea, therefore there might be hot spots of sea-bed litter (MONAS, 2014).

At present there is very little knowledge about MPs in the Baltic Sea and the environmental concentration with toxicity data to the risk assessment (Talvitie et al., 2015; Zobkov & Esiukova, 2017). A fundamental element of ecological risk assessment is the availability of a set of standardized test systems and analytical tools and methods that enable the use of dose-response relationships that are consistent and of sufficient quality (Ruijter et al., 2020). To draw the best analyses from an ecological risk assessment of MPs, by combining the results of both the effect assessment and the hazard exposure, it is necessary to consider multiple data. Additionally, probabilistic approach allows inclusion of all data available at one point in time and gives an overall picture of the situation as it is known and eases the process of risk quantification (Everaet et al., 2018; Everaet et al., 2020; Adam et al., 2021).

The aim of the study is to provide a primary understanding of the risk of MPs pollution in selected coastal regions of the Baltic Sea waters. This chapter presents preliminary data on the presence of MPs in surface seawaters and sediments of the Puck Bay and the Gulf of Gdansk.

The chapter is organized into 4 parts, this Introduction as Section 1, Sections 2–3, and Conclusions as Section 4. In Section 2, the methodology of experimental part is presented, its samples collection, procedure of MPs density separation in samples and macro and microscopic observations of collected MPs are determined.

In Section 3, the results of microplastics analysis and preliminary environmental risk assessment of MPs pollutions from the selected coastal regions of the Baltic Sea are discussed.

2. Methods

One of the important problems during MPs pollution assessment in the Baltic Sea environment is the lack of standardized procedures for sample collection, preparation, and microplastic identification. Elaborating those standardized procedures is essential for microplastics concentration assessment and data comparison between different studies.

2.1. Sample collection

Investigations were conducted at sites associated with predicted presence of microplastics estimated from sea currents and coastal algae accumulation (Filipkowska et al., 2009).

The samples were collected at 5 selected sampling points: Wladyslawowo (*W*), Puck (*P*), Mechelinki (*M*), Sopot (*S*), Brzezno (*B*). Considering the high pollution of beaches, microplastic could be accumulated in these coastal regions of the Baltic Sea. The location of selected areas is presented in Figure 1.

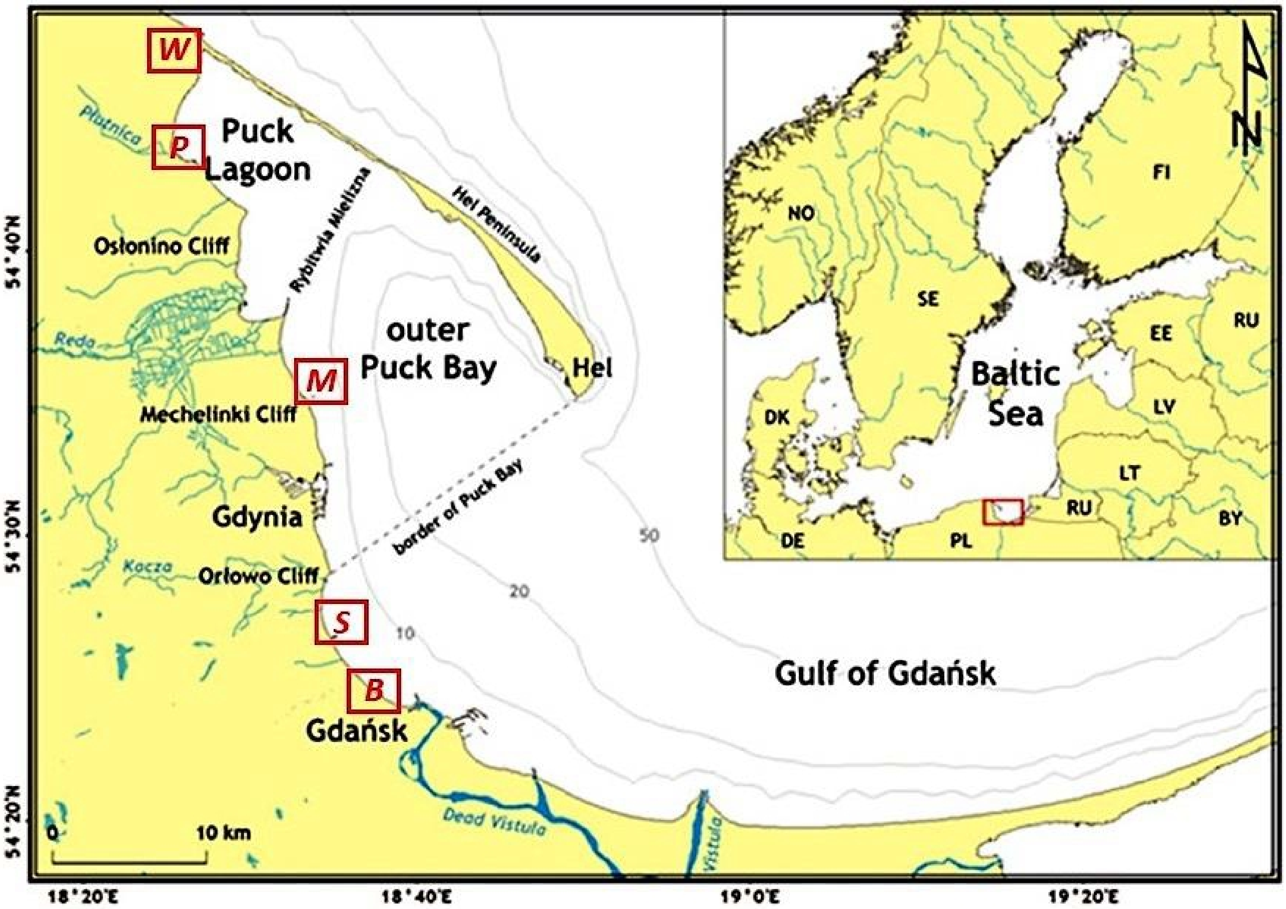

Figure 1. Location of Puck Bay and the Gulf of Gdansk (Sokołowski et al., 2021) with 5 selected areas: Wladyslawowo (*W*), Puck (*P*), Mechelinki (*M*), Sopot (*S*), Brzezno (*B*).

At each sampling area, about 5 litres of surface water was manually collected from the top 20 cm at distance 3 m from coast.

The samples of sediments from each investigated areas were manually collected from 10 cm depth using a metal shovel at about 3 m to coast. Due to the short distance from the shore, sand was predominant in the sediments.

The sediments were stored in labelled glass jars, previously decontaminated. All samples were preserved at 5°C until further analysis.

Both surface seawaters and sediments were collected in February 2022.

Thus, this chapter is based on data from the winter months when Baltic seawater has high level and covers the beaches.

Due to dynamic and changing conditions of coastal regions, the sampling for microplastics should take into consideration that high tide lines are highly variable over relatively short periods of time. To take into account these changes, the further monitoring surveys will be held, once per season (spring, summer, autumn and winter).

2.2. Analysis of microplastics in seawater and sediment samples

The sample analysis of sea sediments and surface seawaters commonly consists of several main steps: drying, sieving, extraction, wet peroxide oxidation, density separation, filtration and visual sorting, microplastics detection.

At the beginning of the analysis of MPs in sediments, an initial disaggregation of dried sediments was involved (using potassium metaphosphate). Next, the disaggregated sediments were sieved using stacked 5 mm and 0.3 mm sieves. All sediment was collected to separation in zinc chloride ($ZnCl_2$) about density 1.6 g/cm^3 (55% aqueous) to isolate the plastic debris through flotation. The floating solids were separated using 0.3 mm nets. The floating solids collected on the 0.3 mm sieve were subjected to wet peroxide oxidation using 30% hydrogen peroxide in the presence of a Fe(II) catalyst (0.05 mol/dm^3 solution) to digest labile organic matter. It was repeated until no natural organic material was visible. The plastic debris remains unaltered. In the next step sodium chloride was added to the mixture to increase the density of the aqueous solution (density about 1.2 g/cm^3). The resulting mixture was transferred to glass density separator to isolate the plastic debris through flotation. The floating plastic debris were collected in density separator and separated using the vacuum filtration set with a 0.3 mm filter. The density separator was rinsed several times with distilled water to transfer all solids to the filtration set. After filtration, the filter with solids covered with aluminium foil was allowed to air dry.

The method of analysis of seawater samples involves the overflow 5 litres water using net with met size 0.3 mm. The sieved material was dried to determine the solids mass in the sample.

The next step was similar to the method of analysis of MPs in sediments. After drying, the organic matter was digested using 30% hydrogen peroxide in the presence of a Fe(II) catalyst.

The resulting the mixture was passed through 0.3 mm sieve to remove the remaining solution and then washed with distilled water. The particles were transferred to the glass density separation using sodium chloride solution diluted to 1.2 g/cm^3 to isolate the plastic debris through flotation. The floating plastic debris were collected in density separator and separated using the vacuum filtration set with a 0.3 mm filter. The density separator was rinsed several times with distilled water to transfer all solids to the filtration set. The filters with solids covered with aluminium foil were allowed to air dry after filtration.

Plastic particles from filtration of both investigated sediments and seawaters were estimated.

2.3. Macroscopic and microscopic observations of microplastics

Firstly, dried and extracted plastic particles obtained during filtration on 0.3 mm sieves were weighed.

After that they were visually sorted and classification based on particles colour and shape was done. The MP particles can be classified into four main groups of shape: fragments, films, fibres and spheres (Xu et al., 2018). In general, the toxicity of non-spherical microplastics (i.e., fragments and fibers) is higher than that of spherical microplastics (Jung et al., 2021).

Fragments are defined as pieces of plastic with all three size dimensions comparable, films as thin sheets of plastic, fibres as thin elongated particles with one dimension significantly greater and spheres as spherical plastic.

Both in the Baltic Sea and other marine or oceanic areas, fibres were estimated to be the most abundant shape category detected in water and sediments. They represent approximately half of the MPs detected and reported in the literature. (Aigars et al., 2021; Ugwu et al., 2021; Zobkov & Esiukova, 2017). Therefore, the use of fibres for effective analysis presents a significant opportunity for the development of quantitative data for environmental hazard assessment (Ruijter et al., 2020).

The common colours of plastic particles are: black, blue, white, transparent, red, green, multicolour and others. Multicolour are identified as microplastics that have one colour on one side and another colour on the other side (e.g. rope or filaments might contain more than one colour). Colours such as purple, pink, grey, yellow or brown are included in the category *others* (Frias et al., 2018).

Finally, microscopic analysis was performed. The MP samples surface structure was inspected using metallographic microscope ALPHAPHOT-2YS2-H Nikon linked to the photo camera Delta Optical DLT-Cam PRO 6.3MP USB 3.0.

3. Results and discussion

3.1. Microplastics analysis

Plastic particles of size 0.3 mm – 5 mm were not detected in all five investigated regions of the Puck Bay and Gulf of Gdansk.

Due to a lack of the plastic particles collected from filtration of selected seawaters the results (including micro and macroscopic analysis) are not presented in this chapter.

In this study, only analysis of solid particles collected from sediments in areas *W*, *P*, *M*, *S* and isolated through density separation in sodium chloride (density 1.2 g/cm^3) is presented.

Theoretically, the density of MPs is a pivotal factor that affects its vertical distribution in the water. MPs which are denser than seawater (1.025 g/cm^3) are likely to sink in the water (Crawford & Quinn, 2016; Xu et al., 2018).

The density and buoyancy of selected common polymers in seawater are presented in Table 1.

If we look at data, all particles collected from sediments may have densities ranging as those presented in Table 1.

Table 1. Density and buoyancy of selected common polymers (Crawford & Quinn, 2016)

Abbreviation	Polymer	Density [g/cm^3]	Buoyancy*
PS	Polystyrene	0.01 – 1.06	↑
PP	Polypropylene	0.85 – 0.94	↑
LDPE	Low-density polyethylene	0.89 – 0.93	↑
HDPE	High-density polyethylene	0.94 – 0.98	↑
seawater		**1.025**	
PA	Polyamide	1.12 – 1.15	↓
PA 6,6	Nylon 6,6	1.13 – 1.15	↓
PMMA	Poly methyl methacrylate	1.16 – 1.20	↓
PVA	Poly(vinyl acetate)	1.17 – 1.20	↓
PC	Polycarbonate	1.20 – 1.22	↓
PU	Polyurethane	1.20 – 1.26	↓

* ↑ – polymer floating or ↓ – polymer sinking

To identify collected particles, polymer compositions by μ-FTIR spectroscopy should be determined. The spectroscopy analysis was not performed in this study because of the very small amount of collected particles in sediments.

The authors analysing the Southwestern Baltic Sea have identified eight types of polymers in marine bottom sediments, beach sediments of the Southern Baltic Sea and at the cliff coast of the Southern Baltic Sea. The most numerous polymers in marine bottom and beach sediments were polyester (50%) and poly(vinyl acetate) (25%). The qualitative composition of microplastics was dependent on the seawater dynamics. After a storm, more polymer types were distinguished (Graca et al., 2017).

According to the microplastic analytical procedure, particles from sediments were visually categorized by colour and shape.

Colour can be used to identify the source of MP particles. Coloured plastics are commonly used as packaging, clothing materials and many other applications. Very often, visual identification of colour plastic particles can be difficult because MPs lose their original colour due to weathering in the aquatic environment (Frias et al., 2018; Xu et al., 2018).

In this study, the colour and shape of particles from sediments varied between sampling areas. Macrographs of MPs collected in sediments from selected areas are presented in Figure 2.

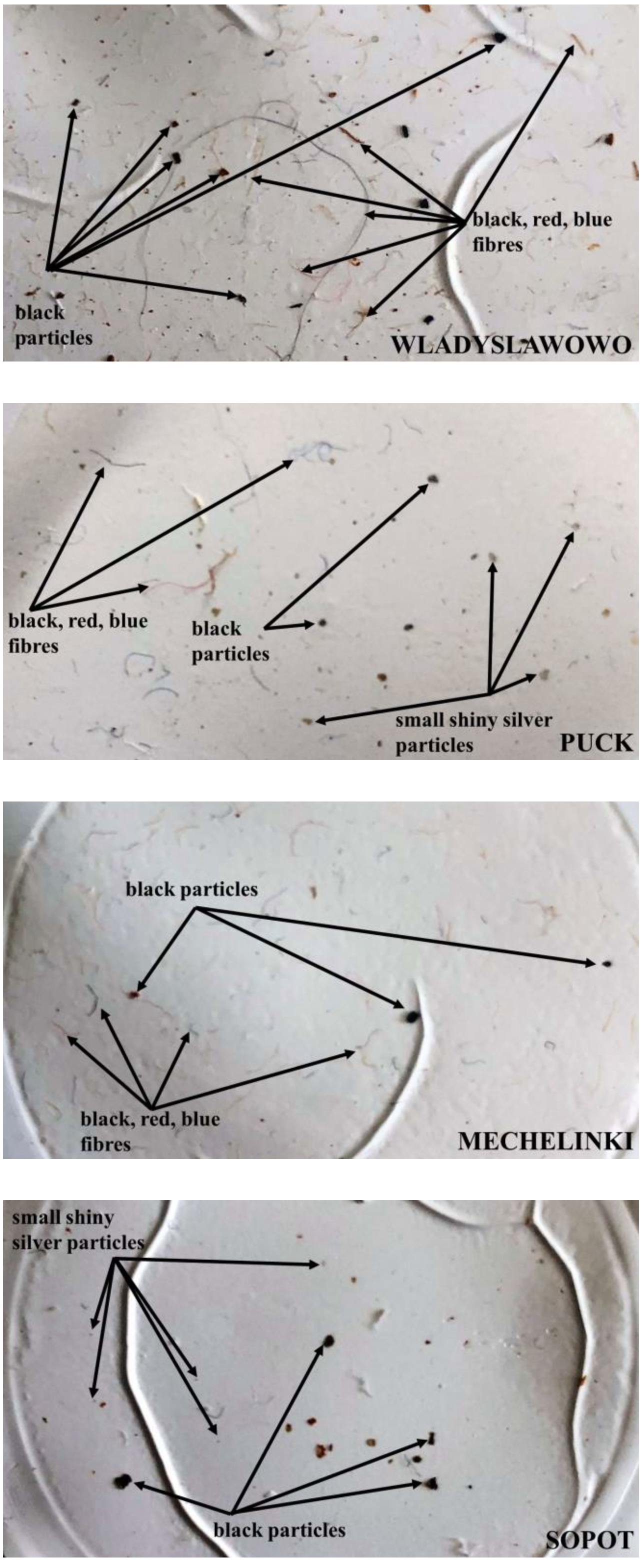

Figure 2. Macrographs of MPs collected in sediments from selected four areas: *W*, *P*, *M*, *S*.

If we look at macrographs presented in Figure 2, we can see differences in areas. The small black fragments were evident in four areas but their quantity depending on the analysed area.

Colourful fibre (including black, blue, red) comprised the majority of the MPs in the collected samples from Wladyslawowo, Puck and Mechelinki.

The fibres found in sediments from regions ***W***, ***P***, ***M*** were usually small shreds, and it was difficult to reliably estimate the material of the fibre using only optical microscopy. In this study, macrographs of detected textile fibres (inorganic and organic) are presented (Figure 2). Although natural fibres do not accumulate in a marine environment and should be safe because they will biodegrade, the non-synthetic fibres may be a threat to marine life as cotton clothes are treated with various toxic chemicals.

One explanation for the higher concentrations of fine inorganic fibres in Mechelinki may be the sampling location near the discharge point of wastewater from the large Polish city of Gdynia.

A similar high fibre concentration in the Baltic Sea waters has been observed in the area of Helsinki archipelago (Talvitie et al., 2015).

Wik and Dawe (2009) and Talvitie et al. (2015) also noted significant amounts of black carbon particles in this region, resulting from road traffic and fossil fuel combustion. These anthropogenic, oil-based particles have a specific shiny blue-black appearance, which distinguishes them from other dark particles.

In this study, black particles were also observed in sediments from regions ***P***, ***W***, ***M***, and ***S*** (Figure 2, Figure 3a, Figure 3c, Figure 4), but it is not possible to characterize their specific shiny appearance via visual analysis because their size.

Additionally, small shiny silver fragments were found in particles collected in Puck and Sopot (Figure 3a and Figure 4). The presence of these fragments may be related to the fact that the sediments were collected near the pier and marina.

The authors analysing the Warnow estuary (southwestern Baltic Sea) drew attention to the emissions of paint particles from shipping activities as a source of microplastics (Piehl et al., 2021).

Primary microplastic particles originating from post-consumer products (e.g. scrubs) or raw pellets were not found in this study.

Results of microplastic weighing are not provided in this chapter because of the very small nature of fibres and fragments observed in sediments. Moreover, these particles are hard to transfer into the vial for weighing.

Microscopic observations presented in Figure 3 and 4 were in good agreement with macroscopic observations (Figure 2). The surface structure categorized by shape and size are presented in Figure 3 and 4.

Only the fragment and fibre shaped particles were found. The majority of the MPs collected in sediments from Wladyslawowo, Puck and Mechelinki were fibres.

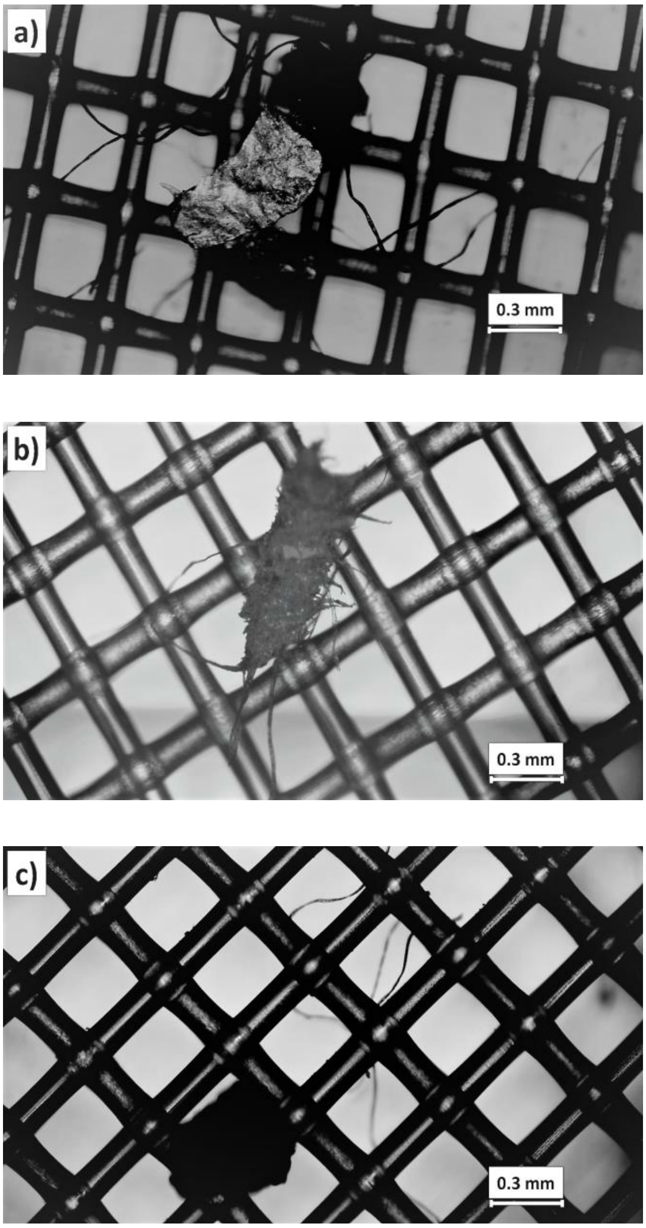

Figure 3. Micrographs of different MPs collected from three areas on 0.3 mm net: **a)** black fragment, fibres and shiny silver fragment from sediment in area ***P***, **b)** cluster of fibres from sediment in area ***M***, **c)** black fragment and fibre from sediment in area ***W***.

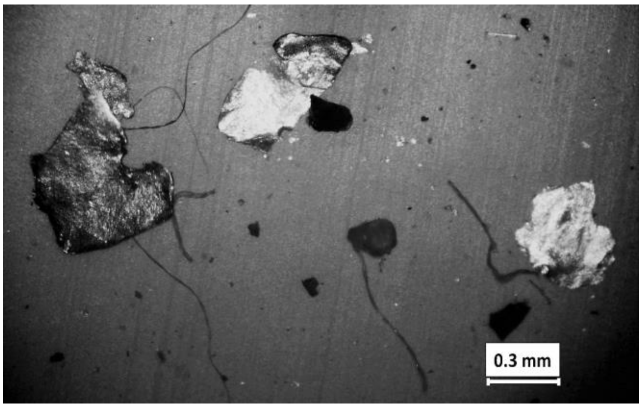

Figure 4. Micrograph of MPs from sediment in *S* region collected on filter.

Higher concentration of fibres in regions ***W***, ***P***, ***M*** can be explained by location near the land and hence near to many different land-based microplastic sources and by inflow of wastewater from WWTP.

It is known that the average fibre concentration is 25 times greater and the particle concentration three times greater in discharged wastewater compared to seawater (Talvitie at al., 2015).

Therefore, it indicates that WWTPs may operate as a point source for introducing microplastics into the water environment. Even though increasingly modern filter systems are being used in WWTP, not all particles are collected.

3.2. Risk assessment

Regular integrated assessment of the state of the marine environment and overall ecological conditions is needed due to the intense and currently growing anthropogenic impact on the natural environment of the Baltic Sea coastal areas characterized by increased pollutants input.

Environmental risk assessment of MPs pollution requires an extensive data set from diverse sampling sites. The Baltic Sea basin is very poorly characterized in this respect. The data for the Polish coasts is especially poor.

A risk assessment determines whether a substance is present in the environment in concentrations known to have a negative effect on organisms living in the ecosystem. For microplastics, the origin, chemical composition and products of the various degradation steps shall be determined where possible. In the case of the microplastics collected from the samples studied, all were of a size that prevents such analysis.

The observed concentration of microplastics in the vicinity of the pier and marina requires an increased concentration of research in this area. If such a tendency is confirmed, remedial measures should be taken to protect the coastal zone in the vicinity of facilities subject to various types of renovation works.

4. Conclusion

A preliminary assessment of microplastic pollution of surface waters and bottom sediments of two Polish Baltic bays was performed. The preliminary data suggested that MPs pose no immediate threat to the environment, but the research was limited in time. The variety of sizes and shapes of the microplastics analyzed in this research makes it difficult, at this stage of the study, to assess the environmental risk they may cause. It is also important to assess how stable and recurrent the results obtained will be over an entire year.

Taking into account the longevity of plastics in the marine environment, the distribution patterns of MPs should be monitored on a much longer timescale than what was used in this study.

This study highlights the need to gain additional knowledge about the presence of MPs to better assess their fate in the Baltic Sea, especially when the amount of MPs is estimated to rise in the marine environment.

In order to improve the situation and reduce the risk of marine environment pollution, the following ought to be introduced:

- monitoring of the coastal zone for the Baltic Sea,
- effective implementation of the best accessible technology and ecological procedure,
- pro-ecological education of community,
- effective supervision to obey the regulations referring to the Baltic Sea environment protection,
- identification of various microplastic sources, which can be used by authorities to prioritize and establish emission reduction measures.

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