# Microplastics in Södertälje

## From Lake Mälaren to the Baltic Sea

Anna Rotander and Anna Kärrman

Örebro University
MTM Research Centre, School of Science and Technology, 70182
Örebro, Sweden

ÖREBRO UNIVERSITY

NATUR VÅRDS VERKET
SWEDISH ENVIRONMENTAL PROTECTION AGENCY

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# Table of contents


Svensk sammanfattning 3
Background and summary 5
Methods 7
Sampling in surface water 7
Sampling sediment cores 9
Databearbetning 8
Analysis 10
Particles > 300 µm in surface water 10
Particles 50-300 µm in surface water 10
Particles > 50 µm in sediment 10
Data handling 13
Results 14
Microlitter > 300 µm in surface water 14
Types of microplastic 15
Polymer composition 16
Microlitter 50-300 µm in surface water 18
Types of microplastics 19
Microlitter in sediment 20
Discussion 21
Comparisons 21
Comparison with other studies 21
Comparison of microplastic particles > 300 µm and 50-300 µm in surface water 23
Comparison of microplastic particles > 300 µm and 50-300 µm in sediment 23
Polymer types 24
From lake Mälaren to the Baltic sea 25
Future aspects 27
Acknowledgements 27
References 28
Appendix 1-Appendix 4 29-32

# Svensk sammanfattning

Trots att ett ökat antal studier de senaste åren slagit fast att betydande mängder mikroplaster kontinuerligt släpps ut i den marina miljön så finns det en utbredd okunskap vad gäller vilka källor som bidrar mest. Det finns således ett behov av att identifiera och karakterisera punktkällor för utsläpp av mikroplaster.

Den här studien har genomförts i Södertälje och prover har tagits uppströms Södertälje i Mälaren och nedströms till Östersjön. Området är förutom befolkningen påverkat av olika typer av industrier. Södertäljeviken är väldefinierad och har få tillflöden förutom från avrinning från staden och industriområden. Syftet med studien är att studera källor och spridning av mikroplaster till havet genom att analysera hur Södertäljeområdet påverkar förekomst och typ av mikroplaster i ytvatten och sediment.

Ytvatten provtogs i nio stycken lokaler i Södertäljeviken, inklusive två tillflöden, vid två tillfällen under hösten 2017. Vid sex av dessa lokaler och vid ett tillfälle togs även sedimentkärnor. Ytvatten provtags med en pump som sorterade in partiklarna i två fraktioner: >300 µm och 50-300 µm. Halterna mikroskräppartiklar (mikroplast, fibrer och övriga antropogena partiklar) var i samtliga ytvattenprover högre i 50-300 µm fraktionen med skillnader som varierade mellan ca en faktor 5 och faktor 160. Halterna mikroplaster >300 µm i ytvatten varierade mellan 0.1 och 1 partiklar/$m^3$. Det relativt låga antalet mikroplaster i kombination med variationer mellan de två tidpunkterna i halter försvårar slutsatserna om punktkällor.

De vanligaste polymererna visade sig vara polyeten och polypropen baserat på analys med infraröd spektroskopi. Hälften av partiklarna som testades kunde dock inte tillskrivas en polymertyp och hamnade i kategorin ”oidentifierad polymer”. Ett karakteristiskt format rött fragment återfanns i flera av ytvattenproverna och sedimentproverna och var sannolikt färgflagor efter t.ex. bottenfärg.

Halterna i ytvatten är jämförbara med studier från Östersjön, Gullmarsfjorden och Nyköpingsåarna (Nyköpingsån, Kilaån, Svärtaån och Trosaån) men lägre jämfört med ytvatten i Göteborg (Mölndalsån, Kvillebäcken, Säveån, Lärjeån och Stora ån).

Halten mikroplast i ytvatten ökade inte nämnvärt från bakgrundsnivån i referenspunkten i Mälaren till början av Södertäljeviken (Snäckviken) med industrier, båttrafik osv. samt till centrala Södertälje (Maren) där Mälaren möter Östersjön. Nedströms centrum kunde en viss ökning av ytvattenhalten urskiljas i lokalen Igelstaviken med sina större industrier och Södertälje hamn. Halten mikroplast minskade sedan nedströms och ut i Östersjön. Detta överensstämde med sedimentproverna, dock kan man i ytsedimentet se en ökning redan i Snäckviken.

Resultaten tyder på att det finns punktkällor kopplade till lokalerna Igelstaviken och Torpaviken men deras betydelse för det totala utsläppet av MP från land är inte fastlagd. Både båttrafik, industrier, och värmeverk finns kopplade till lokalerna. Inga kända plasttillverkare finns i områdena och det bör därför utredas hur mycket mikroplast som släpps ut från övrig tillverkningsindustri. Sedimentresultaten visar på gradienter med ökande halt i Södertäljeviken

fram till Igelsta och därefter en gradvis minskande halt nedströms. Halten mikroplast i sediment är högre i bakgrundslokalen i Östersjön jämfört med bakgrundslokalen i Mälaren vilket tyder på en påverkan från Södertälje. Fler sedimentprov behöver analyseras för att säkerställa skillnaden då variationen av mikroplast i sediment inte är känd.

# Background and summary

Although an increasing number of studies in recent years have established that a significant amount of microplastics is continuously released into the marine environment, there is a lack of knowledge as to which sources contribute the most. Several studies suggest that the major sources are land-based and that the pollution is spread by fresh water systems before reaching the ocean [1-3]. Although the number of published articles on microplastics in the environment has increased dramatically in recent years, studies on fresh water environments are still scarce and reported to compose of less than 4% of all published studies associated with microplastics [4]. The purpose of this study was to evaluate how urban areas influence the emission of microplastics to the sea and if possible characterize sources of microplastics.

The study was conducted in Södertälje and samples have been taken upstream from Södertälje in lake Mälaren, and downstream into the Baltic Sea. In addition to the human population, the area is affected by different types of industries. The Södertälje strait is well-defined and has few influents except from run-off from the city and industrial areas.

Surface water was sampled on nine locations in the Södertälje strait, including two influents, on two occasions during the autumn of 2017. At six of these locations and during one occasion, sediment cores were also taken. Surface water was processed with a pump that sorted the particles into two fractions: >300 µm and 50-300 µm. The concentrations of anthropogenic particles (microplastics, fibers and other anthropogenic particles) were higher in all the surface water samples in the 50-300 µm fraction with a difference that varied between about a factor of 5 and a factor of 160. The levels of microplastics >300 µm in surface water varied between 0.1 and 1 particles / $m^3$. The relatively low number of microplastics, in combination with variations in levels between the two replicate samples, make the study of point sources more difficult.

The most common polymers were polyethylene and polypropylene based on infrared spectroscopy analysis. However, half of the particles tested could not be attributed to a polymer type and ended up in the category "unidentified polymer". A characteristically shaped red fragment was found in several of the surface water samples and the sediment samples, and was probably paint chips from for example antifouling paints.

The microplastic concentrations in surface water were comparable with studies from the Baltic Sea, the Gullmar fjord and rivers in Nyköping and Trosa (Nyköpingsån, Kilaån, Sväraån and Trosaån), but lower compared to surface water in Gothenburg (Mölndalsån, Kvillebäcken, Säveån, Lärjeån and Stora ån).

The occurrence of microplastics did not increase notably from the background level at the reference point Björkfjärden in Lake Mälaren to the beginning of the Södertälje strait (Snäckviken) with industries, boat traffic etc. and to central Södertälje (Maren) where Mälaren meets the Baltic Sea. Downstream the city center, a certain increase in occurrence could be distinguished in Igelstaviken with its larger industries and Södertälje harbor. The levels of microplastic then decreased further downstream out into the Baltic Sea. This was also seen in

the sediment samples, but in sediment one can see an increase in concentrations already in Snäckviken.

The results indicate that there are point sources connected to Igelstaviken and Torpaviken, but their importance for the total emission of microplastics from land is not established. Both boat traffic, industries, and heating plants are connected to these locations. There are no known plastic manufacturers in these areas and it should therefore be investigated how much microplastics are released from other manufacturing industries. The sediment results show gradients with increasing levels in Södertäljeviken down to Igelsta, and then a gradually decreasing level downstream. The level of microplastic in sediment is higher in Oaxen representing the background level in the Baltic Sea compared to Björkfjärden representing the background level in lake Mälaren. This indicates an influence from Södertälje. More sediment samples need to be analyzed to ensure the difference since the variation of microplastic occurrence in sediment is not known.

# Methods

## Sampling in surface water

The nine sampling sites are described in Table 1 and Table A1.1 (Appendix 1), and the locations are depicted in Figure 1. Two samples from each site, with the exception of Maren (Ma) and Torpaviken (T) with one sample, were collected during the fall of 2017. The first sampling round between 17-19 October, and the second round between 7-9 November.

**Table 1.** Description of the nine sampling locations for microplastics in surface water and sediment* in Södertälje.

| Sample ID | Location | Description |
|---|---|---|
| B* | South Björkfjärden, Mälaren | Lake Mälaren, no known point sources. |
| S* | Snäckviken, Mälaren | Start of the Södertälje strait. Affected by urban sources, stormwater, industries, boat traffic etc. |
| Ma | Maren, Baltic Sea | Central Södertälje where Lake Mälaren meets the Baltic Sea (Sampling from a pedestrian bridge on the Baltic Sea side). |
| Ig* | Igelstaviken, Baltic Sea | Surrounded by large industries, for example the Igelsta power plants (Söderenergi), Gärtuna industrial area (for example Astra Zeneca), and the port of Södertälje. |
| Ha* | Halsfjärden, Baltic Sea | Affected by Södertälje as a whole. |
| Hi* | Himmerfjärden, Baltic Sea | Recipient for a sewage treatment plant (Himmerfjärdsverket). |
| O* | Oaxen, Baltic Sea | The Baltic Sea, no known point sources. |
| Må | Måsnaren, lake | Lake adjacent to Vasa wetland that receives a large part of Södertälje's stormwater. Sampling from a pedestrian bridge between Stora and Lilla Måsnaren. Influent, runs out to the Baltic Sea south of Bränningestrand. |
| T | Torpaviken, Baltic Sea | Narrow bay that receives stormwater runoff from a large industrial area (Scania), and the location for a large boat marina. Influent to the Baltic Sea north of Bränningestrand. |

* Indicate locations where sediment was also sampled.

Samples were collected using a second generation pump that was originally developed by KC Denmark in cooperation with researchers at Örebro University during the EU CleanSea project (grant no. 308370) in 2012-2014 (Figure 2). The pump (230 V AC, 0,55 kW) is made of stainless steel and has a total length of 160 cm, a maximum width of 29 cm, and a total weight of roughly 35 kg. The motor is situated on top, followed by an inlet grid for water, a filter stack with removable filters to collect particles in different size fractions, and an electromagnetic flow transmitter (PD340) on the bottom that measures the volume with high precision (±0.01% at 20000 L/h). The pump has a maximal velocity of 25000L/h and can operate down to a depth of 60 m. For this study the pump was held in a horizontal position and hung from the side of a boat or from a bridge with the water inlet 5-10 cm below the surface. The filters are of stainless steel and laser cut with a diameter of 14 cm. For this project, two sets of filters with mesh sizes of 300 µm and 50 µm were used. One blank sample was taken on each day of sampling. The blank samples were processed and stored similarly except they were not submersed under water. All filters were stored in lidded metal jars lined with aluminum foil and stored at 6 °C awaiting analysis.

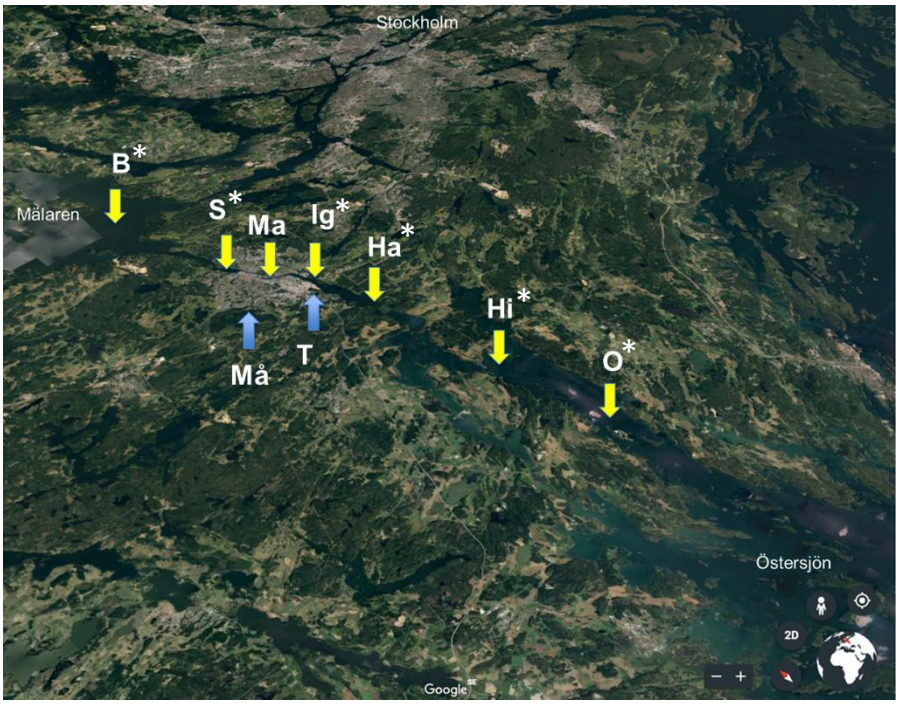
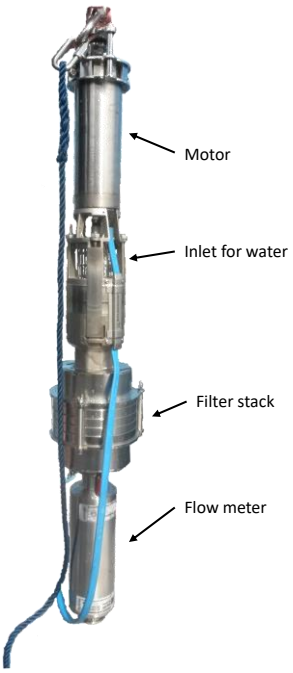



**Figure 1.** Sampling locations for microplastics in surface water in the Södertälje strait from lake Mälaren to the Baltic Sea. Yellow arrows B and S represent lake Mälaren and the other yellow arrows represent the Baltic Sea. Blue arrows indicate influents to the strait and the symbol * indicates locations where sediment cores were taken.




**Figur 2.** The pump consists of a motor on top, followed by an inlet grid for water, a filter stack with removable filters, and an electromagnetic flow meter on the bottom that measures the volume with high precision.

# Sampling sediment cores

The sediment sampling was performed by NIRAS between 7-8 November. Accumulation bottoms close to the locations for the surface sampling were identified using bathymetric charts provided by the Swedish Maritime Administration (Sjöfartsverket). Six core samples (50 cm) were taken at Björkfjärden, Snäckviken, Igelstaviken, Halsfjärden, Himmerfjärden, and Oaxen. The cores were sliced in 2 cm thick layers and transferred to glass jars, which were stored at 6 °C awaiting analysis.

# Analysis

## Particles > 300 µm in surface water

The analysis was performed directly on the stainless steel filters under a light microscope using shape, texture, and color to separate anthropogenic particles from organic material. One sample contained a lot of organic debris and was treated with 30% hydrogen peroxide solution prior to analysis.

Particles that were identified as anthropogenic were transfered to a petrie dish and sorted into categories that are commonly used for microlitter; These categories are listed in Table 2. Pictures of representative particles of the different categories were taken with an Axiocam ERc 5s mounted on a light microscope (Stemi 508, Zeiss).

Particles >500 µm that were feasible to transfer with tweezers were tested using Attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR, Perkin-Elmer) to verify the visual analysis and determine the type of polymer. The analyses were performed by matching the obtained spectra for the particles with a spectral library containing nine of the most common industrial polymers (PE, PP, PS, PA, PET, PVC, PHA, PHB, PLLA). The criteria for a positive match was set to ≥ 95%.

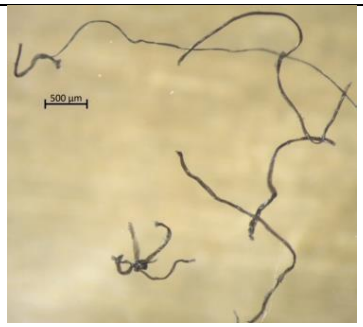
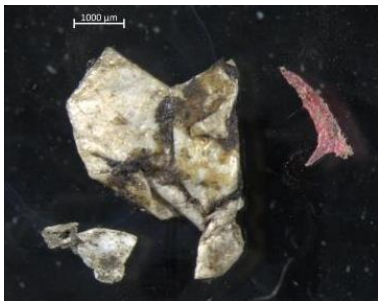
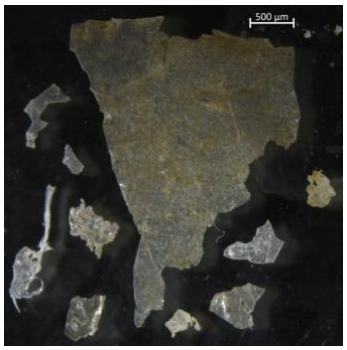
## Particles 50-300 µm in surface water

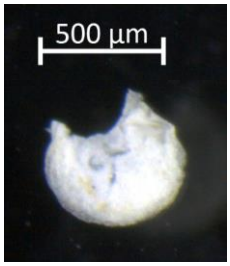
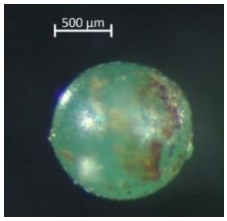
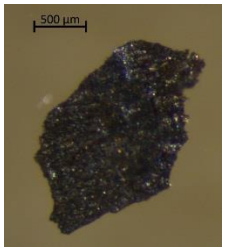
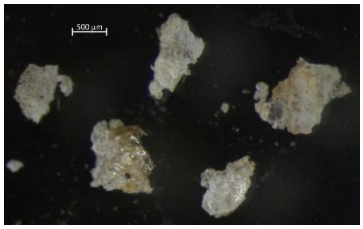
The content on the 50 µm filters was transferred to glass jars by gentle rinsing with tap water in a wash bottle and a spatula. The resulting material was treated with 30% hydrogen peroxide to digest any organic constituents, and then the liquid was passed through glass fiber filters (10 µm pore size). The analysis was performed under a light microscope in the same manner as for the larger particle fraction.

## Particles > 50 µm in sediment

The lighter microplastic particles were separated from sediment using the principle of elutriation (upcurrent separation). Details of the elutriation system set up are described in Appendix 2. The dry weight was determined by weighing three replicates of a subsample before and after drying at 105°C for 24h. The upper 0-4 or 0-6 cm of the sediment core (100-300 g wet weight, w.w.) was placed at the bottom of a 2.5 m high PVC pipe on top of a 50 µm stainless steel filter. Water was pumped through the filter allowing to fill the column bottom to top at 1.5-2.5 L/min during one hour. At the top the water flows over into a second pipe fitted with two filters (300 µm and 50 µm) that trap the particles. Between samples the system was taken apart and rinsed with tap water and thereafter flushed for 30 min using maximum flow. One blank sample using a 50 µm filter was processed in between two of the samples. Two validation experiments were performed prior to extractions of the samples using colorful PE and PP fragments (approx. 200-1000 µm) added to 100 g of sediment (w.w.). The resulting recoveries were 68% and 83%. This extraction method had previously been evaluated using heavier polymers such as PVC and abrasions of SBR-rubber, and found to extract < 20% of the PVC and 0% of the SBR-rubber.

**Table 2.** Categories used to classify microlitter (eg. solid and semi solid anthropogenic particles).

| Particle type | Classification | Representative image |
|---|---|---|
| Fibres | Fibres |   Fibres from Himmerfjärden. |
| Filament | Microplastic | Filaments from Halsfjärden. |
| Particle/fragment | Microplastic |   Fragments from Torpaviken. |
| Film | Microplastic |   Film from Igelstaviken. |

| | | |
|---|---|---|
| Foam | Microplastic |  Foam from Halsfjärden. |
| Pellets<br><br>No pellets were found in this study | Microplastic |  Pellet from Huskvarna river, Jönköping. |
| Black particles (for ex. bitumen) | Other anthropogenic particles |  Black particle from Halsfjärden. |
| Semi solid synthetic particles (for ex. paraffin) | Other anthropogenic particles |  Paraffin particles from Igelstaviken. |

# Data handling

A 300 µm mesh size is not optimal for fibre analysis since the diameter of fibres is commonly in the 25-50 µm range. The amount and nature of organic debris on the filters may affect the amount of fibres that ends up on the filter so comparison between samples should be made with caution. A detection limit of 11 fibres was set for the > 300 µm particle fraction based on background contamination on three blank filters (average plus three standard deviations). A detection limit of 15 fibres was calculated in the same way for the 50-300 µm but was based on the background contamination of two blank filters. No particles were found on any of the blank filters, including the sediment blank. On the sediment blank filter one fiber was found.

The results are reported as number of microlitter particles per $m^3$ ($ML/m^3$) divided into the categories microplastics ($MP/m^3$), fibres ($F/m^3$), and other anthropogenic particles ($OA/m^3$) (Figure 3). The lower and upper size limits were 50 µm and 5 mm, respectively.

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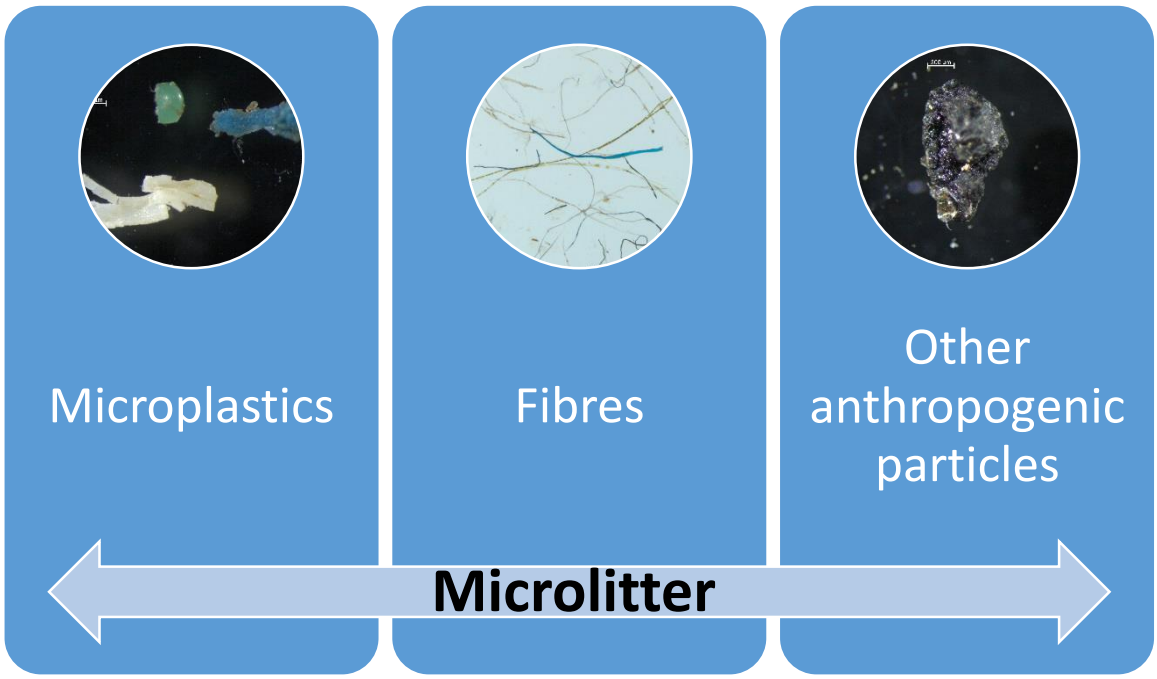



**Figur 3**. In this study microlitter was divided and reported in three categories; Microplastics, fibres, and other anthropogenic particles.

# Results

## Microlitter > 300 µm in surface water

Table 3 summarizes the results of microlitter per cubic meter (ML/m$^3$) divided into microplastics (MP/m$^3$), other anthroplogenic particles (OA/m$^3$), and fibers (F/m$^3$). Fibers were found most frequently and constituted 53% of the microlitter >300 µm, followed by MP (41%) and OA (6,0%). Out of the 28 OA counted, 13 were black particles, and 15 were semi solid particles.

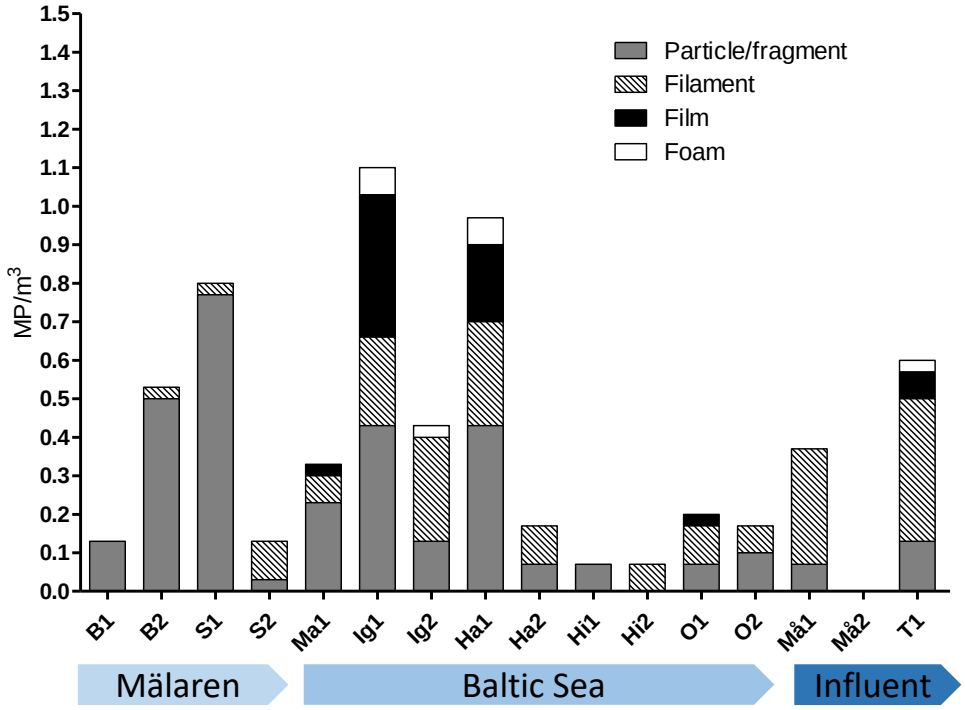
**Tabell 3.** Results of microlitter > 300 µm per cubic metre (ML/m$^3$) divided into microplastics (MP/m$^3$), other anthroplogenic particles (OA/m$^3$), and fibers (F/m$^3$).

| ID | Volume (m$^3$) | Date | # MP | # OA | # F | MP/m$^3$ | OA/m$^3$ | F/m$^3$ | ML/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| B1 | 30 | 17/10 | 4 | 3 | 12 | 0.13 | 0.10 | 0.40 | 0.63 |
| B2 | 30 | 8/11 | 16 | 0 | < 11 | 0.53 | 0.00 | < 0.4 | 0.53 |
| S1 | 30 | 17/10 | 24 | 0 | 17 | 0.80 | 0.00 | 0.57 | 1.37 |
| S2 | 30 | 8/11 | 4 | 3 | 16 | 0.13 | 0.10 | 0.53 | 0.77 |
| Ma1 | 30 | 19/10 | 10 | 4 | 20 | 0.33 | 0.13 | 0.67 | 1.13 |
| Ig1 | 30 | 17/10 | 33 | 5 | 25 | 1.10 | 0.17 | 0.83 | 2.10 |
| Ig2 | 30 | 8/11 | 13 | 0 | 14 | 0.43 | 0.00 | 0.47 | 0.90 |
| Ha1 | 30 | 18/10 | 29 | 1 | < 11 | 0.97 | 0.03 | < 0.4 | 1.00 |
| Ha2 | 30 | 7/11 | 5 | 0 | 14 | 0.17 | 0.0 | 0.47 | 0.63 |
| Hi1 | 30 | 18/10 | 2 | 0 | < 11 | 0.07 | 0.00 | < 0.4 | 0.07 |
| Hi2 | 30 | 7/11 | 2 | 0 | 53 | 0.07 | 0.00 | 1.77 | 1.83 |
| O1 | 30 | 18/10 | 6 | 0 | < 11 | 0.20 | 0.00 | < 0.4 | 0.20 |
| O2 | 30 | 7/11 | 5 | 0 | 16 | 0.17 | 0.00 | 0.53 | 0.70 |
| Må1 | 30 | 19/10 | 11 | 0 | 13 | 0.37 | 0.00 | 0.43 | 0.80 |
| Må2* | 30 | 9/11 | 0 | 8 | 14 | 0,00 | 0,27 | 0,47 | 0,73 |
| T1 | 30 | 19/10 | 18 | 4 | 24 | 0.60 | 0.13 | 0.47 | 1.50 |

The detection limit < 0.4 was calculated using the background contamination on three blank filters (average plus three standard deviations) divided by the sample volume. * Filter treated with 30% hydrogen peroxide.

## Types of microplastic

A total of 182 microplastic pieces were found and the majority were particles/fragments (52%) and filaments (33%), followed by film (12%) and foam (3%). For images of the different categories see Table 2. Figure 4 depicts the concentration and the composition of the different microplastic types for each sample.




**Figur 4.** Composition and concentrations of microplastics (MP/m$^3$) > 300 µm in surface water.

## Polymer composition

Infrared spectroscopy (ATR-FTIR) was used to analyze as many particles as feasible, which excluded for example most filaments and particles < 500 µm. A total of 65 particles (43%) was tested and the composition is shown in Figure 5. For some particles of PE and PP with spectral interferences peak matching was performed using the most abundant peaks instead of the ≥95% matching criteria. The most common polymers identified were PE (23%) and PP (20%) (Figure 6), followed by PE/PP blend (2%), PA (2%), and PS (2%). The PE/PP blend fragment was identified by matching the common absorption bands for PE and PP with the reference spectra (Figure 7). A large part of the particles that were identified visually as microplastics based on color and texture, 49%, could not be assigned a polymer type using the spectral library and were grouped in the category "unidentified polymers" (Figure A3.1, Appendix 3).

Two of the semi solid waxy particles from Igelstaviken were analyzed and were identified as paraffin using a reference spectrum. A characteristically shaped red fragment was found in seven of the 16 samples and not in the blanks. The FTIR analysis confirmed that they were of the same polymer type, which indicates a common origin. Black particles cannot be analyzed using FTIR. In this study, based on appearance and texture, they were of either soot or bitumen origin, and classified as other anthropogenic particles.

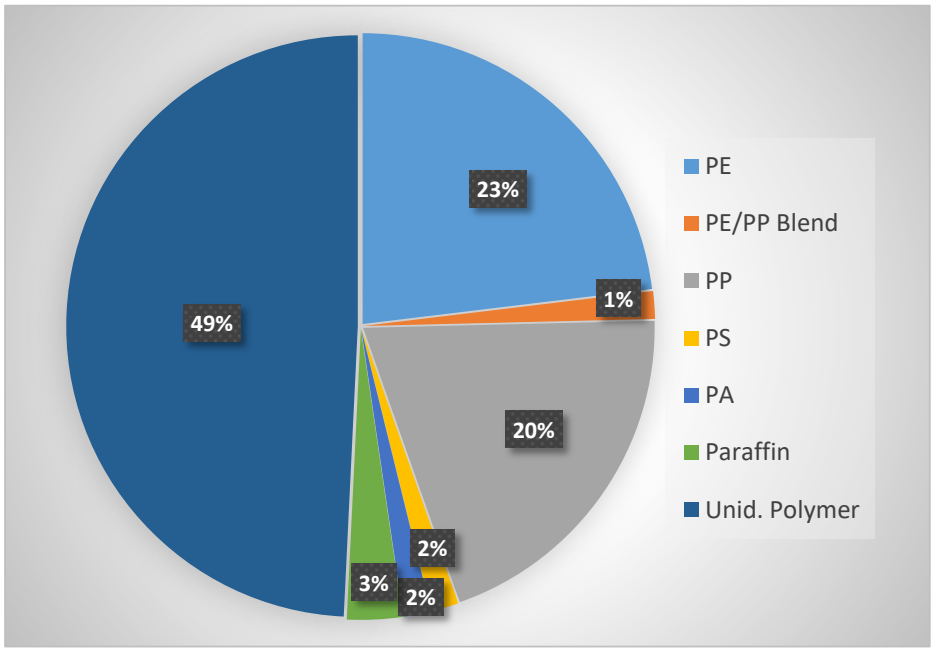



**Figure 5.** Polymer composition of 65 out of the total 152 anthropogenic particles (most filaments excluded) analyzed using ATR-FTIR.

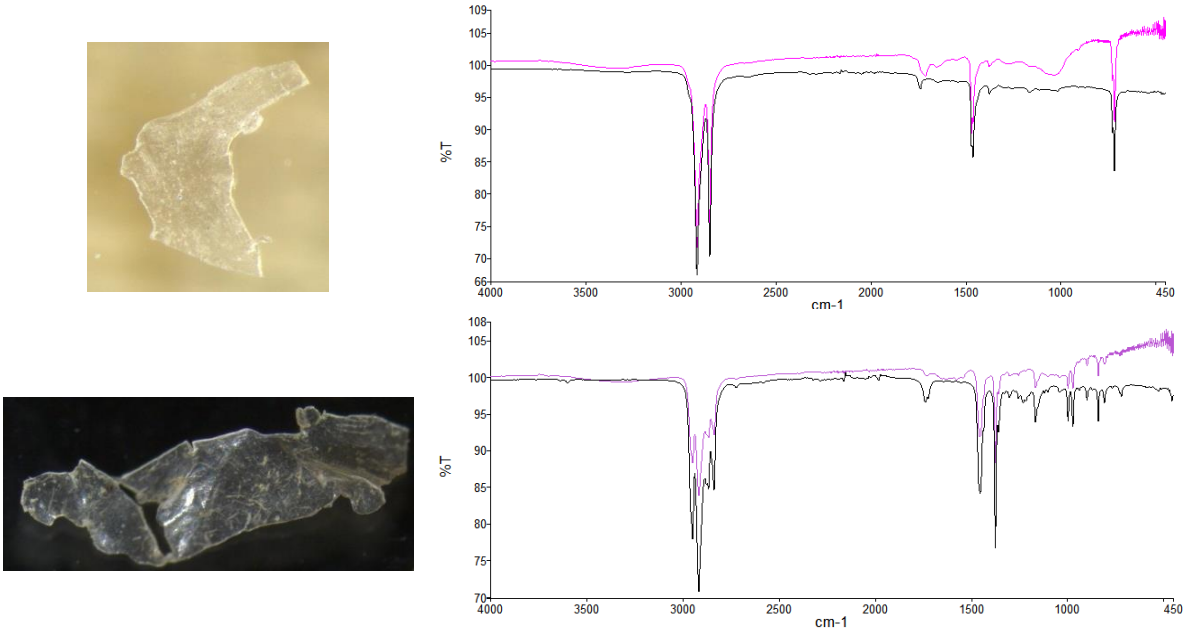



**Figure 6.** Film from Oaxen identified as PE (top) and film from Halsfjärden identified as PP (bottom) using ATR-FTIR and a ≥95% spectral library match. The pink spectra represent the film and the black spectra represent the PE and PP reference plastic.

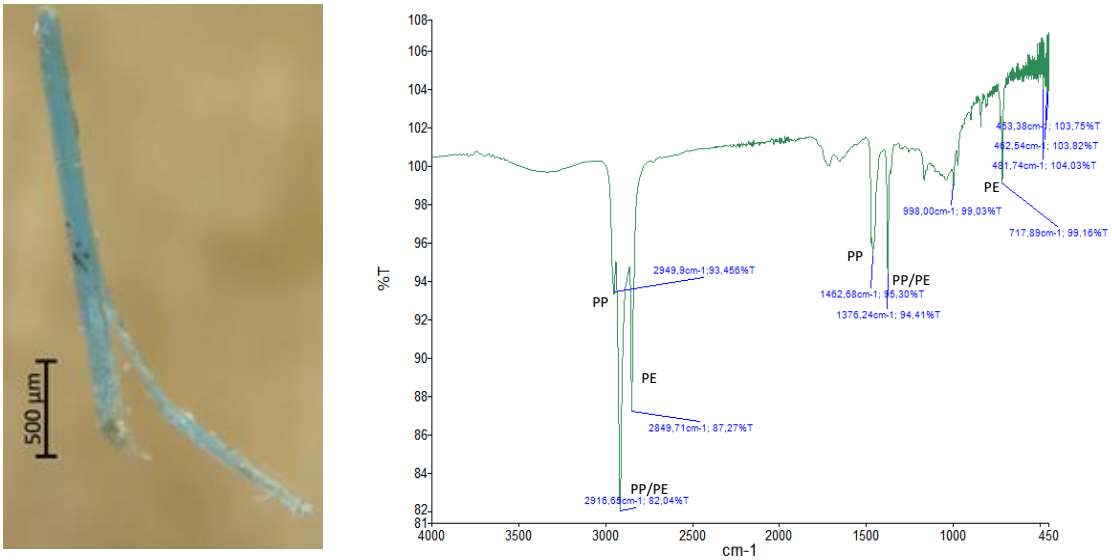



**Figure 7.** Filament from Halsfjärden identified as a blend of PE and PP by matching the common absorption bands for PE and PP with the reference spectra.

# Microlitter 50-300 µm in surface water

Table 4 summarizes the results of microlitter per cubic metre (ML/m$^3$) divided into microplastics (MP/m$^3$), other anthropogenic particles (OA/m$^3$), and fibers (F/m$^3$). Fibers were found most frequently and constituted 60% of the microlitter 50-300 µm, followed by MP (40%), and OA (0,6%). Out of the seven OA counted, five black particles, one semi solid particle, and one metal particle were identified.

**Tabell 4.** Results of microlitter 50-300 µm per cubic metre (ML/m$^3$) divided into microplastics (MP/m$^3$), other anthropogenic particles (OA/m$^3$), and fibers (F/m$^3$).

| ID | Volume (m$^3$) | Date | # MP | # OA | # F | MP/m$^3$ | OA/m$^3$ | F/m$^3$ | ML/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| B1 | 3.6 | 17/10 | 40 | 1 | 18 | 11 | 0,3 | 5,0 | 16 |
| B2 | 3.7 | 8/11 | 21 | 0 | 47 | 5.6 | 0.0 | 13 | 18 |
| S1 | 3.1 | 17/10 | 9 | 0 | 28 | 2.9 | 0.0 | 8.9 | 12 |
| S2 | 3.8 | 8/11 | 76 | 0 | 112 | 20 | 0.0 | 29 | 49 |
| Ma1 | 3.7 | 19/10 | 19 | 0 | < 15 | 5.2 | 0,0 | < 4.3 | 8.5 |
| Ig1 | 3.7 | 17/10 | 73 | 1 | 47 | 20 | 0.3 | 13 | 33 |
| Ig2 | 3.9 | 8/11 | 54 | 2 | 89 | 14 | 0.5 | 23 | 37 |
| Ha1 | 3.7 | 18/10 | 20 | 0 | 28 | 5.3 | 0,0 | 7.5 | 13 |
| Ha2 | 3.6 | 7/11 | 7 | 0 | 47 | 1.9 | 0.0 | 13 | 15 |
| Hi1 | 3.9 | 18/10 | 32 | 0 | < 15 | 8.2 | 0.0 | < 4.3 | 11 |
| Hi2 | 4.0 | 7/11 | 7 | 0 | 21 | 1,8 | 0,0 | 5.3 | 7.1 |
| O1 | 3.9 | 18/10 | 30 | 0 | < 15 | 7.7 | 0,0 | < 4.3 | 10 |
| O2 | 4.0 | 7/11 | 19 | 0 | 44 | 4.8 | 0.0 | 11 | 16 |
| Må1 | 2.4 | 19/10 | 7 | 0 | 25 | 3.0 | 0.0 | 11 | 14 |
| Må2 | 1.5 | 9/11 | 1 | 0 | 13 | 0.7 | 0.0 | 8.6 | 9.2 |
| T1 | 3.4 | 19/10 | 68 | 3 | 35 | 20 | 0.9 | 10 | 32 |

The detection limit < 4.3 was calculated using the background contamination on two blank filters (average plus three standard deviations) divided by the average sample volume.

## Types of microplastics

A total of 483 microplastic pieces were found and the majority were particles/fragments (69%) and filaments (29%), followed by foam (2.1%) and film (0.6%). Figure 8 depicts the concentration and the composition of the different microplastic types for each sample.

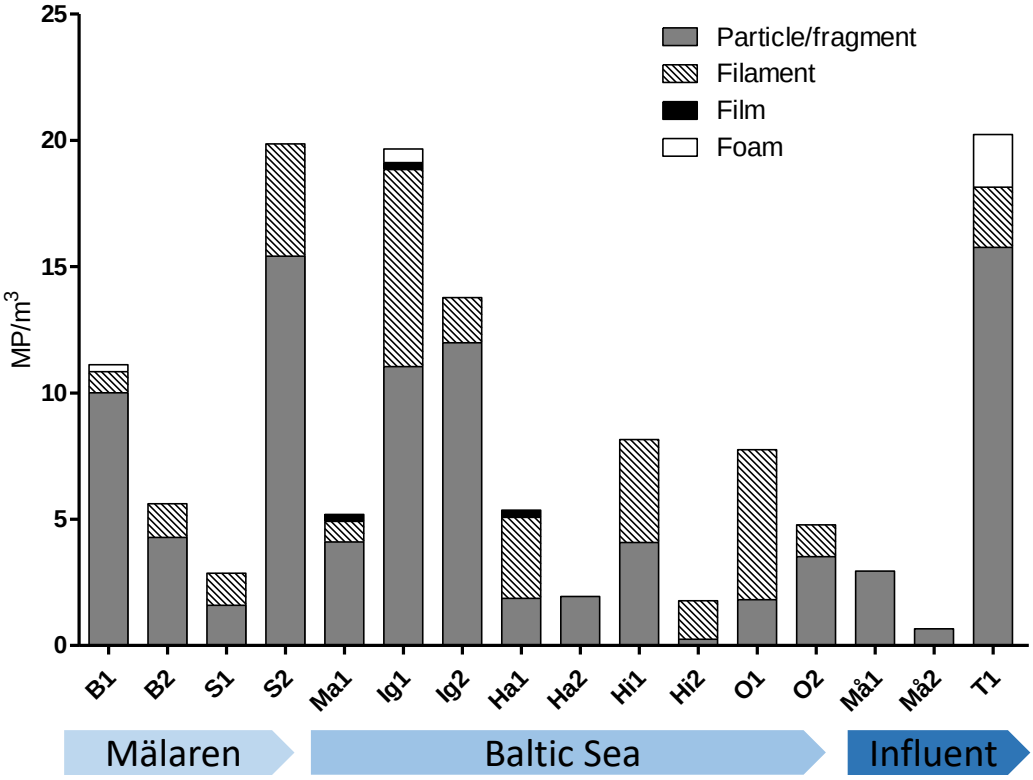



**Figure 8.** Composition and concentrations of microplastics (MP/m$^3$) 50-300 µm in surface water.

# Microlitter in sediment

The results of microlitter in sediment are presented in table A4.1 in Appendix 4. In the > 300 µm size fraction fibers were found most frequently and constituted 77% of the microlitter, followed by microplastics (22%), and other anthropogenic particles (1 %). The microplastics constituted filaments (8%), particles/fragments (8%), and film (6%). In the 50-300 µm size fraction microplastics were found most frequently and constituted 82% of the microliter followed by fibers (22%). Adding the two fractions, a total of 83 microplastic pieces > 50 µm were counted and Figure 9 depicts the concentration (MP/g dry weight) and composition of the different microplastic types for each sample. Five characteristically shaped red fragments, same as the ones found in surface water, were found at Snäckviken (3), Fläsklösa (1), and Skanssundet (1). In this study no ATR-FTIR analysis could be performed on particles found in the sediment.

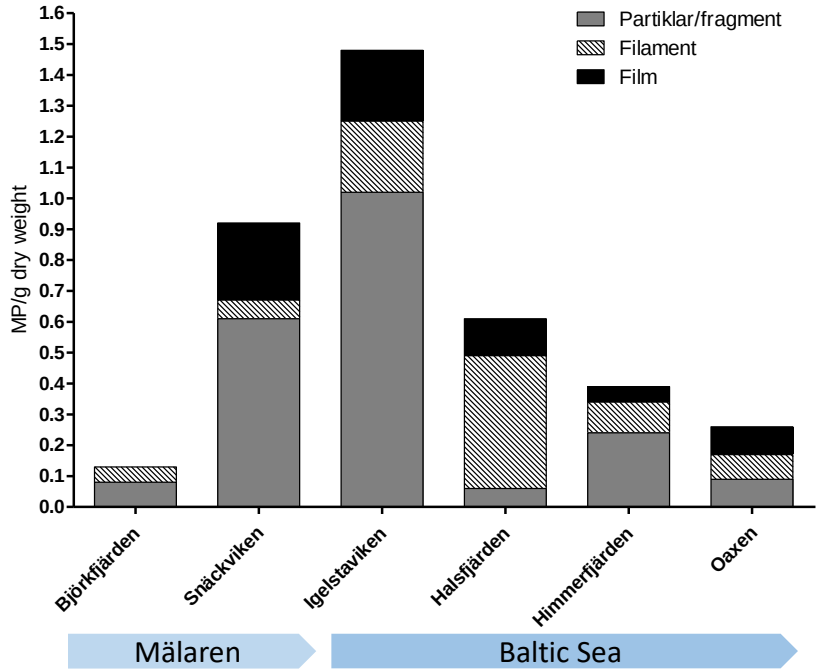



**Figure 9.** Composition and concentration of microplastic (MP/g dry weight) > 50 µm in surface sediment.

# Discussion

## Comparisons

### Comparison with other studies

The levels of MP > 300 µm in surface water in this study are generally comparable to studies performed by Örebro University in the Baltic Sea 2014, in the Nyköping rivers (Nyköpingsån, Kilaån, Svärtaån and Trosaån), and in Gullmarsfjorden outside Lysekil 2017 (Table 5). The concentrations, on the other hand, are lower compared to surface water in Gothenburg (Mölndalsån, Kvillebäcken, Säveån, Lärjeån and Stora ån) in a recent study (also by Örebro University). The total concentrations of ML (MP + OA + F) can be compared with average levels measured in cities along Sweden's west coast in 2013 and 2014 in a study performed by Norén and Magnusson (Table 6).

**Tabell 5.** Average concentrations of microplastic > 300 µm in the Baltic Sea, Gullmarsfjorden, rivers in Nyköping and Trosa, and in Gothenburg measured using the same methodology as in this study.

| | Median concentration (average concentration) MP/m$^3$ | min-max MP/m$^3$ |
|---|---|---|
| Baltic Sea 2014 (n=9) | 0.1 (0.3) | 0.0–1.5 |
| Gullmarsfjorden 2017 (n=6) | 0.2 (0.2) | 0.0–0.6 |
| Rivers in Nyköping and Trosa 2017 (n=4) | 0.4 (0.3) | 0.0–0.6 |
| Gothenburg 2017 (n=30) | 0.8 (2.2) | 0.1–22 |
| Sweden's four Great lakes 2017 (n=36) | 0.3 (0.9) | 0.0–7.2 |
| **Södertälje, this study (n=16)** | **0.2 (0.3)** | **0.0–1.0** |

**Tabell 6.** Average concentrations of microlitter in Swedish cities, industrial areas, and rural areas during 2013 and 2014 along the the Swedish west coast using different methodologies compared to the current study [5].

| | 2013 average concentration microlitter/m$^3$ | 2014 average concentration microlitter/m$^3$ |
|---|---|---|
| Cities | 25 | 1.0 |
| Industrial areas | 3.6 | 0.9 |
| Rural areas | 2.1 | 0.1 |

The levels of MP 50-300 µm are compared in Table 7 with other studies performed by Örebro university. The range in concentrations in this study was narrower compared to the Baltic Sea and Gothenburg, and the median concentration was comparable to the Baltic Sea. Although there are minor differences, the median concentration was higher compared to rivers in Nyköping and Sweden's four great lakes and lower compared to rivers in Gothenburg.

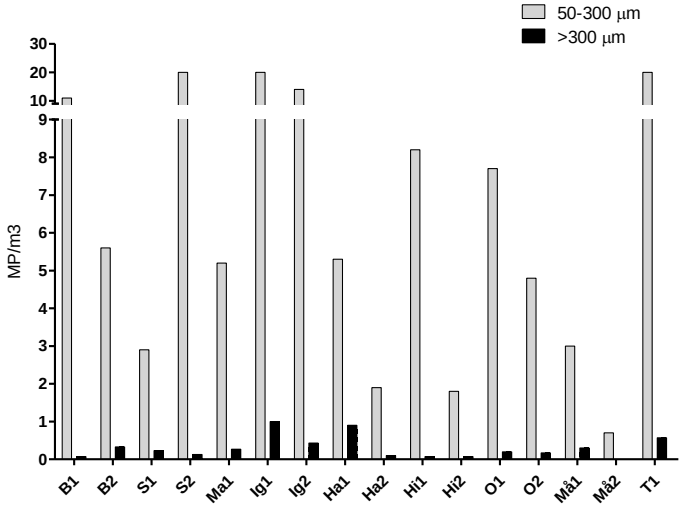
**Tabell 7.** Average concentrations of microplastic 50-300 µm in the Baltic Sea, Gullmarsfjorden, rivers in Nyköping and Trosa, and in Gothenburg measured using the same methodology as in this study.

| | Median concentration (average concentration) MP/m$^3$ | min-max MP/m$^3$ |
|---|---|---|
| Baltic Sea 2014 (n=6) | 5.1 (16) | 0.0–70 |
| Rivers in Nyköping and Trosa 2017 (n=4) | 2.5 (5.0) | 2.0–13 |
| Gothenburg 2017 (n=30) | 6.9 (14) | 0.0–81 |
| Sweden's four great lakes (n=15) | 3.5 (6.8) | 1.5–30 |
| **Södertälje, this study (n=16)** | **5.5 (8.3)** | **0.7–20** |

The sediment results are more difficult to compare with other studies since different extraction methods have different extraction efficiencies, especially of the heavier polymers. In a recent report by Karlsson et al. (2019) results of microlitter in sediment outside the town Stenungsund on the Swedish west coast are presented [6]. Surface sediment from nine sediment cores were investigated and the results for microlitter > 300 are in the same range as this study. The min, max, and average concentration MP/g d.w. outside Stenungsund were 0.03, 0.6, and 0.3 compared to 0.1, 0.8, and 0.4 in Södertälje. However, the concentrations in Södertälje are most likely underestimated in this context as heavier polymers such as tire wear particles were also targeted in Stenungsund. Therefore, a direct comparison of these studies is not possible.

## Comparison of microplastic particles >300 µm and 50-300 µm in surface water

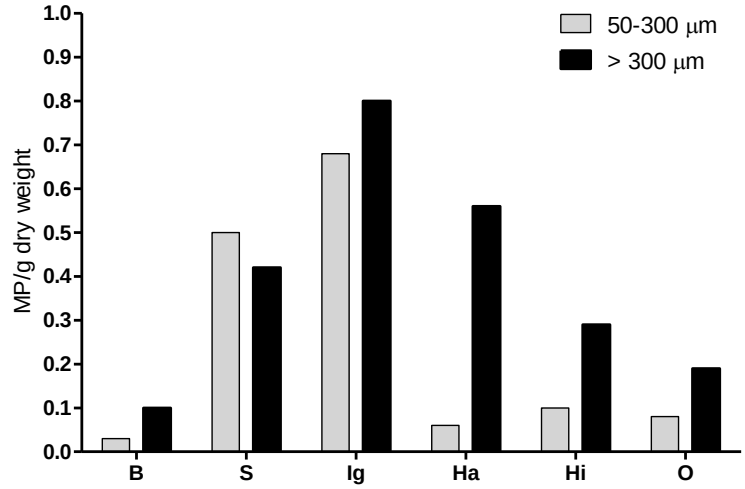
The concentrations of microplastic particles in surface water were in all samples higher in the smaller fraction, and the difference varied between a factor 5 and 160 (Figure 10).




**Figur 10.** Comparison of concentrations in surface water of microplastic (MP/m$^3$) in the particle fractions >300 µm and 50-300 µm.

## Comparison of microplastic particles > 300 µm and 50-300 µm in sediment

The concentrations of microplastic particles in surface sediment were higher the bigger fraction in all samples except S. However, the difference between the two size fractions was much less compared to surface water (Figure 11).




**Figur 11.** Comparison of concentrations in surface sediment of microplastic (MP/g dry weight) in the particle fractions >300 µm and 50-300 µm.

# Polymer types

Determining the polymer type, in combination with visual characterization, can provide useful information on potential emission sources of microplastics but is far from conclusive. Some samples contained a relative large number of fragments or fibers of the same type. For example, in samples S1, B1, and B2 the visual analyses indicated the same type of white fragments and the ATR-FTIR analyses confirmed a common origin (unidentified polymers with close to identical spectra). In this case the sample size and number of replicate samples were too small to provide any solid evidence of a nearby emission source. However, provided a sufficient number of samples and a sampling strategy that allows to sample close to a potential point source, this combination of visual analysis and infrared spectroscopy may prove a promising approach in source tracking.

PE and PP are most common in studies because of their neutral buoyancy and that PE and PP are produced and used in large quantities, including as packaging material. In a previous study by Örebro university in the Baltic Sea, the proportion of MP > 300 µm was confirmed to be 80% PE and PP (where PE dominated), 3% PS, and 11% unidentified polymers using near infrared hyperspectral imaging. Although PE and PP also dominated in this study, the amount of unidentified polymers were similar in size (44% vs. 49%). However, it's not possible to draw any big conclusions from this discrepancy between the Baltic sea and the Södertälje strait since different matching criteria affect the number of particles assigned unidentified polymers. One way to increase the identification rate is to add more polymeric materials to the spectral library. Also, complementary analysis using for example SEM-EDS (Scanning Electron Microscopy - Energy-Dispersive x-ray Spectroscopy) can provide useful information on elemental composition.

The unknown polymers can be of different origin. Polymer based adhesives are commonly used in packaging material to, for example, provide a sealing function. A wide range of polymers and copolymers are for example used in surface coatings, such as epoxy, polyurethane and related polymers in marine boat coatings. The characteristic red fragments of different size and shape that were found in both surface water and sediment are likely paint chips and may originate from antifouling paint (Figure 12). Contamination from the sampling was excluded since surface water and sediment were sampled using two different boats. In surface water they made up 11% of fragments > 300 µm so their contribution to pollution levels is not insignificant.

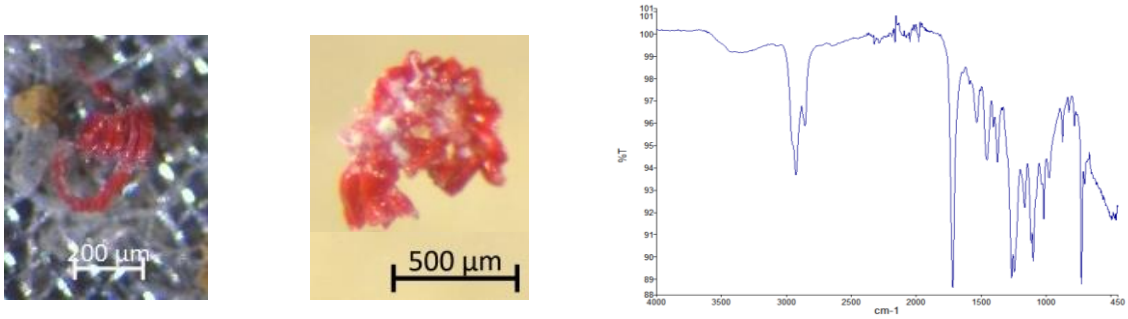



**Figure 12.** Red characteristically shaped fragment in surface sediment from Snäckviken (left), and in surface water from Torpaviken (middle), and ATR-FTIR spectrum of the fragment from Torpaviken.

Södertälje is built on either side of a narrow strait connecting lake Mälaren with the Baltic Sea. The closest sampling point to the city in lake Mälaren (Snäckviken) is located approximately 1,5 km from the culvert at Maren where lake water enters the Baltic Sea at 6 $m^3/s$. From Maren the freshwater from lake Mälaren flows at the surface in the center of the strait until Halls holme, where it expands in a fan formation down to the light house Fläsklösa in Halsfjärden. Brackish water flows toward Södertälje at a depth and mixes with the fresh water at Maren. At Maren the brackish water content varies depending on for example weather and currents, but around 80% is common (Ulf Larsson, Stockholm University, oral communication).

The level of MP in surface water did not increase significantly from the background level in the reference point in Lake Mälaren (Björkfjärden) to the beginning of the Södertälje strait (Snäckviken) and central Södertälje (Maren), where Mälaren meets the Baltic Sea. Downstream the city center, a certain increase in microplastic occurrence was noted at Igelstaviken with its larger industries and Södertälje harbor. The occurrence of MP thereafter decreased when reaching further out into the Baltic Sea.

The different categories of MP varied between both sampling locations and sampling occasions, with a seemingly increase in the categories expanded foam and films > 300 µm in the samples with the highest levels (Igelstaviken and Halsfjärden).

The influent at Torpaviken, affected by industrial surface water runoff and a larger boat marina, also showed an elevated level of MP compared to the background level. The potential influent originating in lake Måsnaren, adjacent to Vasa wetland that receives a large part of Södertälje's stormwater, did not show elevated levels of MP. However, to capture any surges in MP concentration at this location sampling should also be performed for example at high water flows after a rain period.

It should be noted that the occurrence of MP > 300 µm in surface water was very low for all samples, which makes firm conclusions impossible to draw. The levels of MP 50-300 µm were higher. However, also in this case there is great variation between the two sampling occasions making any conclusion from the data, which is subject to random variation, difficult. Several replicates and / or larger volumes are needed to statistically confirm any difference in levels. The markedly higher levels in the smaller size fraction underpins the importance of including particle sizes smaller than 50 µm in future studies.

The occurrence of MP >50 µm in surface sediment (down to 4 and 6 cm) confirms the increase from the background level in Lake Mälaren to Igelstaviken. In addition, an increase can already be seen at the beginning of the strait (Snäckviken). From Igelstaviken, the MP decreases and in the last sampling location in the Baltic Sea (Oaxen) it is higher compared to the background in Mälaren (Björkfjärden). Since only one sediment sample per sampling site has been analyzed, the results are only indicative since the variation of MP levels in sediment is unknown. Also, these results cannot be used to draw any conclusions regarding the occurrence of heavier polymers, such as abrasion particles from car tires, as they were not targeted by the extraction method.

The results indicate that there are point sources connected to Igelstaviken and Torpaviken, but their importance for the total emission of MP from land is not established. Both boat traffic, industries, and heating plants are connected to these locations. No known plastic manufacturers

are found in the area and it would therefore be interesting to investigate how much microplastics are released from the other manufacturing industries. The sediment results show a gradient with increasing levels in the strait down to Igelsta, and then a gradually decreasing level downstream Södertälje.

# Future aspects

Monitoring microplastics is very challenging in every step of the process from sampling to identification and reporting concentrations. Large temporal variabilities and spatial heterogeneity of microplastic pollution, as shown in this study and other studies previously performed by Örebro university [7-9], make source tracking particularly challenging. The complexity of emission sources of microplastics, in combination with for example seasonal changes in water circulation at any given sampling location, put high demand on the design of field studies that aim to characterize and quantify land based sources. Current knowledge is insufficient for designing monitoring programs for microplastics. In order to study associations between microplastic concentrations and changes in different hydrogeochemical parameters, a longer time series is needed. Sampling needs to be performed in close vicinity to the sources to guarantee enough particles in the samples to allow for statistical analysis, as well as to link the obtained microplastic particles with a source. Due to that an increased ecological relevance is suspected the smaller the particles a size fraction in the vicinity of 1 µm should be included in future studies as a proxy for the smallest microplastic particles.

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# Appendix 1

Maps and GPS coordinates for sampling locations of microlitter in surface water and sediment cores.

**Table A1.1.** GPS coordinates for surface water and sediment sampling, as well as depth for the sediment sampling.

| | **Surface water** | **Sediment** | |
|---|---|---|---|
| Prov Id | GPS | GPS | Depth (m) |
| B1 | 59°16'23"N, 17°33'39"O | 59,2693499 N 17,5711861 E | 43 |
| B2 | 59°16'26"N, 17° 33'40"O | | |
| S1 | 59°12'21"N, 17° 37'11"O | 59.2069548 N 17.6205003 E | 17 |
| S2 | 59°12'33"N, 17°37'38"O | | |
| Ma1 | 59°11'31"N, 17°37'49"O | | |
| Ig1 | 59°10'09"N, 17°40'06"O | 59.1703297 N 17.6661887 | 22 |
| Ig2 | 59°10'12"N, 17°40'04"O | | |
| Ha1 | 59°07'73"N, 17°41'10"O | 59.1310847 N 17.6835068 E | 36 |
| Ha2 | 59°07'71"N, 16°41'10"O | | |
| Hi1 | 59°02'33"N, 17°42'63"O | 59.0445211 N 17.7190235 E | 36 |
| Hi2 | 59°03'06"N, 17°42'44"O | | |
| O1 | 58°59'02"N, 17°44'21"O | 58.98389920 N 17.72367563 E | 31 |
| O2 | 58°59'03"N, 17°44'22"O | | |
| Må1 | 59°11'3.6"N, 17°32'55"O | | |
| Må2* | 59°11'3.6"N, 17°32'55"O | | |
| T | 59°09'35"N, 17°39'15"O | | |

# Appendix 2

**Table A2.1.** Details of the Elutriation system used to separate microliter from sediment.

| **Elutriation system** | **Properties** |
|---|---|
| Dimensions of the column (H x W x D, ø) | 250 cm x 40 cm x 15 cm, 10 cm |
| Upper filter mesh size | 300 µm, 50 µm |
| Lower filter mesh size | 50 µm |
| Aeration system | Air stone + air pump (Marina 100) |
| Pump | Hydroforpump (Meec tools art. 731126) |
| Characteristic of the pump | 1300 W – 83.3 $L.min^{-1}$ |
| Flowmeter | Flow transmitter (UCC art. DFC 9000) |
| Characteristic of the flowmeter | 1.0 $L.min^{-1}$ to 25.0 $L.min^{-1}$ – 20 bar – 5V |

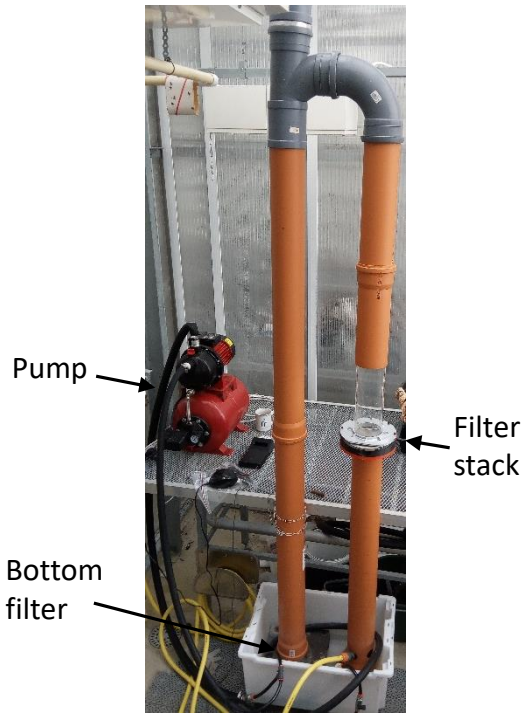


**Figure A2.1.** Experimental setup of the elutriation system used to separate microlitter particles from sediment. The upper 0-4 or 0-6 cm of the sediment core (100-300 g wet weight, w.w.) was placed at the bottom of the 2.5 m high PVC pipe on top of a 50 µm stainless steel filter. Water was pumped through the filter allowing to fill the column bottom to top at 1.5-2.5 L/min during one hour. At the top the water flows over into a second pipe fitted with two filters in a filter stack (300 µm and 50 µm) that trap the particles.

# Appendix 3

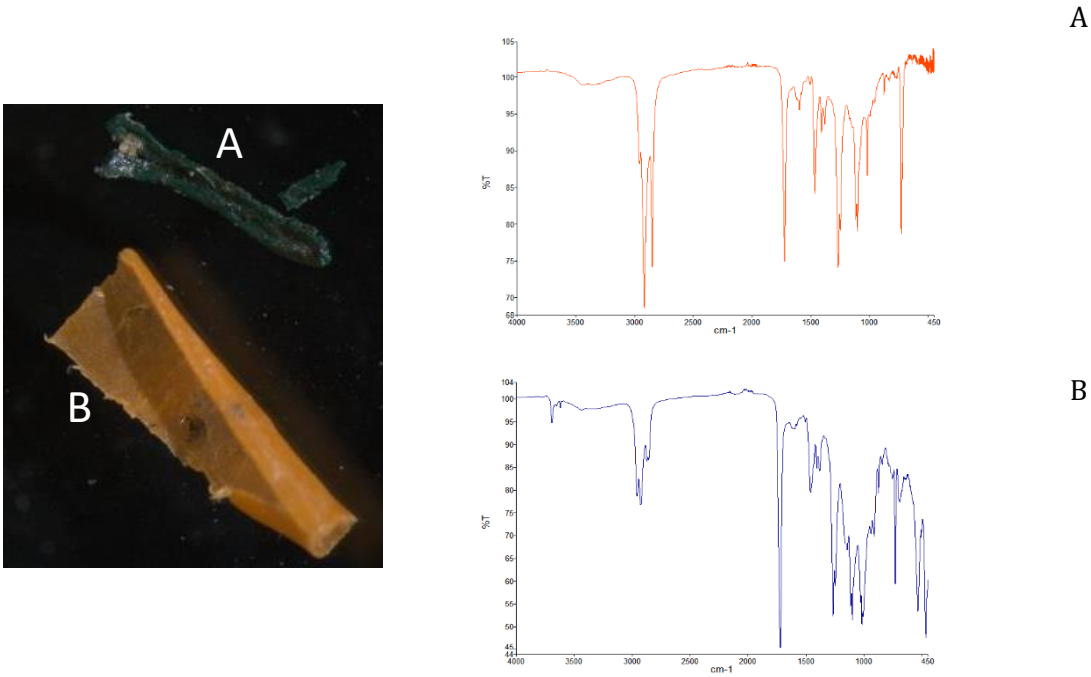


**Figure A3.1.** Two MPs from Maren without a satisfactory spectral library match using ATR-FTIR, and therefore categorized as unidentified polymers.

# Appendix 4

Table A4.1. Results of microlitter in sediment > 300 µm and 50-300 µm per g dry weight (ML/g d.w.) divided into microplastics (MP/g d.w.), other anthropogenic particles (OA/g d.w.), and fibers (F/g d.w.).

| **ID** | Size (µm) | **Dry weight (g)** | **Water content (%)** | **Date** | **# MP** | **# OA** | **# F** | **MP/g d.w.** | **OA/g d.w.** | **F/g d.w.** | **ML/g d.w.** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B | > 300 | 40 | 85 | 7/11 | 4 | | 26 | 0.10 | | 0.65 | 0.75 |
| B | 50-300 | 40 | 85 | 7/11 | 1 | | 4 | 0.03 | | 0.10 | 0.13 |
| S | > 300 | 36 | 80 | 7/11 | 15 | 2 | 50 | 0.42 | 0.06 | 1.40 | 1.87 |
| S | 50-300 | 36 | 80 | 7/11 | 18 | | | 0.50 | | | 0.50 |
| Ig | > 300 | 8.8 | 97 | 7/11 | 7 | | 31 | 0.80 | | 3.51 | 4.30 |
| Ig | 50-300 | 8.8 | 97 | 7/11 | 6 | | | 0.68 | | | 0.68 |
| Ha | > 300 | 16 | 92 | 8/11 | 9 | | 28 | 0.56 | | 1,73 | 2.29 |
| Ha | 50-300 | 16 | 92 | 8/11 | 1 | | 3 | 0.06 | | 0.19 | 0.25 |
| Hi | > 300 | 21 | 79 | 8/11 | 6 | | 19 | 0.29 | | 0.90 | 1.19 |
| Hi | 50-300 | 21 | 79 | 8/11 | 2 | | | 0.10 | | | 0.10 |
| O | > 300 | 53 | 70 | 8/11 | 10 | 1 | 25 | 0.19 | 0.01 | 0.47 | 0.68 |
| O | 50-300 | 53 | 70 | 8/11 | 4 | | | 0.08 | | | 0.08 |