BLASTIC

PLASTIC WASTE PATHWAYS INTO THE BALTIC SEA

Results and experiences from the plastic litter monitoring in the BLASTIC pilot areas

Project	BLASTIC - Plastic waste pathways into the Baltic Sea
Work package	WP3 Results from plastic litter monitoring in the pilot areas
Preparation date	2018-12-21
Prepared by	IVL : Kalle Haikonen and Anna Fråne SEIT : Harri Moora and Evelin Piirsalu SYKE: Outi Setälä and Stjepan Budimir

Interreg Central Baltic

European Union
European Regional Development Fund

Contents

1. Executive Summary

This document is prepared within the BLASTIC project (Plastic waste pathways into the Baltic Sea). The project was supported by EU Interreg Central Baltic (2016-2018). The overall aim is, by mapping and monitoring marine plastic litter, to facilitate the reduction of the inflows of plastic litter and of hazardous substances into the Baltic Sea.

Plastic litter is a prominent environmental problem as almost everywhere, not only in urban environments, you can find plastic debris in some form. Marine plastic litter is anthropogenic plastic waste that has been discharged into the coastal or marine environment. Marine plastic litter have been shown to have a great potential to harm marine wildlife and ecosystems. Its negative effects on the marine environment have prompted not only governments but also, environmental groups and citizens to take action.

The monitoring of marine plastic litter is important not only in order to acquire knowledge about know how much plastic is already in the marine environment but it is also important in order to know how much plastic is being discharged into the oceans. The idea within BLASTIC was to develop a cost efficient, flexible and scalable method for monitoring of riverine plastic discharge. The method of floating litter booms was chosen as litter booms collect the floating litter which then can be quantified, categorised and analysed, which is considered to be a major strength of this method. It was designed with the intention of producing high quality, robust data sets while being flexible in regards to the purpose of the monitoring. The methodology for riverine litter monitoring was developed and tested at four different pilot areas within the BLASTIC project. The methodology and experiences gained from the methodology testing are described in this in this document.

The three project partners that reported results (IVL, SEIT and SYKE) had different experiences and the floating litter booms worked better in some sites than others. The physical conditions of the monitoring site are of great importance when monitoring with floating litter booms. All monitoring was in some way affected by either the width of the river, weather conditions such as wind and/or water flow rate/direction. Based on the experiences from the monitoring in the pilot areas the conclusion by the project members is that the floating litter boom methodology is suitable in narrow rivers with a continuous water flow and a high frequent sampling rate is recommended to obtain high quality data sets.

2. Background and aim of monitoring plastic macrolitter in BLASTIC

The monitoring of plastic litter or litter in general, can have multiple purposes. Monitoring can for example be carried out as a mean of verifying the sources and pathways identified as "hot spots" from a desktop study. It could also have the purpose to control if implemented measures to decrease littering have had the desired effects and/or it can be used for awareness-raising means. The awareness-raising purposes could for example be to demonstrate how much plastic litter or litter in general that originates in general or from specific areas or events in the city during a given period of time.

Monitoring of plastic litter in BLASTIC plastic was carried out in Work Package 3: Monitoring of plastic litter. The aim of monitoring macroplastic litter in BLASTIC was twofold:

1. To develop and practically test a monitoring methodology suitable for the Baltic Region.

2. To monitor the pilot areas contribution of plastic marine plastic macro litter in to the Baltic Sea.

3. Monitoring methodology development

A literature screening review of existing methodologies for monitoring marine plastic macro litter was conducted in or order to see where the methodology development in BLASTIC could fill some gaps.

It has been estimated that the annual input of plastic waste from rivers to the oceans is between 1.15 and 4 million tonnes. with the majority of these emissions occurring between May and October (Lebreton, Van der Zwet et al. 2017, Schmidt, Krauth et al. 2017). However, even if it's well known that rivers are a major pathway of the plastic input to the world's ocean, not much actual monitoring has been performed. Most studies have focused on measuring microplastics (<5mm) by either using manta trawls (Yonkos, Friedel et al. 2014, Dris, Gasperi et al. 2015, van der Wal, van der Meulen et al. 2015), stationary drift nets, Neuston nets (Lechner, Keckeis et al. 2014, Rech, Macaya-Caquilpán et al. 2015, Vianelloa, Acrib et al. 2015) or by pumping water through a fine mesh filter (Zhao, Zhu et al. 2014). All these methods are limited by the volume of water that can be sampled which becomes an issue when sampling for macroplastics. The concentration (item / dm^3) of macro plastics has been shown to be significantly lower than the concentration of microplastics (Lebreton, Van der Zwet et al. 2017), hence it is important to be able to sample a large volume of water to get good quantitative results. The area of macroplastic riverine monitoring is not well explored and as all pilot areas (Södertälje. Turku. Helsinki and Tallinn) in the BLASTIC project have rivers flowing through them the project group decided to focus on the development of a method for riverine plastic litter monitoring.

3.1. Method

Measuring riverine plastic can be performed in several different ways and depending on where in the river (water column, river bank or riverbed) the plastic is to be measured; the monitoring methods will differ greatly. Another factor that affects the monitoring method is what size fraction (micro. meso or macro plastics) is to be measured.

The idea was to develop a cost efficient, flexible and scalable method that could monitor a large volume of water in order to get quantitative results of the amount and composition of macroplastic litter in the water column of a flowing river. As visual observation methodology protocols for floating plastic litter and beach litter already exist (Cheshire and Adler 2009, Ryan, Moore et al. 2009, Directive 2013) and as seabed monitoring was considered by the project group not to be cost efficient, it was decided to develop a method to monitor the water surface and column. The method of floating litter booms was chosen as litter booms collect all the floating litter which then can be quantified, categorised and analysed, which is considered to be a major strength of the litter booms. It is designed with the intention of producing high quality, robust data sets. The method is flexible in regards to the purpose of the monitoring, it can be for scientific purposes if standardizing the sampling or it can be simplified to work in e.g. awareness projects. Also the litter booms stop the litter from reaching the ocean, in contrast to e.g. visual surveys. Litter/trash/debris-retention booms are already being used in some rivers to stop litter from reaching the ocean. The debris-retention systems that are made for collecting floating litter are often large, expensive, not very flexible in regards to moving them around and they are used in rivers with a high load of floating litter such as Seine and Thames (Gasperi, Dris et al. 2014, Morritt, Stefanoudis et al. 2014). The floating litter boom methodology described within BLASTIC is less expensive, easy to deploy, easy to scale in size, flexible in regards to where it can be placed and easily moved. The original idea was to monitor upstream and downstream the city centres in all pilot areas to get an indication of the contribution to marine plastic littering from urban areas. This was not practically possible at all locations.

3.2. The floating litter boom

The floating litter boom creates a barrier where floating litter is trapped. As over 2/3 of all produced plastics have lower density than water (Yeo, Muiruri et al. 2017) it has the potential to float. However both the shape and density of the plastic will affect the plastic items buoyancy and hence affect where in the water column of the river that the litter will be. For example flexible, film-like litter, tends to stay mixed in with the water column while more dense plastics without trapped air pockets may sink and travel along the river bottom if not completely embedded in sediment. However if the more dense plastic package has air trapped in it (like a PET bottle) then it may float on the surface. The floating litter boom method focuses mainly on measuring the surface water (top 0.5m) but the boom can advantageously be supplemented with different net curtains to increase the sampling depth. In the BLASTIC project different kind of set-ups where tested.

The floating litter booms used within BLASTIC were modified cylindrical containment booms (Sjuntorp C500). The general area of use for these booms is to contain oil and/or chemical spills or protect areas against floating contamination agents. As the C500 was designed for rapid and easy deployment and several booms could be connected to get a desired length they were chosen for the project. The booms were modified with additional loops so that net curtains easily can be connected to them.

Figure 1. Litter booms (C500) equipped with net curtains.

3.3. Net curtains

As the focus of this project was macro plastics (>2.5cm), net curtains with a mesh size of about 8 mm were chosen. Net curtains with different mesh size can be connected if one wants to monitor other size fractions of plastic litter. The mesh size of about 8 mm was chosen so that the nets would catch cigarette buds and that mesh size was not expected to clog too fast with organic material. A smaller mesh size could have been chosen but that was expected to require more effort in terms of monitoring, as fine mesh nets would clog faster and thus require more attention. So to simplify the monitoring design we tested a mesh size around 1cm, which was thought to be adequate to catch a good sample of cigarette butts, candy wrappers etc. while allowing a longer sampling time than a net with smaller mesh size. The height of the net curtain can be modified to suit the monitoring site. Different net curtains where used throughout the project.

3.4. Sample size

Depending on what the results of the monitoring are to be used for (quantitative scientific data. monitoring the results of implemented measures towards reducing riverine litter or public awareness), the setup may vary greatly. The more variable the data is the more repetition is needed to achieve an acceptable level of accuracy and precision. If the monitoring is to be used for a scientific publication or to monitor the effects of implemented measures against litter, multiple sampling sessions are needed in order to produce high quality data. But if the monitoring is to be used to raise awareness in an environmental campaign then fewer samples may suffice.

When starting to monitor in a specific area that has no prior monitoring, the general lack of quantitative data regarding litter quantities makes it difficult/impossible to predict how long sampling duration and sampling repetition is needed to obtain high quality results. The needed sampling repetition and sampling duration will be site specific which means that pilot sampling is recommended.

The main task in WP3 was to develop and test a method for riverine plastic litter. The floating litter boom method was chosen. The various partners in the project have performed the monitoring in a few different ways as the physical characteristics of the different sites differ in several ways such as river width, flow rate, depth, changes in current direction, exposure to wind etc.

Based on everyone's experiences, we provide in the end of this report some basic recommendations regarding how the monitoring should be performed.

3.5. Initial test of equipment

Prior to the actual monitoring a pre-trial test of the monitoring set up was performed. The aim of the initial test was to deploy one 10 meter floating litter boom equipped with a net curtain in open water and to examine what was required for the deployment of the litter boom and for the monitoring in general. The test was carried out in Pilgrundet Mälaren in Stockholm county, Sweden (59.302526. 17.878758). The seabed was soft bottom (clay) and the depth at the test site was about 10-12 meters.

The deployment was carried out by two persons in a Cresent Cosmos 450 with a 30 HP outboard engine. The litter boom was a Sjuntorp C500 with a 1.2m net curtain with 8.5mm mesh hanging from the bottom of the litter boom. To moor the litter boom two grapnels were used: one 10 kg grapnel and one 8 kg grapnel.

3.5.1. Experiences

A 10m C500 litter boom weighs about 35-40 kg in total and is quite bulky. The boat used was only 4.5m long and it was too small to be able to perform an effective deployment in open water. If the litter boom is to be deployed completely from a boat then a crew of three persons is recommended: one person to operate the boat and two persons who work with the litter boom. Also it’s recommended to use a boat bigger than used in this initial test (4.5x1.7m) if deployed in open water. A boat that is at least 6x2m in size is recommended if one litter boom that is ten meters is being deployed. If one end of the boom is being moored to a fixed point at shore or a fixed point in the water (e.g. a concrete foundation) then a smaller boat can be used. One end of the litter boom is advantageously anchored in the fixed point first. The other end can then be towed to a desired location and moored accordingly.

The first version with a net curtain hanging down at the bottom of the litter boom created big gaps between the net and the litter boom, as the loops where the net was attached was at the bottom of the litter boom. As plastic and other debris may “leak” through theses gaps during the monitoring and retrieval of the boom another solution to attach the net curtain was considered.

The grapnels used for the mooring of the litter booms were too heavy in this pre-trial. Grapnels with the weight of 8 and 10 kg were tested. The size of the grapnels will be depending of factors that are site specific (bottom substrate and speed of the current) and the size of the litter boom. At this specific site with a soft bottom grapnels weighing 6 kg would have sufficed for the 10 meter boom. The rope length between grapnel and boom is recommended to be at least twice the depth of the water.

3.6. Test of setup

Before the monitoring started in each pilot area, the project team members from IVL, SEIT and FEEE Latvia gathered in Södertälje on the 5th of May 2017 to test and go through the equipment together. The equipment was tested in practice by attaching net curtains to the booms and by placing the booms in the water. Questions regarding practical issues such as how to handle the booms in the water and how to attach the net curtains and the anchors to the boom were discussed and practically tested. It was decided that the equipment set-up would differ depending on the pilot area and the local circumstances. This was considered beneficial as the aim was to develop and test a monitoring methodology and its suitable variations depending on local circumstances. Lessons learned from testing of equipment setup were:

- It is important to bring landing nets to capture the litter when retrieving up the booms.
- Chains at the end of the net curtains are needed to keep the nets in place.
- The mesh size of the net curtains should not exceed 15 mm. The mesh size used during the test was 8.5 mm.

Figure 2. Test of the equipment setup in Södertälje.

4. Monitoring in Södertälje, Sweden

Monitoring in the city of Södertälje was carried out during three different occasions: July 2017. September 2017 and August 2018. Each monitoring session lasted about seven days. The study area was Södertälje channel (which runs through Södertälje City) and Hallsfjärden which is a bay in the Baltic Sea that follows Södertälje channel. Södertälje channel is one of eight outlets from the lake Mälaren (Sweden's largest lake) to the Baltic Sea. A floodgate located in the middle of Södertälje channel separates Mälaren from the Baltic Sea. The aim of the monitoring was to test the litter boom method and to measure riverine plastic litter upstream and downstream of Södertälje City. A total of four different sites with slightly different conditions were selected for the test (Figure 3). Details about the four different sites can be found in table 1. The only method used in these tests was monitoring with litter booms (with and without net curtains).

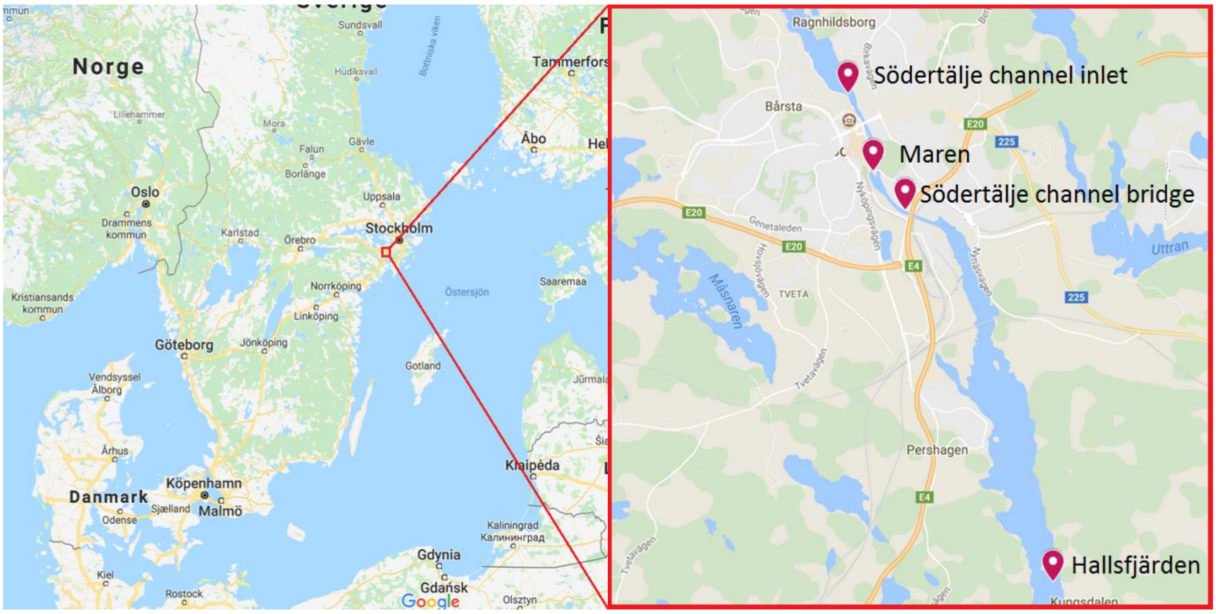

Figure 3. The monitoring sites in Södertälje city.

Table 1. Monitoring session and location details in Södertälje

	Test period	Location	Coordinates (WG S84 Decimal)	Flowmeter	Site depth (m)	Site width (m)
Boom 1	170710 – 170718	Hallsfjärden	59.12519. 17.68770	2030R	6 – 6.5	550
Boom 2	170711 – 170718	Channel inlet	59.20465. 17.62246	2030R	3 – 7	160
Boom 3	170907 – 170914	Channel bridge	59.18563. 17.64055	2030R	2 - 3	65
Boom 4	170907 – 170914	Maren	59.19197. 17.63042	2030R	2 - 3	33
Boom 5	180813 – 180820	Maren	59.19197. 17.63042	N/A	2 – 3	33

4.1. Monitoring session 1 – July 2017

The first monitoring session was performed during July 2017. Two sets of 20m booms that were equipped with net curtains which hanged down to a depth of 1.5 m meter from the water surface were used. Two 10 m booms were interconnected to each other using the integrated interlocking system in the booms in order to get one 20 m boom. Marking buoys were attached to the mooring anchors in order to enable identification of their position and to simplify their retrieval. One flowmeter (General Oceanics 2030R) was attached to each boom set. The flowmeter was attached at two points (one above and one below the flowmeter) to the rope of a marking buoy at a depth of approximately of 1 m.

Two sites were tested: Hallsfjärden (Boom 1) and Södertälje channel inlet (Boom 2). Details about the two sites can be found in Table 1. Details about equipment and environmental factors can be seen in table 2.

Boom 1 was deployed approximately seven days and Boom 2 approximately six days.

Figure 4. Grapnel anchors with marking buoys.

Figure 5. Litter boom with net curtain

Table 2. Setup summary of monitoring session 1 in Södertälje

	Equipment	Length (m)	Net curtain	Mooring	Monitoring duration (days)	Water flow (m^3/s)	Precipitation
Boom 1	Litter Boom	20	Yes	Anchors	7	N/A	No
Boom 2	Litter boom	20	Yes	Anchor+fixed	6	N/A	No

4.1.1. Boom 1 - Hallsfjärden

Boom 1 was placed in Hallsfjärden**,** which is the most northern part of a bay of the Baltic Sea that is located in the municipality of Södertälje (Figures 6 and 7). The monitoring location was a relatively narrow part (550m wide) of Hallsfjärden approximately 8.5km downstream from the floodgate in Södertälje channel. Boom 1 one was placed close to a shallow next to a shipping lane. Due to heavy shipping in Hallsfjärden it was not possible to place the litter boom in the middles of the bay. The depth at the site was about 6 m. Boom 1 covered about 3.5% of the total width of the bay at that location. Boom 1 was moored approximately 140-160 m from shore on soft bottom sediment.

Boom 1 was deployed on the 10th of July 2017 and was retrieved seven days later on the 17th of July 2017.

Figure 6. Boom 1 map.

Figure 7. Boom 1 deployed in Hallsfjärden

4.1.2. Boom 2 - Södertälje channel inlet

Boom 2 was placed in the inlet of Södertälje channel about 1.4km upstream from the floodgate and the city center (Figure 8 and 9). The water above the floodgate belongs to Lake Mälaren. Due to heavy shipping it was not possible to place the litter boom in the middle of the channel why it was placed on the shore side of the channel, stretching from 10 to 30m from the shore. The depth at the site ranged between 3-7m. Boom 2 covered a total of about 13% of the width of the channel (~160m) at that location. The end closest to shore of Boom 2 was moored using an anchor (on soft bottom sediment) and the other end was moored to a fixed concrete foundation about 30m from shore.

Boom 2 was deployed on the 11th of July 2017 and was retrieved seven days later on the 17th of July 2017.

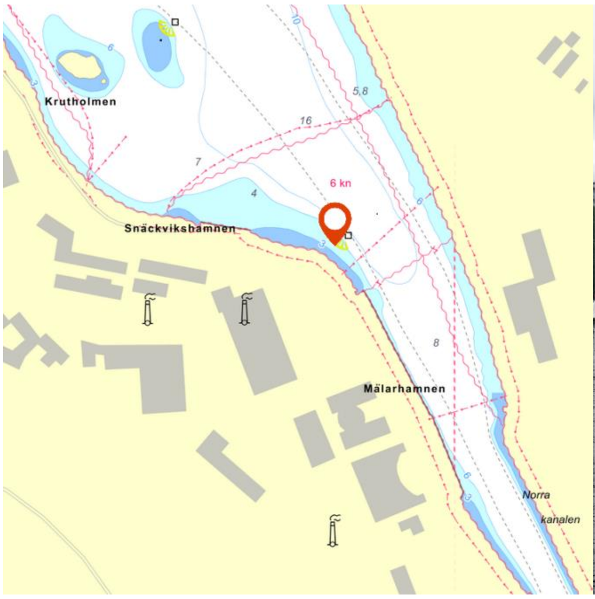

Figure 8. Boom 2 map.

Figure 9. Boom 2 deployed at Södertälje channel inlet.

4.2. Monitoring session 2 – September 2017

The second monitoring session was performed during September 2017. Two floating litter booms were used. Boom 3 was 10m and Boom 4 was 20m. Only Boom 4 was equipped with a net curtain (same as in session 1). The net curtain was excluded on Boom 3 in order to test how much easier it would become to deploy and retrieve it.

Two sites were tested: Södertälje channel bridge (Boom 3) and Maren (Boom 4). Details about the two sites can be found in Table 3. Details about equipment and environmental factors can be seen in table 3.

Both booms were deployed approximately seven days.

Table 3. Setup summary of monitoring session 2 in Södertälje

	Equipment	Length (m)	Net curtain	Mooring	Duration (days)	Water flow (m^3/s)	Rain	Flow-meter
Boom 3	Litter Boom	10	No	Fixed	7	N/A	No	Yes
Boom 4	Litter boom	20	Yes	Anchor+Fixed	7	N/A	No	Yes

4.2.1. Södertälje channel bridge – Boom 3

Boom 3 was placed in Södertälje channel near the channel bridge about 0.9km downstream from the floodgate (Figure 10 and 11). The water downstream from the floodgate is considered to be the Baltic Sea. The litter boom was placed between the shore and a concrete foundation in the channel. Due to heavy shipping it was not possible to place the litter boom in the middle of the channel. The depth at the site ranged between 2-3m. Boom 3 covered a total of about 15% of the width of the channel (~67m) at that location. Boom 3 was moored at a fixed point at shore in one end and the other end was moored to a concrete foundation about 10m from shore.

Boom 3 was deployed on the 7th of September 2017 and was retrieved seven days later on the 14th of September 2017.

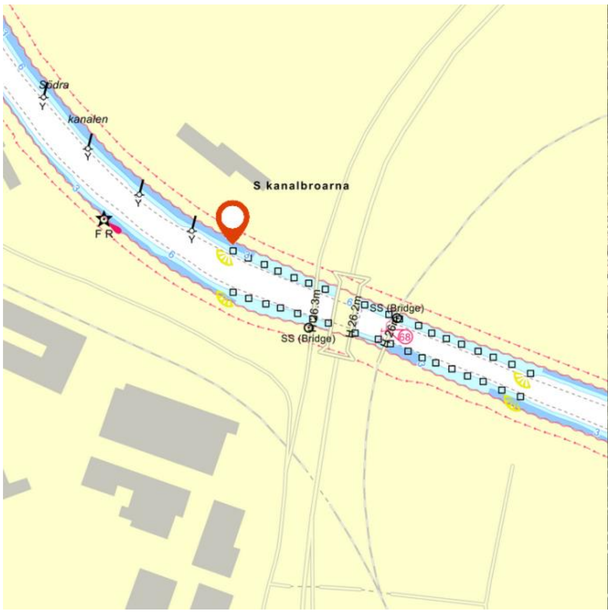

Figure 10. Boom 3 map.

Figure 11. Boom 3 deployed at Södertälje channel bridge.

4.2.2. Maren – Boom 4

Boom 4 was placed in a small outlet in central Södertälje City called Maren (Figure 12 and 13). This outlet runs parallel to the floodgate in the city center. There is no shipping or boat traffic in Maren so the litter boom could be placed in the middle. The depth at the site ranged between 2-3m. Boom 4 covered a total of about 60% of the width of Maren (~33m) at that location. Boom 4 was moored using anchor (on soft bottom sediment) in one end and the other end was moored to a fixed concrete foundation about 3m from shore.

The litter boom was located close to a footbridge, which resulted in a lot of attention from pedestrians and cyclists.

Boom 4 was deployed on the 7th of September 2017 and was retrieved seven days later on the 14th of September 2017. The boom was inspected on a daily basis, but the litter was only collected at the end of the monitoring period.

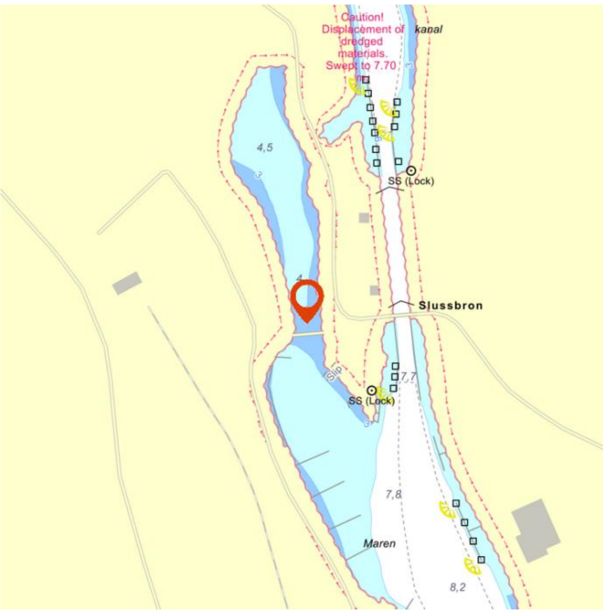

Figure 12. Boom 4 map.

Figure 13. Boom 4 deployed in Maren.

4.3. Monitoring session 3 – August 2018

The third and final monitoring session was performed during August 2018. One 30m (Boom 5) floating litter boom without net curtain was used and one site (Maren) was tested. The net curtain was excluded on Boom 5 in order to examine if it would make a difference in the composition of the litter captured compared to Boom 4 which also was used at the same site. No flowmeter was attached to the boom set as the previous monitoring session showed that the flowrate in Maren was too slow for the flowmeters to measure.

Details about the monitoring site can be found in table 1. Details about equipment and environmental factors can be seen in table 4.

The boom was deployed for approximately seven days.

Table 4. Equipment setup summary of monitoring session 3 in Södertälje

	Equipment	Length (m)	Net curtain	Mooring	Duration (days)	Water flow (m^3/s)	Rain	Flow-meter
Boom 5	Litter Boom	30	No	Fixed	7	N/A	No	No

4.3.1. Maren – Boom 5

Boom 5 was placed in the same location as Boom 4: a small outlet in central Södertälje City called Maren (Figure 14 and 15). This outlet runs parallel to the floodgate in the city center. There is no shipping or boat traffic in Maren so the litter boom could be placed in the middle. The depth at the site ranges between 2-3m. Boom 5 covered a total of about 90% of the width of Maren (~33m) at that location. Boom 5 was moored at two fixed points: one end was tied to a ladder at the edge of Maren and the other end was moored to a concrete foundation about 3m from shore.

The litter boom was located close to a footbridge, which resulted in a lot of attention from pedestrians and cyclists.

Boom 5 was deployed on the 13th of August 2018 and was retrieved seven days later on the 20th of August 2018.

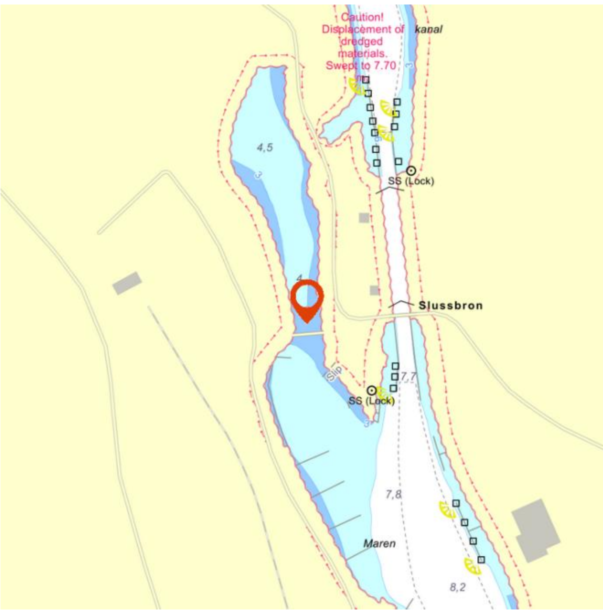

Figure 14. Boom 5 map.

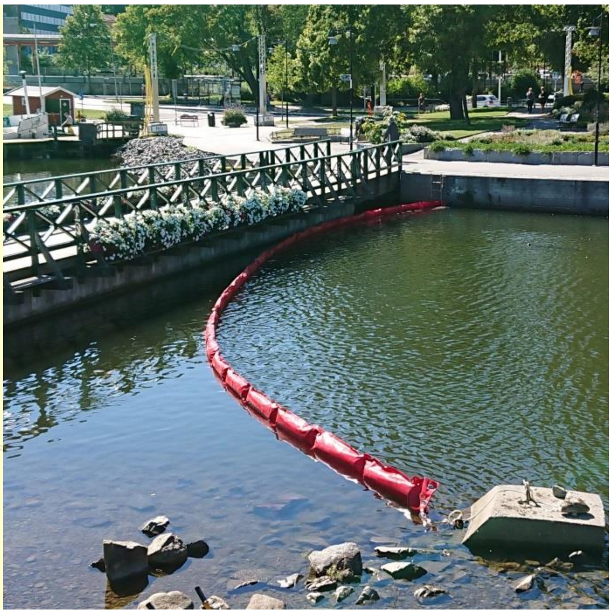

Figure 15. Boom 5 deployed in Maren.

4.4. Results of the monitoring in Södertälje city, Sweden

All monitoring sessions encountered problems that affected the results in some way. The moorings of two litter booms (Boom 1 and 3) were compromised, which resulted in a drastic changed in shape of the booms so that the booms could no longer capture any litter (see 3.5.1 and 3.5.3 for details). The moorings of Boom 2, 4 and 5 were not compromised. Litter was found in two booms (Boom 4 and 5). These booms were placed in Maren which lies in the city center of Södertälje. No litter was found in Boom 2, which was placed upstream of the city center. Flowmeters were used to measure the flowrate of the water at each site. However it was shown that the flowrate at all sites was too slow for the flowmeters (Oceanics 2030R) to measure. Another type of flowmeter is recommended if the flowrate is <10cm/sec.

4.4.1. Monitoring session 1 – July 2017

Boom 1 was placed in Hallsfjärden were it was very exposed to wind. One of the anchors of Boom 1 started at some point during the monitoring session to slip out of its position, why the boom was folded and was no longer able to capture any litter (Figure 16). This was probably due to the fact that the litter boom was exposed to strong winds that dragged the Boom out of position. The wind was significantly stronger than the water current and it was coming from other directions than the water current, hence blowing it out of position. The anchor that got out of its position might initially have landed on hard substrate and not soft substrate as planned. During the monitoring session the wind speed ranged between 0 - 8.4m/s. The strongest winds came from the West, while the current in the water was coming from the North. No litter was found in Boom 1.

The position of Boom 2 was not compromised in any way, it was found just as it was left. The boom and net curtain did catch organic material such as branches, leaves etc., but no litter of any kind was found. A brief visual observation of the river showed that the river appeared clear and not full of visible litter. In summary, no quantitative results of litter captured could be retrieved from monitoring session 1, valuable experience was gained.

Figure 16. One mooring point of Boom 1 came out of position resulting in a deformation of the litter boom. It was not able to capture any litter.

4.4.2. Monitoring session 2 – September 2017

Boom 3 and 4 were placed in locations that were much less exposed to wind compared to Boom 1 in Hallsfjärden. However Boom 3 did also have issues with the mooring. Boom 3 was placed in the Södertälje channel where big cargo ships pass. Boom 3 was moored in two fixed points: one at shore and one on a concrete foundation in the water. However the mooring point at shore was not secure enough so it came loose at some point during the monitoring. This was probably an effect of the big ships passing by. The ships displace large volumes of water that create backwash. These waves probably exposed the litter boom with so much force that the mooring in one end came loose. The flowmeter on Boom 3 broke during the monitoring. No litter was found in Boom 3.

Monitoring session 2 did however gain quantitative results. Boom 4 that was placed in Maren in central Södertälje stayed uncompromised during this monitoring session and did capture litter during the seven days that it was deployed. The litter captured is shown in Figure 17. The quantity of different types of litter items is shown table 5. The protocol developed in BLASTIC was used to categorize the litter (Appendix 1).

The total number of litter captured was 376. The majority of the litter found consisted of cigarette butts (57%). sweet wrappers (10%). unidentified soft plastics (10%). and unidentified rigid plastic pieces (4%) (Figure 18). "Other non-plastic litter items" mostly consisted of paper and cardboard. In addition to macroplastic debris, a large amount (thousands) of polystyrene beads was sticking on to the boom. These beads were less than 5 mm diameter and are defined as microplastics. These beads were not quantified as microplastics are not included in this study.

Figure 17. Litter captured in Boom 4.

Table 5. The results of the second litter monitoring session in Södertälje.

	Boom 4
Waste category	**Items**
Total Plastic	**360**
Cigarette butts and filters	**215**
Cigarette packs and plastic wrappers	**14**
Sweet wrappers	**38**
Plastic bags	**6**
Straws	**4**
Unidentified soft plastics (e.g. film)	**39**
Unidentified polystyrene pieces	**15**
Unidentified rigid plastic pieces	**23**
Other plastic items	**6**
Other non-plastic litter	**16**
Total Litter	**376**

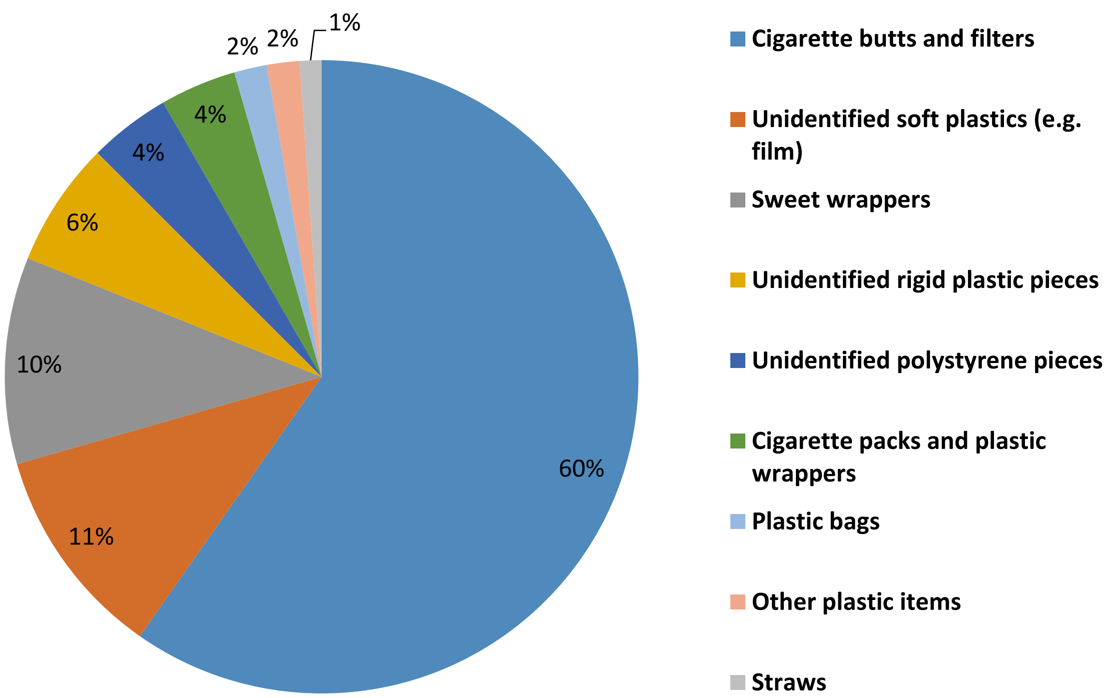

Figure 18. The share of plastic litter items collected from Boom 4.

4.4.3. Monitoring session 3 – August 2018

Boom 5 was placed in the same location as Boom 4: Maren in central Södertälje. This location was chosen again because it was easy to deploy here, it was protected from winds and it was the only site where we had actually captured any litter. The shape of the boom stayed uncompromised and it did capture litter during the monitoring session. When we returned to litter boom after seven days to retrieve the captured litter and the boom, we were surprised by the small amount of litter that we found. When we left it in place seven days earlier we had already observed litter being captured in it, after just having been deployed about 20-30 min. When we returned seven days later there was not much more litter in it than when we left it. The litter in the boom was retrieved using a landing net. The litter was placed in a plastic bag which was placed near us at shore when we started to retrieve the boom from the water. When we were finished we went back to collect the litter, but it was gone. Someone had probably picked up the litter bag and taken it with them.

5. Monitoring in Tallinn, Estonia

5.1. Description of monitoring sites

Monitoring of plastic litter in Estonia was carried out during three different occasions: July 2017, September 2017 and May 2018 at two locations in Tallinn; Pirita River and Mustjõe River (Figure 19). The duration of the monitoring sessions differed between 2-3 days. The main aim of the monitoring was to test the litter boom method and to measure riverine plastic litter in the two rivers. However the physical conditions at two different sites differed significantly, different set ups were used for the monitoring. The set-ups are further described in Chapter 4.1.1 (Pirita River) and Chapter 4.1.2 (Mustjõe River) and the details about the two sites can be found in table 6.

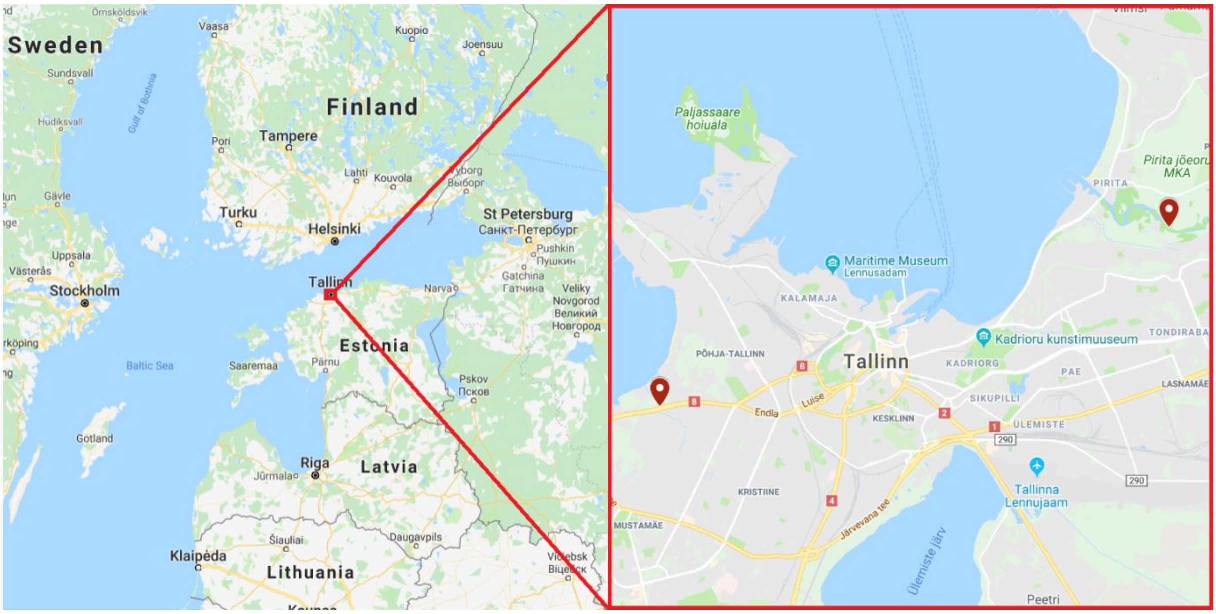

Figure 19. Monitoring sites in Tallinn city.

Table 6. Monitoring session and location details.

Session	Test period	Location	Coordinates (WG S84 Decimal)	Flowmeter	Site depth (m)	Site width (m)
1	170707 – 170709	Pirita Site 1	59.46059. 24.85516	Yes	1	20
2	170918 – 170919	Pirita Site 1	59.46059. 24.85516	Yes	1	20
3	180501 – 180503	Pirita Site 2	59.46485. 24.83433	No	2.5	40
1-3	170707 – 170709	Mustjõe river	59.42857. 24.67763	Yes	0.25-0.5	2.5

5.1.1. Monitoring on Pirita River – Sessions 1, 2 and 3

The Pirita River is a 105 km long river in northern Estonia that drains into Tallinn Bay (part of the Gulf of Finland) in Pirita city district. Tallinn. The basin area of the Pirita is 799 km² and average water flow rate is $8 m^3/s$. The river flows mainly through forests and other green areas, where human settlements are sparse. Also in Tallinn city territory the river flows mainly through green and recreational area.

The Pirita river monitoring was carried out in two locations: one (Pirita Site 1) approximately 2.7 km upstream from the river mouth (Figure 20-21) and the other (Pirita Site 2) approximately 1 km upstream from the river mouth (Figure 22-23). The part of the river that is close to city border is too shallow for the litter booms and the river mouth does not suit for boom monitoring due to boat traffic and the influence of currents and sea-level changes. The first and second monitoring sessions were carried out at Pirita site 1 and the third monitoring session was carried out at Pirita site 2.

During the first and second monitoring sessions the litter boom was used. The boom was inspected two times per day during the monitoring periods. In each monitoring period the boom covered approximately 50 percent of the river width. All floating litter items which were trapped in the boom were collected. Items larger than 2.5 cm were counted and categorized according to the BLASTIC checklist.

Figure 20. Pirita Site 1 map.

Figure 21. Installing of the boom set at Pirita Site 1.

During the third monitoring session a fyke net was used instead of the litter boom. The fyke net was used by the Marine Institute (Tartu University) to monitor and assess the salmon and sea trout population in the river. The fyke net had two 10 m long wings (litter caching area length was 20 m). The net covered approximately 50 percent of the river width.

The fyke net was inspected once per day during the monitoring period. All floating litter items trapped in the booms or fyke net were collected and the items larger than 2.5 cm were counted and categorized according to the BLASTIC checklist (Appendix 1).

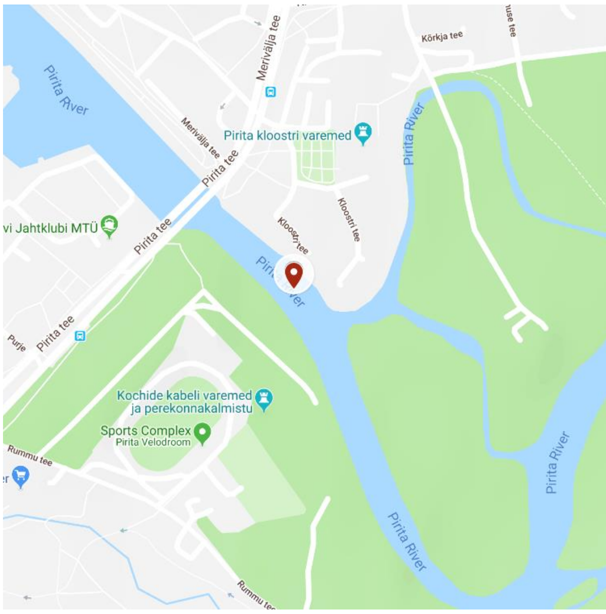

Figure 22. Pirita Site 2 map.

Figure 23. Set up of the fyke net at Pirita Site 2.

In addition to monitoring with booms and fyke net, a visual monitoring on the Pirita River was carried out in two periods: 3rd of July 2017 and 25th of September 2017. During both periods visual survey of floating litter was carried out (in both time ca 3 hours) in different spots in the river. No floating litter was observed.

Details about the monitoring sites can be found in table 6. Details about equipment and environmental factors can be seen in table 7.

Table 7. Setup summary of monitoring session 1-3 in Pirita River Tallinn.

	Equipment	Length (m)	Net curtain	Mooring	Duration (days)	Water flow (m^3/s)	Rain	Flow-meter
Pirita 1	Litter Boom	10	No	Fixed	3	8.99	No	Yes
Pirita 2	Litter Boom	10	No	Fixed	2	8.99	No	Yes
Pirita 3	Fyke net	20	Yes	Fixed	3	8.99	No	No

5.2. Monitoring on Mustjõe River

The Mustjõe River is a small 1.8km long stream which drains into Kopli Bay (part of the Gulf of Finland) in Tallinn. The basin area of the Mustjõe is 13.9km². Most of the riverbed is tangled or regulated and works as a rainwater/runoff water drainage. Runoff mainly flows through underground pipe networks and ditches to the Mustjõe natural channel. The land use within the catchment is mainly residential with detached houses and apartment buildings upstream the channel. Industrial and commercial areas are dominant features in the downstream side within the catchment.

The Mustjõe River was chosen to monitor the type and amount of litter that is typically discharged to the sea through the rainwater drainage system in Tallinn city. The monitoring took place in a location ca 550m from the stream mouth. Monitoring was carried out in three sessions.

Figure 24. Mustjõe site map.

Figure 25. Set up of the net trap in the Mustjõe river.

The net trap was used during all three monitoring sessions. The net covered the whole stream (see Figure 25).

The net was inspected two times per day. All litter items that were trapped in the net were collected, counted and categorized according to the BLASTIC checklist.

Details about the monitoring site can be found in table 6. Details about equipment and environmental factors can be seen in table 8.

Table 8. Setup summary of monitoring session 1-3 in Mustjõe River Tallinn.

	Equipment	Length (m)	Net mesh (mm)	Mooring	Duration (days)	Water flow (m^3/s)	Precipitation	Flow-meter
Mustjõe 1	Net trap	2.5	7	Fixed	3	0.18	No	Yes
Mustjõe 2	Net trap	2.5	7	Fixed	3	0.18	No	Yes
Mustjõe 3	Net trap	2.5	7	Fixed	3	0.18	No	Yes

5.3. Results from the monitoring in Tallinn city, Estonia

5.3.1. Pirita River

The results of three monitoring periods on Pirita River indicate that the amount of the floating litter is the highest in spring period (see Table 9). During the summer and autumn monitoring period only a few items were collected in each monitoring day. During the spring period the daily average litter amount collected was around 80 pieces. This clearly indicates that most of the litter is carried to the sea (via the Pirita River) in spring time.

Table 9. The results of litter monitoring in Pirita River (daily average litter weight in grams and number of litter items).

	Summer (Site 1)		**Autumn (Site1)**		**Spring (Site 2)**	
Waste category	**g**	**items**	**g**	**items**	**g**	**items**
Total Plastic	0.4	**2.0**	5.7	**3.0**	240.7	**78.7**
Cigarette butts and filters	0.4	**2.0**	0.4	**2.0**	7.7	**37.7**
Crisps packets/sweet and ice cream wrappers	0.0	**0.0**	0.0	**0.0**	3.0	**9.0**
Foam insulation and packaging (2.5-50 cm)	0.0	**0.0**	0.0	**0.0**	10.0	**7.7**
Food containers incl. fast food containers	0.0	**0.0**	5.0	**0.5**	36.7	**2.3**
Plastic bags	0.0	**0.0**	0.0	**0.0**	7.0	**9.0**
PET bottles	0.0	**0.0**	0.0	**0.0**	83.7	**2.0**
Bottle caps and lids	0.0	**0.0**	0.0	**0.0**	6.7	**2.7**
Unidentified rigid plastic pieces	0.0	**0.0**	0.0	**0.0**	2.7	**4.3**
Plastic cutlery	0.0	**0.0**	0.3	**0.5**	1.7	**1.0**
Other plastic items	0.0	**0.0**	0.0	**0.0**	81.7	**3.0**
Glass (bottles)	93.3	**0.3**	0.0	**0.0**	430.7	**1.7**
Paper/cardboard	0.0	**0.0**	0.0	**0.0**	0.3	**0.3**
Rubber	0.0	**0.0**	0.0	**0.0**	1.7	**0.3**
Metal	1.0	**0.3**	0.0	**0.0**	0.0	**0.0**
Other materials	2.7	**0.3**	0.0	**0.0**	0.0	**0.0**
Total Litter	97.4	**3.0**	**5.7**	**3.0**	**673.4**	**81.0**

The plastic items constitute the highest share of the floating river litter (96%). The other materials (glass, paper/cardboard, rubber and metal) are represented below 2% of the total number of captured items.

The cigarette butts make up the highest share of the specific items collected. Half plastic litter items (50%) were cigarette buds (Figure 26). The other litter items collected were mainly related to food and drinks usage (packaging) – plastic wrappers, plastic bags, food containers and PET bottles. The items may originate from the nearby recreational areas. Also fragments of plastic foam made up a high share of the collected litter items (9%). Most of the foam plastic represented the common construction insulation material (Figure 27). This indicates that improper handling and collection of this material/waste in construction sites is a significant source for plastic litter in Tallinn.

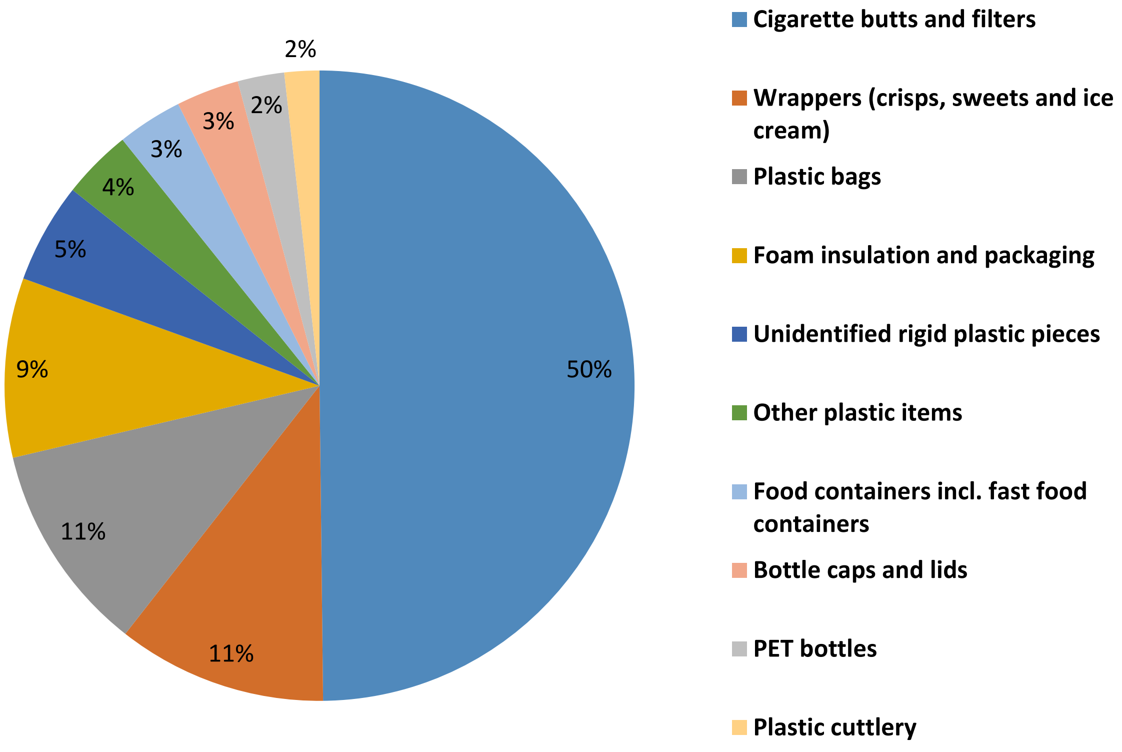

Figure 26. The share of plastic litter items collected (total amount of items) from Pirita River.

Figure 27. Example of plastic litter collected during the monitoring in Pirita River.

5.4. Mustjõe River

The results of three monitoring periods on small Mustjõe River also indicate that the amount of the floating litter is the highest in spring period (Table 10).

Table 10. The results of litter monitoring in Mustjõe River (daily average litter weight and number of litter pieces).

	Summer		Autumn		Spring		Average	
Waste category	**g**	**pcs**	**g**	**pcs**	**g**	**pcs**	**g**	**pcs**
Total Plastic	24.4	**37.3**	28.8	**79.0**	31.7	**113.3**	28.3	**76.6**
Cigarette butts and filters	3.9	**19.3**	11.1	**55.7**	20.0	**100.0**	11.7	**58.3**
Plastic bags	5.3	**8.3**	2.3	**5.3**	3.0	**3.0**	3.6	**5.6**
Crisps packets/sweet and ice cream wrappers	0.2	**1.3**	2.3	**5.7**	2.3	**5.0**	1.6	**4.0**
Foam insulation and packaging (2.5-50 cm)	4.0	**6.7**	10.7	**10.0**	3.3	**3.0**	6.0	**6.6**
Plastic cutlery	0.0	**0.0**	0.7	**1.0**	0.7	**0.7**	0.5	**0.6**
Food containers incl. fast food containers	0.0	**0.0**	0.0	**0.0**	1.3	**1.0**	0.4	**0.3**
Bottle caps and lids	0.0	**0.0**	1.7	**1.3**	1.0	**0.7**	0.9	**0.7**
Unidentified rigid plastic pieces	9.3	**0.3**	0.0	**0.0**	0.0	**0.0**	3.1	**0.1**
Other plastic items	1.7	**1.3**	0.0	**0.0**	0.0	**0.0**	0.6	**0.4**
Paper/cardboard	0.0	**0.0**	0.0	**0.0**	1.3	**1.0**	0.4	**0.3**
Total	24.4	**37.3**	28.8	**79.0**	33.0	**114.3**	28.7	**76.9**

The result of the litter monitoring in Mustjõe river clearly indicates that the collected items are very characteristic for the rainwater/runoff discharge (see also Figure 28).

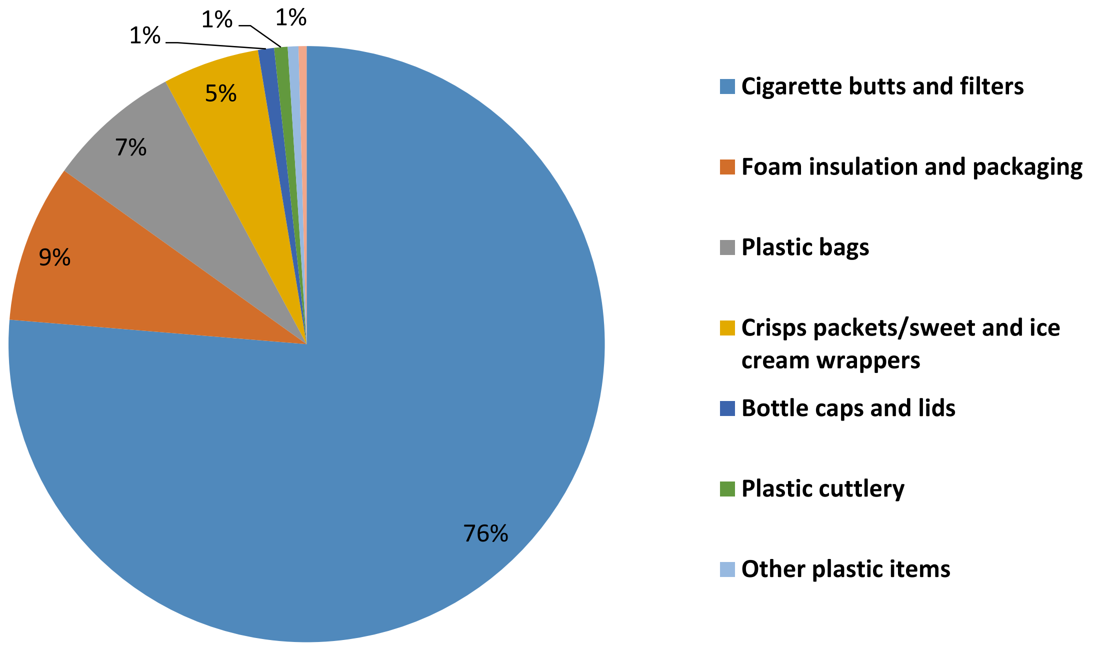

Figure 27. The share of plastic litter items collected (total amount of items) from Mustjõe River. Categories with a share >1% are not presented.

Figure 28. Examples of plastic litter collected during the monitoring in Mustjõe River.

Basically all collected litter fragments were plastic items (only a few paper items were collected during the monitoring periods). The most common litter items were cigarette butts (made up 76% of collected items) followed by small pieces of insulation foam (9%). fragments of plastic bags/film (7%) and wrappers (5%) (Figure 27*).* Other plastic litter categories formed already less than 1% of the average collected litter items.

6. Monitoring in Turku and Vantaa, Finland

Monitoring in the city of Turku was carried out at two occasions in river Aurajoki, in July and August 2017 and at one occasion in river Vantaa on the southern coast of Finland in April 2018. The aim of the monitoring in river Aurajoki was to test different methods for carrying out riverine macrolitter monitoring. The methods chosen were: litter collection with litter booms and bottom traps (in July 2017) and litter booms and visual monitoring with binoculars (in August 2017).

In April of 2018 the monitoring was carried out at the tributary of the river Vantaa, southern coast of Finland. The method used was the same as in the previous year (litter booms), with the exception that no bottom traps were installed. An addition to the year 2018 monitoring was that the water flow was measured daily at the sites where the booms were deployed. The primary aim of was to repeat the boom monitoring to see if its results could be improved based on the experiences from the monitoring the river Aurajoki in in 2017. The second aim was to study if this monitoring method would reveal differences in the amount and type of the collected litter type between the two river branches that were investigated.

Table 11. Monitoring session details for Aurajoki

	Test period	Location	Coordinates (WG S84 Decimal)	Flowmeter	Site depth (m)	Site width (m)
Boom Upstream	170725 – 170730	Aurajoki	60.4534. 22.2756	Yes	2-2.5	32
Boom Downstream	170725 – 170730	Aurajoki	60.4470. 22.2632	Yes	2-2.5	62
Visual Downstream	170830 – 170901	Aurajoki	60.4470, 22.2644	No	2-2.5	62

6.1. Site-description and set-up – River Aurajoki, Turku

The whole river Aurajoki is 70 km long with a catchment area of 874 km². In average it is 50 m wide and rather shallow. In the center of the city of Turku, where the river runs, it is only 2-2.5m deep. Based on available statistics the city of Turku had 187 988 permanent habitants at the end of March 2017. Turku is a touristic city with several yearly festivals and other events. Based on the numbers of nights spent in Turku area, there were almost 500 000 tourists during the summer season 2016. In addition to that, daily travelers or tourists with some other accommodation than registered (e.g. recreational boaters) visit Turku.

The first monitoring session was carried out between the 25th and 30th of July 2017. During this period there were two particularly visible events: Down By the Laituri (DBTL) rock music festival which took place approximately 1 km from the city center and the Europeades (a folk music and dance festival), which was held at the banks of the river where performance platforms were set. Over 40 000 people visited DBTL and 6 500 performers took part in the Europeades, thus the first monitoring period represented a highly touristic season in the city. The second monitoring session was carried out between the 30th of August and 1st of September 2017, after the schools had begun in Finland and the high touristic season was over.

6.1.1. Monitoring with floating booms

The first monitoring in July focused on the use of booms as litter traps, and visual survey of floating litter which was done only once during this survey period. Two sets of booms were placed in the river; upstream and downstream. The upstream boom was placed in front of the Turku cathedral, which is far less exposed to on-site littering by the city inhabitants and tourists than the downstream monitoring site, which was situated in the vicinity of tens of bars and restaurants located a few meters on the river bank. Close to the downstream boom site there were also a few floating restaurants (ships) permanently parked in the river and small ferries trafficking in the river. The river banks in the city center are popular sites for having picnic, especially for the young people. The distance between the upstream and downstream booms was ca. 1.0km (Figure 29).

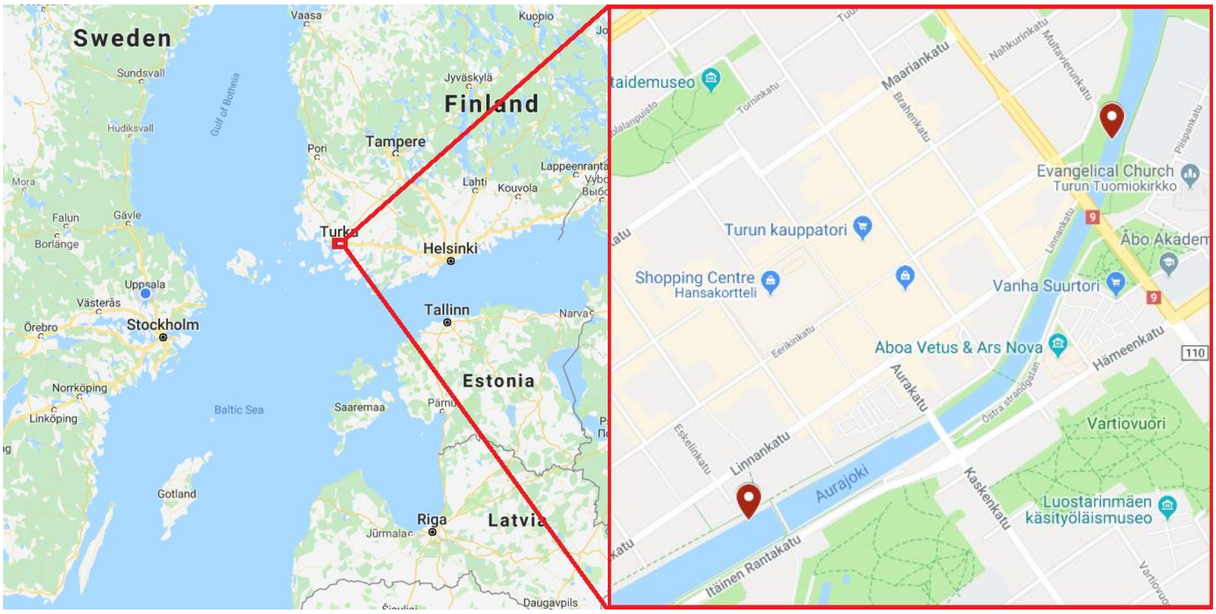

Figure 29. Monitoring sites in Turku city.

Both boom sets consisted of 2x10m boom segments. The upstream booms were placed in the middle of the river by anchoring them to the bottom, where they formed a U–shaped litter trap (Figure 31). A steel box (50 cm x 30 cm; mesh size ca. 0.5 cm) for collecting litter items from the water flow on the bottom of the river was also placed in the middle of the boom sets.

Figure 30. Aurajoki upstream site map. ***Figure 31. Upstream boom deployed in Aurajoki***

The location of the downstream booms was after bridge called Theater Bridge (Teatterisilta). The downstream booms were placed on the side of the river, anchored to the bottom from one end and attaching it to the river wall from one end (Figure 33). Because of the frequent traffic by city ferries and leisure boats it was not possible to deploy it in the middle of the river. Not only the booms, but especially anchoring ropes could have caused problems. The boom was covering about 12-15 meters of total 60 meters width of the river.

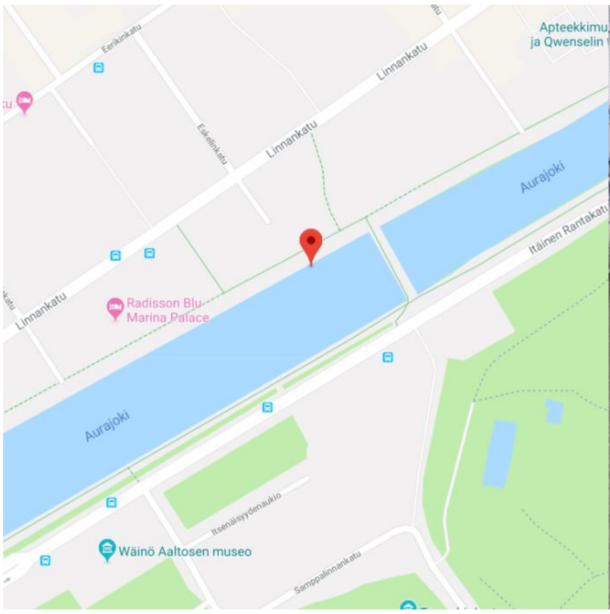

Figure 32. Aurajoki downstream site map.

Figure 33. Downstream boom deployed in Aurajoki. Photo: Pekka Kotilainen.

Both booms were inspected daily between 9:00 and 10:00 in the morning, and between the 26th and 29th of September 1they were inspected an additional time between 19:00-21:00 in the evening. A total of 9 inspection events where litter was collected were performed. All litter items that were trapped in the booms and bottom cages were collected and the items larger than 2.5 cm counted and categorized according to the BLASTIC checklist.

Figure 34. Collection of litter accompanied by Finnish TV. Photo: Outi Setälä.

6.1.2. Visual monitoring

Visual monitoring was carried out during the first (July 2017) and second (August 2017) monitoring sessions. Visual monitoring was carried out by standing on a selected bridge and counting all anthropogenic particles floating by that were detected. Binoculars were used to identify the items. In July 2017 the visual monitoring was carried out once from the Theater Bridge, in order to compare the visual monitoring results with the downstream boom results. The second monitoring session (end of August – beginning of September 2017) was performed by visual monitoring only, from the same bridge (Theater Bridge). The first visual monitoring was performed once by two people for 30 minutes. The second visual monitoring was performed during three days, three times a day spending 60 minutes per monitoring occasion.

6.1.3. Environmental conditions

The main regulating factor of the river Aurajoki is the difference between sea water level and the water level in the river itself. Water level in the center of the city is very close to seawater level, thus it does not have a constant downstream flow. Wind direction, rain and the observed countercurrent also affect the water flow. The changes in the sea level in Turku take place rapidly (Figure 35). In general, July in Turku was rainy. The deviation in the precipitation compared to the average (1981 – 2010) was 31%. However during the July survey period heavy rain took place only once (28/7). During the first day of the July survey there was 3-5m/s wind and downstream flow but after that the water movement ceased, wind turned and countercurrent took place. During the visual survey the water flow was visually observed as slow but downstream.

Turku

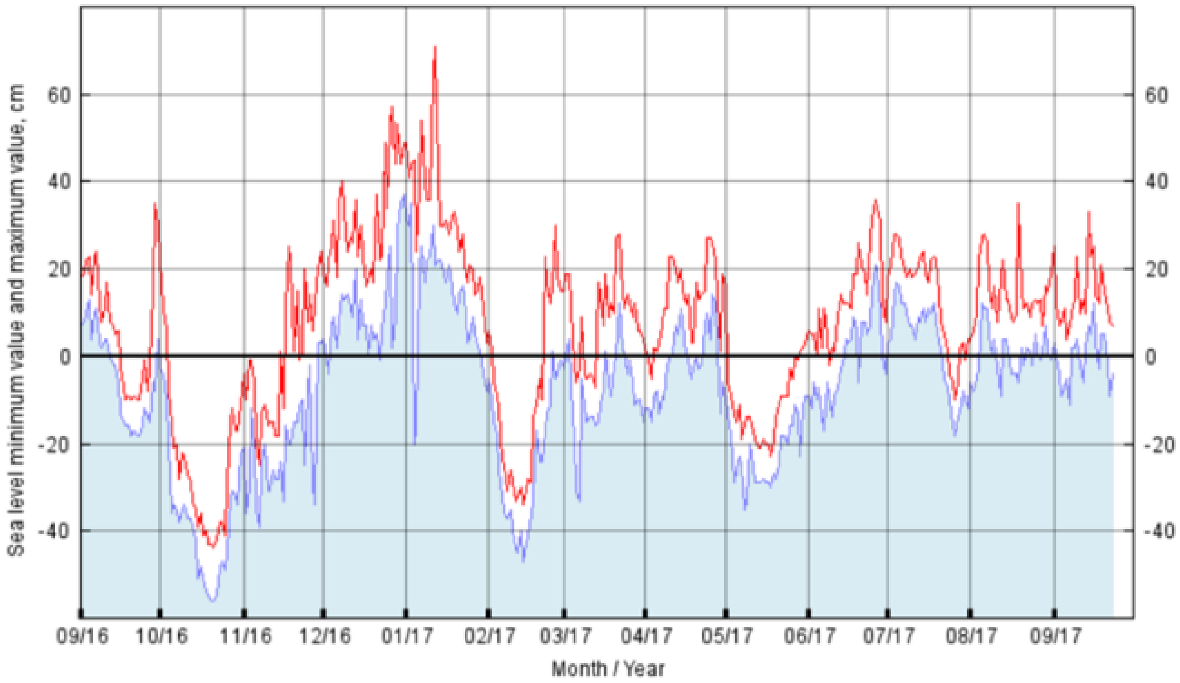

Figure 35. Sea-level minimum and maximum values in Turku between September 2016 and 2017.

In overall the water flow was slow for most of the survey periods. Because of the slow water flow of the river with its changing character, the flow meters turned out not to be an option for describing the river flow. Attempts were made to study the behavior of the river with 2 simple methods: 1) with a GPS tracker and 2) by deliberately placing litter (in this case 0.5L PET-bottles) into the river and following their route. The GPS tracker (Yepzone) was placed in a white waterproof plastic cylinder (ca. 20 x 10 cm) and thrown into the river from two bridges. First attempt was performed from a bridge (Tuomaansilta) about 800m upstream from the upstream booms. The second attempt was performed a bridge about 100m downstream from the upstream boom. Both attempts failed when the cylinder was trapped in the vegetation of the riverbanks. After that the PET bottles were used instead. Altogether 5 plastic bottles were marked and placed in the river next to the upstream boom. They were placed in line perpendicular to the river in the numerical order so bottles 1 and 5 were placed next to the river banks and number 3 in the middle of the river. The next day they were looked for. From the 5 bottles 3 were found. No. 1 and 5 were found ca 500m downstream and number 2 was close to its original site. Numbers 3 and 4 were not found. No bottles were found in the booms. To conclude: no measurements of the changing flow of the river were successfully made.

6.2. Site description and set-up – River Vantaa

Vantaa is in total 99 kilometers long and is between 10 to 50 meters wide. The flowrate of the river is highly variable; between 1.4-317m^3/s. depending not only of the season but also location of the river. As such it is one of the major rivers of the southern parts of Finland with a catchment area of 1 685km^2. It flows through the densely populated areas and discharges into the Gulf of Finland in the metropolitan area of Helsinki, more precisely to the bay Vanhakaupunki (Figure 36). It is estimated that approximately 1.1 million people live around the river and its catchment area.

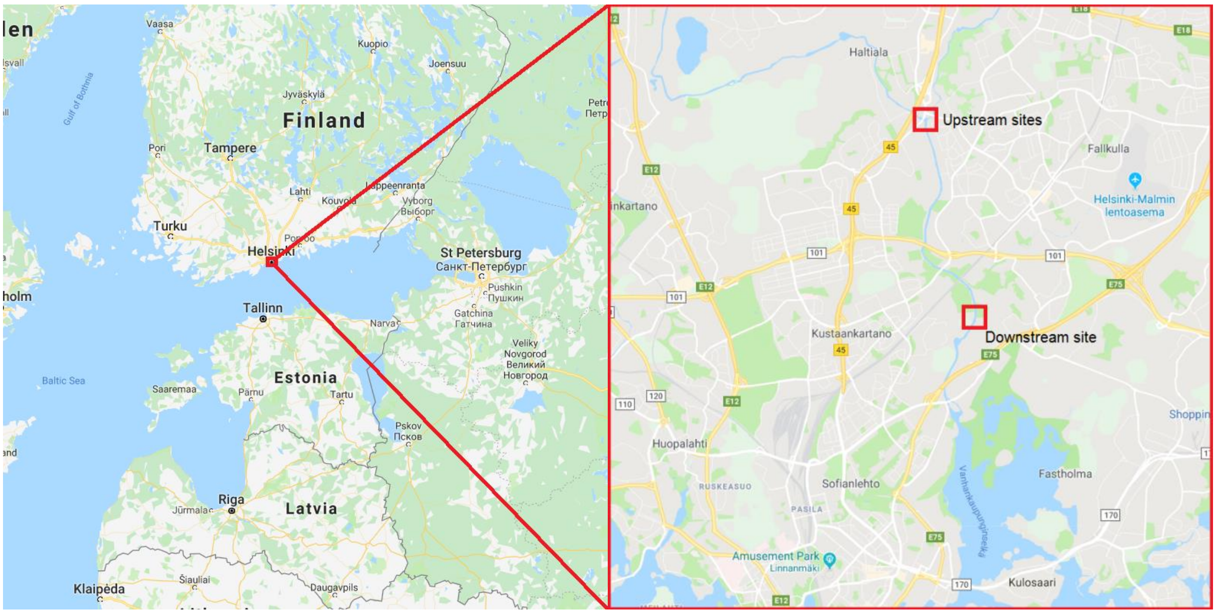

Figure 36. The monitoring sites (upstream Vantaa and Kerava branches and downstream Veräjämäki.

Monitoring was partly carried out on the border of two cities; Helsinki and Vantaa at two upstream sites and one downstream site in Helsinki. The upstream sites were located at two river branches just before their junction (Figure 37). The last few kilometers before the junction the two branches pass through rather different landscapes. The branch of (Vantaa) flows through an agricultural area and the other branch Kerava through a densely populated urban area (Tikkurila), with >40 000 inhabitants. The depth of the river during the monitoring was approx. 2.5m in both branches. The width of the Vantaa branch was 3 times the width of the Kerava branch. The downstream site (Veräjänmäki) was located approximately 2km south from the upstream monitoring site. The maximum depth of the profile in Veräjämäki was 4m.

Table 12. Monitoring session details for Vantaa, Kerava and Veräjämäki.

	Test period	Location	Coordinates (WG S84 Decimal)	Flowmeter	Site depth (m)	Site width (m)
Vantaa Upstream	180424 – 180426	Vantaa	60.2646, 24.9725	Yes	2.5	47
Kerava Upstream	180424 – 180426	Kerava	60.2649, 24.9757	Yes	2.5	14
Veräjämäki	180424 – 180426	Vantaa	60.2311, 24.9897	Yes	4	36

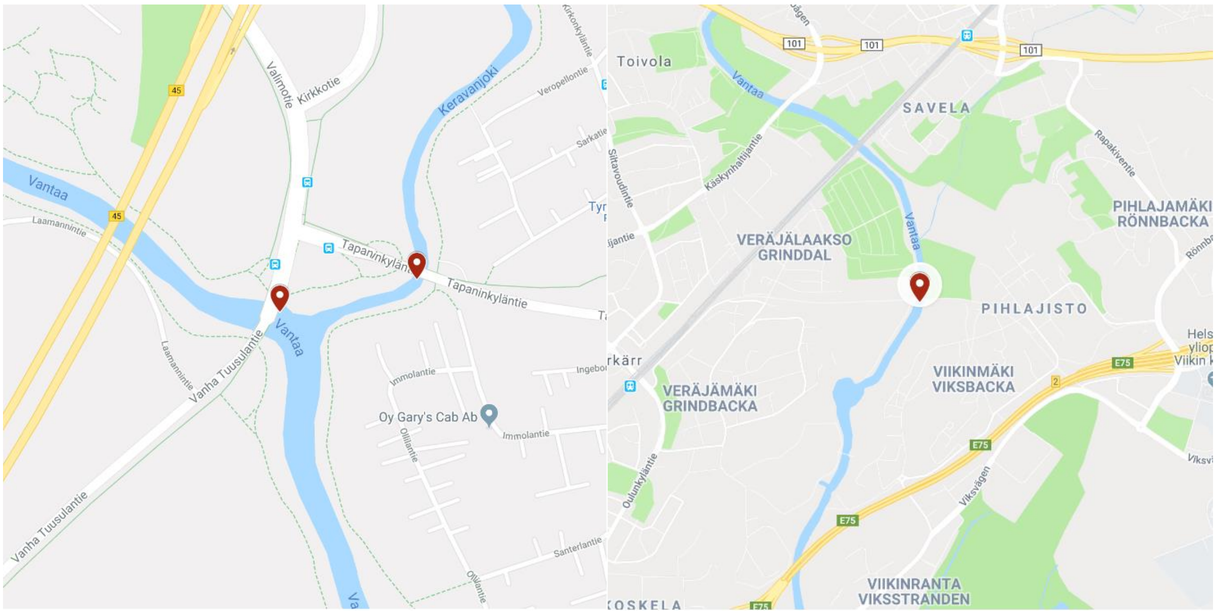

Figure 37. In the left picture: The upstream sites (Vantaa and Kerava). In the right picture: The downstream site (Veräjämäki).

For the monitoring of floating litter, one 10m long boom per study site was deployed (Figure 38). The booms were inspected daily between the 24th and 26th of April). Litter from the booms was collected, counted and categorized by material and item. The water current profile at each location was measured each morning on the days of litter collection with an Acoustic Doppler Current Profiler (ADCP –device). ADCP measures water currents with sound by using a principle of the Doppler effect.

Figure 38. The upstream boom at the Kerava branch. Photo: Outi Setälä.

6.3. Results from the monitoring in Turku and Helsinki, Finland

6.3.1. River Aurajoki

In overall there were 9 collection events, two times a day for four days and one in the morning of the last day. In the upstream boom at 6 times the boom was empty, two times it collected litter on its wrong side because of upstream flow. Downstream boom collected items in 5 morning events and 3 evening events. The first two survey days the river flow was downstream after which the water movement ceased and the booms were facing upstream position. Because of the wind and upstream flow litter was not collected efficiently to the booms. However, cigarette butts were present on the last day (Sunday) morning in high quantities in the downstream boom. The litter captured per day in the downstream boom is shown in Figure 39.

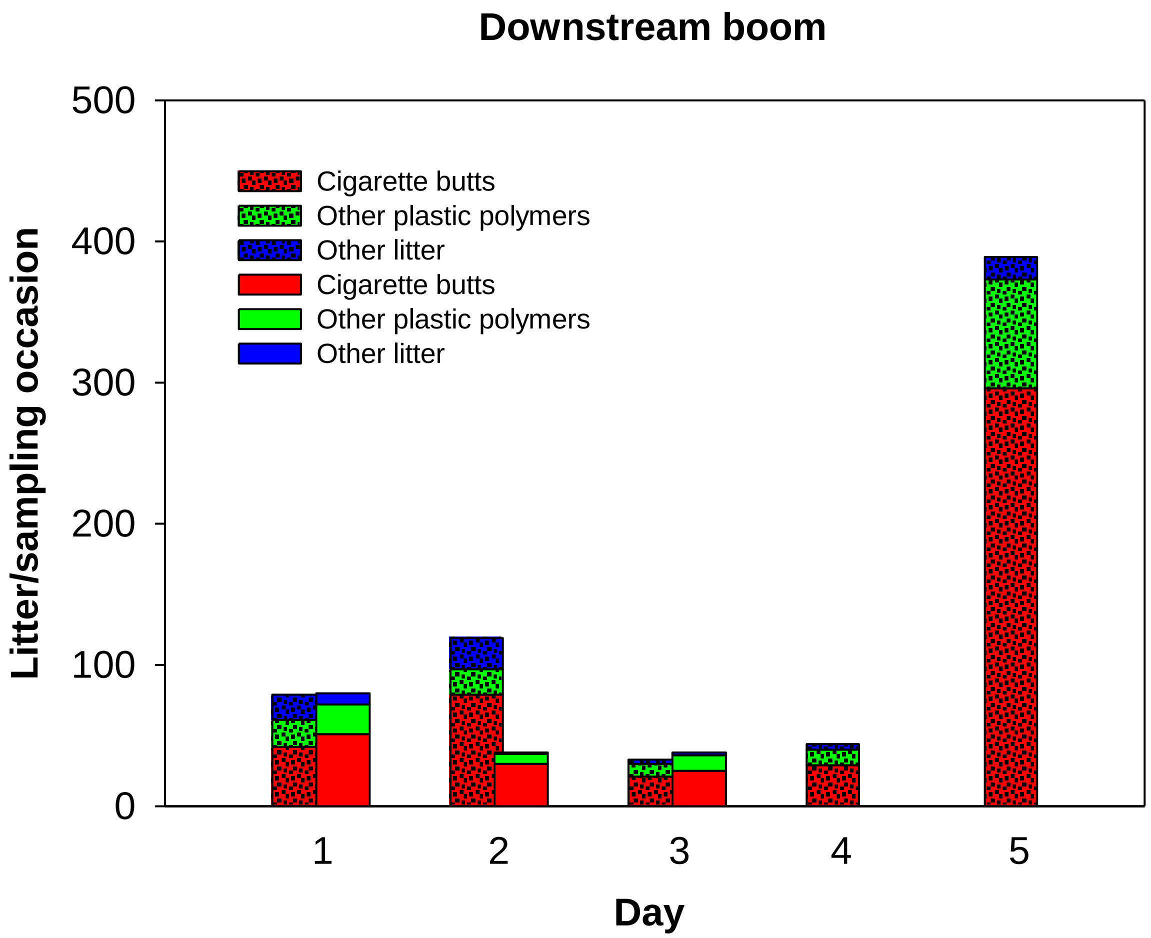

Figure 39. Litter collected by the downstream boom. Bars with dots: morning sampling. Bars without dots: evening sampling.

The downstream boom collected in average 64 items / event. The most common litter items were cigarette butts and aluminum drinking cans, usually beer cans. Most of the litter found was related to food, drinks and tobacco usage. During the whole survey time the upstream boom collected 25 litter items (incl. 16 cigarette butts).

The retrieval rate of the booms was not satisfactory and the use of booms for monitoring litter cannot be recommended in an environment like the river Aurajoki. It was a practical solution to place the downstream boom on the side of the river, but most likely this reduced its retrieval efficiency.

Another drawback was that comparison between boom catch, the actually the differences between pressured producing litter upstream and downstream cannot be done. In our case this was, however not the main issue. Since the booms were not very efficient for catching litter compared to the visual monitoring of floating litter in the river Aurajoki. The use of visual monitoring was tested in the close vicinity of the downstream boom in July during the high touristic season. From the results it is evident that by visual monitoring the number of monitored litter items is higher than by the booms. A 30 minutes visual monitoring session with binoculars in the city center gave in average 45 items (result of the monitoring by 2 persons) of which 32 were identified as being plastic (Figure 40). Cigarette butts were not included in the visual survey because of their small size. To compare: the highest number of litter collected from the booms was on the morning of the last day from the downstream boom when 389 litter items were counted, of which 296 were cigarette butts.

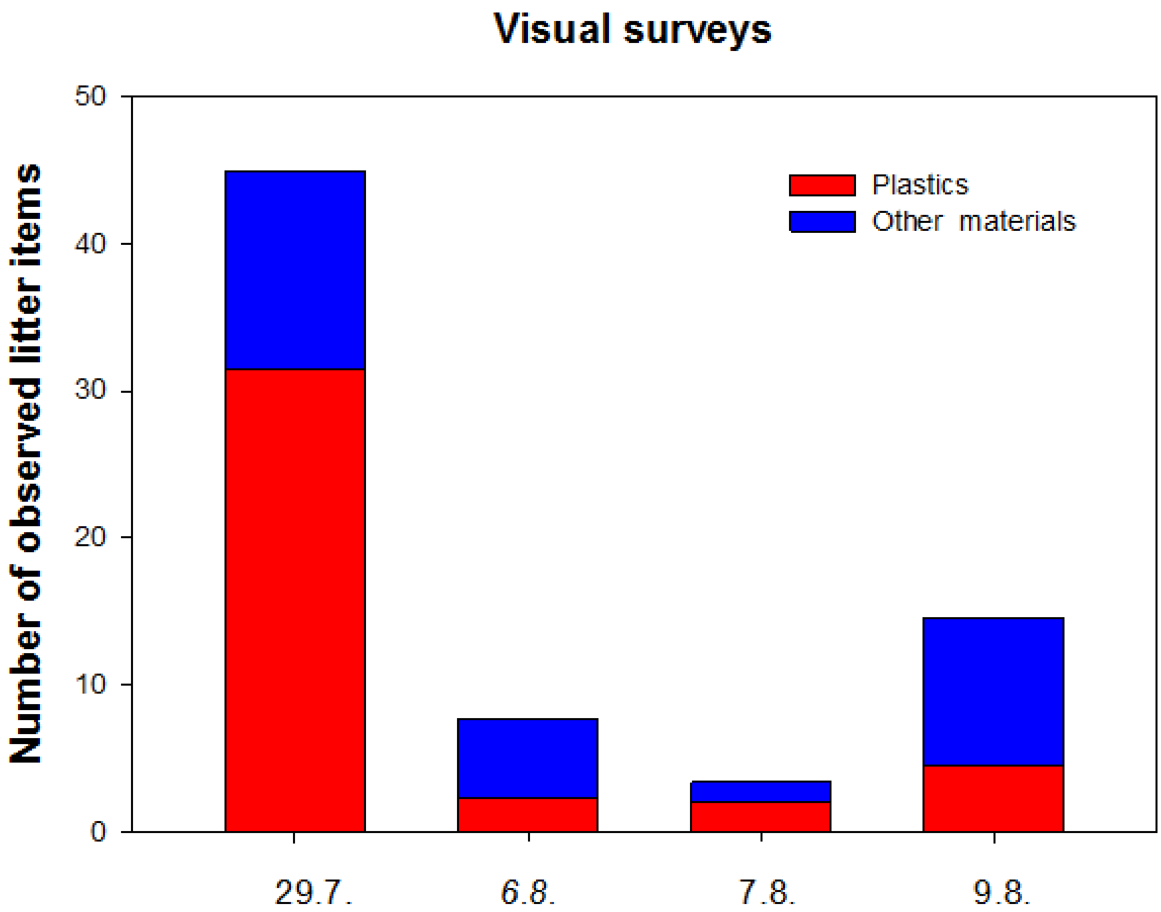

Figure 40. Visual monitoring of floating litter in the river Aurajoki.

The second survey was carried out by visual monitoring only. The off-season was clearly reflecting in the number of litter items found. During three days 62 items were counted (after 9 h of monitoring in total). One factor having an effect of the number of floating litter is improved litter management close to the river. The city of Turku placed collecting canisters for refundable aluminum drinking cans on the river bank after the first monitoring occasion. This may thus have lowered the number of the cans in the river. The bottoms cages did not capture litter, except for a few occasional items.

6.3.1. River Vantaa

In the year 2018 air temperatures below 0°C prevailed longer than in average years. After this period the temperatures rapidly increased and the thermal spring in the southern parts of Finland started. This resulted in fast melting of snow and elevated riverine water levels. This dynamics was also observed close to the discharge site of the river to the sea, where the water level fluctuated greatly within three weeks: 6.29 m (3rd of April). 7.11m (10th of April) and 6.49m (26th of April). Thus the high water level maximum took place two weeks before the deployment of the booms and had by then already lowered by 62 cm. During the high water period (7th to 22nd of April) the water discharge was between 45-70m^3/s at a regular monitoring site in Oulunkylä (500m upstream from the lower boom). Already by observing the amount of litter on the riverbanks it became obvious that the high water period was efficiently transporting various litter items, which were trapped on the river banks when the water level decreased (Figure 41).

During the monitoring period the average discharge of the branch of Kerava was 6.9-7.6m^3/s. which was around 27-30% of the discharge of branch of Vantaa. The average discharge of the branch of Vantaa varied between 24.6 to 25.6m^3/s

At Veräjämäki the average discharge of water during the monitoring was between 31.5-32.5 m^3/s.

Figure 41. Litter items on the riverbank at the junction of the two rivers.
Photo: Outi Setälä.

Most of the material which the booms had captured consisted of parts of various plants which were growing on the riverbanks. The suspended material of the river water formed large patches of foam to the boom (Figure 42).

Figure 42. Foam formed inside the boom during a 24h period (between two samplings). Photo: Outi Setälä.

This probably did not have any effect on the capturing efficiency of the booms. In overall the number of litter in the booms was minor: altogether only 119 items were obtained during the monitoring period (Table 13). From this amount 82% was collected from the upstream boom at the Kerava branch, flowing through the urban Tikkurila area. The share of foamed plastics (EPS) was high at the upstream sites. The prevalence of EPS was evident also on the riverbanks, where a high number of EPS which was identified as insulation material was found. At the downstream boom the overall number of captured litter remained small. It is likely that the litter items from the spring period had already accumulated on the riverbanks between the upstream and downstream sites, as probably also litter from previous years had accumulated. The amount of litter at certain sites at the riverbanks was too high and also seemingly aged to have derived there only during the last spring. This was also confirmed by the regular users of the river, such as kayakers who claimed that only a few weeks earlier the river was transporting not only floating ice and branches of trees and plants, but also lots of litter, especially plastics.

Table 13. The results of litter monitoring in Vantaa and Kerava River.

	Total number of litter	Foamed plastics	Foamed plastics (%)
Upstream Vantaa	8	7	87.5
Upstream Kerava	98	65	66.3
Downstream Veräjämäki	13	4	30.8
Total number of litter	119	76	30.8

7. Experiences and recommendations

7.1. Experiences and recommendations from the monitoring in Södertälje, Sweden

Before starting to monitor there are several things to consider in order to succeed with the monitoring and in order to save as much time as possible when preparing and deploying the booms.

7.1.1. Preparations

- If possible examine the flow pattern of the water before performing any monitoring. The water flow can be really slow, fast or even change direction. These are all variables that will affect how the monitoring set-up should look like in order to succeed.
- Investigate the upcoming weather conditions (currents. wind and precipitation). Strong winds increase the risk of changing the shape and position of the booms and litter can be blown away from the boom. Rain other precipitation can affect the results if there is an increased flow of storm water.
- If possible find a site in narrow part of the river with little to no traffic.
- If possible fins a site where at least one mooring point is fixed.
- Prepare as much as possible at shore (if the booms are to be deployed off shore. For example attaching net curtains on land instead of a boat is less time-consuming as requires a lot of space if to been done efficiently.
- Using plastic straps instead of ropes to attach the net curtain to the booms saves time. The drawback is that the plastic straps cannot be reused.

7.1.2. Deployment and retrieval

- A minimum of two people are required to prepare and place the booms. In monitoring session 1 two people prepared and deployed the booms while a third person maneuverer the boat.
- If anchors need to be used to attach the booms to the river bottom, make sure they are securely fastened to the bottom. If an anchor is not secure then both winds and current can change the position of the boom.
- When retrieving the booms from the water one must be careful that litter doesn't come loose and flow away with the current. If a net curtain is used it's preferably folded over the boom to capture the litter. Use a landing net to pick up litter in the water.

7.2. Experiences and recommendations from the monitoring in Tallinn, Estonia

The experiences with river monitoring in Tallinn (Pirita River) showed that the methods with floating booms and fyke net are suitable for monitoring easily floatable litter items. Also the net system for monitoring litter in the runoff discharge (Mustjõe River) gave acceptable results.

The possible observations are listed as follows:

- The relevant authorities have to be informed before the monitoring starts.
- Booms have to be fixed and set up in a proper way (preferably anchoring in the middle of the boom as well).
- It is important to choose a suitable monitoring location in the river (taking into account water flow/speed. river width. depth. etc.).
- The method (boom/net collection) is more suitable for narrow rivers.

- Monitoring in autumn period means that lot of leaves and other organic material get trapped and therefore it is difficult to separate the litter from the organic material. This could however be solved with more frequent cleaning/litter collection.

7.3. Experiences and recommendations from the monitoring in Turku and Helsinki, Finland

We conclude that the floating boom method, at least as how they were set-up, was not the best method for monitoring floating litter in Aurajoki. The water flow of the river is under the influence of many environmental factors, most importantly sea water level. Also in ideal conditions short counter stream occasions occurred, which can flush away the litter accumulated in the booms. Visual survey can be used as one option for monitoring floating litter in the Aurajoki River. But the drawback of this technique is its weakness in recognizing litter materials and small objects like cigarette butts.

The results from monitoring of litter in river Vantaa strengthen the experiences from the Turku monitoring in 2017 which underlined that care must be taken when the seasonal time frame for surface boom monitoring is being set. In the case on this monitoring in the tributary of the river Vantaa most of the litter had already passed the monitoring site. However, it would not have been possible to set booms in the river while there still was a lot of organic material like branches of trees and bushes and floating ice. It may be thus useful to implement other monitoring methods for areas which are subjected to the melting waters of snow and ice like in Finland it usually is the case. After monitoring floating litter at two relatively large rivers in Finland, we recommend using pragmatic visual observation of floating litter instead of deploying surface booms. The booms might, however be useful for monitoring surface litter in smaller river systems.

The monitoring could possibly be carried out at the highest water (=fastest water flow) immediately after the ice has melted but after the ice in order to avoid damaged the booms.

7.3.1. Recommendations for choosing the site for the boom installation

The booms were installed from a rubber row boat by two persons. The depth of the monitoring site was verified with a rope and a weight. Two lead weights of 20-25kgs were used to anchor each boom. Ropes were just slightly longer than the depth of the site. Monitoring sites were defined in advance. But as booms covered only part of the river, some known flow measurements could have been used as background information in order to place the booms wherein the flow was the fastest.

Figure 43 presents the river depth profiles at each boom deployment site. The images of the filtered water speed show how the river flow rate varies horizontally. Red color represents location of the highest flow rates and blue color indicates the slowest speed. In the case of this monitoring only the downstream boom was successfully placed at the site of the highest water flow rate.

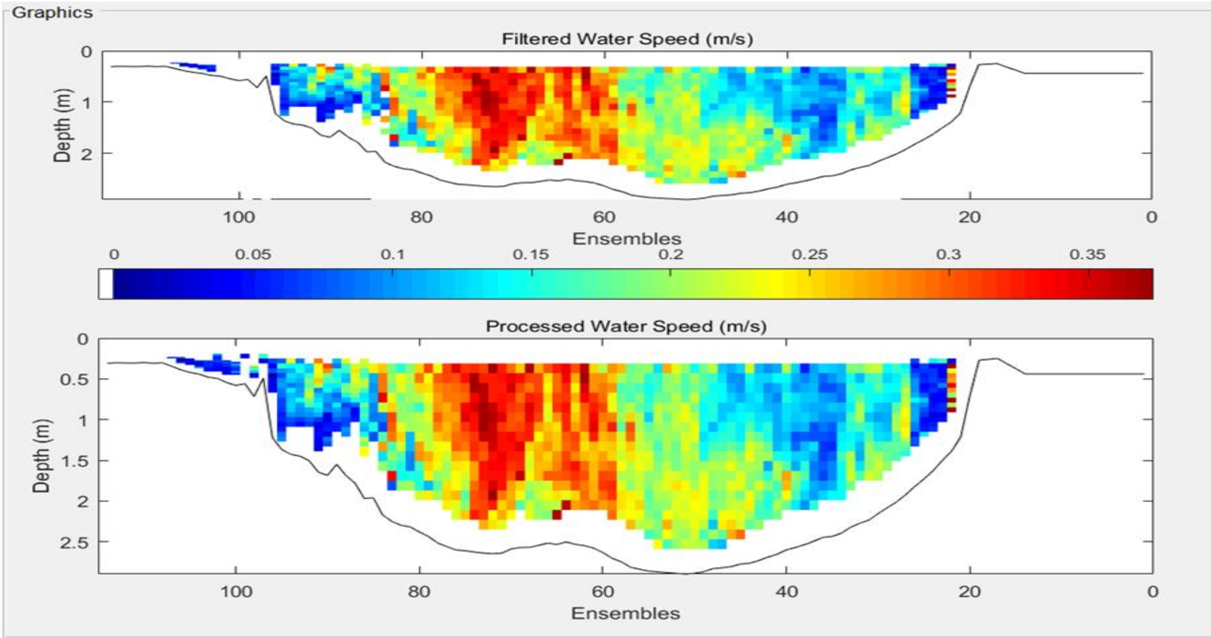

Figure 43. The river depth and water flow profile at the Kerava upstream site.

8. Conclusions

The main aim of the monitoring was to test the floating litter boom methodology, not to monitor riverine plastic litter discharge. Even if we can see some similarities in the results (e.g. that cigarette buds were the most dominant plastic litter category in regards to number of items captured) the results from the different sites and pilot areas cannot be compared directly, as both methodologies and environmental factors such as wind, currents and precipitation differed between them.

The three project partners that reported results (IVL, SEIT and SYKE) had different experiences and the floating litter booms worked better in some sites than others. The physical conditions of the monitoring site are of great importance when monitoring with floating litter booms. All monitoring was in some way affected by either the width of the river, weather conditions such as wind and/or water flow rate/direction. Based on the experiences from the monitoring in the pilot areas the conclusion by the project members is that the floating litter boom methodology is suitable in narrow rivers with a continuous water flow. However in wide rivers river this monitoring method might not be suitable.

In Aurajoki and Hallsfjärden the physical conditions made the monitoring very unreliable. Hallsfjärden is a wide river/bay, which presented two problems. Firstly, the litter boom only covered about 3.5% of the width of the bay which makes the monitoring most uncertain. Even if there was litter in the bay then it was unlikely to be captured by the litter boom. Secondly, the width of the river made the litter boom very exposed to wind which can blow away captured litter and blow the litter boom out of its position, which did happen.

In Aurajoki another problem occurred, as the water level of the river is very close to sea-level at the center of Turku, the current can go both downstream and upstream depending on winds, rain and countercurrents. If the current changes direction during monitoring, the litter captured in the boom may drift away as the boom changes shape and the litter floats away. SYKE concluded that visual monitoring could be an option for monitoring floating plastic litter in a river like Aurajoki. However a weakness of visual monitoring is recognizing litter materials and detecting small objects like cigarette butts.

The monitoring sessions Aurajoki and in Södertälje channel were also limited by the traffic of boats and ships. The litter booms had to be placed so that they didn’t interfere with this traffic. This can affect the monitoring by not being able to use ideal sites for measurements. In Södertälje channel the litter boom had to be placed near shore, where the water flow is low and the boom was exposed to backwash from big ships that passed by.

The monitoring which took place in narrower rivers that had a continuous water flow did not encounter any issues that affected the monitoring results.

SEIT also tried a set-up that used fyke nets instead of a litter boom and a net system for monitoring litter in the runoff discharge (Mustjõe River), both methods gave acceptable results.

Both SEIT and SYKE had daily inspections of the litter booms, at each occasion captured litter was collected. IVL did not have the possibility to do so frequent inspections which might have had a significant impact on the results. During IVL´s final monitoring it was observed that a noticeable amount of litter had been collected in the boom after less than one hour of sampling. However when the litter boom was inspected and litter was collected about one week later, the amount of litter was relatively small to what was expected after the first observation. If the results were affected by winds, currents or people who were picking up the captured litter is unknown. However the impact of such factors can be minimized by more frequent inspections of the boom.

In summary, we find that the physical conditions in a sampling area are crucial for successful measurements with the floating litter booms. Narrow rivers are preferable, but wider rivers can be tested but one must be aware of the problems that may arise. If possible then block the entire river width with the boom and use mixed points for mooring. In order to produce high quality, robust data sets frequent sampling is recommended.

8.1. Summary of monitoring recommendations

Based on everyone's experiences, we present some basic recommendations regarding the monitoring.

8.1.1. Pre-monitoring recommendations

Before starting to monitor in a specific area there are several factors that needs to be considered when defining the monitoring sites in order to succeed with the monitoring. The physical conditions of a monitoring site are of great importance when monitoring with floating litter booms. The monitoring is affected by the width of the river, weather conditions such as wind and/or water flow rate/direction. The recommendations for site selection are:

- A site where relevant authorities allow monitoring.
- A site with minimal influence of the tidal currents or counter currents as these can push away already captured litter and compromise the moorings of the boom. Examine the flow pattern and speed of the water before performing any monitoring. If the flowrate is too slow or the flow direction is unstable then another site or method should be considered.
- The method (boom/net collection) is more suitable for narrow rivers. Chose a narrow river or a site that is located at a narrow part of the river.
- A site where a large part (preferably the entire width) of the river can be blocked by the boom. If this is not possible due to e.g. boat traffic then it's recommended to sample both sides of the river. The more of the river that is blocked the more reliable results can be obtained.
- A site where the litter is not exposed to wind, as captured litter can be blown away and the shape of the litter boom can be changed in a negative way.
- The site selection also could depend on available information on potential litter emitters or convenience of the sampling locations.
- A site with easy access to simplify both deployment/retrieval of the boom and litter collection.
- A site where at least one fixed mooring point is available is recommended.

8.1.2. During monitoring recommendations

While performing the monitoring there are several things to consider in order to simplify the monitoring and in order to save as much time as possible when preparing and deploying/retrieving the booms.

- Prepare as much as possible on land (if the boom is to be deployed off shore). It is more time efficient to attach net curtains, grapnels, marking buoys etc. on land where space is available.
- A minimum of two persons are recommended to prepare and handle the booms. If deployed and retrieved with a boat then three persons are recommended: two to handle the booms and a third person maneuverer the boat.
- If anchors are be used to moor the booms to the river bed, make sure they are securely fastened to the bottom. If an anchor is not secure then both winds and currents can change the position of the boom. Booms have to be fixed and set-up in a proper way (preferably by anchoring the middle of the boom as well).
- Investigate the upcoming weather conditions. Strong winds increase the risk of changing the shape and position of the booms and litter can be blown away from the boom. Rain and other precipitation can affect the results if there is an increased flow of storm water. Rough weather might also limit the possibility to deploy and retrieve the booms.
- Timing: periods with heavy water discharge (early spring an autumn) are associated with much organic material in the water. Leaves, branches and other organic material will get trapped in the boom and might clog net curtains. This could overflow the litter booms and it can result in difficulties to separate the litter from the organic material. However, frequent litter collection from the booms can reduce this issue.
- Use a landing net to capture floating litter
- When retrieving the booms from the water one must be careful that litter doesn't come loose and float away with the current. If a net curtain is used it is preferably folded over the boom to capture the litter.

8.1.3. Post monitoring recommendations

After the monitoring has been performed there are a few things to consider when quantifying data. It is very important to separate absolute and relative results. A high quality data set will be more comparable between repeats, seasons and other sites. In addition, we would like to assess in real terms, what is the contribution of different sources to riverine litter. Doing this with compositional data alone and acquiring any degree of accuracy is impossible as it is not standardized in any way to litter abundance. For this reason, the preferred method is to characterize, weigh and count the litter sampled in the river; use the protocol developed in BLASTIC (**Fel! Hittar inte referenskälla.**) when doing this. The litter should be dried before weighing, and any significant silt or algae deposits should be removed.

An absolute result is the total litter captured in the litter boom, regardless of flowrate of the river and the duration of the sampling. Absolute values e.g. litter abundance cannot be compared between repeats, seasons and other sites as the sampled volume of water can vary greatly, even between repeats at the same site. A relative result tells us how much litter (number of items and/or weight) there is per sampled volume of water (e.g. items or weight per m^3 water). The relative result is an estimation which requires information about the flowrate, the total area (m^2) in the water column where litter is captured, sampling duration and the absolute results of litter captured.

With these variables we can first estimate the water throughput of the net:

Water throughput (m^3) **=** *(Average flow velocity) (m/s)* **x** *submerged area of the boom/net (m^2)* **x** *sample duration (s)*

Then we estimate the litter load:

Litter load (kg/m^3) = sum of the weight of the litter captured (kg) / Water throughput (m^3)

If we're at a site where we don't know the total water discharge of the river then we can estimate it:

Discharge (m^3/s) **=** *Average flow velocity (m/s)* **x** *area of river cross section (m^2)*

Finally we can use these numbers to estimate the total litter load of the river, i.e. the amount of litter passing by a particular point in one day or for longer periods:

Total Litter (kg/time) = Litter load (kg/m^3) x Discharge (m^3/s) x time (s)

These calculations are rough estimations. The biggest issues are that the flowrate is not constant, not over time and not throughout a cross section of a river and that the litter load is not constant. So depending on where in the river the flowrate is measured and depending on the specific litter load during the sampling duration, the results may differ greatly. This is why a high frequency of sampling and multiple flowrate measurements are recommended. Also it is important to know that there are quite a few items that because of their weight will sink to the bottom and are unlikely to be sampled by this method.

9. References

Cheshire, A. and E. Adler (2009). "UNEP/IOC guidelines on survey and monitoring of marine litter."
Directive, S. F. (2013). "Guidance on monitoring of marine litter in European Seas."

Dris, R., J. Gasperi, V. Rocher, M. Saad, N. Renault and B. Tassin (2015). "Microplastic contamination in an urban area: a case study in Greater Paris." Environmental Chemistry **12**(5): 592-599.

Gasperi, J., R. Dris, T. Bonin, V. Rocher and B. Tassin (2014). "Assessment of floating plastic debris in surface water along the Seine River." Environmental pollution **195**: 163-166.

Lebreton, L. C., J. Van der Zwet, J.-W. Damsteeg, B. Slat, A. Andrady and J. Reisser (2017). "River plastic emissions to the world's oceans." Nature communications **8**: 15611.

Lechner, A., H. Keckeis, F. Lumesberger-Loisl, B. Zens, R. Krusch, M. Tritthart, M. Glas and E. Schludermann (2014). "The Danube so colourful: a potpourri of plastic litter outnumbers fish larvae in Europe's second largest river." Environmental Pollution **188**: 177-181.

Morritt, D., P. V. Stefanoudis, D. Pearce, O. A. Crimmen and P. F. Clark (2014). "Plastic in the Thames: a river runs through it." Marine Pollution Bulletin **78**(1): 196-200.

Rech, S., V. Macaya-Caquilpán, J. Pantoja, M. Rivadeneira, C. K. Campodónico and M. Thiel (2015). "Sampling of riverine litter with citizen scientists—findings and recommendations." Environmental monitoring and assessment **187**(6): 335.

Ryan, P. G., C. J. Moore, J. A. van Franeker and C. L. Moloney (2009). "Monitoring the abundance of plastic debris in the marine environment." Philosophical Transactions of the Royal Society of London B: Biological Sciences **364**(1526): 1999-2012.

Schmidt, C., T. Krauth and S. Wagner (2017). "Export of plastic debris by rivers into the sea." Environmental science & technology **51**(21): 12246-12253.

van der Wal, M., M. van der Meulen, G. Tweehuijsen, M. Peterlin, A. Palatinus and M. Kovač Viršek (2015). SFRA0025: Identification and Assessment of Riverine Input of (Marine) Litter.

Vianelloa, A., F. Acrib, F. B. Aubryb, A. Boldrinb, E. Camattib, L. Da Rosa, T. Marcetac and V. Moschinob (2015). "Occurrence and distribution of floating microplastics in the North Adriatic Sea: preliminary results." MICRO2015: 29.

Yeo, J. C. C., J. K. Muiruri, T. Warintorn, Z. Li and C. He (2017). "Recent advances in the development of biodegradable PHB-based toughening materials: Approaches, advantages and applications." Materials Science and Engineering: C. Volume 92, 1 November 2018, Pages 1092-1116

Yonkos, L. T., E. A. Friedel, A. C. Perez-Reyes, S. Ghosal and C. D. Arthur (2014). "Microplastics in four estuarine rivers in the Chesapeake Bay, USA." Environmental science & technology **48**(24): 14195-14202.

Zhao, S., L. Zhu, T. Wang and D. Li (2014). "Suspended microplastics in the surface water of the Yangtze Estuary System, China: first observations on occurrence, distribution." Marine pollution bulletin **86**(1-2): 562-568.

Appendix 1: Protocol used for the collected litter items

BLASTIC: PROTOCOL FOR CATEGORISATION OF MARINE PLASTIC LITTER		
The categorisation is based on the master list of categories of marine litter found in the European guidelines, "Guidance on monitoring of marine litter in European Seas"		
The categorisation is used for litter collected by booms and net curtains.		
Date for placing the booms in the water:		
Date for picking up the booms:		
Number of collection days:		
Weight of the total collected amount:		
Weight of the collected amount of plastic items:		
Total number of items collected:		
Number of plastic items collected:		
CATEGORY	Weight (g)	Number of items
Plastic items		
4/6-pack yokes, six-pack rings		
Buckets		
Carrier bags		
Cigarette butts and filters		
Cotton bud sticks		
Crisps packets/sweet wrappers		
Cups and cup lids		
Cutlery and trays		
Diapers		
Dog faeces bags		
Drink bottles		
Fishing equipment		
Flower pots		
Food containers		
Jerry cans (square plastic containers with handle)		
Lolly sticks		
Miscellaneous plastic items		
Other plastic bags (e.g. freezer bags incl. pieces)		
Other plastic containers		

Pens and pen lids
Plastic caps and lids
Plastic fragments < 5 mm
Plastic pellets
Strapping bands
Straws and stirrers
Synthetic ropes
Toys and party poppers
Unidentified plastic film > 50 cm
Unidentified plastic film 2.5 cm ><50 cm
Unidentified plastic film 5 mm-2.5 cm
Unidentified polystyrene pieces > 50 cm
Unidentified polystyrene pieces 2.5 cm ><50 cm
Unidentified polystyrene pieces 5 mm-2.5 cm
Unidentified rigid plastic pieces > 50 cm
Unidentified rigid plastic pieces > 50 cm
Unidentified rigid plastic pieces 2.5 cm ><50 cm
Unidentified rigid plastic pieces 5 mm-2.5 cm

Other items
Food waste
Leafs and sticks
Metal
Miscellaneous
Newspapers/magazines
Paper/cardboard
Shoes
Textiles
Wood