PlasticFreeDanube

SAMPLING STRATEGY AND CONSTRUCTION RECOMMENDATIONS FOR DIRECT MACRO PLASTIC MEASUREMENT DEVICES IN LARGE RIVERS

Report

DOCUMENT INFORMATION	
Work Package	4 Collection and sorting analysis of plastic waste in and along the river system
Activity	4.3 Measurement of plastic passing the inlet grate of Freudenau or Gabcikovo
Detailoutput	D 4.3.1 Sampling strategy and construction recommendations for direct macro plastic measurement devices in large rivers

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1. Introduction

Although terrestrial environments and freshwaters are recognized as the origins and transport paths of plastics, the majority of research to date focuses on the marine environment (Horton et al., 2017). However, studies in freshwater environments have been rapidly advancing over recent years. Horton et al. (2017) gave a detailed overview of freshwater studies ranging from lakes, (e.g. Imhof et al., 2016; Fischer et al., 2016), to rivers (Baldwin et al., 2016; Dris et al., 2015; Faure et al., 2015; Lechner et al., 2014; Mani et al., 2015; McCormick et al., 2014 and Yonkos et al., 2014) and river sediments, (e.g. Klein et al., 2015; Horton et al., 2017). A number of studies have been performed that addressed the transport of microplastics in riverine systems. Measurements were undertaken in recent years in tributaries of the Great Lakes (Baldwin et al., 2016), the Seine River (Dris et al., 2015; Dris et al., 2018), various rivers in Switzerland (Faure et al., 2015), the Rhine River (Mani et al., 2015), various river sites near Chicago (McCormick et al., 2014) and the Danube River (Lechner et al., 2014). The researchers all used benthic nets (Lechner et al., 2014) or surface trawls as first used by Carpenter et al. (1972), described by Brown and Cheng (1981) and proposed as a standard methodology for surface waters by Lippiat et al. (2013). Moore et al. (2011) tried to address multiple depths by using different devices including a modified large Helley Smith sampler in concrete-lined creeks near Los Angeles. Also, Dris et al. (2018) addressed different depths in one point in the center of the Seine River by coupling a plankton net (addressing fibres) with a propeller-type current meter to sample down to 2 meters. But so far, only Liedermann et al. (2018) sampled the entire cross-section with a multi-point method to address microplastic transport in medium and large rivers. For the given research question, it is indispensable to address not only the water surface but the entire water column downstream of the hydropower plant. The high flow turbulence and turbulence caused by the turbines necessitates sampling in multiple depths. Therefore, a device is needed, applicable in highly turbulent environments which enables sampling in multiple depths. Furthermore, alternative measurement systems using GPS-tagged items to evaluate the influence of hydro power plants on macro plastic transport need to be investigated.

Within activity 4.3 “Measurement of plastic passing the inlet grate of Freudenau or Gabcikovo” a sampling device for direct sampling of **macro plastics** in free-flowing water bodies was developed and used to measure the amount of plastic passing the inlet grate of a hydropower plant as well as concentrations from the Donaukanal, a tributary entering the Danube River in the project reach. The device was developed, tested and adapted during measurements at different discharge stages. The methodology for measuring macro plastic transport was newly set up and optimized based on the device available for micro plastics. Net-frame diameter and mesh sizes had to be optimized to find the best possible assemblage for the given question.

A second approach, using GPS tagged items released upstream of the hydro power plant Freudenau was tested and optimized in order to obtain information on the possibility of macro plastic particles to pass the hydro power plant. Therefore, a long-term test using different available as well as self-constructed GPS systems with respect to hydrological conditions was performed in order to better understand plastic transport paths in fluvial systems.

A literature review was performed to get the current state of the art of science and technology. The findings finally were summarized and transferred into a sampling strategy for measuring macro plastic in fluvial fresh water bodies.

2. Material and methods

2.1. Net measurement

Within this chapter important boundary conditions when developing a measurement device for macro plastic measurements in medium and large sized rivers shall be addressed. An interaction between hydraulics, frame size, mesh size and equipment carrier is mutually depended on each other and has to be tested in the field before giving recommendations therefore.

2.1.1. Spatial distribution

When looking for an appropriate methodology to address macro plastic transport based on net measurements, it should then follow the research experience available for suspended sediment sampling, where the spatial distribution is addresses by multi-point method measurements described in ISO 4363 (2002). Liedermann et al. (2018) clearly showed, that plastic concentrations are highly heterogeneous both in vertical and cross-sectional directions depending on the hydraulic situation. Therefore, only measuring e.g. the surface is insufficient when evaluating plastic pollution in flowing waters.

2.1.2. Equipment carrier

The second important challenge, next to the spatial distribution, for collecting measurements, is keeping the device stable at the required position. High flow velocities and turbulence provide a demanding environment especially when handling large-sized nets. Similar problems occur for bedload transport measurements and are solved by using heavy, hydraulically optimized devices. Liedermann et al. (2017) adapted a basket sampler (BfG sampler) (see Figure 1 left original, right adapted) currently used by the Federal Institute of Hydrology in Koblenz, Germany, which is based on the bedload transport meter of Delft Hydraulics (1958) and applied it for bedload transport measurements in the Austrian Danube River up to a 200-year flood event (10.738 $m^3 s^{-1}$). The modified BfG sampler was used also as equipment carrier for micro plastic measurements by Liedermann et al. (2018) builds the basis for a newly developed device within the scope of the PlasticFreeDanube project.

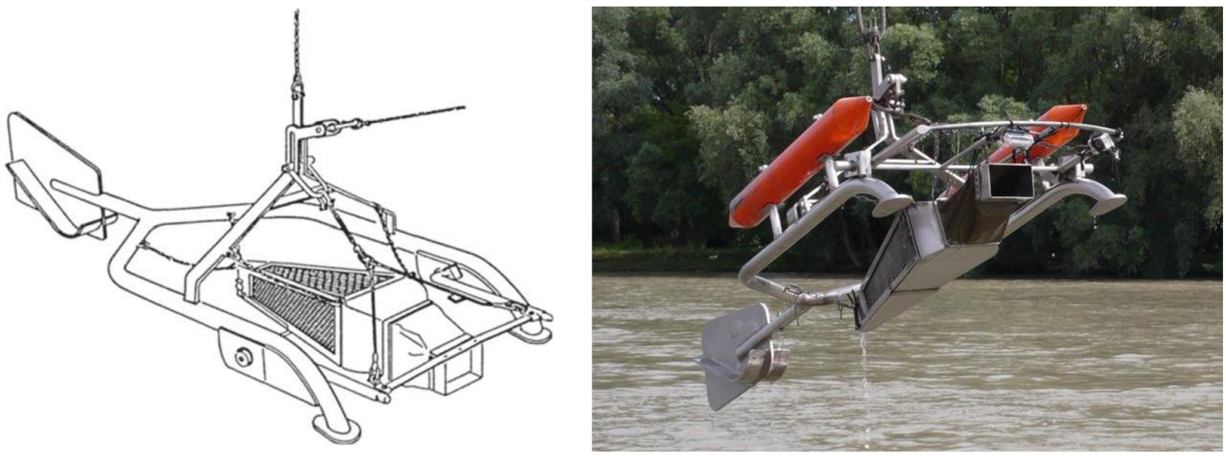

Figure 1 BfG basket sampler currently used by the Federal Institute of Hydrology in Koblenz, Germany (left) and adapted BfG basket sampler (right)

2.1.3. Mesh size

Mesh sizes vary throughout the different studies (between 80 µm and 800 µm), depending on the focus of the work. In most studies in riverine environments, a mesh size of 300 µm was chosen to focus on primary (manufactured in the micrometer size) and secondary microplastics (secondary fragments). When addressing fibers, an even smaller diameter should be used (Dris et al., 2018) had a 250-times higher probability of sampling fibers when using an 80 µm mesh compared to a 330 µm mesh). As only macro plastic is addressed within the project, a mesh size equal or smaller than 5 mm seems appropriate. Therefore several mesh sizes from 250 µm to 8 mm have been tested within the PlasticFreeDanube project to evaluate their performance. Nevertheless with comparable quality characteristics, it is aimed to use mesh sizes as small as possible to get the most out of the sampling which is complex and expensive. For the chosen nets, an actual porosity must be calculated and an adequate length must be chosen to reach the required "open area ratio" of three (Tranter and Smith, 1968).

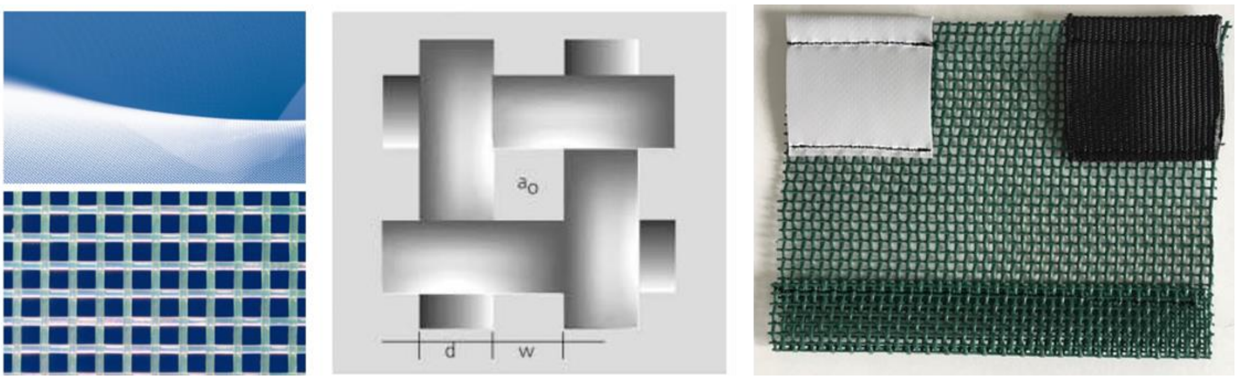

Figure 2 details of the used Sefar (left, centre) and Heberle (right) nets (Source: Sefar AG (2014) and Heberle (2020))

2.1.4. Frame size

The last matter of optimization for the sampling macro plastic in rivers, is the frame size. The bigger the frame gets, the more water can be filtered, which increases the significance of the measurements. But with the size of the frame, also instability and resistance within the flow rises. Therefore an optimal frame opening must be found for the measurement and was tested within the scope of the project.

2.2. GPS tracker

Besides direct net measurements throughout the water column, also another strategy to investigate macro plastic transport and its behaviour especially related on the influence of hydropower plants was followed within the PlasticFreeDanube project. As e.g. Tramoy et al. (2020) showed, this methodology can be a suitable method to evaluate macro plastic transport in riverine systems. Important aspects when using GPS trackers for detection of macro plastic items are describes in the following chapters.

2.2.1. GPS trackers

During the development of a sampling strategy for macro plastic measurement based on GPS trackers, several products have been tested and evaluated. As a starting point, the experience of Tramoy et al. (2020) was used within this task. There are several requirements and boundary conditions for the trackers as listed below:

- Battery lifetime should be as long as possible
- Size and weight of the tracker should be as small as possible in order to not influence plastic item transport
- Robustness and water resistance of the tracker is important
- Trackers should send positions to an online platform in real time
- Individual setting of tracking intervals should be possible
- Alarms when entering or leaving a predefined zone can ease the tracking
- Prize of the used GPS tracker

One important aspect to be mentioned for this measurement system is its measurements limit related to the data transfer, which is only possible, if the tracker is floating on the surface. Therefore, it is obvious, that measurements targeting macro plastic transport in rivers using GPS trackers is not possible for submerged particles, like fragmented plastics, foils or other items transported in the water column or bottom near due to its density.

2.2.1. Tracked items

Another very important point for such monitoring campaigns refers to the used items. As explained before, the methodology can only be used for floating items. Another criteria is the size and the weight of the tracker, limiting the minimum size of used particles to track. Furthermore, it is clearly of great interest, to track those items mostly responsible for pollution in the investigated area.

For the PlasticFreeDanube project, sampling activities showed, that PET bottles, PU foam, XPS, EPS, shoes and tennis balls are frequently found in accumulation zones. Subsequently, these items were fitted with GPS transmitters for the tests.

3. Results

3.1. Net measurement

For the field tests used to develop a suitable sampling strategy and a device able to directly measure macro plastic in large river, 2 locations were chosen as depicted in Figure 3. At the location downstream of the HPP Freudenau, only one single point measurement could be carried out. At the second locations, the Donaukanal at Freudenauer Hafenbrücke, 2 cross-sectional measurement were carried out. Within the measurements, the equipment was therefore exposed to different hydrological and hydraulic conditions. At the same time, frame sizes, mesh sizes of the net as well as a new equipment carrier were tested and evaluated.

Figure 3 Locations for test measurements in order to develop a measurements device for macro plastic measurements - Single point measurements: downstream of the HPP Freudenau - cross-sectional measurement: Donaukanal at Freudenauer Hafenbrücke

3.1.1. Measurement device

3.1.1.1. Equipment carrier

The modified BfG sampler as used for plastic measurements by Liedermann et al. (2018) built the basis for the newly developed equipment carrier within the PlasticFreeDanube project. Facing some advantages of the modified BfG sampler when addressing plastic measurements like the smooth positioning in the water and its usability up to high hydraulic forces, there are also disadvantages. Due to its construction only a very small net could be attached within the frame to measure bed near concentrations. Also it was aimed, to get a more flexible system towards the used weights in order to a better adaption to the hydraulic boundary conditions. Furthermore it was aimed, to develop a much easier equipment carrier compared to the complex constriction of the BfG sampler.

The resulting device is depicted in Figure 4 as sketch and during a field test. The frame basically consists of 48 mm steel pipes. Two cross beams connect the net frame at the bottom. In the rear the frame is connected at the fin, giving stability in the water column. The dimensions of the used frame for the macro plastic measurement net are 600x600 mm. Connections between the parts (e.g. net frame and cross beams) are not welded in order to be able to disassemble the device quickly. To attach the weights, 12 threaded bars are welded to the frame. Each bar can be attached with 2 weights of approximately 10 kg, so in total 240 kg additionally to the weight of the carrier itself.

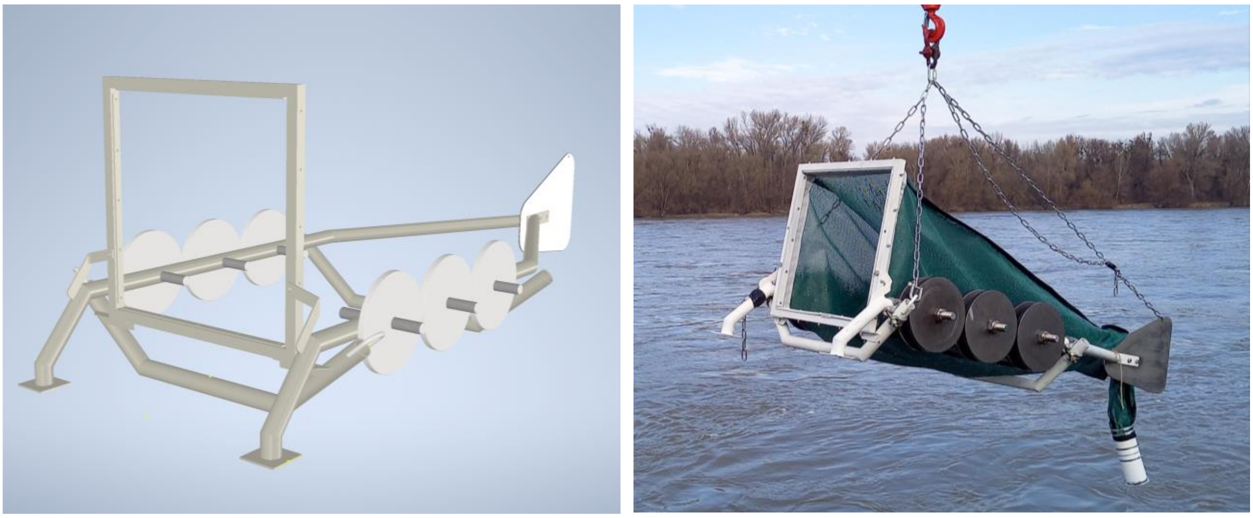

Figure 4 left: Visualisation of the construction plan of the equipment carrier, right: field test of the newly developed equipment carrier

3.1.1.2. Mesh size

As mesh sizes varied throughout the previous studies, different sizes were used within the PlasticFreeDanube project, to also address the differences between larger and smaller mesh types. The following mesh sizes were tested during several measurements:

- 250 µm with 34 % porosity
- 500 µm with 38 % porosity
- 2,43 mm with 44 % porosity
- 8 mm with very high but undefined porosity

Based on the porosity values and to reach the required “open area ratio” of three (Tranter and Smith, 1968), the net length was calculated. Calculations were performed for the 250 µm and the 500 µm nets, resulting in a used length of 2,5 m. The two bigger meshes characterized by a higher porosity were produced with the same dimensions and therefore fulfill the required “open area ratio”.

For the evaluation of the performance of the different mesh types towards macro plastic measurement 2 major aspects are relevant, (i) the sampling efficiency and (ii) the filtration efficiency. Besides these constrictions (iii) the usability in the field during sampling and cleaning of the nets as well as (iv) the robustness of the nets have an influence for choosing the right material.

Regarding sampling efficiency, an example of the distribution of concentrations in a cross-sectional profile is shown in Figure 5. Since the distribution is subject to a very high temporal and spatial variability, it is difficult to perform an analysis towards the sampling efficiency with only a few measurements. In the top layer the 2.43 mm mesh and the 250 µm mesh are compared, in the middle layer the 500 µm and the 8 mm mesh respectively. It can be seen that there is no clear trend in terms of collection efficiency, since depending on the vertical, either the one or the other net has a higher concentration.

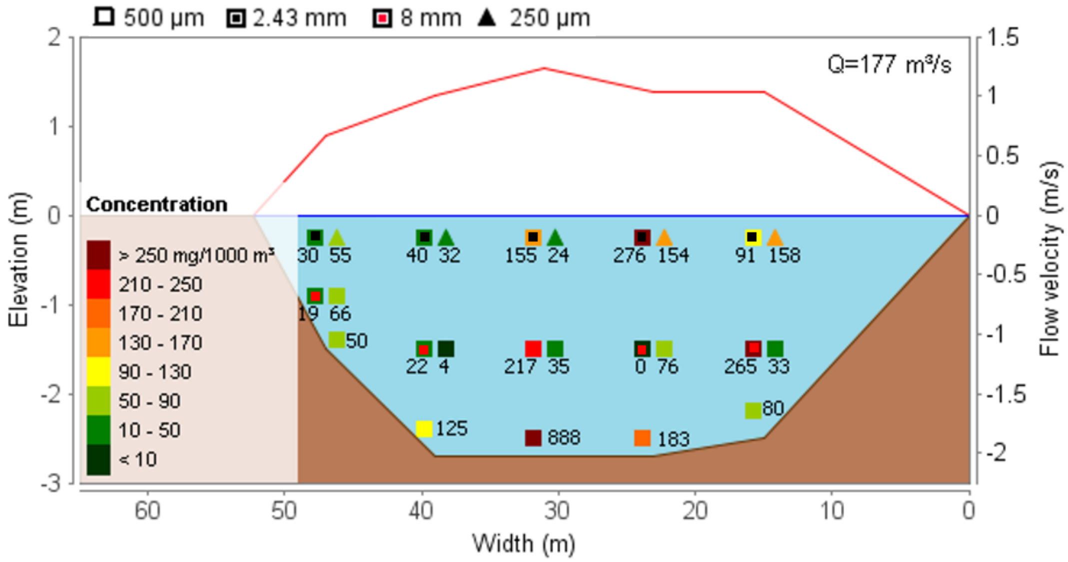

Figure 5 Measured concentrations using 4 different mesh types (250 µm, 500 µm, 2,43 mm, 8 mm) at the Donaukanal for the discharge of 177 m³/s – 13.10.2020

In terms of filtration efficiency, Liedermann et al (2018) compared the 250 µm and 500 µm nets and found that the 500 µm net had a better efficiency. The comparison with the 2.43 mm and 8 mm nets shows that both nets have a significantly better filtration efficiency. With the given concentrations of suspended and floating matter and the selected measurement times, no loss in sampling efficiency was observed for any of the nets used. When using the coarser nets, a significantly longer measuring time can be achieved under different boundary conditions (higher suspended matter load). Therefore, the coarser meshes should be preferred when addressing macro plastics. However, since the 8 mm net does not cover the complete range of macro plastic, the 2.43 mm net is recommended for sampling.

Besides this, the 2,43 mm was characterized by a good usability during sampling and cleaning, whereas the 8 mm net showed some disadvantages regarding these aspects. Therefore, when addressing macro plastic, the presented 2,43 mm net is recommended.

3.1.1.3. Frame size

For the frame size, the aim was to use the largest possible net dimensions in order to get the highest possible discharge through the nets. For the used device, the nets are positioned at the surface, in the middle of the water column and at the bottom of the river. At the center and surface layer two nets are attached parallel, at the bottom layer one net is directly attached at the equipment carrier. The uppermost net assemblage was equipped with a buoyant body to ensure that these nets are skimming the water surface. As previously mentioned, the frame size is directly influenced and is vice versa influencing the mesh dimensions (due to its open area ratio) as well as the length of the used net.

Hence, during the tests, double frames with the dimensions of 600x600 mm as well as 900x900 mm were exposed within a measurement downstream of the HPP Freudenau as depicted in Figure 6. Several things were recognized limiting the size of the frames:

- To ensure an open area ratio of three, a 3.5 m net length with an opening of 900x900 mm was necessary. It turned out, that handling and the positioning of the nets in the water without twisting is problematic

- The frame size of 900 x 900 mm itself limits easy handling of the equipment.
- Hydraulic forces for the frame size of 900x900 mm are very high under the tested boundary conditions and led to instability and drifting off of the device

With respect to the findings of the performed tests, therefore, a frame size of 600x600 mm was considered as most suitable for macro plastic measurements and is therefore recommended.

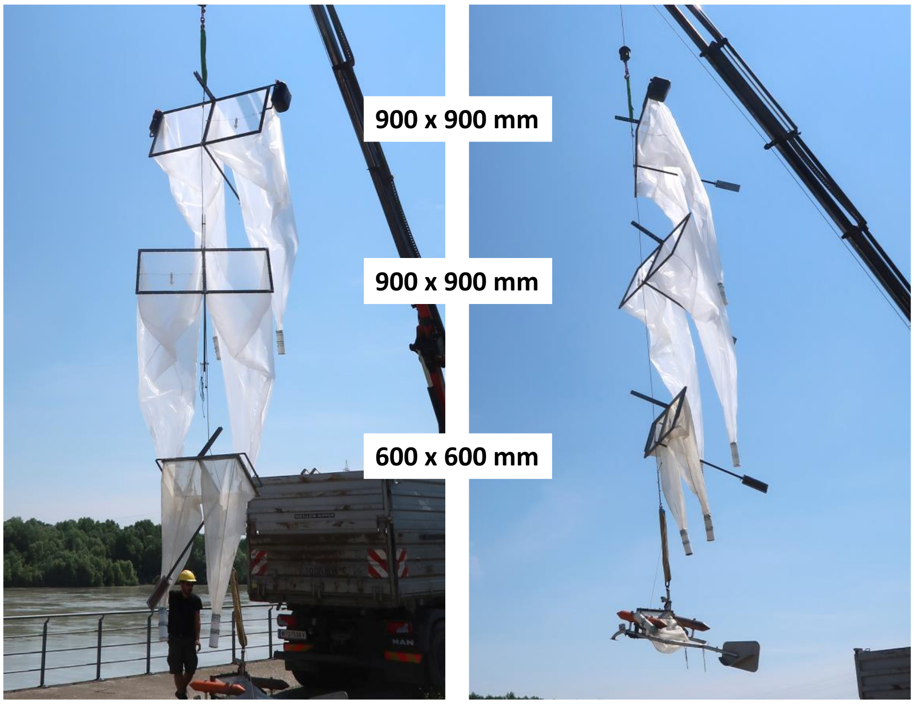

Figure 6 Test of different frame sizes for macro plastic measurements downstream of the HPP Freudenau

3.1.1.4. Macro plastic measurement device and assemblage

Based on the presented results the device used by Liedermann et al. (2018) was adapted within the project for the measurement of macro plastics. Both devices are depicted in Figure 7. As the graph shows, the double net frames are equipped with a 1.6 m-long fin was in the middle of the frame to assure streamwise alignment and good positioning within the water column. The top and center nets can be adjusted in height according to the prevailing water depth by using a displaceable stopper. For the lowermost net assemblage, a single net with the same dimensions of 600x600 mm is directly attached to the equipment carrier. An inclination rack is used, which allows the nets to have an upright position when deployed. The sampling containers at the end of the nets are used to reduce the emptying time. A mechanical flow meter is attached to measure the discharge through the nets, which is required for calculating plastic concentration. More detailed pictures of the device are provided in Figure 8.

Figure 7 left: measurement device used by Liedermann et al. (2018) and right: newly developed device for macro plastic measurements within the project PlasticFreeDanube

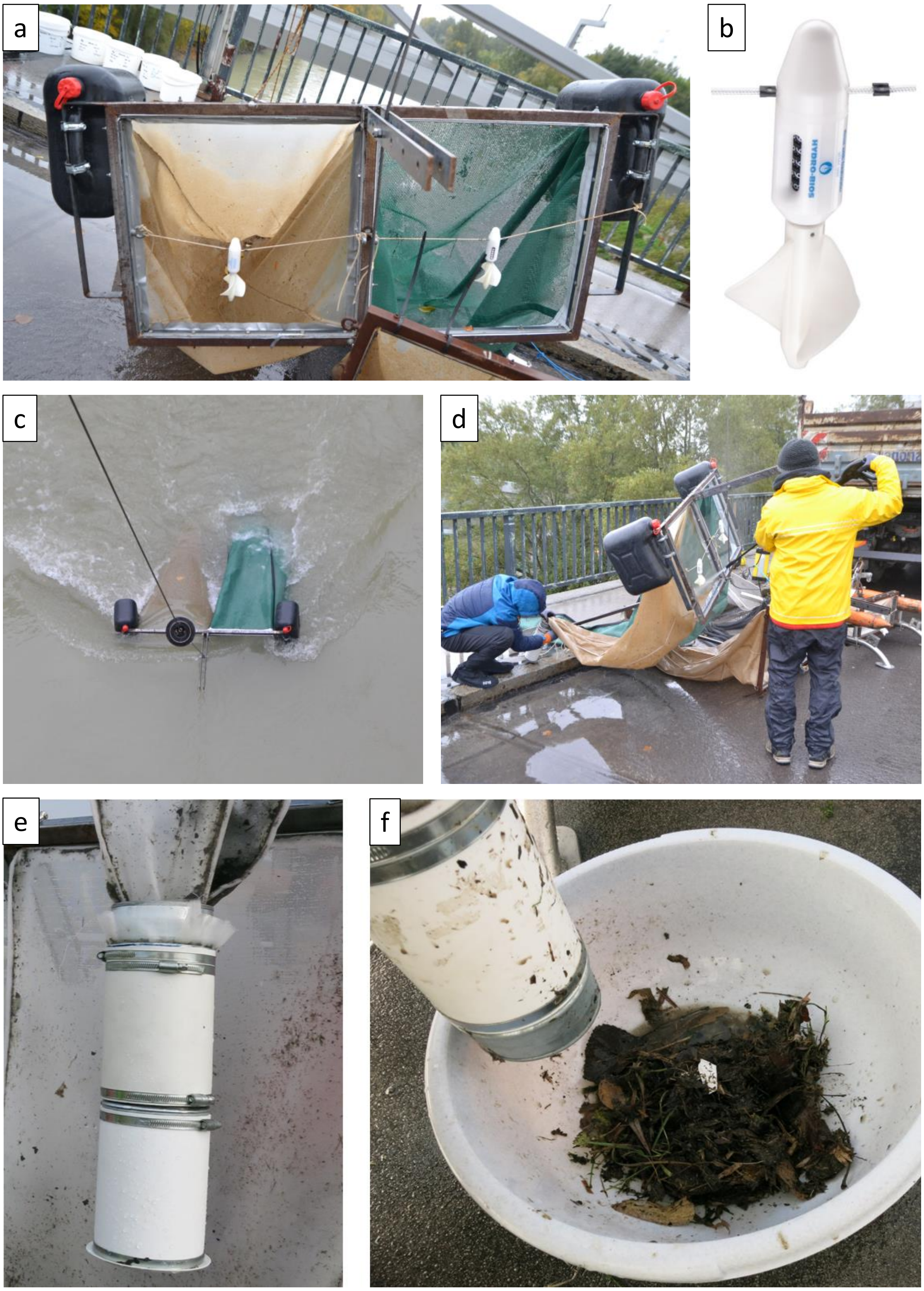

Figure 8 (a) position of the mechanical flow meters, (b) mechanical flow meter, (c) deployed device during measurement, (d) cleaning of the nets after measurement, (e) sampling container, (f) emptying a sample from the sampling container

3.1.2. Sampling strategy

When performing direct macro plastic measurements with the presented device, it is important to carry out the measurements according to a tested and approved sampling strategy. Therefore, within this chapter, the sampling as well as sample analysis and the transport calculation is described.

3.1.2.1. Sampling

The mass transport of the plastic per time is to be determined by recording the measuring time for each measuring point and determining the mass of the caught plastic. Following the methodology of suspended matter measurement, a multipoint measurement is performed. The aim is to determine the spatial and temporal variability of the plastic transport in order to be able to make a reasonable estimate of the annual load.

In order to determine the spatial variability, several verticals are sampled at a cross-section (depending on the cross-sectional profile and flow rate: 5-10 verticals). The measurements are intended to provide information regarding the characteristics of the transport and areas of higher/lower transport. Nets are therefore deployed at the bottom, centre and top layer of the water column. Furthermore, to account for the temporal variability of plastic transport, measurements need to be conducted at various hydrological conditions. In this way, the influence of discharge on the plastic concentration can be determined and long-term assumptions of the yield can be derived.

In addition to the filtered plastic particles, the flow velocity is needed to determine the filtered water volume in the nets with mechanical flow meters. Alternatively, this information can be derived using ADCP measurements or – if available – by means of 3D numerical modelling. The duration of each individual measurement needs to be adapted to the respective current flow rate and thus varies for each vertical. However, the aim is to achieve the highest possible flow rate under approximately isokinetic conditions without clogging of the nets. For a single vertical measurement a minimum timeframe between 30 to 60 minutes is recommended.

3.1.2.2. Sample analysis

Before further analysis of the samples conducted during measurements, several steps have to be followed as described below.

<u>Drying and sorting</u>

As the samples conducted during measurements contain a lot of water and organic material, they need to be prepared in advance. Therefore, samples must be dried and separated from organic matter as depicted in Figure 9. The sorting, as shown in the graph, is carried out manually. After the sorting and extraction of plastic particles, the found pollutants need to be cleaned in order to get the right mass for further transport calculation.

Figure 9 Sample preparation –drying and separation of organic matter

Classification and mass determination

After drying and cleaning, the sorted particles can be classified into micro plastic or macro plastic fractions based on their size, with the limit set at 5mm (ARTHUR et al., 2008). The fractions are then photographed, weighed and the particles are counted. Furthermore a delineation towards fibres, foils, fragments, pellets, etc. can be made. An example of a sorted sample is given in Figure 10.

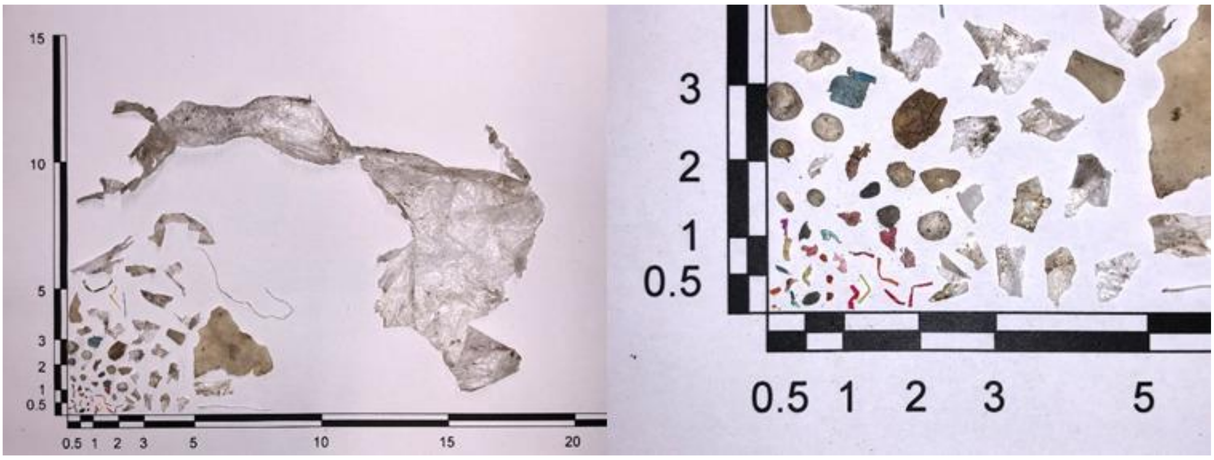

Figure 10 Example for a sorted out sample containing micro and macro plastic particles, left: whole sample, right: detail of micro plastic particles

3.1.2.3. Transport calculation

Plastic concentration

The plastic concentration $C_{Pl,i,j}$ in [g/m³] per net *j* and vertical *i* is given by the mass of trapped plastic particles $m_{Pl,i,j}$ per net divided by the filtered water volumen $V_{i,j}$.

$$C_{Pl,i,j} = m_{Pl,i,j}/V_{i,j} \qquad (1)$$

The filtered water volume $V_{i,j}$ per net is determined from mechanical flow meters at the inlet of the trapping net or ADCP measurements.

Then, an average plastic concentration per measurement height h and vertical $\overline{C_{Pl,i,h}}$ is calculated for each double net. In further consequence, a plastic concentration per measuring height and perpendicular can be calculated.

Plastic transport

Based on the suspended sediment measurements, the conventional evaluation procedure for multipoint sampling can be applied for the computational evaluation of the plastic transport, as it is also defined in the guideline for the assessment of suspended sediment transport (BMLFUW,2008). A flow chart for the calculation is provided in Figure 11.

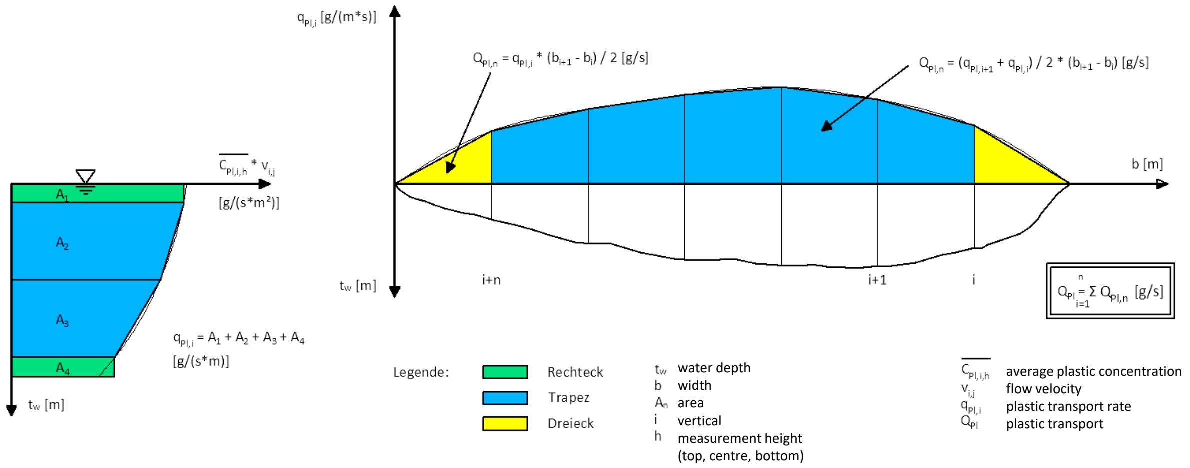

Figure 11 Principle of the graphical evaluation of a suspended matter multipoint sampling (modified according to DVWK, 1986)

At each measuring point, the product of the averaged plastic concentration $\overline{C_{Pl,i,h}}$ and the flow velocity $v_{i,j}$ is calculated. The plastic transport rate $q_{Pl,i}$ in [g/(m*s)] is then calculated from the sum of the surface areas of the partial areas formed by this product and the water depth $t_{w,i}$ per perpendicular. For this purpose, the areas between the sampling points are approximated by trapezoids and the areas from the uppermost measuring point to the water surface and from the lowermost measuring point to the bottom are calculated as rectangles. The plastic transport Q_{Pl} in [g/s] per measurement day is obtained by integrating the plastic transport rates $q_{Pl,i}$ of the individual measurement verticals over the entire transverse profile. The same method is used to calculate the particle transport in [p/s]. For this purpose, the number of plastic particles caught and sorted out is used for the calculation instead of the plastic quantity in grams.

The weighted mean plastic concentration $\overline{C_{Pl}}$ per measuring day in [g/1000m³] is calculated from the ratio of plastic transport Q_{Pl} to flow rate Q. The result is converted from g/m³ to g/1000m³ by a factor of 1000. This value is used for a more descriptive comparison of the different plastic concentrations.

$$\overline{\mathrm{C_{Pl}}} = Q_{Pl} * 1000/Q \tag{2}$$

If more measurements at a certain measurement site over a range of hydrological boundary conditions are available, concentrations can be plotted against the occurring discharge. In this way, mathematical functions (linear, power, polynomial) can be applied to the data set in order to derive rating curves between discharge and plastic concentration. With the help of these curves and long-term discharge data, subsequently the annual mean value of the plastic transport [kg/a] can be calculated.

3.2. GPS tracker

3.2.1. Measurement device

During the development of a sampling strategy for macro plastic measurement based on GPS trackers, several products have been tested and evaluated as listed below and depicted in Figure 12.

- Copenhagen Cobblestone GPS tracker
- modified WINNES tracker
- INETIS GPS mini tracker

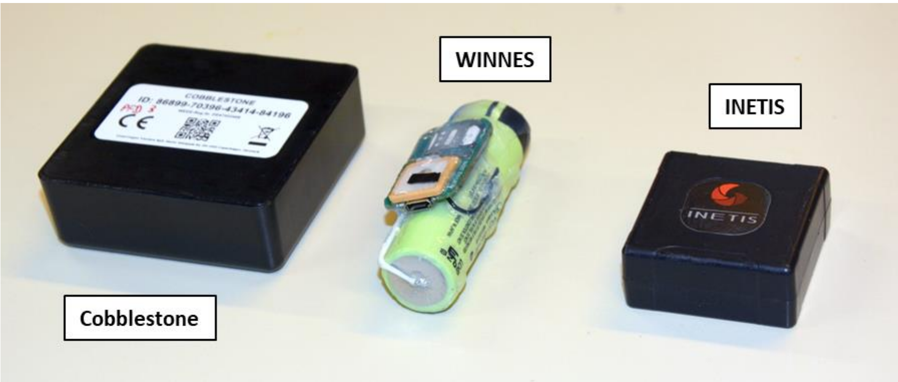

Figure 12 Tested GPS trackers within the PlasticFreeDanube project - left: Copenhagen Cobblestone, centre: modified WINNES, right: INETIS GPS mini tracker

It has to be mentioned that there are much more products available, as tracking of macro plastic in rivers is an upcoming methodology. However, based on research these three products were chosen and used for a performance test under the given boundary conditions.

While the all of the presented trackers were featured with an online platform in order to receive real time information on their position, the INETIS tracker offers more setting options like an alarm when entering or leaving a predefined zone. Also size, weight and robustness of the INETIS tracker can be evaluated as “good”. However, regarding battery lifetime and signal transmission, the Copenhagen and modified WINNES trackers performed better. Also regarding the prize, the Copenhagen and modified WINNES trackers are preferable. However, all of the used trackers seem to be suitable devices in the field of GPS based macro plastic monitoring.

3.2.2. Sampling strategy

As mentioned in chapter 2.2.1 a very important information for a GPS based macro plastic monitoring strategy refers to the used items, as it is of great interest, to track those items mostly responsible for pollution in the investigated area. Therefore, it is recommended, to investigate – weather by samplings, literature research or information from experts in the research area – the composition of waste in the target area. For the PlasticFreeDanube project, sampling activities showed, that PET bottles, PU foam, XPS, EPS, shoes and tennis balls are frequently found in accumulation zones. Subsequently, these items were fitted with GPS transmitters for the tests as listed below and shown in Figure 13.

- plastic bottle empty
- plastic bottle filled
- XPS
- tennis ball
- shoe

Figure 13 Used items for the field survey within the PlasticFreeDanube project

The number of items obviously plays an important role in order to get significant results. Therefore, also the price of the single tag is of importance. Furthermore, battery lifetime in connection with tracking intervals, and therefore temporal/spatial resolution of the data recording have to be determined in advance with respect to the project goals.

4. Summary and conclusion

Within this report sampling strategies and construction recommendations for measurement of macro plastic transport in large rivers are provided, namely for (i) direct cross-sectional net based measurements and (ii) GPS based tracking of plastic items.

Towards the net measurement device, a device used previously for micro plastic measurements was further developed within the PlasticFreeDanube project. Several field tests were performed in order to build a new equipment carrier, optimize frame sizes and define a new mesh type for macro plastic in particular. Besides construction recommendations, a monitoring strategy is provided within the report. As plastic transport in rivers underlie both temporal and spatial variabilities, it is recommended to measure at several verticals (depending on the size of the river 5-10) and several depth in the water column (top, centre and bottom) over the entire cross section. Furthermore, to cover the hydrological flow regime and its influence on plastic transport, repeated measurements at various discharge stages should be carried out in order to be able to calculate annual yields of plastic transport.

Tracking of macro plastic by means of GPS transmitters is an upcoming methodology to get more insights into behaviour of riverine pollution. Therefore, this methodology was investigated within the scope of the project. Several available GPS systems were tested showing good results, each having advantages and disadvantages concerning price, robustness, battery lifetime and setting options. The choice for a certain project therefore mainly depends on the research question. However, an important precondition for performing such monitoring campaigns is the knowledge of commonly found macro plastic waste, as it is of great interest, to track those items mostly responsible for pollution in the investigated area. Therefore, it is recommended, to investigate – weather by samplings, literature research or information from experts in the research area – the composition of waste in the target area.

5. Directories

5.1. List of figures

6. References

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