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Riverine Litter Monitoring - Options and Recommendations

MSFD GES
TG Marine Litter
- Thematic Report

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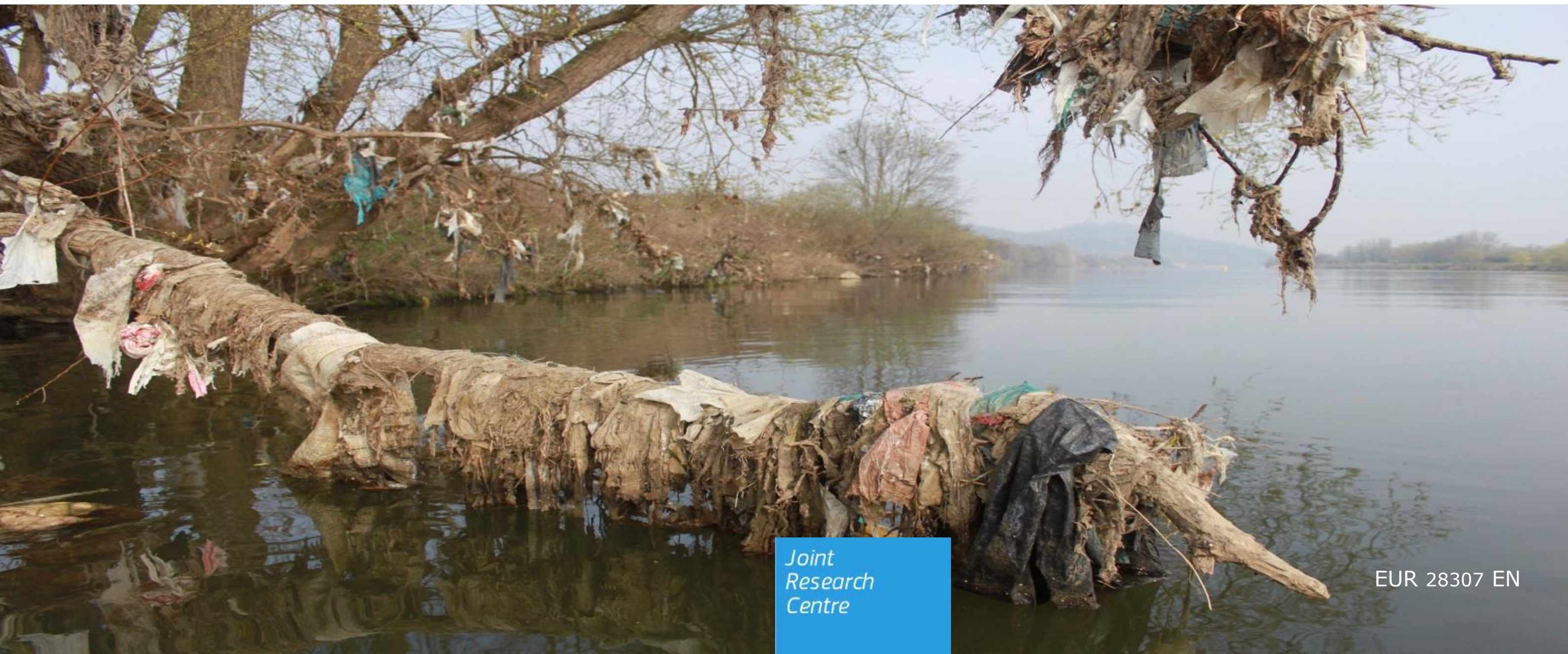

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Foreword

The Marine Directors of the European Union (EU), Acceding Countries, Candidate Countries and EFTA Countries have jointly developed a common strategy to support the implementation of Directive 2008/56/EC, the Marine Strategy Framework Directive (MSFD). The main aim of this strategy is to allow for the coherent and harmonious implementation of the Directive. The focus is on methodological questions related to a common understanding of the technical and scientific implications of the Marine Strategy Framework Directive. In particular, one of the objectives of the strategy is to develop non-legally binding and practical documents, such as this report, on various technical issues of the Directive.

The MSFD Technical Group on Marine Litter (TG Marine Litter) acts through a mandate of the European Marine Directors. It is chaired by the Institut Français de Recherche pour l'exploitation de la Mer (IFREMER), the European Commission's Joint Research Centre (JRC) and the German Environment Agency. TG Marine Litter members include EU Member State delegates, Regional Sea Conventions, other stakeholders and invited technical experts. The TG Marine Litter supports EU Member States in implementing the MSFD, reviews scientific developments and prepares technical guidance and information documents.

This present technical report is part of a series of thematic reports issued by the TG Marine Litter that provide guidance on specific topics: ***Riverine Litter Monitoring – Options and Recommendations***, *Identifying Sources of Marine Litter* (Veiga et al., 2017) and *Harm caused by Marine Litter* (Werner et al., 2017). These thematic reports are written for experts who directly or indirectly implement the MSFD in marine regions.

This report should further support EU Member States in the implementation of monitoring programmes and the planning of measures to tackle marine litter.

The members of the Marine Strategy Coordination Group will assess and decide upon the necessity to review this document in the light of scientific and technical progress and experience gained in implementing the MSFD.

Disclaimer:

This document has been developed through a collaborative programme involving the European Commission, all EU Member States, Accession Countries, Norway, international organisations (including the Regional Sea Conventions and other stakeholders) and Non-Governmental Organisations (NGOs). The document should be regarded as presenting an informal consensus position on best practice agreed by all partners. However, the document does not necessarily represent the official, formal position of any of the partners. Hence, the views expressed in the document do not necessarily represent the views of the European Commission.

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Abstract

Marine litter is an issue of global concern, as recognised by the Marine Strategy Framework Directive (MSFD). In order to establish programmes of measures that aim to reduce plastics and their possible impacts, sources of litter and their pathways to the marine environment need to be identified and quantified. Riverine litter input is estimated to be a major contributor to marine litter, but there is no comprehensive information about the amount of litter being transported through rivers to the sea. Furthermore, there are no harmonised methodologies for providing quantitative data for comparable assessments of riverine litter.

This technical report compiles the options for monitoring riverine litter and quantifying litter fluxes, focusing on anthropogenic litter. It includes the current scientific and technical background regarding litter in river systems, their flow regime and basic properties. The document aims to provide recommendations for monitoring approaches and methodologies. It also provides indications on the issues which need to be further developed in a collaborative approach.

An extensive literature review has been performed in order to identify the existing options for the monitoring of litter items in rivers. Different monitoring methods are used in two environmental compartments: river water bodies and riverbanks. For a river water body, the river water surface can be monitored by visual observation and image acquisition, while collection methodologies of the water column include the use of retaining structures and sampling using grids, nets and filtration systems (with different mesh sizes and openings) at different water depths. Riverbank monitoring comprises the observation and eventual collection of litter items and sediment samples from the riverbanks. Methodologies are described and technical details are reported whenever available.

As methodologies are further developed and basic research is ongoing, it is currently not possible to provide clear guidance on how to monitor riverine litter, though some initial recommendations can be made. General recommendations highlight the need for additional scientific knowledge, which should be made accessible to facilitate communication and coordination among key players in order to harmonise efforts and provide guidance at international level in a collaborative way. Knowledge gaps should be filled by analysing the outcome of these ongoing activities (the recommendations include a list of identified gaps). As there are no agreed monitoring methodologies at the international level, guidance on the monitoring of riverine litter is needed, including metadata requirements and reporting units. In order to quantify riverine litter input to the marine environment, monitoring methods have to provide data that can be related to river flow in order to be able to calculate litter fluxes (e.g. visual observation of the river water surface and collection method for the river water body).

1. Introduction

1.1 Background

Marine litter is an "emerging" issue of global concern, and is included in the Marine Strategy Framework Directive (MSFD) (European Commission, 2008) as one of the Descriptors of marine environmental status. The MSFD requires Member States (MS) to develop strategies that should lead to programmes of measures to achieve or maintain Good Environmental Status (GES) in European Union (EU) marine waters. Furthermore, marine litter has been identified as a priority in the G7 process (G7 Summit, 2015), highlighting the concern about plastic waste and the risks it poses to marine life at the global level. To develop effective strategies for the establishment of programmes of measures that aim to reduce (plastic) litter and its possible impacts (Werner et al., 2017), it is necessary to identify and quantify sources of litter and their pathways to the marine environment.

The main concern is related to anthropogenic polymers (plastic) that occurs in a wide range of sizes, referred to as macro, meso and micro litter. Literature mentions riverine and freshwater inputs as main sources of litter to the seas, with. An estimate of 80% of marine debris coming from land-based sources has been cited (Faris and Hart, 1994; Allsopp et al., 2006), although no comprehensive field data exists. Knowledge on marine litter sources and quantities is still very limited. It can be expected that the actual riverine input is highly variable between different river catchment areas and periods. Furthermore, litter pathways within riverine systems are complex, and transport mechanisms are not well understood.

At the EU scale, there is no comprehensive information available which would allow for the quantification of the amount of litter being transported through rivers to the sea. While the Water Framework Directive (WFD) (European Commission, 2000) could refer to the identification of litter as "other pressure" (WFD, 1.4 Identification of other pressures: "Estimation and identification of other significant anthropogenic impacts on the status of surface waters."), it does not include any explicit provision. There are no long-term, systematic monitoring programmes in place for assessing litter items in the riverine environment. Although several options exist and different approaches are currently being used and investigated, there are as yet no (harmonised) methodologies that can be used to provide quantitative data for making comparable assessments and prioritising efforts with respect to MSFD Programmes of Measures or other policy frameworks.

Recently, research projects and authorities have started to quantify riverine litter using a range of different methodologies and tools. Examples of recent efforts are the EU project "Identification and assessment of riverine input of (marine) litter", sampling litter in four European rivers using different methodologies (van der Wal et al., 2015), the Riverine Input Project (Surfrider Foundation Europe, 2014), and the project "Plastics in the Danube" (Hohenblum et al., 2015). Other initiatives are currently being developed, such as the RIverine and Marine floating macro litter Monitoring and Modelling of Environmental Loading (RIMMEL) project (JRC, 2015).

The present report has been developed by the MSFD Technical Group on Marine Litter (TGML), as part of the MSFD implementation strategy (http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/index_en.htm). The link with other environmental legislation concerns in particular the WFD (European Commission, 2000) and the Habitat Directive (EC, 1992). The TGML informs the WFD Common Implementation Strategy working group on chemicals through regular briefings about the ongoing activities, thus helping to link the implementation strategies. The TGML is composed of experts from EU MS, Researchers, NGOs and delegates from Regional Sea Conventions. As research on the topic is ongoing, it is expected that additional knowledge will soon become available.

Notwithstanding this rapid evolution, a comprehensive overview of monitoring options is needed in order to prepare for the harmonisation of approaches. Scientific developments need to be closely followed in order to provide clear guidance for the future monitoring of riverine litter.

1.2 Scope

This technical report compiles the options for monitoring riverine litter and quantifying litter fluxes, with a focus on anthropogenic litter. While it is not a guidance document, it aims to provide recommendations for monitoring approaches and methodologies. It will also provide indications on the issues that need to be further developed in a collaborative approach.

The report presents preliminary information about the current scientific and technical background regarding litter in river systems, their flow regime and basic properties. The main topics addressed are:

- The present state of riverine litter methodology studies, research and knowledge gaps;
- The relevant morphological and hydrological aspects of the river as a transportation medium of litter, and how this affects monitoring methods;
- The categorisation of litter items and how the material, shape and size of litter items interact with the aqueous environment;
- The seasonal and meteorological aspects that influence the temporary storage and release of litter items on banks or in basins;
- Possible ways of sampling and methods to establish trends in the occurrence of riverine litter.

The purpose is to enable the building of datasets which enable the comparison of litter flows from different rivers into the marine environment and to quantify litter in the freshwater environment. The report also elaborates on the type of data that is needed with respect to the implementation of the MSFD. It should be mentioned that this report, while prepared under the MSFD Common Implementation Strategy, is also expected to provide information to Regional Sea Conventions, in particular those for marine basins that are shared with the EU, but also those further afield.

While discussing the sampling of micro litter, the report does not tackle the issue of sample preparation and analytical procedures, nor the management of riverine litter sources through waste management, prevention or cleaning.

1.3 Monitoring data needs

Marine Litter, as Descriptor 10 of the MSFD, is subject to reduction through target setting and the implementation of measures at the EU and national levels and within the Regional Sea Conventions. For the effective design and planning of measures under the MSFD, information is needed on the flux of litter from rivers into European Seas. Such data would ideally allow for the budgeting of litter amounts between sources and litter found at sea.

It is important to note that, due to the nature of litter, its spatial and temporal variability, the multitude of items, etc., precise data on the flux of litter cannot be obtained. Proxies must be developed which provide fit-for-purpose data with a reasonable amount of effort. This can also include information about the abundance of litter in watersheds where flux data cannot be obtained. The uncertainty of monitoring data must be minimised by carrying out quality assurance and quality controls.

Data must have sufficient spatial and temporal coverage to be able to support representative estimations of fluxes of litter. The representativeness of datasets can be evaluated by power analysis to reduce uncertainty. The temporal and spatial coverage of litter monitoring must be such as to allow for its use at the EU scale. More detailed work could be carried out in research projects that would compare datasets derived for different purposes.

While certain approaches will provide information on the quantities of litter in a river basin, other methodologies will provide flux data. A thorough evaluation must be made of the effort involved in gathering data and how it is used, in order to select the best approach.

2. Riverine Litter

Riverine litter refers to litter present in rivers and on riverbanks. The rivers act as pathways which collect litter from run-off and direct input, transporting it towards the marine aquatic environment (the sea). Litter may also remain in the river catchment, to possibly be released at a later date in its entirety or after physical degradation.

Plastics make up the largest proportion of litter in marine regions (Bergmann et al., 2015) and are dominant in riverine litter (van der Wal et al., 2015; Hohenblum et al., 2015). Non-floating items (e.g. made of glass or metal) are also present in river catchments and transported along the river beds.

The behaviour of litter in riverine systems depends on its sources, pathways, composition and properties (such as size, density and shape).

2.1 Sources

To address riverine litter issues and to allow appropriate and pragmatic measures to be taken, sources need to be identified. Possible sources include public littering on riverbanks or directly in the river, and waste from cities and harbours; poor waste management practices such as poorly managed landfill sites, fly tipping; improper disposal or loss of products from industrial and agricultural activities; debris from the discharge of untreated sewage, either through lack of waste-treatment facilities or from sewer overflows; and storm water discharges, which also sweeps litter collected in storm drains into the rivers (Faure et al., 2012; van der Wal et al., 2015).

The TGML has elaborated parameters and a procedure to allocate the likelihoods of sources to the different items of marine litter (Veiga et al., 2017). Here, we use the same strategic parameters and a procedure to allocate sources of riverine litter, making use of the characteristics of the sources and pathways of riverine litter.

Identification of the sources and pathways of riverine litter is challenging due to the multiple factors involved (see diagram on Figure 1).

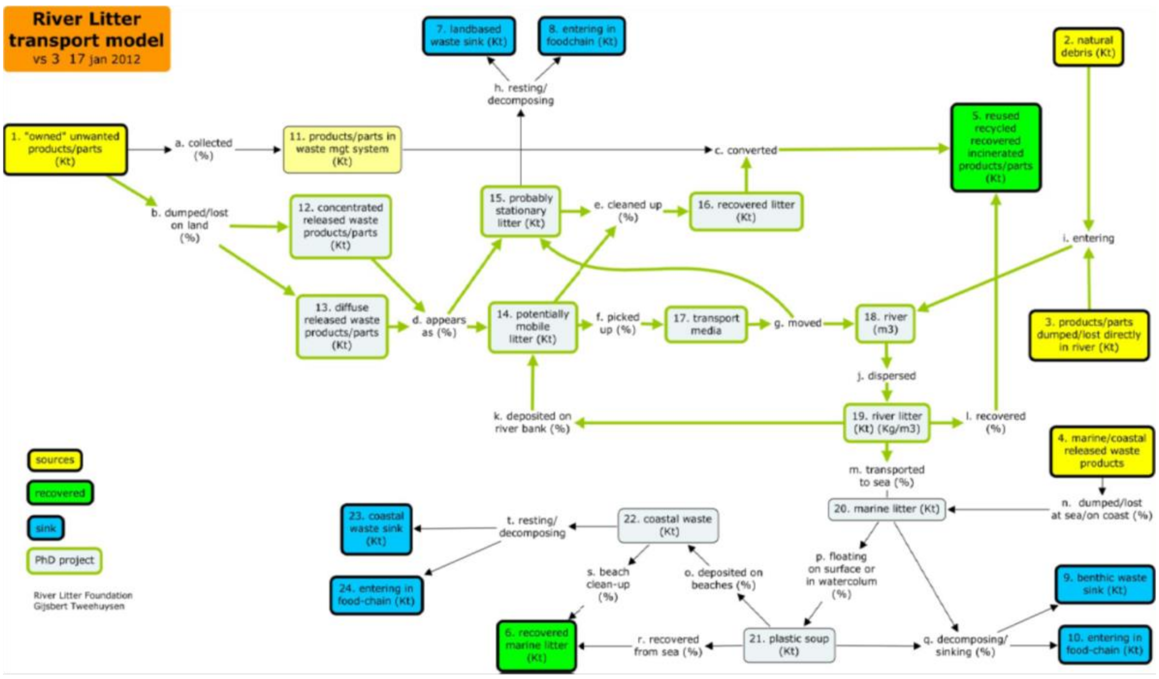

Figure 1: Diagram of marine and riverine litter pathways (van der Wal et al., 2013)

It is often difficult to assign a source with a robust level of accuracy. In riverine litter, the packaging of consumer products is often found (on riverbanks). This, however, can originate from many different sources. Also, the industrial sector is an important source of (micro) litter in rivers, as mentioned in the literature (van der Wal et al., 2015).

Microplastics in rivers can originate either from direct input (as primary microplastics) or from indirect input (as secondary microplastics). Primary microplastics include pellets used as raw material in the plastics industry or added to products as abrasives (e.g. in cosmetics, air-blasting media) that can reach the riverine system through industrial and domestic discharges, e.g. in wastewater treatment plant (WTP) effluents (when not fully removed by the treatment process). Secondary microplastics are fragments of degraded or broken down larger plastic pieces (Arthur et al., 2009; Bergmann et al., 2015). Macro litter trapped on vegetation or deposited on the riverbank could be a continuous source of micro litter due to fragmentation of items by weather conditions (rain, wind, etc.). Other examples of secondary microplastics are car tyre particles and textile fibres (RIVM, 2014).

2.2 Composition

Litter items that are found in rivers can be whole objects, but are mostly parts or fragments of products. Litter is mostly composed of anthropogenic polymers (Bergmann et al., 2015), but other materials (metal, processed wood, paper/carton, glass, textiles, etc.) can also be found.

Litter composition has been described often in riverine and estuarine studies, both for macro and micro litter (Moore et al., 2011; Faure et al., 2015; Gasperi et al., 2014; Morrit et al., 2014; Rech et al., 2014; Sadri and Thompson, 2014). Items have been grouped into size, type and material categories, even at the detail of the composition of plastic polymers.

Macro litter identification

The need to document macro litter items in a harmonised way has led to the development of agreed lists by Regional Sea Conventions and the United Nations (UN). The MSFD Master List of Categories of Litter Items from the "Guidance on Monitoring of Marine Litter in European Seas" (European Commission, 2013) has been developed on that basis, and has already been used in various studies (KÜFOG GmbH, 2013; van der Wal et al., 2015). It provides the basis for necessary comparability between studies of litter in rivers and their adjacent seas. The list differentiates between seven material categories: plastic, rubber, metal, cloth/textile, glass and ceramics, processed wood, paper and cardboard. In total, there are 217 categories, but not all of them are relevant to riverine litter. As an example, van der Wal et al. (2015) used 124 categories in their study, and the Riverine Input Project used 116 categories (Surfrider Europe, 2014). The list can link the identification of an item with its use, and thus supports source identification.

Material

Most litter items in marine and riverine environments are made of anthropogenic polymers. While for macro litter the identification of the objects is of importance for source allocation, micro litter can often only be characterised by its chemical composition and particle shape (van der Wal et al., 2015). Analytical procedures include visual identification, Fourier-transform infrared spectroscopy, Raman micro spectroscopy, energy dispersive X-ray spectrometry, and attenuated total reflection (Dris et al., 2015).

Mixed materials are often found, with one object being made of a combination of different polymers. E.g. a polyethylene terephthalate (PET) bottle can have a polypropylene (PP) cap and a polyethylene (PE) sleeve.

2.3 Properties

Litter consists of items of different sizes, densities, shapes and substances, determined by production processes or changes during their lifetime. These properties determine the behaviour of litter items and particles in terms of their floatability and pathway in the aquatic environment.

Size

Anthropogenic waste items and fragments occur in the aquatic environment in a wide range of sizes. They range from very large items (metres) down to particles and molecular sizes. For practical reasons, size range categories are differentiated as follows:

- macro litter (>25 mm)
- meso litter (5-25 mm)
- micro litter (<5 mm)

These size fractions allow for comparability also beyond Europe. Monitoring strategies and methodologies vary for the macro and micro fractions, while the meso litter fraction can, in some cases, be monitored along with both fractions. Further, litter particles of less than 100 nm are referred to as nano litter (Bergmann, 2015). In the existing literature, the litter size terminology is not always used consistently, thus e.g. in pilot-studies where nets are used to sample, meso litter is often referred to as macro litter. The reported sizes refer typically to the largest dimension of the particles. The TGML has proposed to also report the size of macro litter according to agreed size ranges (Galgani et al., 2013) to allow for more quantitative reporting, enabling the linking to e.g. weight-based assessments:

- 2.5 - 5 cm
- 5 - 10 cm
- 10 – 20 cm
- 20 – 30 cm
- 30 – 50 cm
- >50 cm

While the reporting of size categories is a simple way to derive a link between visual observations and the quantification of litter material, the reporting of an approximate numerical size value is also feasible and could slightly improve estimates, while still being compatible to size class reporting.

Density

The density of litter items depends on the characteristics of the polymer material, modifications such as foaming or the addition of fillers during their production, and processes such as the ageing and biofouling of the materials. The shape of the items can also determine the buoyancy, such as in hollow containers. Depending on the water density (salinity), items will sink or float. Water turbulences may mix items/particles, with a density close to that of the surrounding water, under the surface. The speed of rising or sinking does not only depend on the density of the matter but also, particularly for small items and particles, on their shape.

In calm water with no turbulence, all items with a positive buoyancy will be at the surface and items with negative buoyancy will be at the bottom, but in rivers this is a rare condition.

The transport process of plastic litter in rivers shows some analogies with the transport of other material: transport of vegetation, wood and sediments. The literature concerning the transport of seeds might give some indications regarding the behaviour of plastics in the riverine environment, but seeds tend to change during their time in the water and are not as inert as most of the litter items (Gurnell, 2007). Plastic material becomes covered with a biofilm, which leads to a change in their density. However, the rate at which this occurs is slower than for organic materials.

The behaviour of litter in riverine conditions is different from that in the sea. In estuaries, different effects such as stratification, flocculation, precipitation and density change can occur in the mixing zone and affect the litter pathway.

Most of the available knowledge about the behaviour of suspended solid particles relates to sediment. While the knowledge regarding the hydrological and geological conditions for sediment transport in a river may be used for estimates, litter items and particles may behave differently.

Shape

Shape appears to play a role in particle movement as a function of the ratio between particle surface area and volume (s/v ratio). An item with slightly lighter density than water and a compact shape, e.g. a plastic pellet, will rise to the surface quickly after downward mixing. Instead, an item with a flat shape, e.g. a sheet of plastic, will rise more slowly. The s/v ratio, combined with its buoyancy, determines the terminal velocity of the particle in a viscous medium such as water, either upwards or downwards. Biofilms can also alter the shape of litter particles and thus their hydrodynamic properties. As an additional means of description, plastic particles have been categorised according to their shape into: Fragments, Foil, Fibres, Foam and Pellets (Hohenblum et al., 2015).

This might suggest that microplastics have a terminal velocity which is so low that they will be evenly suspended in the water column regardless of the turbulence, while the larger particles are much less subject to a greater difference in turbulence because of their higher terminal velocity. Compact particles are most likely to be found on the surface or bottom, while flat and long particles will most likely be found in suspension. Rech et al. (2014) used this as a starting point, and distinguished litter based on the type of material and its buoyancy. Plastics, polystyrene and manufactured wood, which can float over long distances without sinking or decomposing, were classified as ‘‘persistent buoyant’’ litter. Many of these persistent buoyant litter items have the potential to float from the headwaters to the mouth of the river, and into the ocean. Therefore, they were used in their study to analyse riverine litter transport. Cigarette stubs, paper and cardboard, textiles, rubber and ‘‘other’’ items made up the category of ‘‘short-time buoyant’’ items, as they initially float and get carried away by a stream, but will sink or decompose after a relatively short period of time, and many of these may not reach the ocean by riverine transport. Concrete, pottery, glass and metal objects were referred to as ‘‘non-buoyant’’ items, as they do not float, although they can be transported in the long term over great distances by river. The transport of "non-buoyant" items is more comparable to the saltatory migration linked to extreme hydraulic events such as floods or high velocity flow. Both pottery and glass can be accumulated on riverbanks.

Van der Wal et al. (2015) concluded that the larger the items/particles, the more vertical segregation occurs. This is a result of the differences in the surface-to-volume ratio at a given density. Compact, particles that are lighter than water, such as closed PET-bottles, expanded polystyrene (EPS) foam, PE pre-production pellets, etc., will always be present at the surface, while larger films or fragments will be drawn into the water column, being subjected to the turbulence in the current. It is necessary to sample both at and below the surface to determine the presence of the whole spectrum of litter in rivers.

3. Rivers

The great variety in river length, catchment size, population, catchment characteristics, meteorological/climatic differences and the level of their management (e.g. through dams and weirs) across Europe and beyond leads to differences in the amounts of litter contained and transported in their river basins. The flux of litter to the sea is related to all of these aspects, and all events occurring in the watershed have an impact on the amount and type of litter.

More than 2 500 rivers (with a catchment area greater than 100 km^2) discharge freshwater into the marine environment in the European shared basins: the Mediterranean Sea, the Atlantic Ocean, the North Sea, the Baltic Sea and the Black Sea. About 1 800 of these rivers are in EU MS (+ Norway). Over 750 rivers are located in non-EU countries. As there are few large rivers (e.g. 63 rivers with an average flow greater than 100 m^3/s; or 62 rivers with watershed area greater than 10 000 km^2), the number of small and medium rivers is dominant and their contributions to litter fluxes is of relevant importance. As an example, 45 rivers have catchment areas associated with populations of more than 1 million inhabitants, while about 1 000 rivers have catchment areas associated with populations of between 10 000 and 1 million inhabitants.

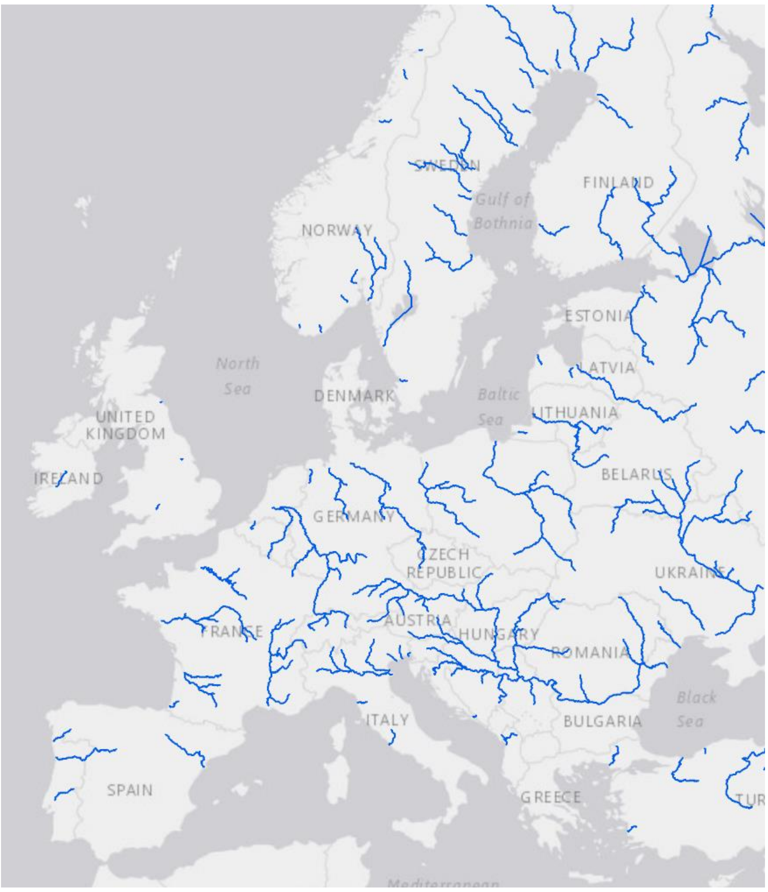

Figure 2: Rivers with an annual average discharge > 100 m^3/s

Figure 3: Rivers with a watershed population > 1 million inhabitants

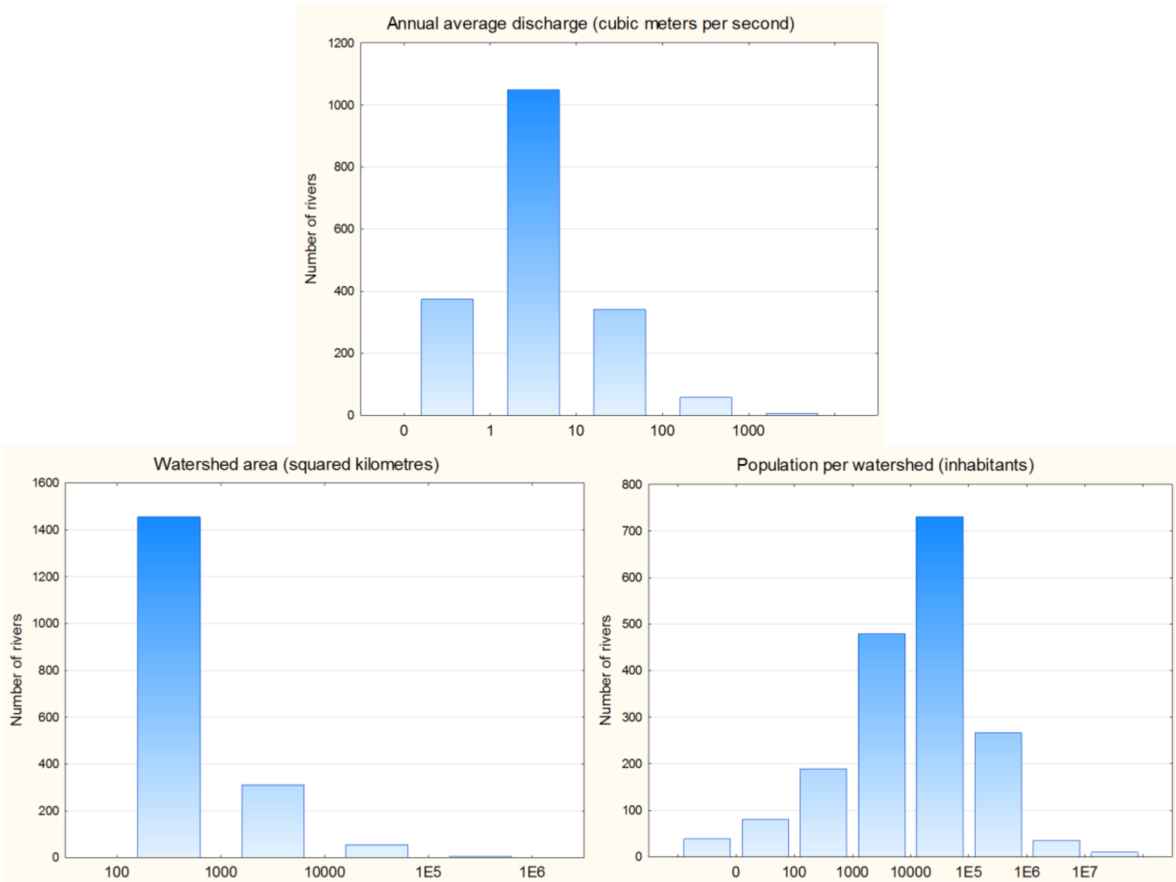

Figure 4 Histograms of average discharge (m^3/s), watershed area (km^2) and population (inhabitants) per watershed for EU MS (+ Norway) rivers. There are 1 765 rivers with catchment area >100 km^2

River morphology and hydrological conditions are important factors for the behaviour of litter in a catchment area. The following subsections describe general aspects of riverine (geo)morphology and hydrology, which are essential when developing a riverine litter monitoring system.

3.1 Morphology

The pathway of litter in a river is related to the (geo)morphological characteristics of the channel/bed and those of the catchment area. Small built-up catchments show a rather quick response to local influences such as storm flood events, and the storage/release of litter is easier to correlate with the presence of litter at the land/water boundary. Large catchments are subject to influences on a very large scale (e.g. storm events that occur in different countries and release stored litter in only a part of the catchment area). Some characteristics of the river catchment area can give indications about the sources and what to expect in the samples. A relevant factor is land use, such as urban, industrial, agricultural and recreational use (van der Wal et al., 2015).

The width, depth and the transect shape are principal characteristics of a river that are directly related to its discharge. Among the riverbed morphological parameters is the bottom gradient, which can be steep in mountain regions or even less than 0.00003% (3 ppm), as in the lower Danube. Waterfalls, rapids or steep alpine gradients are cases of extreme water mixing, whereas lowland rivers with small bottom gradients can exhibit some stratification which could result in a vertical gradient of litter distribution (e.g. microplastics).

Furthermore, the degree of sinuosity (i.e. curves present in the river), the degree of braiding (i.e. the percentage of a channel divided by bars) and the degree of anastomosing (i.e. the percentage occupied by large islands) (Brice, 1964) can have significant influence on how litter items are transported in a river system. Meandering rivers may deposit floating items in the bends and release them only in periods of rising water levels or after physical degradation.

There are various types of human infrastructures that will have an effect on river flow and therefore on the transport of litter to the sea. Some of these infrastructures include: storage areas, dams (e.g. of hydropower plants or tidal barrages), locks, weirs, barrages, groins and channels. They control river flow and flood events, affecting the retaining and release of litter. These barriers can block litter, release it or introduce internal river turbulence. Bridges and piers can also affect the litter distribution, especially due to perturbation of the river flow and the erosion of the river bed and banks downstream of the infrastructure. The location of infrastructures and their influence on sampling sites and sampling results must be considered. They may facilitate monitoring activities, by providing stable structures e.g. for the collection of litter, visual observation or the deployment of nets.

A specific factor is the abundance and type of vegetation on riverbanks and shorelines. Depending on the flow velocity and the type of vegetation present, litter can be trapped in bushes and trees. With high discharges, litter items will be deposited higher on the bank and may remain there when the water level drops. Even under high discharge conditions, riverbanks can be effective in retaining litter (Williams & Simmons, 1997).

3.2 Hydrology

The hydrological properties of a river, determined by its shape and the meteorological situation, are to be considered when developing a riverine litter monitoring system.

Discharge and Flow velocity

The river discharge and thus its flow directly depend on the meteorological conditions upstream. The timing of and delay between precipitation events and the increase in discharge, the hysteresis, are determined by the properties of the watershed. Besides seasonal variations, changes in discharge can be large and rapid, depending on the watershed. Annual discharge regimes vary between different climate zones and are affected by extreme events. Within a river, the flow velocity changes vertically (water depth) and across sections (distance to riverbanks), and steep gradients can therefore be present (van der Wal et al., 2015).

A specific case of a discharge regime are intermittent rivers which are completely or almost dry during seasons of the year or even carry water only during very short periods. They constitute one half of the global river networks and their number is expected to increase due to climate change (Datry, 2014). The beds of intermittent rivers often contain litter that is flushed downstream during rain events or snow melt. They are of particular importance in southern European countries and are mostly tributaries to the Mediterranean Sea and the Black Sea. Certainly, rivers can also be temporary in northern countries, in particular in the Arctic regions, if they freeze, with similar effects on litter transport.

Windage

Wind can affect the surface water layer, in particular in slow-flowing, large rivers and estuaries, influencing if and where floating litter will accumulate. In particular, macro litter items protruding from the surface will be affected by windage. Very localised processes, such as a change in wind direction, could release beached items to be transported further (Tweehuysen, 2013). On the other hand, in medium-sized rivers with riparian forest and/or vegetation, wind is expected to have a low impact on the surface current and litter distribution.

Tributaries

When tributaries enter the main flow, a segregated flow can be present over a long distance before complete mixing is achieved. Figure 5 shows the stationary sampling location in the Danube near Galati (Romania), where the sediment-laden water from the upstream tributary (Siret-river) was sampled.

Figure 5: Stationary sampling location in the Danube near Galati (Romania)

Tidal regimes

The seas surrounding Europe have different tidal regimes. The North Sea and the Atlantic Ocean have strong tidal regimes, at certain places enhanced by local characteristics, like in the English Channel with tidal ranges in the order of metres. Litter will be transported with the tidal currents, i.e. both incoming and outgoing litter may be observed, and thus the net outgoing litter flux would have to be determined by the monitoring set-up. The three other European shared basins (the Baltic Sea, the Mediterranean Sea and the Black Sea) have only limited tidal ranges.

River internal turbulences

River bottom morphology and the shape and roughness of the river bed determine the internal river turbulences at different scales. While laminar flow could occur in channel type waterbodies, turbulent flows are created by physical disturbances. Furthermore, wind can introduce wave action, and manmade structures and shipping can add to water column mixing. Meandering rivers exhibit an increased flow on the outside of the curve, creating a corkscrew pattern of internal currents that can lead to a further mixing of the water column (Hamblin, 1992). All of these factors determine the behaviour of litter in the river, in particular its presence in the water column, which is of great importance to sampling set-up.

Results of a survey about the Danube River demonstrate the dependency of plastics and microplastics on different morphological situations at different sampling sites in the same river. Stretches with settled flow showed a pronounced stratification of plastic particles throughout the water column. At lower flow rates, more plastic was found floating on the river surface and close to one riverbank than in the middle section. Stretches with settled flow can be in the backwaters (and in the storage area) of hydropower plants. In stretches with higher flow velocity and turbulences this effect diminishes, particularly at higher discharge levels (Hohenblum et al., 2015).

4. Monitoring Strategy

The scope of monitoring riverine litter is the quantification of litter presence, fluxes, and the identification/characterisation of sources to assess the environmental status and to support the development of reduction measures. The monitoring strategy must therefore balance the data needs with the costs of monitoring. The properties of riverine litter and morphological/hydrological conditions of the rivers determine the appropriate strategy to be used. The sampling strategies need to be adapted to local conditions while retaining comparability of the results among different rivers.

In this section, only general considerations can be given. A detailed guidance document should be prepared through a collaborative effort, taking into account the identified parameters.

4.1 Location

To assess the input of riverine litter into the sea, the mouth of the river can provide a cumulative amount of litter, unless there are significant sinks, e.g. in the estuary. The identification of sources and hotspots will require investigative upstream sampling locations.

As estuaries are highly complex systems, sampling should be done upstream to facilitate data acquisition and interpretation. Likewise, in tidal environments, a monitoring site should be chosen that is not subject to the influence of tidal currents on the observed or sampled litter (see also considerations about the timing of the monitoring).

The exact locations will depend on available information, such as population density, potential litter emitters and sampling location opportunities. Further considerations may include, for example, the location at a site which is relevant for management, such as an administrative border between districts of responsibility, combination with an existing monitoring site for the use of synergetic effects for sampling logistics and the selection of a site with an undisturbed linear flow.

The representativeness of the sampling location, in terms of the quantity and typology of litter found, should be taken into consideration, especially when monitoring riverbanks. This is important when assessments foresee the comparison of upstream and downstream sampling locations in relation to the presence of human pressures (industrial, agricultural, urban, etc.).

4.2 Timing

The amounts of litter present in rivers can be highly variable. This is due to short-term variability in sources, such as through event-triggered littering, dumping, the opening of weirs, etc. Furthermore, meteorological events, such as rainfall, leads to rapid input through run-off from roads or channels. In periods of low precipitation, litter can accumulate on the land and then be flushed away by heavy rainfalls. Likewise, litter accumulated on riverbanks can be washed into the river at higher water flows or during flood events. This leads to litter peaks, while the following water will contain less transported litter. Other, slower, variations can be introduced by seasonal changes, such as, for example, snowmelt or the seasonal use patterns of littered items.

As these changes can occur on different time scales, strong variations can occur within minutes, as peaks, or over long periods, also due to mixing effects further away from the sources. Ideally, methods that integrate data over time would be beneficial, although that would often require considerable effort through the installation of medium- or long-term/permanent structures for litter collection. Short-term monitoring, such as observations of 30 minutes to one hour, require more frequent surveys.

Litter sampling and observation schemes need to take these variabilities into account to provide, with reasonable effort, data to support litter management. Monitoring activities should cover different seasons and environmental conditions, in particular at the start of a monitoring programme, in order to understand the underlying litter pathway principles and causes. A triggered sampling activity, although requiring more organisation, can be appropriate to monitor the effects of events such as flushing.

In cases where monitoring locations need to be placed in tidal environments, the timing of the observation/sampling activity should be organised to provide reproducible results. Depending on the functioning of the estuary, this can be done by, for example, always measuring in the same phase of the outgoing tidal cycle.

Temporary or intermittent rivers will also require a dedicated strategy, such as quantifying litter in the dry riverbed before the seasonal water discharge, or at the onset of the riverbed flooding.

The rapid variability of litter fluxes can either be taken into account by high frequency measurements, or by long-term monitoring methods, such as the deployment of litter traps or camera systems.

With the development of monitoring methodologies, the strategy, location and timing of litter monitoring activities will have to be adapted. New tools and technologies will provide solutions for data acquisition, while the better understanding of river pathways will allow for more focused monitoring.

5. Monitoring methods

For the purpose of this report, an extensive list of the literature has been reviewed with a focus on monitoring and assessment methodologies, including field studies carried out on several major European rivers. This chapter describes the relevant methods and techniques used in riverine/estuarine environments for the study of riverine litter. Research and monitoring data were collected upstream, above tidal influences and in estuaries.

Applied methodologies differ in the targeted environmental compartment, litter size fraction and the technology used. Figure 6 presents the main methodologies for monitoring litter by size categories in different compartments of a river.

Environmental compartments:

- River water body
- Riverbank

For a river water body, the river surface can be monitored by visual observation and image acquisition. Monitoring in the river water body can include the use of existing retaining structures and sampling using grids or nets, with different mesh sizes and openings, at different water depths.

Riverbank monitoring, similar to beach litter monitoring in the marine environment, comprises of the observation and possibly the collection of litter items.

Litter size fraction

Monitoring methods target different categories of litter size. Visual observation of litter on riverbanks can include meso and macro litter items (>5 mm), while methods for collecting microplastics (<5 mm) can include meso and macro litter items depending on the configuration of the sampling device (e.g. the size of the net openings). The representativeness of sampling litter of a certain abundance in relation to sampling duration and sampler opening width must be accounted for. This means that, given the amount of litter typically present, samplers with a small opening, for example 50 cm, will not sample macro litter representatively.

Technology used: Observation/Collection methods

The observation monitoring approach is based on observation of a surface. This can be through in-situ human visual observations or the acquisition of surface images by devices. Observational methods are intended to monitor meso and macro litter only. Visual observation is typically a low-technology approach and is easily applicable for monitoring macro litter.

The collection monitoring approach involves the physical collection of litter, and can follow different sampling strategies: selective (collection of individual litter items on site), bulk (collection of a whole sample for later analysis), or volume-reduced (collection of a portion of the sample on site for later analysis), as described by Hidalgo-Ruz et al. (2012). This distinction is valid for all collection methods in both marine and freshwater environments.

Cost and effort

The cost and effort of the different monitoring methodologies is an important factor and needs to be balanced against the information obtained for management purposes. Although a detailed cost-effectiveness analysis could not be made for each method used at this stage, a preliminary description of "effort" per technique is given.

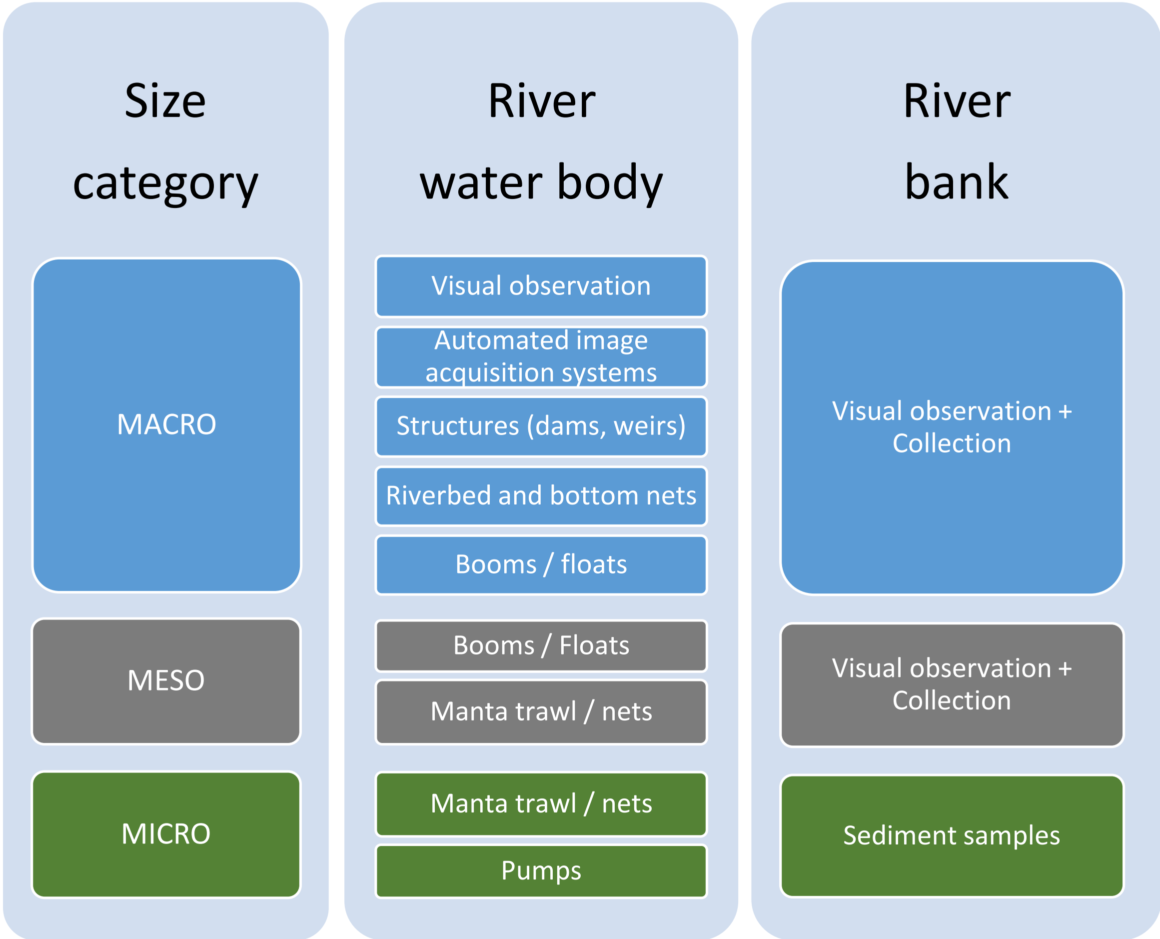

Figure 6: Main methodologies for monitoring litter by size categories in different compartments of a river.

5.1 River water body - surface observation

Macro litter floating on the water surface can be monitored by visual observation. For the purpose of estimating riverine inputs of floating macro litter into the sea, this has been proposed as a simple and cheap method (JRC, 2015). While the lower size limit of 2.5 cm can be observed by selecting appropriate observing conditions, in particular the observation distance, meso and micro litter cannot be reasonably monitored in this way.

Table 1: Scientific studies using observation methodologies for surface floating macro litter

Visual observation of floating litter

Author	Site	Litter size	Methodology	Units
Doyle et al. (in preparation)	River	Macro	Observers on the side of the river looking across half section. (0.5- to 1-hour surveys)	items/hour
JRC RIMMEL project (JRC, 2015)	River	Macro	Observation of river surface (0.5- to 1-hour surveys), documentation by tablet computer application.	Items/river section x time

The observed surface layer depth will depend on the turbidity of the river, and litter may be submerged. While it is difficult to representatively monitor the macro litter present on the water surface, such monitoring could provide direct information about riverine litter flux and exposure. Monitoring can be stationary, from the shore or structures located in the river (e.g. bridge, pontoon, pier, quay wall, etc.). Alternatively, boats can be used in bigger rivers and estuaries, allowing both stationary and dynamic monitoring (e.g. transects).

So far, scientific information about visual observations of floating litter is very scarce and has been mostly cited in mobility/transport studies where tagged items/tracers were introduced in the river stream and monitored downstream for a certain period (William and Simmons, 1997; Wilson and Randall, 2005). These studies combined observations of litter on banks/shorelines and floating on the river to assess the movement of items, which can be stranded or entangled on land for indefinite periods of time, and therefore remain in the watershed without reaching the sea.

Visual monitoring data, combined with river flow data, can lead to estimations of floating litter fluxes. Data can be reported as items/period of time, considering the width of the observation area and the river flow speed.

Methodologies for observing marine litter at sea from vessels can provide experience which could be transferred to river observation. At sea, observers positioned on the side of the vessel recorded floating macro litter items during timed transects (Aliani et al., 2003; Hinojosa and Thiel, 2009), reporting items/km^2 based on observation track width and transect distance. In addition, distance sampling methods (Buckland et al., 2005) can be applied to estimate the densities of floating debris, e.g. line transect methodology (Ryan, 2013; Suaria and Aliani, 2014; Suaria et al., 2015). A protocol for visual observation of floating marine litter at sea has been proposed by the TGML (Galgani et al., 2013).

Regarding freshwater environments, methodologies used for making surface-counts of jellyfish from vessels at sea (Doyle et al., 2007) have been adapted to monitor the composition and abundance of litter in rivers (Doyle at al., in preparation). The methodology consisted of an observer undertaking visual observations of litter items from the side of a river. The observer’s field of view was therefore perpendicular to the main axis of the river, and so it was comparable to making visual observations from a vessel at sea. Floating items were classified according to 62 specific categories (e.g. cigarette butts, sweet wrappers) plus some general categories for unidentifiable items. A large dip net was used to remove both identified and unidentified items from the river to confirm their characterisation. The duration of visual observations was 30 or 60 minutes per sampling event, and in total 31 hours of visual observations were made over 15 days.

The RIverine and Marine floating macro litter Monitoring and Modelling of Environmental Loading (RIMMEL) project (JRC, 2015) collects visual observation data of surface floating litter through a network of collaborating institutions across EU Member States and neighbouring countries in the European shared marine basins. The project aims to cover a large spatial area and to obtain initial data from rivers which otherwise would not be covered. Surface floating litter should serve as an approximation for litter loads. Data are documented using a tablet computer application and are sent to a central database for analysis.

The representativeness of floating macro litter observation at the surface in relation to total loads in the water column is not well known. However, litter characteristics and turbulent flow conditions in rivers suggest that a major fraction can be transported below the surface in the water column (van der Wal, 2013). Very turbid water hinders the observation of sub-surface floating items, even at shallow depths. Buoyant items are expected to travel greater distances downstream (Wilson and Randall, 2005), having a greater probability of making their way to the sea.

The identification, in particular of smaller items or fragments, can be difficult due to the short observation time as they flow by. The observation point is critical, ideally situated on a bridge or structure which facilitates the unobstructed view of the water surface, and also allows for the identification of smaller items (e.g. down to 2.5 cm size), providing a wide field of view which is not disturbed by light conditions. Reduced flows, eddies and turbulences in the vicinity of shorelines must be considered when no bridge or structure is available and observation can only be made from the shore.

While long periods of observation would be desirable, typical observation periods could be half an hour to an hour, as a balance between representative observation and the onset of observer fatigue, which would decrease data quality.

Other approaches, which are developed for the monitoring of public spaces, use a ranking system with five categories to document the abundance of macro litter in and close to water bodies (CROW, 2013). While they allow for a semi-quantitative assessment of the overall amount of litter, they do not provide information about the type of litter item.

The use of automatized camera systems for the continuous long-term observation of river surfaces, sometimes combined with image recognition technology, has been proposed and is being investigated (JRC, 2015).

Effort

The monitoring of floating litter by visual observation is a straightforward process which does not require specific equipment or skills, but should be carried out by trained observers. Representative monitoring will require frequent observations. The measurement or estimations of river flow require additional equipment, when such data is not available from gauge stations.

5.2 River water body - collection

Floating and suspended litter is collected by filtering river water with nets, grids and filters of different mesh sizes for the different litter size fractions. Sampling devices can be deployed at the surface, from where they skim the upper water layer or deeper in the water column.

Table 2 includes a review of monitoring methods for the collection of litter in river waters. Applied methodologies include the deployment of plankton nets, the use of fishing nets, the installation of surface skimming booms, and the deployment of trawling floats lined with a mesh or grid.

Table 2: Scientific studies using collection methodologies for litter in the riverine water body

Litter collection in water body				
Author	Device opening dimension, mesh size	Monitoring depth	Monitoring method	Unit
Moore et al., 2011	90x15 cm, 333 µm	top 15 cm	Stationary manta trawl, deployed with a crane to sample water in the middle of the channel. Three replicates of 15-minute trawls (or until the net is clogged) at each site. Flow rate measured by flow meter or floating objects. Fractions separated with Tyler sieves (4.75 mm, 2.8 mm and 1.0 mm mesh).	items/m^3
	46x25 cm and 43x22 cm, 0.8 mm; 46x25 cm, 333 µm	n.a.	Stationary hand nets (0.8 mm mesh and opening 46x25 cm; 0.8 mm mesh and opening 43x22 cm) to sample at the edge of the channel, and heavy rectangular net (333 µm mesh and opening 46x25 cm) deployed from a bridge. Replicates, time and fractions separation as described for manta trawl.	items/m^3
Faure et al., 2012	60x25 cm, 300 µm	top 25 cm	Dynamic manta trawl. Trawl distance 3.7 km. Sieving (5 mm mesh) in the laboratory to separate micro from macro.	g/km^2, items /km^2
van der Wal et al., 2013	n.a., 3.2 mm	top 10 cm; 10-60 cm	Waste Free Waters (WFW) sampler from MosaPura project: a cage-like construction mounted on a pontoon with two nets (3.2 mm mesh) which sample floating (top 10 cm) and suspended litter (10-60 cm depth).	m^3 macro plastics/year (estimations based on assumptions)
Eriksen et al., 2013	61x16 cm, 333 µm	top 16 cm	Dynamic manta trawl. Trawl distance calculated with onboard speed meter during 60 minutes' surveys. Litter fractions separated in the laboratory by Tyler sieves (0.355–0.999 mm and 1.00–4.749 mm and >4.75 mm).	items/km^2
Faure et al., 2015	60x18 cm, 300 µm	top 18 cm	Dynamic manta trawl. Mechanical flow meter attached at the trawl opening. Lake sampling: trawl distance 3-4 km to filter 320-430 m^3 of surface water (speed of 1.5 m/s, 3 kn). River sampling: Trawl attached on a ridge for 15-30 mins. Micro and macro fractions separated in the laboratory by sieves (>300 µm, >1 mm and >5 mm).	Lake: mg/km^2, items/km^2; River: item/m^3, mg/m^3, items/h, mg/h

Litter collection in water body

Author	Device opening dimension, mesh size	Monitoring depth	Monitoring method	Unit
Free et al., 2014	61x16 cm, 333 µm	top 16 cm	Dynamic manta trawl. Trawl distance 3.1-4.1 km, 60 mins at a speed of 3.5 kn. Litter fractions separated in the laboratory by sieves (0.355–0.999 mm and 1.00–4.749 mm and >4.75 mm).	items/km^2
Gasperi et al., 2014	n.a.	n.a.	Using an extensive regional network of floating debris-retention booms. Manual collection of 2-kg subsamples of 10 kg of crushed debris from the garbage dumpsters. All plastics >5 mm considered.	Weight
Midburst et al., 2014	n.a.	n.a.	Characterisation of debris collected by trash booms near the river mouth.	Weight
Morritt et al., 2014	40 cm diameter ring	bottom 40 cm	Standard and modified eel fyke nets anchored to the riverbed with 40-cm-diameter ring. Nets installed parallel to shoreline in line with tidal direction. Monitoring during three-months fishing programme.	Total number of items during fishing program
Lechner et al., 2014	50 cm diameter, 500 µm	top 50 cm	Stationary conical driftnets (1.5 m long) (covering 60% of total column most cases). Flow meter attached to the net. Simultaneous replicates done at both margins of the river (25 m distance to the shoreline). Samples collected hourly for circadian periods. Items classified as meso debris (2-20 mm) and micro debris (<2 mm).	items/1,000 m^3, g/1,000 m^3
Sadri and Thompson, 2014	50x15 cm, 300 µm	top 15 cm	Dynamic manta trawl. Three replicate samples for both ebb and flood periods. Net towed against the tidal flow at a speed of 4 knots for 30 min during the maximum flow period. Samples sieved in the laboratory and items categorised as >5 mm, 3–5 mm, 1–3 mm and < 1 mm.	items/m^3
Jang et al., 2014	n.a., 5 mm	n.a.	Netting of floating debris (mesh 5 mm) at the mouth of the river.	Weight

Litter collection in water body

Author	Device opening dimension, mesh size	Monitoring depth	Monitoring method	Unit
Hohenblum et al., 2015	30x60 cm and 60x60 cm, 250 and 500 μm	Surface, midwater, bottom	Stationary driftnets system with five nets (mesh sizes 250 μm and 500 μm) at different depths: one at the bottom (sediment trap with 30x60 cm opening), two at middle water (60x60 cm opening) and two at the surface (60x60 cm opening). Monitoring surveys of 45-60 minutes, with flow meters attached to the nets at each depth.	Concentration (g/1,000 m^3); fluxes (g/s and kg/d, tonnes/year)
Tweehuysen, 2015	Surface net 100x10 cm and suspension net 100x50 cm, 3.2x3.2 mm mesh, trapping items > 4.5 mm	top 10 cm + 20-70 cm	Trawling transects sampling with Waste-Free Waters (WFW) sampler on the side of the boat. Doppler current meter used to measure relative speed. WFW sampler is a cage-like structure with two nets.	items/ km^2, items/million m^3
van der Wal et al., 2015	60x10 cm, 330 μm	top 10 cm	Stationary Manta trawl. Trawled from riverbank for maximum 30 minutes. Analysis restricted to <5 mm particles.	items/km^2, g/km^2
	n.a., 330 μm	at 30 cm depth	Stationary pump-manta net method to filter 5,000 L by pumping water into a container using the manta net as a sieve. Analysis restricted to <5 mm particles.	items/km^2, g/km^2, items/m^3, g/m^3
	1-m opening, 3.2 mm mesh	top 5 cm + 20-70 cm	Waste-Free Waters (WFW) sampler: a cage-like construction mounted on a pontoon with two nets at the surface and suspended litter below. Analysis restricted to 5-25 mm particles.	items/km^2, g/km^2
Naidoo et al., 2015	30 cm diameter, 300 μm	top 30 cm	Dynamic trawl with conical zooplankton net at constant speed (5 replicates at each site). Flow meter fixed to the net to ensure 10,000 L filtration. Samples filtered through 1,000-, 500-, and 250-μm sieves in the laboratory.	items/10,000 L
Schulz, 2015	17x9 m, 6 mm; 10x9 m, 8 mm; 13x10 m 10 mm	n.a.	Combined sampling with fish monitoring using commercial stow nets. Flowmeter attached to the net to measure volume filtered.	items/10^5 L

n.a. (not available)

The inclusion of different sized particles in a sample will depend on the mesh size of the net, filter or grid used, which will also influence the amount of sampled material. Harmonisation in this case is not achieved by a precise definition of the size fraction to be sampled, but by agreeing on the grid/net material and mesh shape and size. When e.g. the objective is to sample litter of a minimum of 5 mm (typically expressed as the largest dimension of a fragment), a mesh size of 5 mm will also occasionally allow much larger, longer particles (e.g. fibres or sticks) to pass through the grid. The operational definition of the mesh material will therefore provide harmonisation for comparability of data.

Nets or floats need to be deployed from a fixed structure for stationary sampling. The water flow then provides the flow-through and flux data can be obtained. In larger rivers, sampling can also be performed by dynamic sampling from boats which tow a sampling device. In dynamic sampling, the flow through the sampling device can be considered to be constant if its speed is much greater than the river flow speed or, if it is constant, during multiple sampling runs. The sampling must take place outside the wake or bow-waves from the ship to prevent disturbance of the vertical dispersion of the particles. Possible contamination from the boat, e.g. by paint particles, must be considered. Dynamic sampling can also give the opportunity to sample both on the downwind and the upwind side of the stream, and to eliminate the effect of the input from subsidiaries or from local point sources by crossing the streamlines on the transverse direction (van der Wal et al., 2015). In both cases, filtration volume needs to be measured to calculate the concentration of litter items/particles for a specific sample, which is different from the total flux of litter (see below the considerations with regard to the calculation of fluxes of litter).

The ideal deployment place for nets, booms, pump inlets, etc. should be derived from flow measurements that take into account the river transect, influence of wind, the availability of deployment structures and accessibility. For example, the middle point of a cross section in a straight river reach, where the flow velocity is expected to be at its maximum, could be appropriate for sampling.

The usefulness of these methods in calculating fluxes of litter to the sea will depend on the availability of reliable measurements of riverine flow data. The concentration of litter in a sample can be used to estimate total litter flux. For this purpose, flow measurement by means of mobile ADCP (Acoustic Doppler Current Profiler) sampling next to a gauge metering point would be ideal, while other methods (such as portable current meters or surface flow estimates made by timing the passing of a measured distance) can provide approximate data. Comparison of in-situ measurements with river basin gauge flow data can help improve the understanding of litter variability and dynamics in riverine environments.

5.2.1 Manta Trawls/Nets

The review of employed methodologies showed that nets are mainly used for the monitoring of micro litter. Small mesh sizes, down to 333 μm (as recommended for marine micro litter by the TGML (Galgani et al., 2013)), can clog quickly in riverine environments, leading to shorter deployment times. The representativeness of sampling will depend on the abundance of the sampled litter fraction, the sampler opening and the sampling duration. For a fixed filtration volume, abundance is much lower for larger items, depending also on different distribution patterns across river sections. Therefore, sampling with devices with small openings, such as 50 cm over short time scales, such as 15 minutes to 1 hour, will not allow for a representative sampling of macro litter items.

It should be noted that the recommendation for nets with mesh sizes of 333 μm stems from the ready availability and practical use of these nets, while plastic particles in the environment can be much smaller. For micro litter, the most common method used in freshwater environments employs neuston nets mounted on manta trawls (size range:

300- to 500-µm mesh) with a rectangular frame (manta trawl net) that are towed by boats in dynamic sampling (Eerkes-Medrano et al., 2015; Dris et al., 2015). Manta nets have also been used occasionally in stationary sampling, attached to fixed structures on the river (e.g. bridge) (Faure et al., 2015). Stationary conical driftnets and zooplankton nets can also be used (Lechner et al., 2014; Naidoo et al., 2015). The configuration and dimension of the net opening frame will determine the depth of the surface layer sampled (e.g. a conical net that filters the upper 0.5 metres of the water column). Even if results are reported by some authors as items per surface area, the configuration of the net will obviously include floating and suspended particles, depending on the net submersion depth. Hand nets could also be used for surface sampling (Moore et al., 2011).

In the Danube River, the University of Natural Resources and Life Sciences, Vienna, elaborated a method to examine the spatial distribution of micro litter over the river section. Sampling with drift nets was carried out at 5-10 locations across the river transect, at three different depths, and with five different discharge conditions per sampling site. Individual concentrations of plastic were allocated to the transect locations and depths, and a daily transport rate was calculated. Regression functions can be derived when delineating transport rates of all measurements under different discharge conditions. This allowed for the calculation of an average plastic load of the river (Hohenblum et al., 2015). However, it must be taken into account the fact that the rising phase of a high water period contains a higher concentration of litter than the descending phase (hysteresis), and that high water periods after a long dry period also contain elevated concentrations (first flush).

Hohenblum et al. (2015) also observed a strong variability in the distribution of plastic particles vertically and across the river section. The vertical profile showed stratification under lower energetic conditions (floating particles accumulate in surface layer) and more homogenous distribution at higher discharge levels (higher flow velocity and turbulences).

Fishing nets with large openings and wide mesh sizes could potentially be used for the monitoring of macro litter, although longer deployment times are difficult to achieve for logistic reasons, and only one opportunistic litter monitoring application was found (Schultz, 2015).

Sample preparation and analysis for micro litter

As samples mainly consist of natural suspended particles, sediments and organic material such as leaves, algae or wood, extensive separation techniques need to be applied to finally isolate plastic particles for analysis.

Depending on the size of particles, and particularly for micro litter, samples will need to be mechanically and/or chemically pre-treated to reduce the amount of matrix. Mixtures of micro litter and organic material can effectively be separated by drying the sample (24 hrs at 70°C) and manually removing the brittle organic fraction. Several methods for density separation of micro litter, by using dissolved salts to shift density differences or soft digestive methods (use of hydrogen peroxide or enzymatic methods), are described in the literature (Leslie et al., 2012; Hidalgo-Ruz et al., 2012; Hollmann et al., 2013; Zhao et al., 2014; Claessens et al., 2013; Cole et al., 2014; Nuelle et al., 2014; Imhof et al., 2012). The smaller the particles of interest, the greater the need for instrumental support to confirm plastic material.

Effort

The monitoring with nets of a reasonable size requires logistic infrastructure for deployment from a bridge, quay or pontoon, such as a crane or winches. Dynamic sampling requires a boat of appropriate dimensions. Analysis of micro litter samples requires sample preparation, visual analysis under microscopes, and instrumental analysis with spectroscopic methodologies.

5.2.2 Riverbed bottom nets

Litter items that are heavier than water can be transported on the riverbed, being dragged along by with the bottom currents. The extent of this transport will depend on the flow, the geological riverbed constitution and internal dynamics, including those caused by constructions. While no ongoing monitoring is currently being carried out, these items can be caught by nets which are deployed for bottom fishing (Morritt et al., 2014) and water-column fishing, covering a section of water from the bottom to a significant height of the water column (Schulz, 2015).

Effort

The installation, maintenance and recovery of nets deployed at the bottom of riverbeds requires substantial on-site logistics.

5.2.3 Pump-filtration systems

The filtration of water sampled through a pumping system provides an alternative to net deployment for the collection of micro litter. It requires extremely large-volume pumping systems and filtration units which allow for the utilisation of small mesh sizes without clogging filters over extended periods of time. Permanent installation structures would then allow for more frequent or integrated sampling, which improves the data quality with respect to variability in the microplastic concentrations over time. To avoid discrimination between particle properties in the targeted size fraction, it is important that isokinetic sampling is applied, i.e. the withdrawal from the water sample must occur at the same speed as that of the water flow.

A particular use for the pump-filtration method was shown by van der Wal et al. (2015), where a 5,000 litre volume was filtered by pumping water (inlet nozzle at 0.3 m below surface) into a container, using a manta net as a sieve.

Effort

The pumping of large water volumes requires a logistic infrastructure for the pump set-up, in particular for positioning the sample inlet in the water column or skimming the surface, e.g. with an anchored float or from a fixed structure. Existing riverine water monitoring stations provide opportunities for such installations. Sample preparation and analysis are the same as for sampling with nets.

5.2.4 Booms and floats

Litter booms are surface-floating barriers which divert litter into a collection cage. They work by skimming the water surface, but typically can also have a coarse net attached that acts as a "curtain" in order to collect subsurface floating items (Gasperi et al., 2014; Midbust et al., 2014). The mesh size of the collection cage typically does not retain small particles, as the devices are designed for longer-term deployment. They can cover smaller rivers entirely or be deployed in channels. There are different commercial supplies in the market. These devices avoid litter being transported downstream and can provide time-integrating data on overall litter flux. Other floating litter collectors are devices which have not been constructed specifically for monitoring but potentially could provide data, such as the "passive debris collector" (http://www.thames21.org.uk/). Similar to devices used in the event of oil spills, booms for litter are sensitive to current flows or strong winds, so it is necessary to carefully choose the deployment area. A continuous control and service may also be needed.

Specific floats with small openings in relation to the river width are being used for monitoring litter. An example of a cage-like float structure developed for litter monitoring is the Waste Free Waters (WFW) sampler (Tweehuysen, 2015; van der Wal et al., 2015), which contains two metal nets that allow for surface and subsurface (20-70 cm depth) sampling. The WFW sampler has been tested with different mesh sizes, leading to a recommendation for a 3-4 mm mesh for optimum monitoring without clogging at an opening of 1 metre (https://wastefreewaters.wordpress.com/). The sampler can be towed behind or beside a boat.

As with other sampling devices, previous investigations at different places and under different conditions may reveal the best deployment spots for such devices.

Effort

For longer-term deployment, in addition to the cost of the booms or float devices, necessary permits by the competent authorities and the maintenance costs need to be considered. The use of existing infrastructures can facilitate monitoring activities.

5.3 Artificial structures

Opportunistic sampling can take place at structures which retain riverine litter material through grids or weirs. Retention structures include different man-made infrastructures that alter the river flow and initially reduce the fluxes of litter throughout the watershed to the sea. Some of these structures are: dams, dykes, weirs, sluices and floodgates. Maintenance and clean-up programmes remove large volumes of material from these structures, e.g. floating debris from dykes and upstream of hydraulic structures after floods (van der Wal, 2013), but quantities, composition and sources are often not documented. Non-buoyant litter can be expected to accumulate at barriers such as weirs, dams and sluices.

Water intake structures for hydroelectric facilities, cooling systems and drinking water facilities contain filtering/sieving systems and might be used to collect data. In the Austrian stretch of the Danube River (349 km), there are 11 hydropower plants in which litter is retained. At all sites, waste is separated at the intake structure to prevent the turbine from damage. The share of plastics in the total amount of waste is estimated to be less than 2% (Trennt, 2013). The total amount of waste which is removed from the intake structures of all hydropower plants along the Austrian stretch of the Danube River amounts to an annual average of 7,500 tonnes per year (Verbund, 2010). Considering that 2% are estimated to be made of plastic, approximately 150 tonnes of plastics are removed from the river annually as a rough guess. In addition, micro litter inputs into the riverine system could be monitored at Waste Water Treatment Plant (WWTP) outlets.

Despite its potential for assessing the presence, composition, sourcing and estimation of fluxes in watersheds, scientific information on litter monitoring at retention structures and/or water intakes is currently often difficult to access or not available.

5.4 Riverbanks

Riverbanks can provide easy access to litter stranded on the river margins where current and wind favour accumulation. Litter can, in particular, be deposited during decreasing river levels and remobilised at rising levels. River bends are likely accumulation places. Litter can be swept downstream stepwise with rising and falling water levels. The riverbanks accumulate litter over time, but the time scales depend on meteorological conditions in the upstream river basin.

Riverbank monitoring does not directly provide data on fluxes, but is a proxy for litter abundance in a watershed. Furthermore, the monitoring of beached litter allows for the analysis of litter composition, which is essential to develop measures, and behaviour regarding the identification of accumulation areas or the study of mobility. It can also provide data to transport models for estimations of stock and fluxes in combination with data from other compartments (floating and suspended litter), e.g. comparing results from rivers and estuaries to those obtained in the adjacent beaches as a proxy of riverine inputs (Jang et al., 2014). Mobility studies of tagged items showed the complexity of mechanisms involved in the transport of litter to the sea (William and Simmons, 1997; Wilson and Randall, 2005; Ivar do Sul et al., 2014).

Table 3: Scientific studies quantifying litter on riverbanks

Visual observation on riverbanks

Author	Environment	Litter size	Monitoring methodology	Units
Williams and Simons, 1997a	River	Macro	Shore normal transect (5 m wide)	items/5 m transect
	Estuarine beach		Strand-line transect along 1 km	items/km
Williams and Simmons, 1997b	River	Macro	Clearance of 100 metres bank length, subdivided into 5 m wide transects (cells) and upper/middle/lower bank zones	Cumulative items/day
Simmons, 1993; Earll et al., 2000	River and Estuarine	Macro	3 shore normal transects (5 m wide) per site.	items/100 m bank length
Wilson and Randall, 2005	Estuarine	Macro	Tagged items for mobility monitoring. Three strand line belt transects (10 m x 5 m) per site.	n.a.
CROW, 2013	River	Macro	Clearance of 100 metres bank length	Grades (A+, A, B, C, D)

Collection on riverbanks

Author	Environment	Litter size	Monitoring strategy	Units
Acha et al., 2003	Estuary	Macro	Manual collection during low tide on a 20-m shore normal transect on each site	g/10 m^2
Wilson and Randall, 2005	Estuary	Macro	Manual collection in three strand line belt transects (10x5 m) per site.	n.a.
Browne et al., 2010	Estuary	Micro (<1 mm) Macro (>1 mm)	Strandline sample replicates of 3-cm depth layer of sediment (500 ml) collected in containers	micro items/50ml; macro items/500ml
		Macro	Sampling sites of 50 metres along shoreline to manually collect litter in 5 random quadrats (0.25 m^2)	items/0.25 m^2
Costa et al., 2011	Estuary	Macro (>1 mm)	Random sampling with corer (20 cm diameter x 20 cm height). Sieving (1 mm mesh) in the laboratory	items/m^3
Faure et al., 2012	Lake	Micro, macro	A fixed surface was scraped off and 1 litre of sand was sieved in-situ with mesh sizes of 2 mm and 5 mm. Water was added to collect floating items. Manual collection of coarse fragments	items/l

Visual observation on riverbanks

Author	Environment	Litter size	Monitoring methodology	Units
Imhof et al., 2013	Lake	Micro	Three random grid samples collected at each site from a 20-cm grid (0.04 m²) to a depth of 5 cm.	items/m^2
Ivar do Sul et al., 2013	Estuary	Macro	Three replicates of a 20-metre-wide transects along the shoreline, completely cleared monthly for manual collection and counting of items	items/100 m^2
Faure et al., 2015	Lake	Micro, macro	Sediment collection in 0.3 x 0.3-m quadrats on the drift line (5-cm-depth layer). Four samples per beach or every 15 m in beaches longer than 100 m. Micro and macro fractions separated in the laboratory by sieves (>5mm, >1 mm and >300 µm)	items/m^2, mg/m^2, items/m^3, mg/m^3
Free et al., 2014	Lake	Macro	Manual collection of visible items in 0.1-1.2 km along shore	g/km, items/km (linear because of variability of transect width)
Hoellein et al., 2014	River, Lake	Macro (>1 cm)	Manual collection from river benthos and bank (70-100-m length reaches); and 400-m reaches on lake beach	items/m^2, g/m^2
Rech et al., 2014	River, Beach	Macro (>1.5 cm)	Manual collection. River: 2-5 circles (1.5 m diameter) per site, separated by 30 m and parallel to the river shoreline. Beach: Four quadrats (3 x 3 m) along tidelines in adjacent beaches	items/m^2
Castañeda et al., 2014	River	Micro	Sediment collection with Petite Bonat grab (225 cm^2, 10 cm depth layer) and Peterson grab (950 cm^2, 10-15-cm depth layer). Samples sieved with a 500-µm mesh.	items/m^2, items/l
Naidoo et al., 2015	Estuary	Micro	Sediment collection with corer (50 mm diameter and 10 cm depth). Five replicates of 500 ml on each site for subtidal and supratidal sediments. Samples processing in the laboratory included separation plastic particles sizes of 1,000, 500, 250, 100 and 20 µm by filters (% of particles >5,000 µm also included).	items/500 ml

Visual observation on riverbanks

Author	Environment	Litter size	Monitoring methodology	Units
Surfrider Foundation Europe, 2014	River (catchment scale)	Macro (and meso)	A catchment scale study. Collection of macro litter on predetermined area for 7 riverine spots, and the first beach impacted by river's plume (OSPAR protocol). Each spot represents an anthropogenic pressure (industrial, agricultural, urban, etc.). Areas of collection represent surface from the river to the upper part of the bank.	Quantity of items. Items/m² Weight/spot

n.a. (not available)

5.4.1 Macro (meso) litter on riverbanks

Macro and meso litter on riverbanks and shorelines is monitored by direct observation, collection and documentation (Faure et al., 2012; Hoellein et al., 2014) and used for different purposes, including abundance and composition analysis. Beach litter monitoring is used intensively in the monitoring of marine litter at the seacoasts. The monitoring on river and estuarine banks has been used in specific studies to assess abundance and accumulation of litter, e.g. in studies that defined areas to be cleared and monitored for assessment of stranded litter (Williams and Simmons, 1997b; Wilson and Randall, 2005; Ivar do Sul et al., 2013); or in spatial identification of accumulation areas by comparison of different sampling sites and compartments (Acha et al., 2003). In France, a watershed-scale assessment of a selected river basin included banks' monitoring (Surfrider Foundation Europe, 2014). Data collected through beach and/or bank clean-up programmes have also been used for scientific purposes, although information gathered may not contain much detail (van der Wal et al., 2013), e.g. reporting only the number of garbage bags filled during the clean-up operation.

It is important to identify anthropogenic pressures (according to population density, activities, hydraulic parameters, etc.) in order to define sources and possible activities responsible for litter discharge. On this matter, a full catchment study may lead to the identification of the main sources.

In general, monitoring results are reported as items/area and weight/area. However, on some occasions, data have been treated as items per length of bank/shoreline/beach, which is the standard approach for marine monitoring.

Visual observations on riverbanks/shorelines and estuarine beaches have been used mainly in litter mobility and transport studies (William and Simmons, 1997; Balas et al., 2001; Wilson and Randall, 2005; Ivar do Sul et al., 2014). This approach is initially valid for the identification of macro litter, but meso litter could also be identified.

The monitoring of items deposited on the sediments is often based on transects of the bank covering a determined distance in parallel to the shoreline, e.g. 3 transects (each 5 metres wide) per sampling unit of 100 metres, as proposed by Earll et al. (2000). However, if present, monitoring of estuaries and adjacent beaches can be carried out on longer transects (100-1,000 metres) along the shoreline, covering the whole extension or just following strand lines (Williams and Simmons, 1997; Williams et al., 2002).

A semi-quantitative method for litter assessments on riverbanks is the use of grading systems with five categories based on the amount of litter in an area (CROW, 2013). This method is used in the Netherlands on land and water visible from the shoreline.

Effort

The collection of macro (and meso) litter on banks requires personnel for field work but no specialised equipment. Also, collection on riverbanks can engage volunteers in citizen science programmes on rivers (Surfrider Foundation Europe, 2014), lakes (Hoellein et al., 2015) or beaches (Hidalgo-Ruz and Thiel, 2013). It allows items to be identified for source attribution. The identification and quantification step must be carried out by trained personnel, and is time consuming. There is extensive experience from beach litter monitoring in the marine environment, which can be a source of support in monitoring implementation.

5.4.2 Micro (meso) litter on riverbanks

Micro and meso litter can also be accumulated on riverbanks, depending on the margin characteristics (e.g. on sand, vegetation, less on rocks) and the hydrological conditions. The sampling for micro litter requires methodologies which are similar to the approaches for monitoring microplastic on beaches and in shallow sediment of the marine environment.

The monitoring of micro litter will require sampling, sample preparation and analysis in the laboratory (Hidalgo-Ruz, 2012). Sediment samples are collected for micro litter analysis, which also allows for the analysis of meso litter, depending on sample size and litter abundancy. Sediment sampling can be carried out using corers (Costa et al., 2011), grabs (Castañeda et al., 2014) or simply by filling a container manually (Browne et al., 2010). Care should be taken to avoid contamination (e.g. fibres from clothing and gloves) of the samples during the sampling and sample preparation processes. For micro litter, results have been reported as items/area and items/volume (Faure et al., 2015; Naidoo et al., 2015).

Effort

For the collection of meso/micro litter, sampling requires field campaigns without specialised equipment (although cross-contamination should be taken into account), but processing and analysis of samples requires expertise and instrumentation, similar to that reported in chapter 5.2.1.

6. Data

Data on riverine litter needs to be comparable over time in order to allow for trend assessments, and between different monitoring locations and rivers for comparison of sources (quantities and composition). Harmonised and documented protocols are needed, along with procedures for data quality assurance, reporting of data in agreed units, and accompanied by metadata.

6.1 Data acquisition protocols

Most of the described methodologies are operationally defined, i.e. the employed method directly influences the result. Therefore, in contrast to methodologies which deliver an International System of Units (SI) traceable result, they will need to be harmonised to provide comparable results. This requires the use of agreed methodologies, which are described in detail through monitoring protocols. These protocols should be agreed at international level (River Commissions, Regional Sea Conventions (RSCs), EU and UN) and be available to everyone.

A detailed documentation of sampling and, where applicable, the analytical process is needed. It should cover e.g. the following information:

- Sampling method, compartment and size category
- Sample size (e.g. amount of water sampled)
- Sampling frequency and sampling timing
- Sampling equipment
- Sampling location and river morphology
- Reports on relevant riverine hydrological and meteorological conditions

6.2 Data units and format

A common format for the monitoring and reporting of riverine litter fluxes should be agreed upon. This should allow for the use of a common database structure in countries, Regional Sea Conventions and at overarching portals, in particular EMODNET (http://www.emodnet.eu/). The data should be compatible with the Infrastructure for Spatial Information in Europe (INSPIRE) (EC, 2007) for facilitated data exchange.

Flux data, expressed as litter quantities ((dry) weight and/or number of items) per time unit are preferable to just litter abundance data. Ideally, the data should be traceable to SI Units. Macro litter items should be based on a common litter items list: the MSFD Master List of Categories of Litter Items (Galgani et al., 2013), currently under review. The development and review of that list are closely coupled with UN and Regional Sea Convention activities. The MSFD Master List of Categories of Litter Items should also take the requirements for riverine litter monitoring into account, in order to allow for the correlation between riverine flux data and marine litter concentration data.

Minimal requirements for collected data per compartment (surface, water column, banks) could be:

- Macro litter (> 25 mm): number + item identification + size + weight
- Meso litter (5-25 mm): number + item identification + size + weight (if applicable)
- Micro litter (< 5 mm): number + weight + size

Results from the collection of litter on the surface and in the water body can be reported as litter (item, weight)/time across a section, or litter (items/weight)/volume. In dynamic sampling, litter (items/weight)/area can be measured by calculating the trawl surface based on the transect distance or boat speed, while items/volume need the measurement of filtered volume. Filtered volume is usually measured by attaching a flowmeter to the net/cage device. In the stationary collection of floating litter, direct estimations of litter fluxes to the sea can be provided using appropriate measurements of river flow and sampled volumes. The exact description of data units will depend on the employed methodologies, and is still subject to research and discussion.

6.3 Data quality

The quality of monitoring data should match the needs. Data will often be semi-quantitative or be subject to high uncertainty levels. In such cases, information about the obtained data quality should be available and estimates about the data uncertainty should be reported.

Whereas sampling and analytical procedures for monitoring micro litter can follow the approaches used for quality assurance in the monitoring of chemical contaminants, the observation and collection of macro and meso litter will require new methodologies.

6.4 Metadata

Many factors influence the presence of litter in the river at a given time and location. Therefore, it is critical to provide information about the monitoring conditions to facilitate the interpretation of the results. Metadata to be reported along with the monitoring data should therefore be agreed upon and be reported together with the actual litter data. Databases should include relevant metadata.

The following types of data (metadata) can be relevant for the interpretation and use of data on riverine litter fluxes:

- Geographic location of the sampling site (WGS 84)
- Wind direction during and before the sampling exercise
- Actual and historical precipitation data upstream in the watershed
- Actual and historical discharge data
- Water level of the river
- Depth and flow velocity profiles of the river section
- Distance to the nearest possible sources: sewage treatment plant, urban area (population), etc.
- Estimated uncertainty of quantitative results

6.5 Data storage and availability

It is important that riverine litter data are available and accessible to allow for collaborative approaches, analysis of data and prioritisation of efforts. Databases should therefore have common formats and facilitate data exchange. Joint data storage approaches, as e.g. regionally under the RSCs, have also the added effect that they require data comparability and thus enhance harmonisation.

While some riverine litter data might be more of local or regional interest, data relevant for the marine environment should be made available at a large scale, such as e.g. through European Marine Observation and Data Network (EMODnet).

7. Recommendations

This report presents a first stock-taking of methodologies to monitor riverine litter. As methodologies are further developed and basic research is ongoing, it is currently not possible to provide clear guidance on how to monitor riverine litter. The following recommendations should provide a starting point for necessary discussions at different organisational levels and support the preparation of a roadmap for the next steps of harmonised monitoring and assessment of litter in the aquatic environment.

7.1 General recommendations

Riverine litter monitoring is a new field and requires additional scientific knowledge, which, as it becomes available, should be shared and made accessible.

- The exchange of already existing information from national and international research efforts is the first important step in satisfying the knowledge needs for the efficient monitoring and management of riverine litter, and should therefore be organised.
- As the relevant information becomes available, guidance at international level should be prepared in a collaborative way to ensure resource effectiveness and harmonisation of efforts.
- Regional coordination of Member States and EU neighbouring countries with Regional Sea Conventions and river basin authorities are important processes that will play a role in further awareness raising, coordination of monitoring, and finally in decreasing the input of litter into the aquatic environment.
- Many research and monitoring initiatives are underway, often triggered by the concern for the marine environment. Different research communities and authorities should find ways to communicate and provide joint approaches.
- Non-Governmental Organisations can play an important role in monitoring.
- Ensure compatibility between inland riverine, coastal and marine assessments in order to provide comparability of data.
- Data should be shared between river basins and countries, at EU level and beyond.
- Common database structures should be set up in countries, River basins, Regional Sea Conventions and at overarching portals. The data should be compatible with INSPIRE (EC, 2007) for facilitated data exchange.
- The quantification and source identification of macro litter in the marine environment is based on a litter item categories list, which should be used also for the freshwater environment.
- The existing MSFD Master List of Categories of Litter Items (Galgani et al., 2013) should be further developed, and a sub-list for riverine litter should be added.

While it does not within the scope of this report, it becomes evident that measures under the MSFD Common Implementation Strategy will need to address issues of waste management. Close collaboration between the different stakeholders and across different EU policies will be needed.

The link with activities established under the European Circular Economy Package (EC, 2015) should be provided, if and where necessary.

7.2 Monitoring recommendations

There are currently no agreed monitoring methodologies available at the international level, which is a major hindrance for the implementation of monitoring activities.

- While each river basin has its specificities, the monitoring of riverine litter should follow harmonised approaches and thus allow for the comparison of acquired data.
- Guidance on the methodologies for the monitoring of riverine litter, including approaches for the selection of monitoring sites, should be prepared.
- Monitoring protocols, based on scientific research and large-scale experience, should be prepared at the international level.
- Monitoring methods should refer to the costs of implementation and effort for routine use in order to facilitate their implementation.
- Metadata requirements and reporting units should be agreed at the international level.
- Metadata should meet management requirements.

The technicalities of riverine litter monitoring are just being developed, and few examples of application exist. The implementation of monitoring activities will very much depend on the local conditions and the river system properties.

- At the beginning of a riverine litter monitoring activity, a thorough analysis of the river system should be made (topography, seasonal flow regime, branching, etc.). This information should be readily available.
- Initial monitoring should consider the identification of accumulation spots on riverbanks and potential upstream litter sources.
- The possibility of quantifying plastic litter collected at retaining structures (dams, weirs, water cooling inlets, etc.) in a harmonised way should be explored.
- The distribution of macro, meso and micro litter should be investigated under different flow regimes, vertical in the water column and in the horizontal river profile.
- After initial monitoring, a routine programme with adequate timing can then be set up by selecting appropriate proxies for riverine litter flow.
- Visual observation is a low-tech option for monitoring of litter flows, but requires harmonised approaches.
- Methodologies for sampling micro litter (333 µm – 5 mm) are available (Manta Trawls, Neuston nets, plankton nets) and can be used. Particle sampling of smaller sized litter requires additional effort.
- Meso litter (5 mm to 25 mm) may be included in different monitoring approaches, but care must be taken that the method provides representative results for the abundance of the specific litter fraction.

7.4 Research recommendations

There are still major knowledge gaps regarding litter in rivers and the input into the sea. These should be filled by continuous focused research efforts.

Knowledge gaps should be addressed by analysing existing research outcome, including ongoing research programmes, and then eventually by commissioning dedicated research with a clear mandate to answer well-defined questions.

Among the numerous knowledge gaps the following topics (non-exhaustive list) can be identified:

- There is need to improve the basic understanding of litter pathways, and the behaviour and fate in inland aquatic systems.
- The variability in litter transport, both physical in the rivers and temporal on different time scales should be investigated in order to allow targeted monitoring.
- The formation, transport dynamics and fate of microplastics in relation to their material, size and shape need to be better understood.
- The budgeting of macro, meso and micro litter between sources and sinks requires appropriate data-enabling numerical modelling.
- New methodologies using automated spectroscopic and imaging techniques need to be developed to provide continuous long-term.
- Approaches for the cost-effective identification of litter input hotspots need to be developed to allow for the identification of priority sources for action.
- Investigation into the potential to use (existing) modelling capabilities for riverine transport is recommended.
- Understanding of the harm/effects of riverine litter in the riverine environment should be improved.
- Potential measures for retaining or removing litter as a clean-up measure should be investigated

It is essential that the general aspects of riverine geomorphology and hydrology are considered prior to developing a riverine litter monitoring system. Research efforts should improve the understanding of the influence of these on litter pathways, including:

- Dynamics, flow regime, annual discharge regimes (seasonality, storm, snowmelt, rain, flooding, drought)
- Flow, fluxes, variability (spatio-temporal), including of seasonal rivers
- Internal river water dynamics at the small scale, including the impact of laminar vs. turbulent flow and the role of geomorphology for litter transport in river systems
- Hysteresis and antecedent meteorological conditions influence on litter transport

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List of abbreviations and definitions

Riverbank	Raised area of land along the side of a river
EU	European Union
Flux	Litter quantities transported by rivers per time unit (e.g. g/d, kg/y)
Macro litter	Particles, Fragments and Items > 25 mm
Meso litter	Particles, Fragments and Items in the range of 5-25 mm
Micro litter	Particles, Fragments and Items < 5 mm
ML	Marine Litter
MS	Member States
MSFD	Marine Strategy Framework Directive
Riverine litter	Litter present in rivers and on riverbanks
Shoreline	Edge of a sea, lake, or large river
TGML	MSFD Technical Group on Marine Litter
WFD	Water Framework Directive

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