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Toward a Harmonized Approach for Monitoring of Riverine Floating Macro Litter Inputs to the Marine Environment

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A high percentage of the litter entering the marine environment is assumed to come from land-based sources, but freshwater litter inputs have not been quantified. The lack of data and knowledge on fluxes of riverine litter to the sea, i.e., quantities and sources, hinders implementation of appropriate environmental regulations and mitigation measures. Estimations of riverine litter inputs require a consistent and harmonized approach to gather comparable data. The visual observation of floating litter on rivers has been selected as a simple and robust methodology for litter monitoring. A collaborative network of 36 institutions has been set-up for large spatial coverage. Currently 58 rivers are being observed regularly. A tablet computer application has been developed for the monitoring of floating macro litter (>2.5 cm) to harmonize the visual observations. The application allows recording of the observed items, their size and geo-position data during monitoring sessions. A common agreed list of litter items and size ranges is used, providing a common harmonized approach for data collection and reporting.

Keywords: litter, plastics, floating debris, environmental monitoring, pollution, marine litter, Riverine input

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INTRODUCTION

Marine pollution by anthropogenic litter is a global environmental issue, as recognized by international organizations and environmental policy frameworks in recent years. The European Marine Strategy Framework Directive (MSFD) (European Commission, 2008) provides for the assessment of Marine Litter as one Descriptor of Good Environmental Status: Descriptor 10, properties and quantities of marine litter do not cause harm to the coastal and marine environment. Therefore, assessment of marine litter is a requirement for the 23 European Union Member States (EU MSs) involved in the implementation of the MSFD. Further, the United Nations identify Marine Litter as a factor in the Sustainable Development Goal 14 and the G7 countries have declared commitment to avoid and reduce marine litter, in particular plastics from land-based sources, during the G7 Ise-Shima Summit (26–27 May 2016).

Plastics floating in the oceans have been estimated to count over 5 trillion pieces and weigh more than a quarter million tons globally, with microplastics (as pieces <4.75 mm) being about 92% of total counts and meso+macro plastics (as pieces >4.75 mm) comprising with ca. 87% the bulk of total litter weight (Eriksen et al., 2014). This large amount of meso+macro plastic is exposed to degradation and fragmentation processes, thus being a secondary source of micro plastic (Barnes et al., 2009; GESAMP, 2015). Jambeck et al. (2015) estimated that 4.8–12.7 million tons of plastics could be entering the marine environment from land-based sources yearly, with prediction of a significant increase of this input in the near future if actions are not taken. However, these estimations are based on limited field data and subject to substantial lack of knowledge on litter behavior and transport, therefore significant uncertainties are present.

Floating macro litter, once it has reached the sea, can have a long term residence in the surface waters, which increases the probability of causing harm to marine animals (fish, marine mammals, reptiles, and birds) through ingestion and entanglement (EC JRC, 2016b). Moreover, floating litter fraction has a high mobility and can be transported from inland to remote areas in the oceans, even at global scale.

Although estimations have been made indicating that a high percentage of the marine litter comes directly from land-based sources, quantitative data on freshwater inputs of macro litter are not available. In order to prioritize prevention and reduction measures and to identify sources of litter input to the marine environment, appropriate attention should be given to riverine litter pathways. Consequently, quantitative data on riverine inputs are needed in order to identify hotspots, quantify loads and characterize sources. This information can support the implementation of environmental regulations to reduce marine litter.

In the marine environment, methodologies and protocols for visual observation at sea have been proposed by several institutions and scientific research groups such as UNEP (Cheshire et al., 2009), Hinojosa and Thiel (2009), European Commission (EC JRC, 2013), NOAA Marine Debris Program (NOAA, 2013), Ryan (2013), DeFishGear (2014) and UNEP/MAP (2016). These methodologies can serve as a basis for harmonization of approaches for the establishment of international monitoring programs. Regarding the freshwater environment, no specific monitoring programs have been developed at international level and harmonized approaches are lacking for litter monitoring in rivers (EC JRC, 2016c). Only recently have a few research efforts been dedicated to studying riverine litter and its inputs to the marine environment, mostly focused on micro plastic (Surfrider Foundation Europe, 2014; Hohenblum et al., 2015; van der Wal et al., 2015). In general, approaches lack maturity or do not exist, requiring further development and agreement on basic definitions and methodologies, as e.g., for micro plastics sampling and analytical procedures (Dris et al., 2015). The estimation of riverine litter inputs requires a consistent and harmonized approach in order to gather comparable data. Harmonization is required to facilitate the development of robust databases and eventually allow the use of models to account for spatial and temporal variability.

This paper presents a harmonized collaborative approach for the estimation of floating macro litter inputs to the marine environment. The approach involves a large geographical scale field monitoring network that has been set-up by the European Commission Joint Research Centre (EC JRC) within the RIMMEL project (EC JRC, 2016a). The network uses a tablet computer application, the JRC Floating Litter Monitoring Application (App), for collection of data in river estuaries. The methodology is based on visual observations, using a common agreed list of litter items and size categories. The App allows real time data acquisition during monitoring sessions, thus providing a tool for data collection and reporting.

RIVERINE LITTER OBSERVATION NETWORK–THE APPROACH

Within the JRC exploratory research project RIMMEL: RIverine and Marine floating macro litter Monitoring and Modeling of Environmental Loading (EC JRC, 2016a), a Riverine Litter Observation Network has been set up for acquisition of data on floating macro litter inputs to the sea. The network is a collaborative activity of 36 Scientific Institutes, Authorities, SMEs and NGOs covering 17 countries (**Table 1**). They provide the observations as an add-on to the scientific or monitoring activities they are involved in. Information exchange with and among project partners is achieved through a dedicated communication platform.

Monitoring is performed in 58 rivers and is expected to increase, with geographical distribution in the four European marine shared basins (Mediterranean Sea, Black Sea, North East Atlantic Ocean and Baltic Sea).

At MSFD scale, floating macro litter monitoring refers to items >2.5 cm that, due to their buoyancy properties, are floating or suspended in the water surface layer. In the marine environment, visual observation has been employed in different geographical areas (Galgani et al., 2015), and currently the only method with wider use. Other methodologies such as aerial surveys and automated camera systems would require further development in order to become practical for monitoring programs (EC JRC, 2013). The quantitative physical collection of litter items, which would provide the best information about litter flux and item identity cannot be employed in a large number of sites at a high frequency. While the observation of the water surface has shortcomings, e.g., submerged floating items cannot be seen in turbid rivers and items can only be identified in the short time they float by, it appears to be the only option for low cost and high frequency monitoring at a large number of sites. It is assumed that, to obtain comparative litter flux estimates, it provides a proxy which fulfills the needs. Therefore, the Riverine Litter Observation Network has selected the visual observation methodology as a practical option to collect data on floating macro litter (items >2.5 cm) as a simple and direct methodology that can be used at relevant geographical scale to provide an initial proxy in the short term.

Similarly to monitoring at sea, the visual observation methodology has limitations as litter detection is affected by: weather conditions, sun orientation, the eight of the observation site and characteristics of the litter items (color, size, shape, and floatability); but also by the observer's ability, experience, concentration, and fatigue (Ryan, 2013; Suaria and Aliani, 2014). In rivers, additional factors such as surface water speed and turbulence will be important for litter detection. The height of the selected observation site (vertical distance between observer's eyes and river surface) should allow detection of litter items down to 2.5 cm (lower limit for macro litter), but use of binoculars

TABLE 1 | List of participants in the riverine litter observation network.

Country	City	Institution
Albania	Tirana	Agricultural University of Tirana
France	Perpignan	CEFREM (UMR CNRS 5110)
France	Marseille	Mediterranean Institute of Oceanography (MIO)
France	Biarritz	SurfRider Foundation Europe
Georgia	Tbisili	Scientific Research Firm GAMMA
Georgia	Tbisili	Tbilisi State University
Germany	Wilhelmshaven	ICBM-Terramare, Carl von Ossietzky University
Greece	Anavissos	Hellenic Centre for Marine Research - Department of Inland Waters
Greece	Heraklion	terraSolutions m.e.r.
Ireland	Galway	iSea conservation of aquatic ecosystems (Greece)
Israel	Haifa	IOLR
Italy	La Spezia	CNR-ISMAR
Italy	Fiumicino	Accademia del Leviatano
Italy	Pisa	CNR - Biophysics Institute
Poland	Sopot	Institute of Oceanology, Polish Academy of Sciences (IO PAN)
Portugal	Vila Nova de Gaia	Águas de Gaia Em, SA
Portugal	Lisbon	Instituto Hidrográfico – Marinha
Portugal	Porto	LEPABE - Faculty of Engineering, University of Porto
Portugal	Coimbra	MARE - Marine and Environmental Sciences Centre
Portugal	Castro Marim	Odiana Association
Russia	Rostov-on-Don	Azov Scientific Institute of fishery industry (AzNIIRH)
Russia	Gelendzhik	South Branch P.P. Shirshov Institute of Oceanology of Russian Academy of Sciences
Spain	Barcelona	IDAEA-CSIC
Spain	St. Carles de la Ràpita	IRTA, Aquatic Ecosystems Program
Spain	Madrid	Paisaje limpio
Spain	Barcelona	Universidad de Barcelona
Spain	Puerto Real	Universidad de Cadiz
Spain	Vigo	Universidade de Vigo
The Netherlands	Amsterdam	Plastic Soup Foundation
The Netherlands	Maastricht, Lelystad	Rijkswaterstaat
The Netherlands	Utrecht	Deltares
Tunisia	Tunis	OR Ltd
Turkey	Mersin	Institute of Marine Sciences, Middle East Technical University
Turkey	Istanbul	Turkish Marine Research Foundation (TÜDAV)
UK	London	Thames21
Ukraine	Odessa	Ukrainian Scientific Center of Ecology of the Sea (UkrSCES)

could help with identification if necessary. Regarding observers' capabilities, training and experience in visual observation can improve data quality, as described in different disciplines (Parsons et al., 2009; Bernard et al., 2013).

The methodological approach considers regular short monitoring sessions (30–60 min) in the estuarine section of the river to account for inputs to the sea, using the tablet computer application described in Section The JRC Floating Litter Monitoring Application to perform visual observations from an elevated position (e.g., bridges, piers, pontoons, and others). As in visual observations in other research fields, e.g., cetaceans (Harwood and Joynt, 2009; Richman et al., 2014), marine birds (Titmus and David Hyrenbach, 2011) or jellyfish (Doyle et al., 2007), duration of monitoring sessions is limited in order to avoid observer's fatigue (EC JRC, 2013; Suaria and Aliani, 2014). Observation of the water from above allows an improved view into the surface water layer for identification of floating litter items. It is recommended to perform the observations facing upstream in order to have an unobstructed view of the arriving water surface (**Figure 1**). Observers will have to select the appropriate time of day for monitoring, considering light conditions (e.g., to reduce light reflections or shades). Depending on the geographical region (e.g., North East Atlantic Ocean region), tidal cycle should be considered to schedule the monitoring during ebb tide (ensuring a downstream flow in the river). Definition of observation track width (section where the observer focuses for identification of items) will allow estimation of litter fluxes in relation to the river section total width (distance

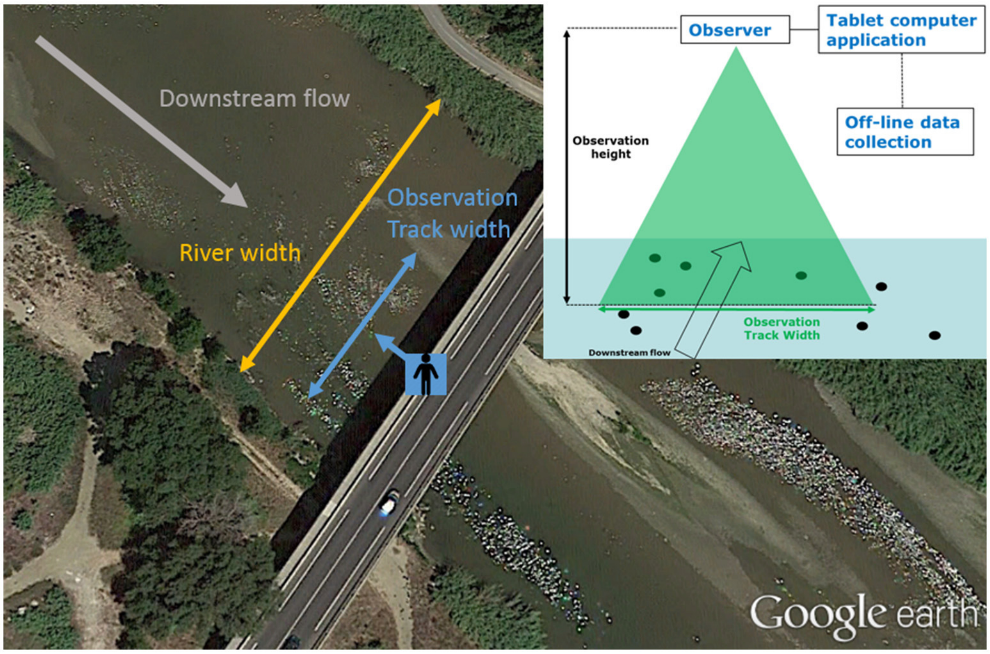

FIGURE 1 | Setup of visual observation from a bridge over a river.

between the two margins at the monitoring site) (**Figure 1**). In addition, the river surface water speed is also considered for surface flux calculation. Monitoring frequency is crucial to account for the expected high temporal variability in litter loads, thus most of the institutions in the network perform weekly or bi-weekly observation sessions.

The network was launched in September 2016 and foresees data collection over 1 year. Monitoring data files are sent to a JRC functional mailbox. Data files are imported into a common database, which is managed by JRC under Microsoft SQL Server 2014. It will be the first ever international database on floating macro litter inputs to the European marine basins. Collected data will be processed to elaborate results and build a statistical inverse model of litter loading based on the characteristics of the catchments. The call to join the monitoring network will remain open until the reporting phase.

THE JRC FLOATING LITTER MONITORING APPLICATION

In this initiative, the key to a harmonized approach for data collection and reporting is the use of the JRC Floating Litter Monitoring Application (App). The App is a dedicated common tool for real time documentation of floating macro litter data acquired during visual observation sessions. In the development of the App, provisions established in the "Guidance on Monitoring of Marine Litter in European Seas" document (EC JRC, 2013) have been considered and adapted to provide the required features and functionalities for floating litter monitoring. The "Guidance on Monitoring of Marine Litter in European Seas" discusses a list of observation parameters based on the assessment of existing approaches for visual ship-based observations, including: HELMEPA (2008), UNEP (Cheshire et al., 2009), Hinojosa and Thiel (2009), NOAA (Arthur et al., 2011), and Ryan (2013); and proposes a protocol for visual monitoring of floating litter within the MSFD implementation process. Additionally, a survey on available portable apps for marine litter monitoring was done, examining the features and functions included in: Marine Debris Tracker for beach and floating litter monitoring (http://www.marinedebris.engr.uga.edu/), Marine LitterWatch for beach litter monitoring (http://www.eea.europa.eu/themes/coast_sea/marine-litterwatch) and Ocean Cleanup Survey App for floating litter monitoring (https://www.theoceancleanup.com/). No published apps were dedicated to the issue of riverine floating litter.

The App concept (monitoring parameters, features, and functions) was designed by EC JRC after evaluation of existing options. Analogies to ship-based visual observations were made for selection of monitoring parameters, using a fixed observation track width to align the approach with MSFD guidance, as described in EC JRC (2013). The software was programmed by an external consultant (Atos IT Solutions and Services Sp. z o.o.), following an iterative testing process (including field work) between EC JRC scientists and the software developers, to fix bugs and make the App functional. **Figure 2** shows the main features and functions of the App.

The App allows selection of "sea" or "river" litter monitoring modes to start a session (**Figure 2A**). Both monitoring modes have similarities and it is important that riverine and sea monitoring consider the same litter attributes for coherence;

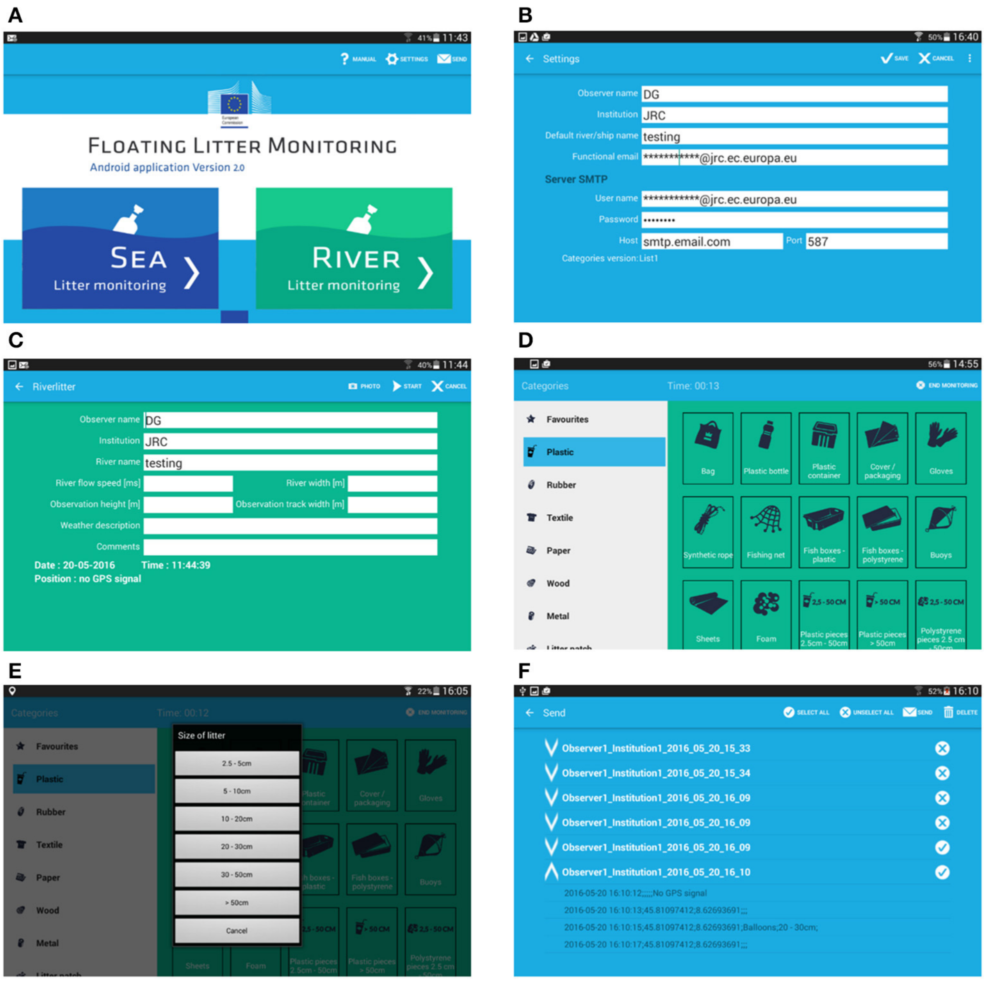

FIGURE 2 | Floating Litter Monitoring Application. Main features and functions: **(A)** start menu, **(B)** general settings, **(C)** river monitoring mode settings, **(D)** monitoring session-litter items categories, **(E)** monitoring session – size categories, **(F)** sending files menu.

however, the sea monitoring mode is not within the scope of this publication and will not be further described.

When the river monitoring mode is selected, a metadata settings menu is accessed (**Figure 2C**), where specific information about the observation set-up, e.g., river and observation site characteristics are entered before starting the session. Other basic information, such as observer name and institution affiliation is retrieved from general settings entered during the device set-up (**Figure 2B**). All details are recorded in the corresponding session data file. During the monitoring (**Figure 2D**), a list of floating macro litter items is available on a menu with icons, organized by materials. This list of items and materials is based on the "Master List of Categories of Litter Items" from the "Guidance on Monitoring of Marine Litter in the European Seas" (EC JRC, 2013), and includes all items that have been described as floating litter. It is also possible to create a list of favorite items to allow faster access to the most common items found in the monitoring area. The item list can be updated through loading of a new official category master list file, e.g., after a revision done by the MSFD Technical Group on Marine Litter. When an icon is selected, a secondary menu pops up for selection of size range classes (**Figure 2E**). Item and size details are registered along with GPS position and time into the data file. The size range classes have been harmonized with the "Guidance on Monitoring of Marine Litter in European Seas" document (EC JRC, 2013).

After ending a monitoring session, the data are saved in an individual.csv file and stored in the tablet computer memory. Data files can be sent directly from the App to a functional mailbox (**Figure 2F**) or copied manually to a PC (e.g., via USB connection). The use of a simple harmonized data format allows importation of the data into the project database.

The monitoring of floating macro litter requires reporting metadata that are crucial to understand the observation conditions and elaborate results. These conditions have been included based on existing MSFD protocol for visual observations at sea (EC JRC, 2013) and field experience gained during the development/testing of the App. For river litter monitoring, observation height and observation track width are required, along with the river section total width. The river flow speed at the water surface is needed for surface flux calculations. Weather description is required and should include state of river water surface (e.g., turbulence and presence of natural foam), wind, cloud/rain, light conditions (e.g., reflections, direction of the sun and shades) and visibility (e.g., fog). There is also the option to register comments, where any other relevant information can be included.

The App (version 2.0) has been developed for tablet computers with an Android operating system. The tablet computer must have GPS functionality to allow position tracking. The App is further developed, based on incoming feedback through the observation network.

CONCLUSIONS

Using a common monitoring tool for data reporting (the JRC Floating Litter Monitoring Application), the riverine litter observation network will provide the first large scale assessment of riverine litter input to the marine environment, following a harmonized approach. This approach considers the monitoring of floating macro litter as a proxy for riverine litter inputs to the marine environment. The observation network includes both EU and non-EU partners in the European marine basins, with potential to grow as additional partners can still join. Through the participation of scientists and experienced observers, the observation procedure is improved in an iterative way, resulting in an observation protocol for future use. Collected data will be processed to elaborate results and build a statistical inverse model of litter loading based on the characteristics of the catchments, providing support to implementation of appropriate environmental regulations and mitigation measures. Results may show geographical differences in litter loads and help in identifying hotspots, meaning mitigation actions could be developed for and applied in specific areas. Additionally, acquired data will provide a list of the most frequent litter items, bringing important information for prioritization of measures to abate plastic pollution in aquatic ecosystems, e.g., identification of consumer products could have an impact on the EU strategy for plastics in a circular economy (http://ec.europa.eu/environment/circular-economy/index_en.htm). Furthermore, the experience in the observation network will be used to revise the MSFD Master List of Litter Categories, which is the official list used in marine litter monitoring by the 23 EU MSs involved in the implementation of the directive. Currently, the approach is open to participation of partners from EU and non-EU countries in the shared marine basins, as marine litter is a transboundary issue. A harmonized monitoring protocol, the App and RIMMEL database will be publicly available after the project has delivered final results. The acquired experience and developed tools will have a potential use worldwide.

AUTHOR CONTRIBUTIONS

DG and GH designed the work and wrote the article.

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