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Joint effort among research infrastructures to quantify the impact of plastic debris in the ocean

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Abstract

Marine debris is one of the most significant problems facing the marine environment, endangering wildlife, polluting oceans and is an issue which holds global significance. Plastics constitute a large proportion of marine debris, and their persistence can cause a number of negative consequences for biota and the environment, including entanglement and ingestion, which can lead to mortality. Most plastics never biodegrade and instead break down into smaller pieces which are more difficult to monitor and eventually become so small (micro and nanoplastics), that they are challenging to observe or intercept in the ocean. Marine-based Research Infrastructures (RIs) monitor several environmental parameters and are situated around the globe; however, none of these are routinely monitoring marine debris or plastics. Currently, the only infrastructures in place with regard to marine debris are 'physical debris interception infrastructure' in the form of barriers constructed to prevent marine debris from entering the ocean. Several knowledge gaps and restraints exist within current *in situ* infrastructure including technological immaturity, diverse methodologies and lack of data harmonisation. Nevertheless, marine RIs could monitor microplastics within the water column on a long-term basis and initial steps towards developing technology are promising.

1. Introduction

Cooperation of Research Infrastructures to address global challenges in the environmental field (COOP+) is a European Commission (EC) funded project, which aims to strengthen links and promote cooperation between European Research Infrastructures (RIs) and their international counterparts on other continents. The COOP+ project focuses on the identification of global challenges, global cooperation, coordination of international integrated platforms and the promotion of best practice/efficient knowledge transfer between RIs.

A list of global challenges was compiled by the COOP+ project to assess how global collaboration between RIs could be fostered to further the monitoring of environmental challenges. A literature review was conducted by COOP+ partners in combination with surveys, both online as well as direct interviews with RI operators, to determine what global challenges should be addressed by the COOP+ consortium. This list was used to analyse where RIs can participate, collaborate and play a significant role within their designated global challenge. Marine debris, including plastics and microplastics was identified as a significant global challenge (International Council for the Exploration of the Sea 2017), where a joint effort among marine RIs to monitor and quantify microplastics in the marine environment is required.

Marine debris can be made up of a variety of compounds, i.e. wood, metals, glass etc, although plastic appears to contribute to a significantly large proportion of this debris. Once plastic enters the marine environment, it is persistent and durable nature presents a significant risk to ecosystem from coastal areas to the deep sea. Plastic has become a serious threat to marine life as it can be ingested and/or cause entanglement, which can lead to mortality. This anthropogenic material also smoothers benthic habitats, can act as artificial substrate for colonisation and transport invasive species between continents (Gregory 2009).

Subsequently, plastic marine debris has been identified as one of the most significant problems facing the marine environment today (STAP 2011). Plastics are persistent as a pollutant and impact on the environment and biota is now a major concern. As plastics persist in the environment, they become weathered through photodegradation by UV light as well as from wind and wave action. This exposure causes chemical bonds to weaken and plastic to become brittle and breakdown. As plastic fragments it produces microplastics. Furthermore, as chemical bonds of plastic polymers weaken, toxic compounds are released into the ocean, which may have a detrimental effect on marine ecosystems (Romera-Castillo *et al* 2018).

The National Oceanic Atmospheric Administration (National Ocean Service 2018) defines microplastics as anything <2.5 cm in size (Lippiatt *et al* 2013), however, microplastics are also defined as <5 mm (Arthur *et al* 2009), or 1 mm in size by the scientific community (Browne *et al* 2011). The contemporary definition of a microplastic is anything smaller than 1mm but the variation in sizing classification is one of the primary methodologies that should be standardised globally. Regardless of the definition used, the smaller the microplastics, the harder they are to observe by the human eye. This observation requires microscopes or optical sensing technology to measure/monitor abundance. Not all microplastics are formed from the breakdown of larger particles in the environment, some are formed from the breakdown during use, whereas others, termed primary microplastics, are initially manufactured in small sizes (Cole *et al* 2011).

A significant amount of debris enters the ocean every year, with sources identified both on land and at sea (Sheavly and Register 2007) and the accumulation of plastics in the environment has been estimated to be between 15 and 51 trillion microplastic particles (Van Sebille *et al* 2015). The large volume of plastic in the marine environment, coupled with the potentially detrimental consequences it has on marine life, has fuelled global motivation to address the issue of marine plastics in order to ensure a cleaner and safer ocean for future generations.

RIs present a unique opportunity where through global cooperation, efficient knowledge transfer of best practises and coordinated international efforts may be used to monitor and assess marine plastic pollution. Therefore, the aim of this manuscript is to understand the role that RIs can play in monitoring the amount and distribution of plastic, with a focus on microplastics, in the oceans. This paper reviews the current ability of RIs to monitor plastic is addressed along with technology and knowledge gaps. Finally, it outlines the requirement for further cooperation between RIs, as well as between RIs and sensor manufactures to develop dedicated, long-term microplastic monitoring systems.

2. Research infrastructures

The European Strategy Forum on Research Infrastructures (ESFRI) defines RIs as ‘facilities, resources or services of a unique nature, identified by European research communities to conduct and to support top-level research activities in their domains.’ RIs can also be defined as anything with institutional, national, or multi-country funding. Consequently, ESFRI and non-ESFI will be defined as RIs within the scope of this work, along with referencing projects such as JERICO, which is an EU-funded infrastructure project. Most infrastructures are mature, have been deployed for ⩾5 years, monitor a variety of environmental parameters and have the ability to expand or integrate new sensors and technologies. Marine RIs have a global distribution and are located within the water column, either at the surface, bottom mounted or somewhere in between. Some marine RIs are fixed point, such as in situ marine observatories; whereas others can either move freely within the water column or drift with ocean currents, such as Argo profiling floats.

The European Multidisciplinary Seafloor and water-column Observatory (EMSO) and European Argo programme (EURO-ARGO) are both recognised European Research Infrastructure Consortia (ERICs). These marine ERICs monitor various marine environmental parameters with EMSO dedicated to fixed point observing and Argo floats moving both up and down the water column (between the surface and 2000 m), but also spatially floating with wind and ocean currents. These ERICs are supported by additional RI projects such as the Joint European Research Infrastructure Network for Coastal Observatories (JERICO), which focuses on the coastal part of a future version of the European Ocean Observing System (EOOS), and includes monitoring infrastructure such as fixed point including shallow-water observatories, data buoys, high frequency radar and mobile infrastructure (including gliders and FerryBox platforms). Additionally, INTAROS (Integrated Arctic Observation Systems; Horizon 2020) includes pan-Arctic monitoring infrastructure that covers the ocean, cryosphere, atmosphere, and terrestrial sphere.

As plastics and microplastics in the marine environment are a global issue, this problem cannot be solved by European infrastructure alone. For example, the Memoranda of Understanding (MoUs) between Ocean Network Canada (ONC) and EMSO formalises a collaborative relationship between both marine observing RIs and will develop joint efforts to deliver high-quality, continuous data for environmental protection (Conti 2018). Euro-Argo also contributes to the international Argo programme, which is part of the Global Climate Observing System (GOOS).

3. RIs and their role in monitoring plastic debris

Plastics can enter the ocean in a variety of ways ranging from indirect sources such as coastal landfill runoff, wind-blown landfill waste, litter washed into drains, rivers and lakes; through to accidental input (for example large containers being washed overboard cargo vessels while in transit), to direct and intentional input via illegal dumping. To put this into perspective, Jambeck *et al* 2015 estimated that ∼275 million metric tons (MT) of plastic waste were created during 2010, and between 4.8 and 12.7 million MT of this ended up in the ocean. More recent studies estimated the plastic emission from rivers into the oceans was between 1.15 and 2.41 million MT (Lebreton *et al* 2017) and 0.41–4 million MT (Schmidt *et al* 2017). The significant volume of plastics flowing into the marine environment presents the need to monitor their release and transport via ocean circulation, tides, and thermoclines (Eriksen *et al* 2013). Ocean currents can also carry marine debris into coastal areas and onto beaches, polluting coastlines and ports.

The European Space Agency (ESA) funded project OptiMAL (Optical methods for MArine Litter detection), reviewed different observational scenarios for marine litter detection, focussing on optical remote sensing techniques. Satellite/remote sensing technology can only monitor large debris including plastics at the surface of the ocean or along the coastline and cannot penetrate into the water column. Furthermore, satellites are not currently able to monitor microplastics as new technology is required to monitor particles of this size. A combination of remote sensing technology as well as water column observations (*in situ* observatories and mobile platforms) would provide a whole scale overview of plastics and microplastics in the ocean. This puts RIs in a well-situated position to address the current limitations of satellites and remote sensing technology.

At present there is a lack of monitoring technology within standalone marine RIs which is hampering the monitoring of microplastics. Optical technology is needed to identify particles smaller than 1 mm, this is currently laking or unsuitable for some fixed and mobile marine observing platforms. Microplastic monitoring is possible in laboratories on-board ships as well as on land. However, there is currently a lack of technology mature enough to carry out this monitoring autonomously in a marine environment. Established RIs should be working with technology developers to integrate such systems within their specific RI. Technological development at this scale requires a significant amount of dedicated funding via specific mechanisms including but not limited to:

- Europe: Horizon 2020, Horizon Europe and Interreg (European Regional Development Funding (ERDF)), ERA-NET, MarTERA, NERC (UK)
- International: National Science Foundation (NSF) United States (US), African Academy of Sciences (AAS) Weather and Climate information SERvices for Africa (WISER) and the Africa Climate Policy Centre (ACPC) (Africa), the Marine and Coastal Research funding instrument (South Africa), National Environmental Science Program (NESP), Australia.

This financial support should be short-to-medium term to initially speed up the technology development and facilitate integration across various RIs.

As reported by Hopewell *et al* (2009) the trend for plastic recycling is increasing, which is encouraging; however, the continued exponential increase in plastic use and production highlights the need to understand the consequences. Marine RIs have the potential to play a major role in monitoring plastics in the future. Baseline investigations have shown promising advancements utilising FerryBox systems to monitor microplastics (NorSOOP Project, funded by the Norwegian Research Council).

Novel technology, which may be integrated onto marine RIs, is currently being developed albeit at very early stage via the COMMONSENSE project (an EU FP7 funded project developing cost-effective sensors, interoperable with international existing ocean observing systems, to meet EU policies requirements). The project is testing a pump that pulls through sea-water and measures the amount of microplastics in the water sample which is based on a suggestion presented by researchers from Ireland (Lusher *et al* 2014, 2015). This project is synonymous to the integration of a microplastic sampler within FerryBox systems. Technology such as this, once it has matured to a sufficient TRL, could then be integrated into some marine RIs.

Knowledge and awareness on the potential harm of plastics, primarily microplastics, to the marine environment, as well as to humans through consumption has been brought before governments with the hope of forming new policies. Policy is an important driver and RIs have the potential to inform policy as well as decision makers regarding current status of plastic and microplastic pollution.

3.1. Identification of requirements

Considerable technological (equipment/sensor) gaps remain in order to monitor plastic in the marine environment. Remote sensing is currently limited to assessing floating debris at the surface and to debris of a large size (e.g. shipping containers). *In situ* monitoring is carried out using nets, trawls and beach clean-ups and it is this kind of multi-faceted approach that is required to tackle the problem of marine litter (Ryan *et al* 2009). *In situ* RIs have the potential to provide autonomous long-term monitoring, which would also provide crucial data along with the manual systems already in place.

Technological advancement in the area of optical sensing could see optical monitoring as one of the primary tools in terms of microplastic monitoring within the marine environment. Further developments need to take place within the research field, which would also then require a marinisation add-on development for deployment at sea. Specific requirements for any device deployed in the marine environment include:

- Calibration (How long can a device be left at sea without calibration?)
- Operation and Maintenance (What maintenance intervals are associated with the device?)
- Power (What are the power demands of the device?)

All of the above will influence the distribution of any device, how long it can be left deployed for and on what types of platforms it can be deployed on. Calibration, as well as operations and maintenance will have a direct impact on integration and running costs as vessels, remotely operated vehicles (ROVs) and divers are required for the installation, removal (for calibration) and maintenance (removal of marine growth) of any device deployed at sea. Power determines what type of platform a device can be deployed on as if it uses a relatively high amount of power then it would be limited to platforms that have a cabled supply of power.

3.2. Case study: increase of litter at the Arctic deep-sea observatory HAUSGARTEN (Bergmann and Klages 2012).

In 1999 the Alfred Wegener Institute for Polar and Marine Research (AWI), established a deep-sea observatory 'HAUSGARTEN' in the Fram Strait, North Atlantic (Soltwedel *et al* 2005). During 2002, a towed camera track was established at a depth of 2500 m at the HAUSGARTEN observatory. This track was revisited in 2004, 2007 and 2011. During the camera tow, images were taken at intervals of either 30 s or 50 s and any shape which could be identified with 90% certainty as human waste were marked as litter (Bergmann and Klages 2012). This study was one of the projects to present long-term monitoring data related to marine litter on the deep seafloor and although it cannot be discounted that some of the litter may have been counted twice over the various track years there was still more litter counted that what was expected for a remote site, such as HAUSGARTEN (Bergmann and Klages 2012). This technique is good for monitoring marine litter, which the human eye can see, however it is limited when monitoring smaller items such as microplastics.

3.3. Future scenarios

ESFRI funded RIs for monitoring marine plastic debris are still lacking the monitoring technology for integration onto the existing infrastructure. Monitoring technology is not yet at a technology readiness level (TRL- used for estimating maturity of a new technology and therefore how far/close it is to market deployment) to allow for integration into *in situ* RIs such as EMSO, OOI (Ocean Observatories Initiative) or Argo. Current technologies (optical sensing for example) are either too large and/or power intensive to be integrated onto *in situ* RIs. Remote sensing infrastructures are currently assessing whether satellite detection/monitoring can be used to monitor marine debris (such as containers and ghost ships) but again, this technology is also at early stage and can only monitor relatively large items (such as those listed above) at the ocean surface. Mid-infrared spectroscopy technique was developed to analyse microplastics with high precision but this technology is relatively expensive and the cost may prove prohibitive for many countries.

3.4. Specific aspects addressed by RIs

RIs require up-to-date reviews with technological developers on any advances in the area of marine plastic monitoring. Collaboration between RIs and marine plastic organisations should be initiated (ENVRI+, a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks and similar initiatives) and host regular meetings for RIs. These meetings could include a section where technological developers have a forum to update RIs on the current status of their technologies as well as future steps and timelines associated with their respective technology. It is imperative that there are open discussions between marine plastic monitoring organisations, RIs, and technology developers and a co-development approach is in place to ensure that commercially ready products will provide the data required for fit-for-purpose monitoring and can be easily integrated into various RIs.

4. Gap analysis

Currently there is a gap between monitoring technology and existing RIs. Marine RIs are in place, but monitoring technology is at a low maturity level and is currently not suitable for integration onto the RIs. Harmonisation of marine plastic monitoring and data collection and data formatting are also issues. Three main tasks are outlined below along with an overview of how they can be used to drive collaboration between RIs as well as the main actors involved in each task.

4.1. Task 1—monitoring methods

4.1.1. Description

The primary focus should be on the harmonisation of existing monitoring methods. As new methods are created, the more difficult it is to harmonise between the various different methods already in use. This is why BASEMAN, a JPI-Oceans funded project aimed at defining the baselines and standards for microplastics analyses in European waters, and similar objectives for RIs are important. BASEMAN's primary goal was to review, compare and evaluate all existing methodology in terms of marine plastic sampling and identification and propose a harmonised approach going forward. Similar initiatives have been followed, including a workshop on the analysis of microplastics, hosted by Quality Assurance of Information for Marine Environmental Monitoring in Europe (QUASIMEME) (QUASIMEME 2018). The aim being improving the quality and reliability of analysis as well as achieving better harmonization of microplastics data. The Japanese government has taken a lead role in harmonising the methods used to monitor microplastics in the ocean. In 2016, the Japanese Ministry for the Environment launched their project of '*Harmonization of Marine Microplastics Monitoring Methodologies*,' (Japanese National Ministry 2018). Such initiatives must be amalgamated to ensure harmonisation between institutions, projects and governments on an international scale.

4.1.2. Type

Data harmonisation, Data Collection, Interoperability

4.1.3. Actors involved and their role

BASEMAN, Japanese Ministry for the Environment, QUASIMEME and similar harmonisation organisations/projects play a crucial role in the harmonisation of marine plastic sampling and identification.

4.2. Task 2—data collection

4.2.1. Description

Data are collected using a variety of methods including satellite (larger debris), *in situ* sampling (nets, trawls, beach clean-ups etc) and increasingly, towards the development of optical monitoring of marine plastic as well as software analytics using video footage via airborne drones etc. There can be harmonisation issues: some nets used to collect microplastics may have larger or smaller mesh sizes; and quantification methods on beach clean-up can often be personal and sizing can be 'rough estimations,' (i.e. measurements taken using estimations instead of correct measuring instrumentation). Specific issues also surround the deployment of any device in a subsea environment including:

- Sensor/Equipment Calibration: there is a cost associated with removal and replacement of equipment in subsea and often-remote environments (i.e. quality of data if instrument out of calibration).
- Biofouling and marine growth on sensor if deployed in an area of high productivity. Cost associated with sending divers or ROVs to clean growth from instruments.
- Power requirements—if instruments are deployed on an observatory with cabled power supply then this is less of an issue. However, to ensure maximum deployment of instrumentation within the marine environment then the device should have a low power-draw allowing for deployment on remote buoys, marine platforms and possibly Argo profiling floats.

4.2.2. Type

Data collection, Experimental Research, Interoperability

4.2.3. Actors involved and their role

With the development of optical sensing for subsea monitoring there are significant amounts of RIs (both ESFRI and non-ESFRI defined infrastructures) capable of hosting these monitoring devices, examples of such include:

- EMSO ERIC: is a large-scale European distributed Research Infrastructure for ocean observation, enabling real-time interactive long-term monitoring of ocean processes and is a recognised ERIC.
- OOI: is based across Northern and Southern Americas, is an integrated infrastructure programme composed of science driven platforms and sensor systems.
- JAMSTEC: The Japan Agency for Marine-Earth Science and Technology, or JAMSTEC, is a Japanese national research institute for marine-earth science and technology and has marine platforms within Japanese territory and territorial waters.
- Euro-Argo ERIC: 12 European countries within the Euro-Argo project with a common aim to provide an optimized and sustained European contribution to Argo by deploying 250 floats per year, and is a recognised ERIC.
- Other non-ESFRI RIs.
- National ocean RIs (Research Vessels etc).
- Oil and Gas companies.
- Marine test site operators.
- Local and national governments.

4.3. Task 3—data modelling

4.3.1. Description

Simulating or modelling the transport of floating marine debris requires a detailed understanding of oceanic processes as well as an in-depth understanding of what happens marine plastic in the marine environment. Modelling of plastic transport also must factor in processes such as freshwater input, coastal oceanography as well as deep-water oceanography including oceanic gyres.

4.3.2. Type

Modelling, Data collection, Interoperability, Experimental Research, Dissemination.

4.3.3. Actors involved and their role

- Copernicus Marine Environment Monitoring Service (CMEMS): uses data from both satellite and *in situ* observations—using the data to provide analyses and forecasts on a daily basis. This analysis then enables scientists to monitor, understand and forecast the marine environment. Mercator Ocean is a privately owned, not-for-profit French company which provides analysis and forecasting services for CMEMS (Mercator is contracted by CMEMS). Scientists and researchers have already begun to use the existing data/models to enhance and develop their models in terms of provide new and improved models for marine debris at the sea surface.

5. Existing and future RIs: requirements

At present, few of the marine RIs are monitoring marine debris or have the ability to monitor marine plastics. Although the majority of RIs do have the capability (already *in situ*, varying degrees of power availability, spare port/plug-in capacity) to monitor marine plastics, there is no mature technology (sensor or equipment) available or at a TRL mature enough to deploy onto RIs. The distribution (both European and on a global basis) and locations (at sea surface, within the water column and at the seafloor) of marine RIs provide infrastructure in key locations for the potential future monitoring of microplastics in the marine environment. Marine RIs have shown that their platforms are future proof (for example EMSO's EGIM (EMSO Generic Instrument Module, an observatory designed by EMSO partners, which has spare ports available for the deployment and/or trial of new sensors and equipment). Some EMSO regional nodes also provide this capacity and are willing to trial new marine technology as it becomes available. The European Argo Programme (Euro-Argo) is developing biogeochemical (BGC) floats as well as profiling floats for the deep ocean. Marine RIs such as these can therefore provide the infrastructure required for the monitoring of microplastics once the monitoring equipment have been developed.

6. Conclusion

RIs play a key role in monitoring a variety of environmental parameters and need to be kept up-to-date with technological advances in the area of marine plastic monitoring. Collaboration between RIs and organisations dedicated to understanding, monitoring and removing marine plastic should be initiated (ENVRI+ and similar initiatives could act as a facilitation platform) and regular collaborative meetings should be planned between RIs focusing on collaboration between RIs, methodology and data harmonisation, as well as technological innovation in terms of monitoring equipment. These meetings could also act as a forum where technology developers update, and build collaborations with, both marine plastic organisations and RIs on the current status of their technologies as well as future steps and timelines associated with their respective technology. RIs can help drive this technological innovation, either by small research funding calls and/or by driving funding policy development at EC and global levels to support these types of monitoring technologies. It is imperative that there are open discussions between marine plastic monitoring organisations, RIs, and technology developers and a co-development approach is in place to ensure the end-products will provide the data required for fit-for-purpose monitoring that can be easily integrated into various RIs. A major driver in terms of global monitoring with regard to marine plastics will be through collaborative research projects, such as joint monitoring programs (i.e. EMSO case study as outlined above).

RIs need to collaborate internationally as marine microplastics is a global issue. International collaboration across RIs and via a multi-RI approach (i.e. satellite remote sensing in combination with *in situ* and mobile autonomous marine platforms) would provide a holistic approach to the monitoring of marine microplastics. As camera technology and optical sensing technologies develop (becoming smaller and less power intensive) these technologies can be integrated into marine observing platforms allowing for more detailed and accurate measurements with regard to the abundance of plastics and microplastics in the marine environment.

RIs have the potential to play a significant role in the monitoring of microplastics. Monitoring is only one aspect in terms of microplastics, another aspect is the removal of existing plastics already in the ocean (e.g. beach clean-ups) however the most significant driver in the reduction of plastics from the marine environment will have to come from a policy orientated solution. There is currently a general awareness of the potential harmful plastics, in particular, microplastics may have on the marine environment and this is being brought before governments and will form new policies into the future. Public mind-sets are also beginning to change, and this could play a significant role in terms of limiting point source entry of plastics into the marine environment. This change in behaviour is slow and must be nurtured and developed by governments with initiatives such as added tax on single use plastics with this income used to facilitate programmes and initiatives to educate the public, fund monitoring as well as clean-up programmes.

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