2016-11-08

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Gago, J

10.3389/fmars.2016.00219
Frontiers in Marine Science
Frontiers Media SA

frontiers in Marine Science

PERSPECTIVE
published: 08 November 2016
doi: 10.3389/fmars.2016.00219

Microplastics in Seawater: Recommendations from the Marine Strategy Framework Directive Implementation Process

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Microplastic litter is a pervasive pollutant present in marine systems across the globe. The legacy of microplastics pollution in the marine environment today may remain for years to come due to the persistence of these materials. Microplastics are emerging contaminants of potential concern and as yet there are few recognized approaches for monitoring. In 2008, the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC) included microplastics as an aspect to be measured. Here we outline the approach as discussed by the European Union expert group on marine litter, the technical Subgroup on Marine litter (TSG-ML), with a focus on the implementation of monitoring microplastics in seawater in European seas. It is concluded that harmonization and coherence is needed to achieve reliable monitoring.

Keywords: marine debris, plastics, microplastics, monitoring

OPEN ACCESS

Edited by:
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National Research Council, Italy

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Specialty section:
This article was submitted to Marine Ecosystem Ecology, a section of the journal Frontiers in Marine Science

Received: *13 June 2016*
Accepted: *24 October 2016*
Published: *08 November 2016*

Citation:
Gago J, Galgani F, Maes T and Thompson RC (2016) Microplastics in Seawater: Recommendations from the Marine Strategy Framework Directive Implementation Process. Front. Mar. Sci. 3:219. doi: 10.3389/fmars.2016.00219

INTRODUCTION

The ubiquity of plastics in the marine environment and in biota from across the globe has highlighted the prevalence of this contaminant within our oceans. The global mass-production of plastics which started mid last century has been followed by the accumulation of plastic litter in the marine environment (Rochman et al., 2013).

The term "microplastics" (referred to as *MPs* from hereon) first entered the published literature in 2004 (Thompson et al., 2004), but is now used extensively to describe small fragments of plastic. There is no widely accepted "*lower boundary*" in size as the limit of detection is dependent on the sensitivity of the sampling technique used (e.g., mesh size of the net or size of the filter).

Microplastics are widely dispersed in the marine environment and are present in the water column, on beaches and on the seabed (Barnes et al., 2009; Law et al., 2010; Browne et al., 2011). Microplastics are a newly recognized type of marine pollution and as such there are few regulations in terms of production, use or emissions.

In the EU, the Marine Strategy Framework Directive (hereinafter MSFD) adopted in 2008 (European Commission, 2008), aims to establish a good environmental status (GES) of the European seas by 2020. The MSFD represents the first instance, worldwide, that *MPs* in the marine environment have been included in a legislative proposal. In this sense is important to mention that *MPs* were not included in the Water Framework Directive (WFD), the main EU directive dealing with pollution of river basins.

The main findings of the MSFD marine litter expert group in relation to *MPs* in seawater are described here. This information may help researchers and governments of EU member states and also other countries to establish legislative tools and to implement programs aimed to study abundance and the impacts of microplastics in the marine environment.

MICROPLASTICS IN THE MARINE ENVIRONMENT

Microplastics can enter the marine environment directly as primary *MPs* (e.g., pre-production pellets and/or granules used as abrasives in cleaning products) or indirectly, as secondary *MPs*, i.e., the result of progressively fragmentation in the environment of larger items. The relative importance of primary and secondary sources of microplastics to the marine environment is not known (Andrady, 2011).

One of the main threats emanating from *MPs* is their potential to be taken up by marine organisms. Potentially affected species include primary producers at the base of the food chain through zooplankton, and all the way up to macro invertebrates, fish, and mammals (CBD, 2012). There is limited information on the extent to which microplastics might cause harm in the marine environment. Cell damage, infections, tumor formation, death are just some of the reported toxicity effects by *MPs* (CBD, 2012).

THE MSFD: AN INTEGRATED ENVIRONMENTAL POLICY FOR THE MARINE ENVIRONMENT

The European Directive 2008/56/EC (MSFD) is a key element in Europe's actions to protect seas and oceans. The Directive calls for all of the EU's marine regions and sub-regions to achieve or maintain "Good Environmental Status" (GES) by 2020. GES is defined by means of 11 qualitative "descriptors." The relevant criteria and indicators applicable to those descriptors are defined in the Commission Decision 2010/477/EU (European Commission, 2010).

One of the most important strengths of the MSFD is the aim to provide a holistic, functional approach; it separates the ecosystem into a set of process-related (functional) objectives, and then recombines these, to ensure the integrity of the ecosystem.

Descriptor 10 relating to marine litter, and their formulation according to the MSFD is that "*Properties and quantities of marine litter do not cause harm to the coastal and marine environment.*" It is the first time that marine litter is addressed, in an integrated way for the protection of the marine environment, in a European directive (Galgani et al., 2013a).

A Technical Subgroup on Marine Litter (TSG-ML) was established in 2010 to support Member States in harmonizing monitoring protocols and streamlining monitoring strategies in the framework of the MSFD (Galgani et al., 2013a,b).

Microplastics in the Context of the MSFD

Microplastics are considered specifically in descriptor 10 of the MSFD [10.1.3 "*Trends in the amount, distribution, and where possible, composition of micro-particles (in particular micro-plastics)*"], and not directly but implicitly in the indicator related with impacts of litter on marine life. The descriptor will establish baseline quantities, properties, and potential impacts of *MPs*. It must be noted however that the decision was reviewed recently for changes in order to make it simpler and clearer, to introduce minimum standards and to be coherent with other EU legislation.

Within the process, the TSG-ML suggested that micro-litter be considered as a size fraction integrating micro-litter along with other litter fractions in the matrix related indicators. Not all of the experts support this view, arguing that micro litter is different from other litter types (meso/macro) and that micro-litter may have considerably different effects to those caused by larger items of litter. The idea of merging indicators 10.1.2 (litter at sea, floating and on the sea floor) with indicator 10.1.3 (microplastics) aimed to avoid treating microparticles as a separate issue while measures to combat marine litter need to be formulated covering all size classes.

Finally, the revised decision (article 9/3 and 11/4) kept (the review has been done but not published yet) criteria separated for macro litter (10DC1) and microplastics (D10C3), now defined as "*The composition, amount, and spatial distribution of micro-litter in the surface layer of the water column, in sea-floor sediment, and possibly on coastlines, is at a level that does not cause harm to the coastal and marine environment.*"

MPs should be categorized according to their physical characteristics including size, shape, and color (see **Table 1**). It is also important to obtain information on polymer type.

The size definition of *MPs* according to the TSG-ML (Galgani et al., 2013b) is in line with the NOAA definition. We strongly suggest using this size (<5 mm) as an international standard. One aspect that should be refined is the definition of the lower size boundary for *MPs* in the MSFD. The lower size has not been defined strictly and nanoparticles have not been considered as a category despite their potential relevance (Galgani et al., 2013a).

Sampling of *MPs* in the different marine compartments (sea water, sediment, and biota) requires different approaches: samples can be selective, bulk, or volume-reduced (see e.g., Hidalgo-Ruz et al., 2012). Selective sampling in the field involves visual identification and manual sorting of fragments from different matrices and is not very effective for *MPs* due to difficulties in handling small size items. The subsequent identification of plastic particles in the matrix follows similar procedures (section Quantification and nature of MPs).

Bulk samples refer to samples where the entire volume of the sample is taken without reducing it during the sampling process. Bulk samples are most appropriate when *MPs* cannot be easily identified visually because in the field because (i) they are covered by sediment particles, (ii) their abundance is small requiring sorting/filtering of large volumes of sediment/water, or (iii) they are too small to be identified with the naked eye (Hidalgo-Ruz et al., 2012).

Volume-reduced samples, in seawater, refers to sampling where the bulk volume of the sample is reduced during sampling, preserving only that portion of the sample that is of interest for further processing. While on board a vessel seawater samples can be volume-reduced by filtering water through nets or screens.

TABLE 1 | Categories used to describe microplastic appearance in the MSFD.

Size	Record size of each item. Minimum resolution is to allocate in to bin sizes of 100 μm
Sources	Consumer product fragments (e.g., fishing net) and raw industrial pellets
Type	Plastic fragments, pellets, filaments, plastic films, foamed plastic, granules, and Styrofoam
Shape	For pellets: cylindrical, disks, flat, ovoid, spheruloids; For fragments: rounded, subrounded, subangular, angular; For general- irregular, elongated, degraded, rough, and broken edges
Erosion	Fresh, unweathered, incipient alteration, and level of crazing, (conchoidal fractures), weathered, grooves, irregular surface, jagged fragments, linear fractures, subparallel ridges, and very degraded
Color	Transparent, crystalline, white, clear-white-cream, red, orange, blue, opaque, black, gray, brown, green, pink, tan, yellow

A Need for Standardization: The Exemplary Case of Sampling Seawater

In the last years studies determining the global quantity of plastic particles in the ocean have been published (Eriksen et al., 2014; Cózar et al., 2014, 2015). In order to ensure inter-comparability between these studies to evaluate when (seasonality) and where (space) contamination is taking place, harmonization is urgently needed.

Seawater samples for *MPs* are mostly taken by nets. The main advantage of using a net is that large volumes of water can be sampled quickly, only retaining the volume-reduced sample. Most studies have been from surface water using neuston nets (Hidalgo-Ruz et al., 2012); manta and bongo nets have also been used at the sea surface. Since most plastics are buoyant they are likely to accumulate at the sea surface. Another instrument, that is widely deployed on a global scale and that has also been used for *MPs* sampling is the Continuous Plankton Recorder (CPR) (Thompson et al., 2004). Some instruments, including bongo and the CPR, are used sub surface making direct comparison rather difficult (Hidalgo-Ruz et al., 2012; Frias et al., 2014).

The most relevant characteristics of the sampling nets used are the mesh size and the net opening. Mesh sizes used for microparticle sampling range from 0.053 to 3 mm, with a majority of the studies (rather than individuals samples collected) ranging from 0.30 to 0.39 mm (Hidalgo-Ruz et al., 2012). The net aperture for rectangular openings of neuston nets (sea surface) ranged from 0.03 to 2.0 m^2.

Techniques using apparatus to collect surface seawater and pass it through a filter on-board ship are being developed for example by CEFAS, UK (T. Maes; personal communication). They use the ships water inlet, collecting seawater from the side at specified depths, mostly ranging between 4 and 1 m depth. The seawater is being passed along a set of sieves or nets after which the sieves or nets can be removed and analyzed for *MPs* in the laboratory (Pitois et al., 2016).

The advantage of such systems is that it can collect marine litter samples from the water column while steaming and thus long transects over several kilometers can be collected autonomous in connection with in-line analytical systems for other parameters like nutrients or oxygen. The development of filtration systems for the quantification of *MPs* appears promising (Lusher et al., 2014).

The recommendation from the TSG-ML is to obtain samples from sea water wherever possible, and to ensure the following details are recorded to accompany each sample: type of net (preferably Manta net), aperture (usually 60 cm), and mesh size (preferably 333 μm). It is also important to record the following parameters: depth (preferably either at the sea surface or within surface 10 m, for greatest inter-comparability among sampling programmes) distance towed, location of tow (in/out of water) and volume of water filtered (with a current meter).

Also prevailing weather conditions and sea state, together with any relevant information on the volume of plankton or other particulates sampled, for example if there is concern that the net may have become clogged due to high concentration of plankton, must be recorded. Samples should be stored in glass jars. *MPs* are determined as the total quantity of items per volume of seawater captured by the net during the period it is deployed.

Samples in seawater can be passed through a 500 μm sieve, and liquid passing through the sieve then filtered through a filter paper using a Buckner funnel. Filter papers can then be examined under a dissecting microscope to quantify microplastics below 5 mm. Sample on CPR silk filter screens can be examined directly under the microscope.

At present and from the experience in the implementation of the MSFD discussed in the TSG-ML, it is not appropriate to recommend one approach over all others. As an example, in **Table 2** are shown *MPs* values available for the Mediterranean with sampling details (mesh size, net). Each approach has advantages and disadvantages and may be preferable according to local availability/sampling opportunities, the characteristics of the area to be sampled and other factors. The mesh size and water volume are important if one wants to compare different surveys and thus harmonization between these parameters is recommended.

QUANTIFICATION AND NATURE OF *MPs*

Once *MPs* have been separated from their environmental matrix (seawater, sediments or biota) they must be quantified and identified.

Identification of *MPs*

The identification of *MPs* polymers is achieved by comparing the spectra from the unknown sample against that of a known standard polymer in a database. We encourage consulting Hummel (2002) for more details on this methodology. It should be noted that this method is only definitive where a good match is obtained and this is not always possible. Due to biofouling and degradation processes of microplastics in the environment, their

TABLE 2 | Summary of some available data for microplastics in surface waters in the Mediterranean Sea.

Location	Habitat	Date	Sampling	Density (min–max)	%Plastics	References
NW Mediterranean	Floating/Micro plastics	2010	40 samples/manta/330 μm mesh	115,000 items/km^2	>90%	Collignon et al., 2012
West Sardinia	Floating/Micro plastics	2012	30 samples/manta/500 μm mesh	150,000 items/km^2		de Lucia et al., 2014
Mediterranean Sea	Floating/Micro plastics	2015	39 samples/manta/200 μm mesh	243,853 items/km^2		Cózar et al., 2015
Strait of bonifacio	Floating/Microplastics	2012	40 samples/manta/330 μm	106,000 items/km^2		Galgani et al. unpublished
NW Basin	Floating/Microplastics	2014	41 samples/ manta/330 μm	130,000 items/km^2		Faure et al., 2015
Italy/South Adriatic	Floating/Microplastics	2013	29 samples/neuston net/200 μm	1,050,000 items/km^2 (100,000–4,860,000)	41% polyethylene	Suaria et al., 2015
Italy/North Adriatic	Floating/Microplastics	2014	11 samples/manta/330 μm	63,175 items/km^2		Mazziotti et al., 2015

spectra are not totally similar to spectra from the virgin material in the library.

If formal identification of particles using Fourier Transformed- Infra Red (FT-IR) or Raman Spectroscopy is applied then polymer type should also be recorded. Spectroscopy is not critical for routine monitoring of larger fragments > 500 μm. However, it should be considered essential for fragments > 50 μm and a proportion (5–10%) of all samples should be routinely checked to confirm the relative accuracy of any visual examination.

A suitable approach proposed by the TSG-ML would be to automatically accept any match >70% similarity (Frias et al., 2016), to individually examine matches between 60 to 70% similarity rejecting any samples which do not show clear evidence of peaks corresponding to known synthetic materials and to routinely reject (as synthetic) any samples which produce spectra with a match < 60%).

It is advocated that when analyzing particles in the range 1–100 μm to subject them to further spectroscopic analysis to confirm polymer identity (e.g., using FT-IR). For particles in the size range 101 μm–4.99 mm we recommend that a proportion (10% of the material in each size class, up to a maximum of 50 items per year or sampling occasion whichever is the least frequent) of the items considered to be *MPs* is subjected to further spectroscopic analysis to confirm identity (e.g., using FT-IR). This step is important in order to; (1) ensure quality control of visual identification and (2) gain information on the relative abundance of different polymer types which can inform on sources.

One important issue is to mitigate contamination of samples, as plastics are present in our daily lives (in clothes, scrubbers) and in labs (labware). People undertaking the sampling and working in the lab should minimize any synthetic clothing. As procedural controls to check ambient cleanliness, place unused clean filter papers in Petri dishes. Remove the lid and leave the Petri-dish open for a fixed time period relevant to the time period for which samples might be exposed to the air during examination. Procedural contamination should be <10% of the average values determined form the samples themselves.

Required Reporting Units

For *MPs* in seawater items/m^3 seawater, average size of particles, relative abundance of main colors and shape are suggested as units. Relating quantities of *MPs* to volume is relevant when considering the sampling of water column through filtration. Expressing quantities by volume also allow to link field studies directly with exposure experiments in the laboratory. The estimation of volumes is however impossible when using neuston/manta nets as the trawl frames are permanently moving vertically at the surface of the sea, complicating correct calculation of the sampled water height covered during tows. For this reason, the sampling of the surface density most often rely on items/m^2, a more relevant estimation of the sample covered. It should be stressed that when possible, more info should be recorded to facilitate reporting in several units in order to ensure comparison with other studies. If FT-IR or Raman is used then polymer type should also be recorded together with shape and color.

FINAL REMARKS

When comparing reported abundances of *MPs* in the water column it is important to keep in mind that even though most surveys are conducted using a neuston net, the mesh size of these nets often differ. In addition, despite recommendations for the definition of *MPs* as particles smaller of 5 mm (Arthur et al., 2009; Galgani et al., 2013a), many authors worldwide are using other size limits e.g., 1 mm (Costa et al., 2010; Van Cauwenberghe et al., 2013). Furthermore, sometimes it is not possible to compare density values due to different methodologies used for sampling (items/km^2 vs. items/km^3). Hence, comparison between studies is quite complex.

There is a need for research to develop and subsequently validate new methods to rapidly and inexpensively identify and quantify *MPs*. These methods could include image recognition equipment to facilitate rapid identification as is currently used for plankton and particulate characterisation (Sieracki et al., 2009) and separation. Development of bulk chemical approaches to provide either an absolute value or an index of extent to which a water sample is contaminated with *MPs* and to indicate the type of particles (as e.g., polymer type) could also prove useful. It is also important to note that methods for detecting nanoparticles in the marine environment should be developed in the coming years.

As this is an emerging field and our understanding of the rates of accumulation and the extent to which *MPs* might cause

harm in the environment is very scarce. Therefore, the experts of TSG-ML advocate a precautionary approach and recommends the development and calibration of methods and initiation of wider scale monitoring should commence straight away.

In our view one of the most important long term needs for the MSFD beyond 2020 are to gain a holistic understanding of marine litter by integrating *MPs* data collected from waters, sediments, and biota with other litter data and by integrating knowledge of temporal and spatial trends across types and sizes of marine litter (Van Franeker and Law, 2015).

Some of the monitoring approaches for the MSFD are still under development, so the implementation and improvement of monitoring will require continuous collaborative efforts. To achieve the greatest efficiency, *MPs* in seawater should be sampled alongside other routine sampling programmes. Similarly sampling of sea water column could also be incorporated into other monitoring programmes. A key consideration in collecting seawater samples is the cost of ship time. Hence the potential to sample during existing cruises or programmes is well worth considering.

The comparable quantification of *MPs*, by the use of common methodologies, is also important for identification of the sources, planning of measures against marine litter and for checking the efficiency of these counter-measures under the umbrella of the MSFD.

AUTHOR CONTRIBUTIONS

JG write the paper and took part in discussions. FG, TM, and RT contribute to the paper discussions.

FUNDING

Participation of JG was financed by Spanish minister of Environment under Project 3-ESMARAC.

ACKNOWLEDGMENTS

This article is based on the activities of the GES-Technical subgroup on Marine litter (2012–2015), specifically on microplastics. We want to express our gratitude to all members of this group. We are very great full to the three reviewers that have made a number of good suggestions to improve this paper.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.