Brief on the Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean: Recommendations and Future Steps






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GESAMP (2019). Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J., Turra A. and Galgani F. editors), (IMO/FAO/UNESCO- IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, 130p.

The full report is available and can be downloaded at the following web addresses:

http://wedocs.unep.org/handle/20.500.11822/30009
http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

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Financial support:
The production of this document has been supported with funds from the Government of Norway.

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GESAMP Group of Experts on the Scientific Aspects of Marine Environmental Protection

Introduction

The effort to promote a more harmonised approach to the design of sampling programmes for the monitoring and assessment of marine litter, including the selection of appropriate indicators (i.e. type of sample and litter item), the collection of samples or observations, the characterisation of sampled material, dealing with uncertainties, data analysis and reporting the results, is the direct result of UN Environment Programme, supported by Intergovernmental Oceanographic Commission of UNESCO, being tasked with supporting countries to implement methodologies and procedures to report against target 14.1 '*By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution*' under Sustainable Development Goal 14.

There has been a growing concern about the quantity of plastic and microplastic debris in the ocean over the years. In June 2014, the United Nations Environment Assembly (UNEA) adopted resolution 1/6 on marine plastic debris and microplastics. As part of implementing the resolution a report was prepared to support the specific request in Paragraph 14 to the Executive Director: '*... building on existing work and taking into account the most up-to-date studies and data, focusing on:*

a) Identification of the key sources of marine plastic debris and microplastics;
b) Identification of possible measures and best available techniques and environmental practices to prevent the accumulation and minimize the level of microplastics in the marine environment;
c) Recommendations for the most urgent actions;
d) Specification of areas especially in need of more research, including key impacts on environment and on human health;
e) Any other relevant priority areas identified in the assessment of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection'.

The report summarised the state of our knowledge on sources, fate and effects of marine and micro plastics as well as describing approaches and potential solutions to address this multifaceted conundrum[1].

1 United Nations Environment Programme (2016) Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change: http://wedocs.unep.org/handle/20.500.11822/7720

One of the summary conclusions in the report was that there is a need to strengthen and harmonise monitoring and assessment efforts, to meet global commitments under the UN Sustainable Development Goals targets, and to target and gauge the effectiveness of marine litter reduction measures[2].

The report covers all size ranges of plastic litter encountered in different compartments of the marine environment, i.e. stranded on shorelines, floating on the sea surface, suspended in the water column, deposited on the seafloor or associated with biota (ingested/encrusted/entangled). The guidelines may also be used for the monitoring of items originating from specific sources, e.g. Abandoned or Lost Derelict Fishing Gear (ALDFG), or specific items to evaluate the efficiency of dedicated reduction measures.

The guidelines include recommendations, directed primarily to assist national authorities and regional bodies in setting up programmes to establish the status and trends of marine contamination by plastic litter, including (indicator selection, method harmonisation, and baselines establishment) in waters under their jurisdiction. The report is intended to complement established monitoring and assessment programmes, such as those developed in the framework of the Regional Seas, the European Union and by several individual countries. These existing initiatives, together with the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation (UNEP/IOC-UNESCO) guidelines published in 2009[3], provided a key input to the development of these updated guidelines. Deciding on what constitutes the target or preferred state of marine litter is beyond the scope of the report. This decision is part of the governance process, irrespective of the geographical or political level, informed by scientific evidence, taking account of other social, economic and political factors.

This brief has been prepared by UNEP for the purposes of outreach, communication and training. It will be translated in all UN languages as well as other identified languages in some regions. The guidelines are also to support the further development of the marine litter monitoring framework under the Sustainable Development Goal (SDG) 14.1 floating plastic litter as a global indicator of marine pollution. This is important in ensuring that harmonized data can be collected globally. Harmonization will assure a collective response to tackle the marine plastic issue where there is no compromise through access to shared monitoring guidelines. This will also provide a clearer picture of the true scale of the problem, and measure the impact of dedicated reduction measures, such as the ban of single use plastics.

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2 United Nations Environment Programme (2016) Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change: http://wedocs.unep.org/handle/20.500.11822/7720

3 UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter, United Nations Environment Programme ; Intergovernmental Oceanographic Commission (2009): http://wedocs.unep.org/xmlui/handle/20.500.11822/13604

Background

Purpose and objectives

The principle purpose of this report is to provide recommendations, advice and practical guidance for establishing programmes to monitor and assess the distribution and abundance of plastic litter, also referred to as plastic debris, in the ocean. It is a product of the GESAMP Working Group (WG40) on 'Sources, fate and effects of plastics and microplastics in the marine *environment*', co-led by the Intergovernmental Commission on Oceanography (IOC-UNESCO) and the United Nations Environment Programme (UNEP). The report was prepared by 19 independent experts from 14 countries, with financial support from a number of agencies and national governments (Annex I of the main Report). The term 'plastic litter' is used throughout, but is synonymous with 'plastic debris'. In some cases the report refers to monitoring strategies and sampling protocols that have been designed for the monitoring of all forms of marine litter (i.e. processed wood, metal, textiles, glass, munitions, and plastics).

The main audience of the report is intended to be national, inter-governmental and international organisations with responsibilities for managing the social, economic and ecological consequences of land- and sea-based human-activities on the marine environment. The decision to produce these Guidelines reflects the lack of an internationally agreed methodology to report on the distribution and abundance of marine plastic litter and microplastics, a topic that is attracting increasing concern. Use of a harmonised system will benefit the development of monitoring programmes, as envisaged under UN Sustainable Development Goal indicator 14.1.1 (marine litter), and help to raise the category of this indicator from Tier 3 ('*No internationally established methodology or standards are yet available*') to Tier 2 *('Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries')* (section 3.2.2). For practical purposes the number of references provided has been kept relatively small, citing a limited number of key sources of information that, where possible, are publicly accessible and provide an entry point to more in-depth literature.

This document is intended to inform the establishment of national and regional field monitoring programmes. It provides links to protocols and data recording sheets that are intended to be used in the field. The scope is to monitor plastic litter in the marine environment. However, many of the techniques described can be used in other litter items and in freshwater environments, specifically for monitoring rivers and lakes, with appropriate modification.

The Global Partnership on Marine Litter (GPML) was set up to share information and good practices, facilitate capacity building, make links, provide access to training and collaboration among partners. Those interested in this topic are encouraged to take part in this initiative, which can be accessed through the Marine Litter Network[4]. In partnership with the Open University, Massive Open Online Course (MOOC) on Marine Litter are being run using the guidelines as training material[5].

Plastic litter as a global ocean concern

Humanity has long used the ocean to dispose goods and materials regarded as waste, either directly or indirectly (e.g. via run-off). Since the 1950s, when large-scale production of plastics began, an increasing proportion of

4 Global Partnership on Marine Litter: http://marinelitternetwork.com/the-partnership/
5 Massive Open Online Course: http://elearning.unep.org/moocs/www.unep.org

solid waste in the ocean has consisted of this material, representing up to 80% of marine litter found in surveys (UNEP, 2016)[6]. This is a result of both land-based and sea-based human activities. Plastic litter is most obvious on shorelines, where litter accumulates due to current, wave and wind action, river outflows and by direct littering at the coast. However, plastic litter occurs on the ocean surface, suspended in the water column, on the seabed and in association with biota, due to entanglement or ingestion (Figure 1).

We know the total global production of plastics with reasonable confidence (8.3 Gt from 1950 to 2015, Geyer *et al.* 2017)[7] but not the proportion that has entered the ocean. Major sources or 'leakage' points include poorly managed solid waste and effluents on land, through either direct entry in the ocean or via rivers, activities on the shoreline, shipping and fisheries.

The term 'plastic litter' covers an extremely wide variety of materials, ranging in size from ocean-going boat hulls many metres in length to particles a few nano-metres in diameter. 'Plastic' covers a very wide range of compositions and properties. Size, shape and composition all influence the distribution, fate and effects in the environment and need to be accounted for where possible. These factors are discussed in Chapter 2 of the Report.

The role of monitoring and assessment

Monitoring the marine environment for the presence of plastic litter is a necessary part of assessing the extent and possible impact of marine litter, devising possible mitigation methods to reduce inputs, and evaluating the effectiveness of such measures. However, it is important to use consistent and reliable methods of sampling and sample characterisation (e.g. number, size, shape, mass and type of material; Chapter 2) to gain greatest benefit.

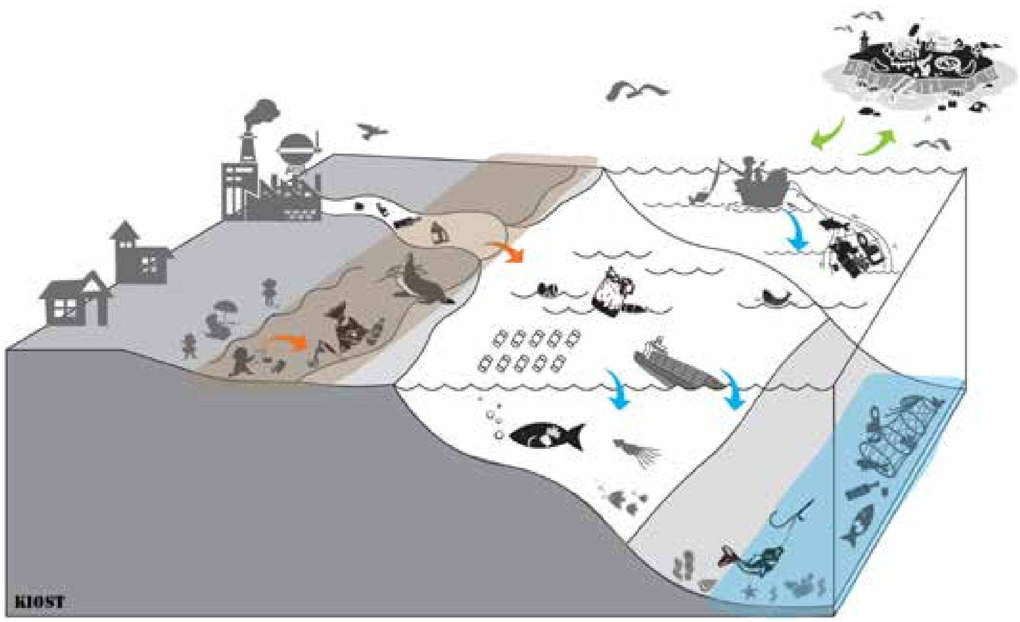


Figure 1 *Schematic representation of sources of marine plastic litter and microplastics (adapted from GESAMP 2015)*[8].

6 United Nations Environment Programme (2016) Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change: http://wedocs.unep.org/handle/20.500.11822/7720

7 Geyer, Roland & Jambeck, Jenna & Law, Kara. (2017). Production, use, and fate of all plastics ever made. Science Advances. 3. e1700782. 10.1126/sciadv.1700782: https://www.researchgate.net/publication/318567844_Production_use_and_fate_of_all_plastics_ever_made/citation/download

8 GESAMP (2015). "Sources, fate and effects of microplastics in the marine environment: a global assessment" (Kershaw, P. J., ed.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90, 96 p.: http://www.gesamp.org/publications/reports-and-studies-no-90

When setting up a sampling programme the design needs to take into account the management objectives (e.g. compliance, efficacy of reduction measures), the environmental setting and the most appropriate indicators to be targeted (Chapter 3). Indicators are selected to describe the 'state' of the environment, such as the quantity of litter per unit of measurement (i.e. area, length, number of organisms). It is common to compare the measured 'state' against a baseline or reference state. But, as plastic litter is ubiquitous in the ocean, it is unlikely that the baseline will be zero. There needs to be a degree of consistency in the techniques used and in the frequency and location of sampling to allow reliable estimates of changes in space and time. The magnitude of the change to be detected, coupled with the inherent variability in the measured indicator, determines the sampling effort required to detect spatial and temporal trends. This is discussed in Chapter 3 of the Report.

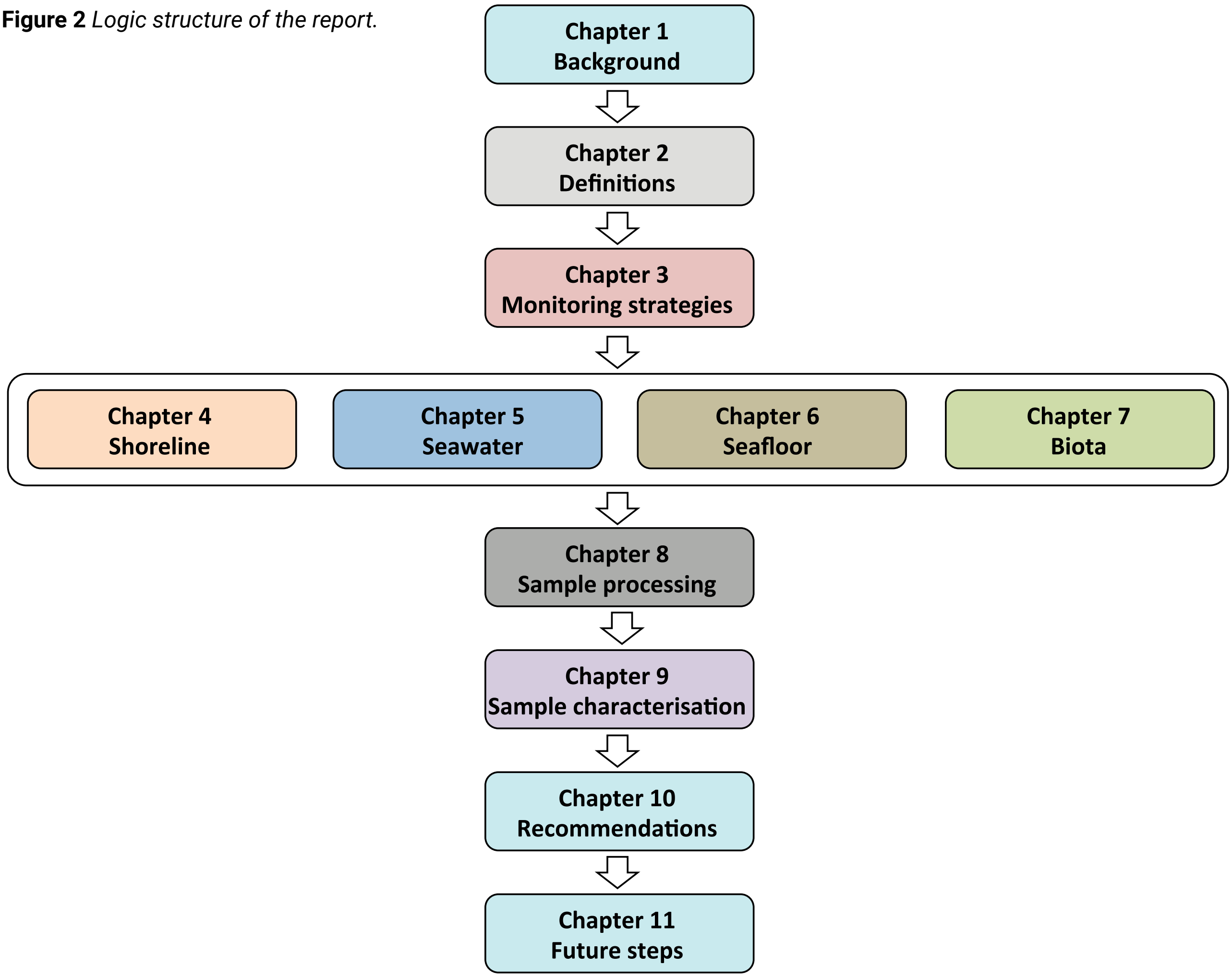
How to use the report - structure

The report is intended to provide a step-by-step approach to designing and implementing a programme for monitoring marine plastic litter, assuming no prior knowledge (Figure 2). Using definitions and terminology that are widely accepted and understood by the user group is key to creating a harmonised approach and increasing the potential for sharing data and information. Chapter 2 provides definitions of common terminology used in existing marine litter monitoring. It is followed by a description of some basic principles of monitoring and assessment that are applicable in most cases (Chapter 3). This is intended to maximise the utility of the data gathered, recognising that in many cases resource constraints will limit the scale of any monitoring programme. Chapters 4 – 7 describe the environmental settings, selection of monitoring strategies and special considerations for each of the environmental compartments: shoreline, sea-surface and water column, seafloor and biota. Some degree of sample preparation in the laboratory is usually required, whichever sampling methods are used in the field. A selection of common procedures is included in Chapter 8. Chapter 9 presents a range of more sophisticated laboratory-based techniques for recording the biological, chemical or physical characteristics of the sample, if this information is required. Links are provided throughout the report to sources of supplementary information, including existing monitoring programmes, more detailed descriptions of methods and case studies. The report concludes (Chapter 10) with a series of recommendations, including selection criteria dependent on both resource/capacity limitations and policy questions being addressed.

The recommendations are directed, primarily, to assist national authorities and regional bodies in setting up programmes to establish the current status and trends of contamination by marine plastic litter (indicator selection, method harmonisation, establishment of baselines) in waters under their jurisdiction. They are intended to complement established monitoring and assessment programmes, such as those developed in the framework of the Regional Seas[9], the European Union[10] and the United States[11]. These existing initiatives, together with the IOC/UNEP guidelines published in 2009[12], provided a key input to the development of these updated guidelines. This decision is part of the governance process, informed by scientific evidence, taking account of other social, economic and political factors. The report ends presenting future steps towards more effective monitoring programmes, as the improvement of the SDG 14.1.1 indicators and new developments regarding data management (Chapter 11).

9 Special Monitoring and Coastal Environmental Assessment Regional Activity Centre. http://cearac.nowpap.org/activities/marine-litter/
10 MSFD Technical Group on Marine Litter; TG Litter is a technical group under the MSFD Common Implementation Strategy: http://mcc.jrc.ec.europa.eu/dev.py?N=41&O=434&titre_chap=TG%20Marine%20Litter
11 Marine Debris Monitoring and Assessment Project: https://marinedebris.noaa.gov/research/marine-debris-monitoring-and-assessment-project
12 UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter United Nations Environment Programme ; Intergovernmental Oceanographic Commission (2009): http://wedocs.unep.org/xmlui/handle/20.500.11822/13604

Figure 2 *Logic structure of the report.*



The full report is available and can be downloaded at the following web addresses:

http://wedocs.unep.org/handle/20.500.11822/30009
http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

Recommendations

1. Recommended definitions and strategies

1.1 Marine litter definitions

The Guidelines reflect the fact that several size categories are in routine use in established monitoring programmes. In addition, several of the commonly used descriptors, such as meso, macro and mega, are not recognised as international standards, which would otherwise provide a basis for making a recommendation. Table 1 provides a summary of definitions for four broad size categories, giving the commonly-used size range together further alternative options that are in regular use, in particular for litter in the micro and meso categories. GESAMP recommends that < 5mm should be used as the upper size limit for microplastics for routine monitoring purposes. GESAMP acknowledges that research scientists may choose to use other definitions but concludes it is not helpful for regulatory authorities to have to wait until a scientific consensus is achieved.

GESAMP recommends that <5mm be used as the upper size limit for microplastics for monitoring purposes, based on its common usage in existing national and regional monitoring programmes

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The selection of which size ranges to use is the responsibility of those designing and implementing new monitoring programmes. They will need to take into account the policy concern being addressed as well as the capacity and expertise of those personnel and organisations entrusted to carry this out (Table 2).

Table 1 Recommended size categories for routine marine litter monitoring. R = recommended F = feasible/acceptable.

Size	**Recommended**	**Alternative options for operational monitoring and research purposes**	
		Alternative 1	Alternative 2
Mega	R > 1m		
Macro	R 25mm – 1m		
Meso	R 5-25mm	F 1-25mm	F 1-5mm and 5-25mm
Micro	R <5mm	F <1mm	F <1mm

There is currently no standardized scheme for morphological characterization of plastic litter, but five general categories are used (fragments, foams, films, lines and pellets). While these morphological descriptions can be subjective, it is recommended that these 5 general categories may be subdivided in finer portions (e.g. granules/flakes, EPS/PUR, sheets, fibres/filaments/strands, beads/pellets) with the recognition that subdivisions can be combined for ease of harmonizing and comparing data.

Like morphology, there is currently no standard scheme for colour designation for plastic litter. While broad colour classifications are not sufficient, being too particular would be unreasonably time-consuming, if not impossible on a large scale, understanding also that colour may fade/change. The Report recommends either the 12 basic colour terms of the ISCC-NBS (Inter-Society Colour Council National Bureau of Standards) System of Colour Designation or the eight-colour classification scheme being proposed by the European Marine Observation and Data Network (EMODnet)[13] (Galgani *et al.* 2017)[14].

13 The European Marine Observation and Data Network (EMODnet): www.emodnet.eu
14 Galgani, F., A. Giorgetti, M. Vinci, M. Le Moigne, G. Moncoiffe, A. Brosich, E. Molina, M. Lipizer, N. Holdsworth, R. Schlitzer, G. Hanke and D. Schaap (2017). Proposal for gathering and managing data sets on marine micro-litter on a European scale, EMODnet Thematic Lot n°4 - Chemistry. Project Documents, 35 pp.: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112895/jrcreport_mldatabase_eur29469_final_online.pdf

Table 2 Summary of the recommended (R) sampling approaches for different compartments and plastic sizes, regarding their feasibility (1, more feasible; 7, less feasible; based on resource sampling and processing requirements) and common policy concerns addressed, with reference to the specific chapters in the report. The policy relevance index is the sum of the policy concerns addressed by the sampling approach. Compartments: SL – shoreline, SF – seafloor, B – biota, SS – sea surface. Sub-compartments: BE – beach, FISH – fish, INV – invertebrate, SEAB – seabird, MEG – mega-fauna. Plastic sizes: MA – macro-plastic, ME – meso-plastic, MI – micro-plastic.

	Compartments and plastic size			Resource sampling and processing requirements (costs increase from left to right)							Examples of policy concerns									
													Impacts on							
Feasibility	Compartment	Sub-compartment	Plastic size	People	Basic field equipment	Sieves	Nets	Dissecting microscope	Ship	Chapter	Distribution and Abundance	Source identification	Tourism	Seafood safety	Human health and injuries	Navigational hazards	Fisheries and aquaculture	Animal welfare	Biodiversity	Policy relevance index
1	SL	BE	MA	R	R					4	R	R	R		R				R	5
2	SL	BE	ME	R	R	R				4	R		R						R	3
3	SF		MA	R			R		R[a]	6	R	R				R	R		R	5
3	SF		MA	R[b]	R					6	R	R	R			R	R	R	R	7
4	B	FISH	ME MI	R		R		R		7	R			R			R	R	R	5
4	B	INV	ME MI	R				R		7	R			R			R	R	R	5
5	B	SEAB[c]	ME MI	R		R		R		7	R	R						R	R	4
5	B	MEG[c]	MA ME MI	R				R		7	R							R	R	3
6	SS		ME MI	R		R	R	R	R[d]	5	R						R		R	3
7	SS		MA	R	R				R[e]	5	R					R	R	R	R	5

[a] Opportunistic sampling using fishing vessel, [b] Opportunistic observations using recreational divers, [c] Stranded organisms, [d] Research vessel, [e] Visual observation from ship of opportunity.

For larger litter, the monitoring of specific items may require additional specific categories to assess the efficiency of targeted reduction measures. As an example, the monitoring of abandoned or lost derelict fishing gears and action to lower their amounts in a specific area may require the consideration of specific categories of fishing related items (buoys, nets, ropes, lines, boxes, tags etc.).

1.2 Developing a national or regional monitoring strategy

The selection of the most appropriate monitoring strategy must include a consideration of the policy question being addressed as well as the resources available to carry it out. This section provides a hierarchy of methods to assist in the selection of the most resource-efficient approach to answer a series of typical policy concerns.

In terms of fishing gear, it is probably useful to highlight that fishing industry stakeholders may need to be included in the process of developing such a strategy since they may play an active role in delivering it. Table 2 presents a list of environmental compartments and litter size categories, summarises the resource requirements (personnel, equipment) for each combination and provides examples of typical policy questions that government agencies may be facing.

It is critical to design and implement monitoring programmes that are cost-effective, to make best use of often scarce resources and ensure that programmes are more likely to be maintained. A number of factors are key and the following approaches are recommended:

i) prioritise the monitoring programme to address the most significant risks and associated indicators (i.e. scientific, technical, policy/social relevance and data requirements);
ii) favour innovative and opportunistic approaches;
iii) encourage cooperation (common services; common cruises);
iv) build on existing monitoring activities; and finally
v) encourage monitoring by organisations responsible of the environmental effects (industry, municipalities).

Table 3 provides a summary of estimated costs, based on experience in a European setting (Galgani *et al.* 2013). It is appreciated that staff costs may vary considerably between countries.

Table 3 Estimated costs and level of expertise for the different protocols adapted from (Galgani *et al.* 2013)[15].
L: Low (< 10K USD); M: Medium (<50K USD); H: High (<100K USD); VH: Very High (>100K USD). ROV: Remote Operated Vehicles.

Component	Beach	Seafloor			Seawater		Biota		Microplastics			
Protocol	Visual	Diving <20m	Trawling <800 m	ROV	Trawl	Ship surveys	Ingested	Entanglement	Beach	Seawater	Sediment	Biota
Sampling	L	M	M	VH	L	M	M/H	M/H	L	M/H	M/H	M/H
Processing	L	L	L	M	L	M	H	M	M	M	M	H
Analysis	M	M	M	M	M	M	H	M	H	H	H	H
Expertise	**M**	**M/H**	**M**	**H**	**L**	**M**	**M/H**	**M/H**	**M**	**M**	**M**	**M**
Equipment	L	M	H	H	M	L/H	M	L/M	M	M	M	M
Overall costs	L/M	M	M	H	L/M	M	M/	M	M	M/H	M/H	M/H

15 Galgani F., G. Hanke, S. Werner, L. Oosterbaan, P. Nilsson, D. Fleet, S. Kinsey, R. Thompson, J. van Franeker, T. Vlachogianni, M. Scoullos, J. Mira Veiga, A. Palatinus, M. Matiddi, T. Maes, S. Korpinen, A. Budziak, H. Leslie, J. Gago and G. Liebezeit (2013). Monitoring Guidance for Marine Litter in European Seas. MSFD GES Technical Subgroup on Marine Litter (TSG-ML). Final REPORT: 120 pp. :https://academic.oup.com/icesjms/article/70/6/1055/639375

2. Summary of recommended sampling methods (Chapters 4 – 7)

2.1 Recommended sampling methods for the shoreline

Recommended methods for different litter components on shorelines are summarised in Table 4.

Table 4 Overview of sampling protocols for different litter size categories (see Table 1) at three main shoreline types: Sandy Beaches, Rocky Shores (including cobble and boulder beaches) and Mangroves and Salt Marshes. R = recommended, F = feasible

Survey goal	Size	Sandy beaches	Rocky shores	Mangroves and Salt Marshes	Comments
Baseline surveys	Mega	R	F	F	One-off visual surveys
	Macro Surface	R	F[a]	F	One-off visual surveys
	Macro Buried	F			Sieve to collect litter; sample to at least 10 cm deep
	Meso	R			Sieve to collect litter to ≥5-10 cm deep
	Micro	F (cores[b])		F (cores)	Surface sieving or sediment cores
Monitoring	Mega	R	F		Mark litter and resample at regular intervals
	Macro Surface	R	F	F	Remove litter and re-sample
	Macro Buried	F			Accumulation estimates not feasible
	Meso	R			Sampling with 1 m quadrats by sieving > 5 mm
	Micro	R			Dry or wet sieving two or more size categories

[a] only larger items on boulders, [b] across beach profile

2.2 Recommended sampling methods for the sea surface and water column

Sampling the open water surface and water column, while technically is an easy task, is clearly more challenging to make results meaningful due to heterogeneous distribution, mechanisms of degradation and buoyancy, and the many influences of the type of plastic polymer, and the size and shape of the product or packaging. These variables affect the distribution and persistence of microplastics, which are also confounded by the location of the input, whether it is from maritime activities, effluent, rivers or shorelines. If the objective is to understand source or simply understand a local or regional standing stock of marine plastics, all of the above variables must be considered. Recommended methods for sampling different litter components on the sea surface or in the water column are summarised in Table 5.

Table 5 Overview of sampling protocols for different plastic size categories (see Table 1) in two sub-compartments : sea surface and water column. R = recommended, F = feasible.

Compartment	Size	Recommendation	Method	Comments
Sea Surface	Mega	F	Aerial survey	Expensive to charter a plane
	Mega	R	Visual survey	Use ship as the platform to conduct survey
	Macro	R	Visual survey	See above
	Meso	R	Net tow	Affordable and litter is restricted to surface
	Micro	R	Net tow	Affordable and litter is restricted to surface
	Micro	F	Bulk water pump	Costs involved, and training, but will get good microplastic data
Water Column	Mega	F	Fisheries observer	Cost effective, as you only need to train staff
	Macro	F	Fisheries observer	Cost effective, as you only need to train staff
	Meso	F	Bulk water pump	Costs involved, and training, but will get good microplastic data
	Meso	R	Underway sampling	Cost effective. Some equipment involved and training
	Meso	F	Bongo net	Need vessel with winch, net relatively expensive
	Micro	F	Bulk water pump	Costs involved, and training, but will get good microplastic data
	Micro	R	Underway sampling	Costs involved, and training, but will get good microplastic data
	Micro	F	Bongo net	Need vessel with winch, net relatively expensive

2.3 Recommended sampling methods for the seafloor

Macro-plastics

Monitoring marine litter on the sea floor is not common since working in underwater areas is based on the use of specialist and expensive means, such as the need for support vessels and skilled operators (divers, trawl specialists and ROV pilots). It is recommended to focus on the most common or critical litter items, particularly monitoring the effectiveness of specific reduction measures. To reduce costs, litter can be monitored using opportunistic approaches such as:

i) including marine litter as additional and relevant indicator in regular monitoring of biodiversity by divers or ROVs in Marine Protected Areas;
ii) recording the recovery of litter in bottom trawls during fisheries assessment surveys of demersal fish stocks; and
iii) recording the presence of litter in ROV and submersible surveys of the seafloor, carried out for other purposes such as engineering or mineral exploitation.

Microplastics

One of the main difficulties at present is the lack of harmonisation of sampling and extraction methods for microplastic particles. We recommend the following:

i) use box-corers/corers rather than grabs, when available, to provide more reliable estimates of sampling volume;
ii) sample through opportunistic approaches when possible to limit excessive costs in the deep sea; and
iii) report microplastic abundance as number per sediment dry weight (kg^{-1}).

More effort is required to improve methods and develop new products and initiatives, such as reference materials, proficiency testing schemes, ring tests, inter-calibration exercises and standard operating protocols.

Recommended methods for sampling different litter components on the seafloor are summarised in Tables 6 and 7.

Table 6 Overview of sampling protocols recommended for initial assessments for different plastic size categories (see Table 1) by survey method, water depth and type of seafloor (soft or rocky). R = recommended, F = feasible.

Survey Goal/Method	Water Depth	Size	Soft bottom	Rocky bottom	Mixed
Initial Assessment					
Diving	Shallow (0-30m)	Mega/Macro	R	R	R
		Meso	F	F	F
		Micro	not visual		not visual
	Deep	any size			
Trawling	Shallow (Net + pole)	Mega/Macro	R		
		Meso	F		
		Micro			
	Deep (<200m), net + pole	Mega/Macro	R		
		Meso	F		
		Micro			
	Ultra deep (<5000m) (pole only)	Mega/Macro	< 5000 m		
		Meso	F		
		Micro			
Remote Operated Vehicle (Imagery)	Shallow	Mega/Macro	R	R	R
		Meso	F	R	R
		Micro			
	Deep (shelves/ slopes)	Mega/Macro	R	R	R
		Meso	F	R	R
		Micro			
	Ultra deep	Mega/Macro	R	R	R
		Meso	F	R	R
		Micro			
Core/grab	All depths	Mega/Macro			
		Meso			
		Micro	R		F

Table 7 Overview of sampling protocols recommended for routine monitoring for different plastic size categories (see Table 1) by survey method, water depth and type of seafloor (soft or rocky). R = recommended, F = feasible.

Method	Water Depth	Size	Soft bottom	Rocky bottom	Mixed
Diving	Shallow (0-30m)	Mega/Macro	R	R	R
		Meso	F	F	F
		Micro	not visual		not visual
	Deep	Any size			
Trawling	Shallow (Net + pole)	Mega/Macro	OPP		
		Meso			
		Micro			
	Deep (Shelves slope), net + pole	Mega/Macro	OPP		
		Meso			
		Micro			
	Ultra deep (pole)	Mega/Macro	F		
		Meso	F		
		Micro			
Monitoring					
Remote Operated Vehicle	Shallow (0-30m)	Mega/Macro	F	F	F
		Meso	F	F	F
		Micro			
	Deep (shelves)	Mega/Macro	OPP	OPP	OPP
		Meso	F	F	F
		Micro			
	Ultra deep	Mega/Macro	OPP	OPP	OPP
		Meso	F	F	F
		Micro			
Core/grab	All depths	Mega/Macro			
		Meso			
		Micro	R		

2.4 Recommended sampling methods for biota

Monitoring the interactions and effects of plastics on biota is heavily reliant on organisms' physiology and life history, which express whether organisms are more or less likely to experience negative consequences. Suitable monitoring methods must be adapted to the life cycle of these organisms and consider the regional representation, the abundance and distribution, the availability of scientific background, the costs, the ecological and commercial importance, and the feeding strategy. Recommended methods for sampling different litter components associated with biota are summarised in Table 8.

Table 8 Overview of sampling protocols for different survey goals (ingestion, entanglement, and effects on habitat) litter size categories (see Table 1) in biota. R = recommended, F = feasible.

Survey goal	Size	Marine mammals	Birds	Fish	Invertebrates	Corals	Epibionts	Remarks
Ingestion	Mega	F						Opportunistic, strandings
	Macro	F	R					OSPAR monitoring
	Meso	F	R					
	Micro	F	R	R	R	F	F	
Entanglement	Mega	R	R			F		Opportunistic strandings
	Macro	R	R			F		
	Meso				F	F		
	Micro							
Habitat	Mega					R	R	
	Macro		R			F	R	
	Meso		F			F	R	
	Micro						R	

3 Recommended methods for marine litter characterization (Chapters 8 – 9)

3.1 Recommended methods for sample processing

Recent developments have led to the sample processing of ever-smaller sizes of plastics (to micro and now nano). There has been a growing interest in employing chemical and biological means of reducing interference by natural organic and inorganic material (matrix removal) to avoid misidentification of natural materials. The methods include density separation, biological/chemical digestion and sieving/filtering; each of these can be used in isolation or in concert, in a different order (Table 9).

Table 9 Overview of sampling processing protocols for different environmental compartments and litter size categories (see Table 1). R = recommended, F = feasible.

Environmental compartment	Size	Hand sorting	Sieving/ filtering	Density separation	Digestion		
					Enzymatic	Alkaline	Oxidative
Shoreline (Chapter 4)	Meso	R	R	R			
	Micro	F	R	R		R	R
Seawater (Chapter 5)	Meso	R	R	R			
	Micro	F	R	R	F	R	R
Sea Floor (Chapter 6)	Meso	R	R	R			
	Micro	F	R	R	F	R	R
Biota (Chapter 7)	Meso	R	R	F	R	R	R
	Micro	F	R	F	R	R	R

Table 10 Overview of physico-chemical characterization methods applicable for different litter size categories (see Table 1). R = recommended, F = feasible.

Size	Visual observation (naked eye)	Visual observation (microscopy)	Microscopy and spectroscopy (FTIR, Raman)	Alternatives (FTIR-FPA Nano-IR Pyro-GC/MS SEM-EDS)	Comment
Mega	R				
Macro	R				
Meso 5-25 mm	R				Confirmation spectroscopy
Large micro 1-5 mm		R	R	R	Microscopy + spectroscopy
Small micro 0.02-1 mm			R	R	
Very small micro 0.001-0.02 mm			F[a]	R	[a]FTIR/Raman Challenging
Nano < 1 µm				R[b]	[b]Exploratory

Complexity

a only larger items on boulders
b across beach profile

Obtaining information to support management decisions requires a thorough and detailed understanding of plastic particle characteristics. This includes appropriate analytical methods to characterise physical, chemical and biological properties of plastics (Table 10). Once collected, this information is vital or optional to develop reliable risk assessments and management procedures. Among the characteristics observed or analysed, some are very crucial to meet the purpose of the monitoring program. The strategies defined to characterize plastic particles rely on two main options, that are the relevance of analytical procedures (option 1, robustness, validity, maturity etc.) and the costs (option 2).

3.2 Physical characterization of macro-plastics

Option 1: Categorization of selected core (major) items on the UNEP guideline-based survey list regarding situation of different compartment (shoreline, sea surface, seafloor, and biota) or region/nation specific items is recommended.

Option 2: Categorization of full items on the UNEP guideline-based survey list regarding situation of different compartment (shoreline, sea surface, seafloor, and biota) or region/nation specific items is recommended.

It is further recommended to record additional information:

1) *label (brand name, barcode, address, and production country) to infer origin;*
2) *functional characteristics of fishing nets (knot types) to infer origin of fishing industry; and*
3) *other physical characteristics to provide specific information.*

3.3 Physico-chemical characterization of microplastics

Option 1: It is recommended to identify mesoplastics (5 - 25 mm) and large microplastics (~0.3 - 5 mm) by visual identification (naked eyes, magnifying glass and stereomicroscopy) and to record shape, size and colour. Additional physical observation with probing particle with tweezers, a hot needle, and solvent dissolution assay provide confirmation whether the particles are plastic or not.

Option 2: It is recommended to characterize large microplastics (0.3-5 mm) by microscopy, and subsequently at least sub-set samples should be confirmed by spectroscopy. In case of small microplastics (0.02-0.3 mm), it is recommended to identify every plastic-like particle by spectroscopy or alternative novel methods, such as staining with Nile Red (Shim *et al.* 2016[16], Maes *et al.* 2017[17]).

It is recommended to record basic physical information (e.g. shape, size and colour) and polymer type (e.g. PE, PP, PS etc.). Further categorization/classification of microplastics by physical characteristic (e.g. blue fibre, red fragment, and microbeads) is recommended.

Quality assurance and quality control procedures should be strictly applied from plastic sampling in the field to instrumental analysis in the laboratory.

16 Shim, W. J., Y. K. Song, S. H. Hong and M. Jang (2016). Identification and quantification of microplastics using Nile Red staining. Marine Pollution Bulletin, 113(1): 469-476: https://www.ncbi.nlm.nih.gov/pubmed/28340965
17 Maes, T., R. Jessop, N. Wellner, K. Haupt and A. G. Mayes (2017). *A rapid-screening approach to detect and quantify microplastics based on fluorescent tagging with Nile Red*. Scientific Reports, 7(1): 44501: https://www.ncbi.nlm.nih.gov/pubmed/28300146

3.4 Analysis of chemicals associated with plastics

The monitoring of chemicals associated with plastic litter will provide a better understanding of the relative contribution of plastic ingestion to the total chemical exposure of organisms as well as humans. Methods for chemical contaminant monitoring of a variety of compartments (shoreline, sea surface, seafloor, and biota) are well established[18]. Quality assurance and quality control procedures should be strictly applied from plastic sampling in the field to instrumental analysis in the laboratory.

Recommended options for chemical analysis

Option 1 – simple: Analyse shoreline resin pellets, or plastic fragments of the same shape, colour and polymer, for at least one sorbed chemical (e.g. PCBs) and one additive chemical (e.g. BDE209).

Option 2 – more comprehensive: Analyse plastic litter categorized based on size (e.g. 1 mm – 5 mm and >5 mm), shape (e.g. fragment, pellet, fibre, and foam), colour (e.g. pigmented, gray, non-pigmented yellowed, white), polymer type (e.g. PE, PP, PS, PET, PVC), and weathering status (e.g. fresh vs. aged). It is recommended to target chemicals of concern including both sorbed (e.g. PCBs, DDTs, HCHs, and PAHs) and additive chemicals (e.g. PBDEs, HBCDs, Phthalates, and UV stabilizers).

3.5 Biological characterization

Biological characterization of macro-litter can be conducted using the identification of attached epibiota, including, for example, Gooseneck barnacles, or be focused on identification of potential invasive species.

Identification of microorganisms on both micro and macro plastic items is expensive and requires advanced methods. Therefore this is not recommended for basic monitoring and more suited to scientific investigations.

18 OSPAR Assessments Contaminants: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/contaminants/

Future steps to improve monitoring and assessment.

SDG 14.1.1 indicator development

A key intention of the guidelines is to support the further development of the marine litter monitoring framework under SDG 14.1.1. This includes the selection of sub-indicators related to the source (or attribution), the environmental state and the impacts of marine litter. Using more harmonised methods will encourage the development and implementation of regional or global monitoring programmes, and facilitate the exchange of monitoring results. In doing so it is expected that it will be possible to move SDG 14.1.1 from tier three to tier two.

Regional Seas Programmes and action plans have actively been involved in the development of harmonised methodologies for monitoring and have been involved in the review of the guidelines. In addition, the guidelines will be considered by the Open-ended ad hoc expert group on marine litter, under the UN Environment Assembly (UNEA) process.

Data management

The greater harmonisation of sampling protocols and reporting will help to reduce barriers to data sharing and support the development of effective global data management, linked to existing regional and global platforms where possible. For example, at a regional scale the European Commission has developed the European Marine Observation and Data Network (EMODnet)[19], a system designed to collect, harmonise and share a wide range of marine environmental data in partnership with those Regional Seas covering the NE Atlantic (OSPAR), Baltic (HELCOM), Mediterranean (UN Environment MAP) and the Black Sea (Black Sea Commission). Recently, EMODnet has been extended to include data on marine litter, specifically from the shoreline, seafloor (trawl surveys) and sea surface (microplastics).

At a global scale, the Deep-sea Debris Database was launched in March 2017 to allow public access to seafloor images collected since 1983. The database is managed by the Global Oceanographic Data Center (GODAC) of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC)[20]. It contains data from multiple sources from the North and South Pacific, Indian, North and South Atlantic Oceans. The deepest record was of a plastic bag found at 10898 m in the Mariana Trench.

A key priority will be to ensure the inter-operability of different databases, to ensure that disseminated data storage and management is not a barrier to data exchange and integrated regional and global monitoring.

Towards more effective monitoring programmes

The guidelines are based on sampling and analysis methods that are generally accepted, and that are commonly available at least in relatively well-resourced institutions. They are not intended for research purposes. They have been based on techniques developed for investigating natural features of the environment, such as the

19 The European Marine Observation and Data Network (EMODnet): www.emodnet.eu
20 Chiba *et al.* 2018. Human footprint in the abyss: 30 years of deep-sea plastic debris. Marine Policy, 96, 202-212: https://doi.org/10.1016/j.marpol.2018.03.022

abundance of zooplankton using towed nets (floating microplastics) or fish stock assessment using bottom trawls (seafloor macro-litter). Both techniques under-sample smaller size categories of litter. This means that estimates of litter abundance based on these methods will be subject to a consistent bias. There may be an advantage to improving how we capture a more representative sample of the actual size range of marine litter present in the environment. However, this will also present a challenge when comparing spatial or temporal trends of marine litter that were obtained using different sampling methods.

A common challenge is to account for the inherent heterogeneity of marine litter distributions, resulting in variations of abundance that may exceed a factor of 10 at any one 'site'. This needs to be addressed as part of the overall sampling strategy. In future, increasing automation of sampling and sample analysis may allow a greater throughput of material and reduce some of the uncertainty in the measurements. The UN Decade of the Ocean presents an opportunity to collaborate with the wider ocean science community, to develop a more effective, more reliable and more cost-effective global monitoring framework to address this pressing issue.

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