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Review

Marine litter within the European Marine Strategy Framework Directive

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There have been numerous anthropogenic-driven changes to our planet in the last half-century. One of the most evident changes is the ubiquity and abundance of litter in the marine environment. The EU Marine Strategy Framework Directive (MSFD, 2008/56/EC) establishes a framework within which EU Member States shall take action to achieve or maintain good environmental status (GES) of their marine waters by 2020. GES is based on 11 qualitative descriptors as listed in Annex I of the MSFD. Descriptor 10 (D 10) concerns marine litter. As a follow-up to the related Commission Decision on criteria and methodological standards (2010/477/EU) in which 56 indicators for the achievement of GES are proposed, the EC Directorate-General for the Environment, on the request of the European Marine Directors, established a Technical Subgroup on Marine Litter (TSG ML) under the Working Group on GES. The role of TSG ML is to support Member States through providing scientific and technical background for the implementation of MSFD requirements with regard to D 10. Started in 2011, TSG ML provides technical recommendations for the implementation of the MSFD requirements for marine litter. It summarizes the available information on monitoring approaches and considers how GES and environmental targets could be defined with the aim of preventing further inputs of litter to, and reducing its total amount in, the marine environment. It also identifies research needs, priorities and strategies in support of the implementation of D 10. The work of TSG ML also focuses on the specification of monitoring methods through the development of monitoring protocols for litter in the different marine compartments, and for microplastics and litter in biota. Further consideration is being given to monitoring strategies in general and associated costs. Other priorities include the identification of sources of marine litter and a better understanding of the harm caused by marine litter.

Keywords: Descriptor 10, harm, litter, marine debris, marine litter, Marine Strategy Framework Directive, monitoring, MSFD, research, sources, targets.

Introduction

It is widely recognized that pressures and demands on marine resources are often excessive, and that action must be taken in order to minimize negative impacts on the marine environment (Barnes and Metcalf, 2010). Therefore the European Commission developed the Marine Strategy Framework Directive (MSFD) for the protection and sustainable use of marine ecosystems. The MSFD builds on sector-based approaches such as the Common Fisheries Policy, Natura 2000, and the Nitrates Directive. It is the environmental pillar of the Integrated Maritime Policy for the European Union, which aims at sustainable growth of maritime sectors (Markus *et al.*, 2011). The MSFD establishes a framework within which Member States must take action to achieve or maintain Good Environmental Status (GES) for the marine environment by 2020. It explicitly refers to the management of human activities, recognizing that the "environmental status" also includes the effects of human activities. From mid 2012 to 2016 EU Member States have to take six procedural steps to develop a marine strategy for their waters: (i) an initial assessment of the current environmental status (Article 8, 2012), (ii) the determination of good environmental status (Article 9, 2012), (iii) the establishment of a comprehensive set of environmental targets and associated indicators [Article 10(1), 2012], (iv) the establishment and implementation of a monitoring programme for ongoing assessment and regular updating of targets [Article 11(1), 2014], (v) the development of a programme of measures designed to achieve or maintain good environmental status [Article 13(1–3), 2015], and (vi) the entry into operation of the programme of measures [Article 13(10), 2016].

With reference to the initial assessment, EU Member States shall determine a set of characteristics that define GES of their relevant waters, taking into account the indicative lists of "pressures" and "impacts" elements of Annex III of the Directive. The characteristics are to be determined based upon the list of 11 qualitative descriptors in Annex I and by reference to Commission Decision 2010/477/EU on "Criteria and methodological standards on good environmental status of marine waters", which proposes 56 indicators for the 11 descriptors. This approach aims at the use of consistent criteria and methodologies across the European Union (EU) and at a meaningful harmonization between different regions of the extent to which GES is being achieved. The MSFD recognizes that the conceptualization of GES is not a one-time matter but will continue to evolve and be adaptive, due to dynamic factors such as ecosystem changes, new scientific knowledge and the development of new technological capabilities (Juda, 2010). Periodic assessments of the state of the marine environment, monitoring, and the formulation of environmental targets are perceived as part of the continuous management process. Accordingly, provisions are made for the modification of adopted marine strategies and measures.

Human pressures on the oceans have increased substantially in recent decades. The expansion of coastal and marine activities has adversely affected the marine environment as well as ecosystem goods and services. In addition, coastal and marine human activities generate considerable quantities of waste, which has the potential to contaminate the marine environment. Much of this litter will persist in the sea for years, decades or even centuries. On average three-quarters of all marine litter consists of plastics that are known to be particularly persistent. The occurrence of litter has been demonstrated worldwide: in oceanic gyres, on shorelines, in sediments and in the deep sea. Litter is accumulating in densely populated areas and remote regions such as the Antarctic alike (Barnes *et al.*, 2009).

Of the 11 descriptors listed in Annex I of the MSFD for determining GES, Descriptor 10 has been defined as "Properties and quantities of marine litter do not cause harm to the coastal and marine environment".

Commission Decision 2010/477/EU identifies the following criteria and associated four indicators for Descriptor 10.

Criteria 10.1 Characteristics of litter in the marine and coastal environment

(i) trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source (10.1.1)

(ii) trends in the amount of litter in the water column (including floating at the surface) and deposited on the sea-floor, including analysis of its composition, spatial distribution and, where possible, source (10.1.2)

(iii) trends in the amount, distribution and, where possible, composition of microparticles (in particular microplastics) (10.1.3)

Criteria 10.2 Impacts of litter on marine life

(iv) trends in the amount and composition of litter ingested by marine animals (e.g. stomach analysis) (10.2.1)

As a follow-up to the Commission Decision 2010/477/EU, the European Marine Directors requested the Directorate-General for the Environment (DG ENV) of the European Commission in 2010 to establish a technical subgroup under the Working Group on GES (WG GES) for the implementation of MSFD Descriptor 10.

Based on the definition from UNEP (Cheshire *et al.*, 2009), the group defined marine litter as any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment. Litter consists of items that have been made or used by people and deliberately discarded or unintentionally lost into the sea or on beaches, including such materials transported into the marine environment from land by rivers, draining or sewage systems, or winds.

The initial mandate for the Technical Subgroup on Marine Litter (TSG ML) was drafted by DG ENV, discussed by WG GES and approved by the EU Marine Directors for the year 2011. IFREMER (France), UBA (Germany) and the Joint Research Centre (JRC) chair the work of this group. The group's mandate contained the following work items: (i) identify and review existing data and ongoing data collection on marine litter; (ii) describe data needs and methods for future assessment of marine litter; (iii) consider standards for recording of marine litter; (iv) develop proposals for the development of impact indicators for each of the regions; (v) address how to develop objectives (characteristics of GES), environmental targets and associated indicators in relation to marine litter; (vi) discuss effectiveness of measures leading to reductions in marine litter; and (vii) recommend proposals for further research priorities. The work of the group resulted in a report published in the JRC scientific and technical reports series in 2011: "Marine Litter. Technical Recommendations for the Implementation of MSFD Requirements" (Galgani *et al.*, 2011). The report identifies and presents 15 options (the so-called toolbox) for the monitoring of litter in the different marine compartments and the biological impact of the ingested litter or microlitter. It furthermore contains considerations about sources, GES, objectives, environmental targets and research needs, as well as a roadmap for further tasks in 2012 and 2013. This roadmap, including a detailed work programme, was agreed upon by EU Marine Directors in order to further support the implementation of monitoring programmes under the MSFD. It includes the development of monitoring protocols and additional recommendations on (i) general monitoring strategies and associated costs, (ii) sources, and (iii) the understanding of harm. (See http://publications.jrc.ec.europa.eu/repository/handle/111111111/22826).

Despite previously existing actions against litter (Port Reception Facilities, Fishing for Litter; International Coastal Cleanups, No-Special-Fee; Adopt-a-Beach; Blue Flag, etc.), current knowledge of the quantities of litter in European seas, the degradation and fate of litter in the marine environment and its potentially harmful biological, physical and chemical impacts on marine life and habitats is insufficient. Methods of monitoring marine litter, and our understanding of the sociological factors that underpin behavioural change in relation to littering, are also inadequate. Hence, evaluation and regulation of the sources of marine litter alone will not be sufficient to achieve Good Environmental Status.

Marine litter

What started as an aesthetic problem, is now giving concern about the various potentially harmful implications of marine litter on the marine environment.

The majority of reported litter-related incidents of individual marine organisms are related to plastic items. In terms of plastic litter-type or use, in year 2012, rope and netting accounted for 57% of encounters, followed by fragments (11%), packaging (10%), other fishing-related litter (8%) and microplastics (6%) (CBD, 2012). Encounters with marine litter were reported for 663 species (CBD, 2012). Over half of the reported species (about 370) were associated with entanglement in and ingestion of marine debris, representing an increase of more than 40% since the last review in 1997, when 247 species were reported affected by those two impact categories (Laist, 1997).

The entanglement of species in marine litter, often as a result of their normal behavioural patterns, has frequently been described as a serious mortality factor leading to potential losses in biodiversity. Among the most problematic marine litter is derelict or discarded fishing gear (nets, traps and pots), which may continue to "fish" for years, a process that has been termed "ghost" fishing. It is estimated that 10% of all litter entering the oceans annually consists of so-called ghost nets (Macfadyen *et al.*, 2009). However, it is assumed that large numbers of losses remain unreported (UNEP, 2009). Entanglement in marine debris has been reported for pinniped species, cetaceans, all seven species of marine turtles, and more than 56 species of marine and coastal birds (Katsanevakis *et al.*, 2007). The decline of deep-water sharks in the North Atlantic has been linked to ghost fishing in the region (Large *et al.*, 2009).

At least 43% of existing cetacean species, all species of marine turtles, approximately 44% of the world's seabird species, and many species of fish have been reported to ingest marine litter, either because of misidentification of debris items as natural prey or accidentally during feeding and normal behaviour (Katsanevakis, 2008; Gregory, 2009; CBD, 2012). More recently, commercially important invertebrates have been found to have ingested plastics (Murray and Cowie, 2011). For some species, a considerable proportion of the population is affected by interactions with litter that affects their body condition, ability to forage and reproduce, and may ultimately lead to mortality (van Franeker *et al.*, 2011).

An emerging area of concern is the accumulation of microplastic fragments in the water column and in sediments (Thompson *et al.*, 2004). Pieces of common polymers (including polyester, nylon, polyethylene and polypropylene) of less than 20 μm have been recorded in the marine environment worldwide (Barnes *et al.*, 2009). Plastics are biologically inert. They degrade to tiny particles that probably stay in the marine environment for long periods. Because of their size they are available to a wide range of organisms including deposit feeders, filter feeders and scavengers (Thompson *et al.*, 2004). If ingested, plastics release chemicals (such as nonylphenols, polybrominated diphenyl ethers, phthalates or bisphenol A) but also sorb hydrophobic pollutants (including PCBs and DDT). These may be transferred to organisms and there is concern about subsequent adverse effects (Mato *et al.*, 2001; Teuten *et al.*, 2009). Ingestion of microplastic material, therefore, presents a route by which chemicals could pass from plastics into the food chain. More research is needed to establish the full environmental relevance and potential impact of these microparticles, notably on distribution, transport, degradation/weathering processes and sorption/release mechanisms.

In its ecological sense, the "level of litter that causes effects on the environment" depends on the type and quantity of litter being measured and the environmental or ecosystem components being affected. In contrast, the effect of microplastic particles resulting from e.g. the degradation of fishing nets, will remain for decades or centuries in the sea, and may affect a range of species through mechanical and chemical consequences of ingestion.

Other known impacts of marine litter include alteration, damage and degradation of benthic habitats (Katsanevakis *et al.*, 2007) such as coral reef and soft sediment abrasion from derelict fishing gear or smothering from macro- and microplastics on sandy sediments in the intertidal zones (Katsanevakis *et al.*, 2007). Litter can disrupt the assemblages of organisms living on or in the sediment. Microplastics and litter fragments on beaches have been reported to alter the porosity of the sediment and its heat transfer capacity. Furthermore, marine litter items can assist invasions of alien species, including of algae associated with red tides (Barnes, 2002; Barnes and Milner, 2005).

From a socio-economic perspective, harm can [0]include the cost of degradation of ecosystem goods and services. Social harm includes the reduction in recreational, aesthetic or educational values of an area such as beaches, as well as risks to human health such as the threat of floating objects to navigation. Economic harm includes significant impact by direct costs and loss of income due to marine litter and affects a range of maritime sectors (including aquaculture, agriculture, fisheries, shipping and leisure boating), power generation and industrial use, local authorities and tourism. Levels of economic "harm" may run into millions of euro annually even at subregional scales (Mouat *et al.*, 2010).

Marine litter is also a serious offence to the visual and aesthetic sensitivities of tourists and local visitors to beaches. Furthermore, sanitary, sewage-related and medical waste may cause injuries and/or be a risk to human health (Ivar do Sul and Costa, 2007). Where livelihood and health of local coastal communities are affected, environmental issues caused by marine debris can have wider social impacts (Tinch *et al.*, 2012). In relation to MSFD Descriptor 10 and what constitutes harm in a socio-economic sense, this has yet to be defined for marine litter.

There is no consolidated common understanding of what exactly constitutes "harm" from marine litter or how it can be assessed with respect to the implementation of the MSFD. Research must consider and assess the available evidence base and attempt to develop a consensus on how to approach the issue. Research efforts to develop robust approaches for assessing harm will have to be identified and facilitated, where possible, and the outputs considered by the TSG ML. There are some potential environmental impacts arising from marine litter that are not currently being considered enough due to a lack of monitoring or uncertainty over how best to approach the issue, e.g. how to assess levels of entanglement or ingestion of litter by species such as fish. Identification of potential gaps in our understanding and development of proposals for pilot monitoring schemes to address such gaps in a coordinated manner is crucial before advice can be given on whether robust monitoring tools and protocols can be realistically and cost-effectively implemented.

As litter can originate from numerous sources, measures to reduce pollution from litter need to target these different sources. Identifying the source of many litter items is a complex task as marine litter enters the ocean from both land- and sea-based point and diffuse sources and can travel long distances before being deposited onto shorelines or settling on the bottom of the ocean, sea or bay. Litter from land-based activities and resulting from poor waste management enters the marine environment via drainage or sewage systems, drains, rivers, winds, road run-offs and storm-water outflows. Land-based sources include tourism and recreational uses of the coast, general public, fly tipping, local businesses, industry, harbours and unprotected waste disposal sites. Sea-based sources of marine litter include merchant shipping, ferries and cruise liners, commercial and recreational fishing vessels, military fleets and research vessels, pleasure craft, offshore installations such as oil and gas platforms, drilling rigs and aquaculture sites. Factors such as ocean current patterns, winds and tides, and the proximity to urban centres, industrial and recreational areas, shipping lanes, and fishing grounds also influence the types, nature and amount of litter that is found in the open sea or collected along beaches, waterways or underwater.

Sources of marine litter can be characterized in several ways. One common method is to classify sources as either land-based or sea-based, depending on how the litter enters marine waters. These broad categories can be further broken down into sources such as recreational litter, shipping litter and fishing litter. Some items can be attributed with a high level of confidence to certain sources such as some fishing items, sewage-related debris (SRD) and some tourist-related litter. Such so-called use categories provide valuable information for setting targets and reduction measures, as they can easily be linked to measures. Whilst the production or the geographical source of litter can also be identified, this information is of less use for implementing effective measures and targets than use categories given the increasing globalization of markets. Information on the sources of the litter can be obtained from monitoring beaches, the sea surface or sea floor, and a common approach to categorizing litter in the different marine compartments is needed.

For the Mediterranean Sea, PNUE/PAM/MEDPOL (2009) reported that most of the marine litter comes from land-based rather than sea-based sources (e.g. ships). Litter enters the sea mainly from the shoreline and results from recreational activities. It is composed mainly of plastics, aluminium and glass. Recordings of floating litter confirmed the overwhelming presence of plastics in the Mediterranean Sea. Plastic accounts for about 83% of the observed marine litter items. In some tourist areas more than 75% of the annual waste production is generated in the summer season. The situation in the North Sea is different. The large diversity of items found on the coasts of the North Sea and the composition of the litter recorded during the OSPAR Beach Litter monitoring programme indicate that in the North-East Atlantic, maritime activities in the form of shipping, fishing and offshore installations are the predominant sources together with coastal recreational and tourism activities (Fleet *et al.*, 2009; OSPAR, 2009). A considerable proportion of litter enters the North Sea through transport by wind, currents and rivers and via the English Channel. Plastics account for around 75% of litter items found in the North East Atlantic Sea.

The EC has commissioned pilot projects in the four regional seas (OSPAR, HELCOM, MEDPOL and Black Sea regions) to identify loopholes in the plastic cycle. The project results will provide input for a further analysis of sources and fate in the TSG Litter (see the final reports by ARCADIS, BIPRO and RPA at http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm).

Upcoming work will lead to a more precise understanding of waste pathways depending on the type of litter. Mapping the sources and their quantities remains a necessary step in order to plan effective measures. The reduction of litter inputs at sources (domestic, industrial, tourism, rivers, shipping, fishing and aquaculture activities) in national marine strategies will contribute to reaching GES for marine litter at a regional level. Although not all pathways of litter to the sea have yet been identified, it seems likely that some sources of litter will lie outside national jurisdiction and that the national GES cannot be achieved solely through national measures.

Monitoring

In order to have information on the geographic origins of coastal waste and thus to have a basis for the implementation of actions aimed at reducing litter pollution, it is necessary to make regular litter surveys and analyse the results in relation to local weather conditions and geomorphology of coasts. The existing different, but compatible, methods for monitoring need to be adapted and harmonized to take account of regional differences, e.g. in the type of coastline or prevailing currents in offshore areas.

Methodologies for source assessment are mostly based on the identification and reporting of collected/observed marine litter. Due to the difference in the monitoring approaches, the possibilities for identifying the nature (category) of objects vary between the different environmental compartments. TSG ML recommended that the categories for reporting should be compatible between different survey types (beaches, sea surface, sea floor) so that outcomes are comparable. Reporting of marine litter for source attribution needs still further development as the efficiency of measures targeting specific litter sources requires the distinction of the nature/categories of litter in the different environmental compartments.

The 2011 TSG ML report and other forums in the context of MSFD implementation provide guidelines for existing approaches. These are summarized in Table 1 (after Galgani *et al.*, 2010; Galgani *et al.*, 2011).

Litter will persist in the sea for years, decades and centuries. Therefore, the assessment of sources alone will not be enough, and long-term monitoring in the marine environment will be required to understand trends. When planning monitoring schemes, consideration should be given to adequate spatial and temporal scales. Beach-litter surveys, sea-floor monitoring on continental shelves and socio-economic studies can be readily applied at a European scale, but priority should be given to the monitoring of marine areas that are most affected by litter. Methodological protocols in Europe are currently available for the assessment of certain types and occurrences of litter on coastlines (OSPAR, 2009). These standards should be adjusted to MSFD needs and harmonized for an extension to other regions. Pilot projects have also indicated that litter on the sea floor could be measured alongside routine biological trawling surveys (e.g. International Bottom Trawl Surveys in the OSPAR area, Mediterranean International Trawl surveys in the MEDPOL area) and could include an evaluation of sources. Larger parts of floating litter can be quantified by aerial observation and image recognition systems, whereas floating microlitter can be monitored by using townets or filtered water samples. In the framework of the OSPAR Convention, amounts of plastics in Fulmar stomachs are used to assess temporal trends, local differences and compliance with a set target for acceptable pressure in the North Sea (van Franeker *et al.*, 2011). Such monitoring could be extended to other marine Regions using region-specific indicator species, such as turtles for the Mediterranean Sea. Further work of TSG ML to support the monitoring of marine litter will have to focus on (i) developing common monitoring protocols, including advice on the strategies which could be adopted to ensure

Table 1. Summary of approaches for assessing GES with regards to marine Litter (after Galgani *et al.*, 2010 and 2011).

Compartment	Approaches	Positive aspects	Poorly covered and negative aspects
Coastline	Counts of the amount of litter items on known stretches of coast.	Allows for assessment of composition, amounts, sources, trends, social harm (aesthetic, economic).	Very small items and microparticles in sediments are not quantified. Not all coasts are accessible or appropriate.
Sea surface	Ship observers.	Precise evaluation at local scale.	Depending on weather. Not at large scale, small debris not considered, strong temporal variation.
Sea surface and water column	Trawling and water filtration.	Precise evaluation at local scale, consider smaller debris.	Costs, strong temporal variation.
Sea surface	Aerial counts of the number of litter items floating on the sea surface along transects.	Assessment of densities of litter on water surface over large areas possible; correlation with shipping or fisheries activities.	Smaller items not covered. Only counts of items from TetraPak size upwards are possible.
Sea floor shallow	Visual survey with divers.	All substrate types, replicability, feasible to account for detectability.	Depth limitation (<40 m).
Sea floor, deep sea litter	Trawling.	Replicability, possible standardization.	Only where trawling is possible.
Sea floor, deep sea litter	Submersibles and remote operated vehicles.	All sites accessible.	Only small areas, costs.
Entanglement rates of marine organisms	Entanglement rates in birds found on the coastline.	Can be carried out as part of existing surveys.	Standard protocol would need to be developed and implemented.
OSPAR Fulmar Plastic Ecological Quality Objective (EcoQO)	Mass of plastic in stomachs of beached seabirds (Fulmars).	Operational and tested in North sea. Applicable everywhere in most of OSPAR area.	Focuses on surface litter in offshore habitats; not yet operational in all EU regions: need further developing.
Ingestion by other marine organisms	Abundance of plastic by mass.	Potentially similar to Fulmar EcoQO approach.	Need to be developed and tested.
Microplastic on shorelines	Extraction of fragments from sediment samples and subsequent identification using FT_IR spectroscopy.	Positive identification of specific polymers.	Analysis is time-consuming and is unlikely to detect all of the microparticles. This is especially true for very small fragments (<100 μm).
Microplastic at sea surface	Manta trawl (330 μm) and subsequent identification using FT_IR spectroscopy.	Positive identification of specific polymers.	Analysis is time-consuming and is unable to detect all of the microparticles.
Socio-economic	Assessment of direct costs through survey-based methods.	Provides indication of economic burden on marine and coastal sectors.	Does not capture full impact of degradation of ecosystem goods and services due to marine litter.

comparability of monitoring programs; (ii) facilitating the implementation of fit for purpose monitoring programmes, advising on potential common monitoring tools, identifying opportunities to improve comparability, ensuring appropriate quality assurance and control of data is in place etc.; (iii) evaluating new monitoring tools, considering promising monitoring tools as they are being developed, providing advice on their suitability for meeting EU Member States' monitoring and assessment needs; (iv) estimating the costs for the implementation of the monitoring tools in order that EU Member States can make informed choices about appropriate monitoring tools; and (v) developing standardized litter categories, working closely with the Regional Seas Conventions to align the categories of marine litter currently reported in order to improve comparability across Member States.

The evaluation of waste flows between the different compartments of the marine environment is a necessary step and goal for understanding the mechanisms of transport, fluxes and potential impacts. Figure 1 shows a diagram of the fate of litter, summarizing the relationship between different habitats, the different biological entities, and major interactions. Fluxes will still have to be evaluated in terms of quantities and nature/composition of litter for each type of debris.

Finally, understanding the transport mechanisms will help to clarify transformation and provide a better description of the

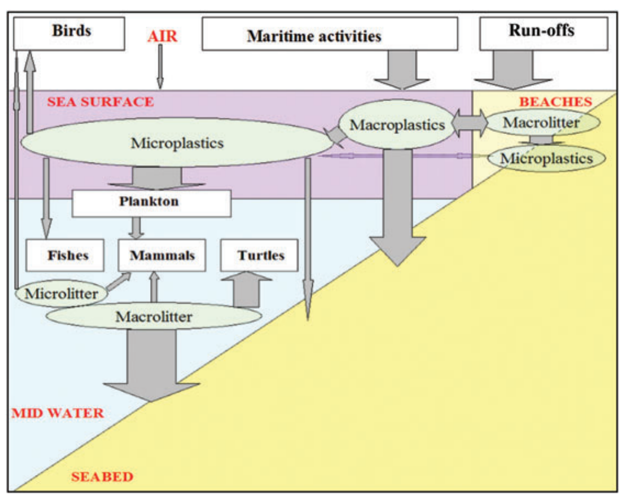

Figure 1. A schematic cycle of litter at sea.

spatial distribution of marine litter. The accumulation of litter on the seabed, the rate of its degradation at sea, the kinetics of chemicals sorption/desorption, and the rate of litter being ingested by the different marine organisms are all poorly understood mechanisms.

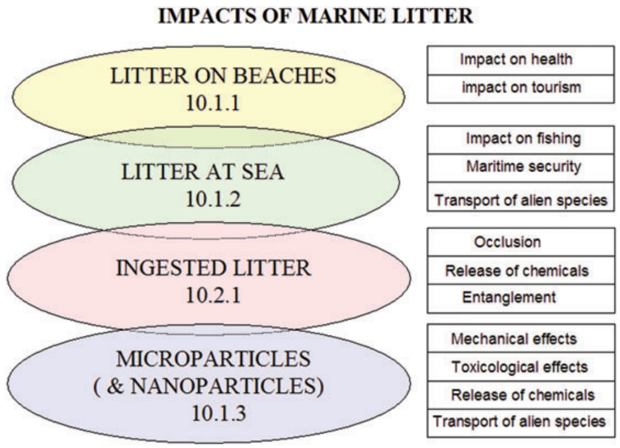

Figure 2. Major impacts of marine litter and related MSFD indicators. Other impacts such as entanglement in pelagic species, transport of alien species to beaches etc. could be important in specific cases.

The gaps in knowledge are a constraint in identifying targeted and effective measures to reduce litter pollution.

The abundance of litter at sea can be estimated either by direct observations of large debris items (e.g. submersible remote observation vehicles (ROVs) for monitoring litter on the seabed, or ship-based and aerial observations for debris floating at the sea surface) or by large-scale imagery application (Hanke and Piha, 2011) and net trawls (for smaller items). Net-based evaluation surveys are the most widespread and adequate methods to date (Goldberg 1994; Galgani and Andral, 1998).

General protocols for investigating debris on the seabed are similar to the methodology for monitoring the benthic species. More emphasis should be given to the number and the nature/category (e.g. bags, bottles, pieces of plastics) of litter items rather than their mass. The interpretation of trends is difficult because the fate of plastics at depth is not well researched, and the accumulation of plastics on the seabed had begun long before specific scientific investigations started in the 1990s. Of the areas investigated to date along the European coasts (Galgani *et al.*, 2000), Mediterranean sites tend to show the greatest densities of litter accumulation. Debris, mainly plastic, that reaches the seabed may have been transported a considerable distance from its source, only sinking to the ground when weighed down by fouling. The consequence is an accumulation of plastic debris in bays and canyons rather than in the open sea (Galgani *et al.*, 1996; Katsanevakis *et al.*, 2007). However, due to large-scale residual ocean circulation patterns, some accumulation zones in the Atlantic Ocean and the Mediterranean Sea have very high debris densities despite being far from coasts (Galgani and Lecornu, 2004).

We know little about the trends in accumulation of debris at sea, but available data indicate considerable variability. Abundances slightly decreased in the Gulf of Lion (France) during a 15-year period (1994–2009). However, in some areas around Greece the abundance of debris at depth has increased over a period of 8 years (Koutsodendris *et al.*, 2008). Debris is progressively fragmented in the marine environment (Thompson *et al.*, 2004) to microparticles (<5 mm, Arthur *et al.*, 2009). There is considerable concern about the accumulation of microscopic pieces of plastic ("microplastic") due to their high prevalence at sea and the slow rate of their chemical and biological degradation. This includes also the spillage of pre-production (resin pellets) plastics (Ryan *et al.*, 2009), granules e.g. from cosmetic products, and fibres from washing machines. Those granules and fibres may originate from discharges of sewage treatment plants (Liebezeit and Dubaish, 2012). The prevalence of small pieces and granules (<5 mm in diameter) varies considerably between areas. At most locations current quantities appear to be relatively low. However, plastic microparticles have been reported in quantities exceeding 100 000 items km^{-2} (Thompson *et al.*, 2009) in the North Sea. Similar quantities of debris have been reported in the northwest Mediterranean Sea (Collignon *et al.*, 2012) where 115 000 items km^{-2} were calculated, giving an extrapolated total of 250 billion items in the whole basin.

In a number of reports, the Ecological Quality Objective (EcoQO) for litter in fulmar stomachs in the OSPAR framework proved able to provide valuable information on the temporal changes in, and the spatial distribution of, the abundance of marine litter, on the differences between trends in industrial and user plastics, and on the sources of marine litter (van Franeker *et al.*, 2011). The EcoQO currently applies to the North Sea, but can be adapted to apply in most areas of the Northeast Atlantic. Pilot studies for biomonitoring of litter should also consider other species, especially marine turtles that are regularly stranded in the Mediterranean region and which often contain fatal quantities of ingested litter. Monitoring does exist in some Mediterranean countries and could provide a framework for the evaluation of litter ingestion, following harmonization of monitoring methodologies. Fish, zooplankton species, shellfish and seals may be considered in the future as generally applicable target species for most European seas or as target species for one or more of the (sub) regions listed in the MSFD.

Determination of good environmental status

One of the key challenges for EU Member States in implementing the MSFD is to determine "good environmental status". Whilst the term is defined in the Directive (Article 3(5) MSFD), GES will have different meanings in the EU marine regions or subregions, and is therefore open to interpretation (Barnes and Metcalf, 2010). The MSFD requires a holistic assessment of the impacts of anthropogenic pressures on the components of the marine ecosystem. For marine litter, more than one indicator will be required to assess GES in relation to the different compartments of the marine environment and the different aspects of litter pollution. Metrics are not yet available for evaluating most of the biological impacts that litter may have (Figure 2). In their absence, the thresholds may be replaced by trends in pressure-related indicators, such as the amount of litter on the sea floor or on beaches, to provide proxies for evaluating progress towards GES.

As stated above, "harm" caused by marine litter can be divided into three general categories: (i) social harm, i.e. loss in aesthetic value and public health; (ii) economic harm, such as the cost to tourism, damage to vessels (net and ropes in propellers) and fishing gear and facilities and cleaning costs; and (iii) ecological harm e.g. mortality of, or sublethal effects on, animals through entanglement by e.g. ghost nets, derelict traps, pots or other fishing gear, or harm resulting from ingestion of litter, including the uptake of microparticles (mainly microplastics).

Building upon the MSFD-definition of GES for Descriptor 10 quoted above, GES could be regarded as achieved when litter and its degradation products present in and entering EU marine waters (i) do not cause harm to marine life and habitats; (ii) do not pose direct or indirect risks to human health, and (iii) do not lead to negative socio-economic impacts.

At a national level, EU Member States may consider additional priorities in the evaluation of GES. With the exception of Descriptor 9 on the contamination of seafood, Descriptor 10 is particularly related to human health (such as the risk for beach visitors and swimmers to be cut on sharp litter items, and for divers to get entangled with litter items) and to socioeconomic interests (such as costs for cleaning of beaches and fishing nets, or risks of entanglement of ship propellers). The use of trend indicators as listed in the Commission Decision (10.1.1; 10.1.2; 10.1.3), aimed to observe and assess trends in litter occurrence in the different marine compartments, will help to predict both health and socio-economic consequences.

It is not generally feasible for assessments to provide information on the extent of harm at the population, community or ecosystem level and it is actually unlikely that we can develop an assessment procedure that can show effects at a population or ecosystem level. It is thus essential to consider harm at the level of the individual organism. Estimates of the number of individuals affected are likely to offer the most feasible and representative conclusions about biological impacts. Following the example of the OSPAR EcoQ for plastic litter items in fulmar stomachs in the North Sea region, additional indicator species must be found for the other EU marine regions (such as sea turtles for the Mediterranean Sea), and additional indicators on ecological impacts of litter (e.g. on entanglements) may be required by reference to Commission Decision 2010/477/EU. While litter has the potential to aid the transport and introduction of non-indigenous species, this impact is not suggested for assessment by a specific indicator under Commission Decision 2010/477/EU.

Defining targets

Reaching GES may be understood as a continuous reduction of inputs with the aim of reducing the total amount of marine litter by 2020 to a level that does not cause harm to the coastal and marine environment. Activities to remove litter that has already entered the marine environment will assist in reaching this goal, but some important points have to be considered.

One of the difficulties in target setting for some marine regions is the lack of data for developing a baseline. In order to achieve this, a classification according to the potential harm to different species and habitats for different litter categories based on materials (such as plastics, glass, metal, etc.) and use (e.g. nylon nets, plastics from households and industry, sanitary items) needs to be carried out. So-called use-categories provide the most valuable information for setting targets and reduction measures.

Any assessment of marine litter should consider short-term variations caused by meteorological and/or hydrodynamic events and seasonal fluctuations, which could influence our ability to detect underlying trends. Given the variability of litter data, which is influenced greatly by season, weather conditions and water currents, a five-year running mean is considered appropriate for providing a baseline in terms of an average level of pollution. However, the reduction in litter inputs may not lead to a measurable reduction of total litter levels in the marine environment in the short term. This is due to the persistence of some materials the time-scales and the long degradation time of many litter categories (plastics, metal, glass and rubber). Time-scales of observations should therefore be adapted to ensure multiannual frequency of surveying.

Finally, the aggregation of data for the evaluation at subregional or even regional scale will be different for the various parameters being considered. For example beached litter surveys can be applied to the European spatial scale while deep-sea floor monitoring, restricted to a few areas, is more relevant at smaller scales and over longer periods.

Even though it is reasonable to say that plastics, as a major part of the problem of marine litter, are completely unnatural, it would not be reasonable to argue that the ultimate goal of the MSFD should be 0% of plastic in the marine environment. Targets for the different compartments of the marine environment need to be set by EU Member States on the basis of their national initial assessments according to Article 8 MSFD and depending on the initial level of pollution within the area considered. An appropriate target for clean areas would be the maintenance of this status and for areas assessed to have unacceptable levels of litter pollution to ultimately achieve clean area status.

The amount of litter present in the different marine compartments is, amongst other things, dependent on regional topography, including seabed topography and the prevailing currents, winds and tidal cycles. Increasing knowledge of the amount and dynamics of litter in the marine environment will help to determine whether targets need to be defined at the regional level in addition to targets set by individual EU Member States.

For litter on beaches, for which appropriate monitoring is already in place in some regions, it is proposed that the reduction goal recommended by TSG ML is adopted as a first step. This goal is to achieve a general measurable and statistically significant reduction in beach litter until 2020. Despite natural fluctuations (annual variability, effects of storms etc.) that may affect quantities washed ashore, and despite local applicability and technical feasibility (confidence, monitoring implications, spatial scale, etc.) as well as trends and inflicted harm, trend-based targets may be appropriate until the evidence supports other procedures. These may include quantification of the following potential targets currently under discussion: (i) [XX%] overall reduction in the number of visible (>2.5 cm) [new] litter items on coastlines by 2020 and, more specifically, (ii) XX% reduction in the number of plastic/fishing/sanitary litter items on coastlines by 2020.

Different protocols, though yet to be harmonized, enable the evaluation of litter floating on the sea surface, but selected areas for monitoring will need to be chosen. Litter on the seabed has been surveyed at a few sites in the EU and data are sparse, making assessment difficult. Consequently a trend target is being considered. Data would be derived from existing monitoring programmes or from programmes still to be extended in order to improve the temporal and spatial scale. Opportunistic sampling of litter on the seabed takes place together with on-going fish stock assessment and contaminant surveys (IBTS/ MEDITS programmes). Those monitoring programmes would support the application of, the following potential targets for marine litter: (i) overall reduction [XX%] in litter density in nationally defined affected areas of litter surface floating on the sea surface, and (ii) overall reduction (XX%) in litter density by 2020 on the seabed, as measured by trawl surveys, through diving in selected shallow waters and through litter harvested in fishing operations.

Microplastics are not currently measured on a regular basis, and no baseline is available. This means there is at present insufficient information available for most waters to set quantitative or qualitative targets. Before any target can be set, sufficient monitoring should be carried out and a baseline established. Sampling with a manta trawl or with filtration systems enable the assessment of microparticles at the sea surface or in the water column. Based on such monitoring, a potential target for the significant decrease of microparticles by 2020 could be formulated. The occurrence of microparticles in sediments should also be considered.

Recent studies on industrial plastics found in beached fulmars in the North Sea (van Franeker *et al.*, 2011) showed that reductions in abundance of specific marine litter items in the order of 50% per decade are a feasible target if adequate measures are taken. In order to prevent items ending up as marine litter, it is important to tackle the problem at the source. Operational targets set in relation to specific sources can help setting targeted measures to reduce the amount of litter entering or being present at sea. They can be set to assess the effectiveness of measures but cannot substitute for environmental targets.

OSPAR has defined its target for ecological pressure concerning litter in the North Sea that $<$ 10% of Northern Fulmars should be allowed to have $>$ 0.1g plastic in their stomach (undated target for the Greater North Sea). The OSPAR EcoQO cannot be directly transferred to other marine areas where fulmars do not occur. To monitor ingestion of litter in other EU marine regions, appropriate indicator species still need to be established (e.g. sea turtles in the Mediterranean Sea). Similar to target setting for beach litter, it may be more suitable for the present to describe GES in relation to the ingestion of litter in terms of a trend, e.g. *x*% annual reduction in the quantity of ingested litter. It would then be important to quickly establish the reference value against which such reduction should be measured.

Further support for Member States

The MSFD definition of Good Environmental Status, the objectives to achieve or maintain GES by 2020, and related monitoring needs require a thorough understanding of the mechanisms and processes associated with litter at sea. This requires considerable research effort, seeking e.g. to clarify fundamental research gaps in order to link quantities of litter and associated harm in the context of GES; to define priorities; to improve the scientific and technical basis of monitoring; to harmonize and coordinate common and comparable monitoring approaches; and finally to support the development of guidelines for assessing GES.

An initial evaluation, jointly undertaken by EU Member States, on the current state of research in their region/subregion is underway with a view to providing a scientific and technical basis for monitoring of marine litter and defining knowledge gaps and priority areas for research. Harmonization will require the coordination of actions by a group of experts from EU Member States. Harmonization is necessary for common and comparable monitoring approaches and for recommendations and guidelines to assess GES at regional, national and European scales. Research will need to incorporate the improvement of knowledge concerning impacts of litter on marine life, degradation processes of litter at sea, the study of litter-related microparticles, the study of chemicals associated with litter, the factors influencing the distribution and densities of litter at sea (human factors, hydrodynamics, geomorphology etc.), the comparability of monitoring methods, and the determination of thresholds for GES. The assessment and monitoring of socio-economic harm will also need to be addressed and research will have to consider novel methods and automated monitoring devices, and finally the rationalization of monitoring.

The implementation of the MSFD is a long-term and cyclic process with the goal of achieving GES by 2020. Research will have to be engaged upon quickly, in particular to support the start of monitoring by 2014. A number of short-term priorities were identified by the GES TG group in 2010 (Galgani *et al.*, 2010), including:

(i) evaluation of the behaviour (floatability, density, effects of wind, biofouling, degradation rates) and factors affecting the fate of litter (weather, sea state, temperature-driven variations, slopes, canyons, bays, etc.) and affecting the transport of litter;

(ii) use of comprehensive models to define source and destination regions of litter (especially accumulation areas, permanent gyres, deep sea zones), estimate residence times, consider the average drift times and Tran boundary transport to and from MSFD regions/subregions;

(iii) evaluation of the rates of degradation of the different types of litter, quantification of the degradation products (to nanoparticles) and evaluation of the environmental impact of litter-related chemicals (phthalates, bisphenol A, flame-retardants, etc.) on marine organisms;

(iv) identification of sources for direct inputs of microparticles of litter;

(v) establishment of the environmental impacts of microliter, in particular in relation to the potential physical and chemical impacts on wildlife, resources and the food chain;

(vi) evaluation of biological impacts (on metabolism, physiology, survival, reproductive performance and ultimately on populations or communities);

(vii) evaluation of the risk of the introduction of invasive non-indigenous species;

(viii) study of dose–response relationships in relation to the types and quantities of marine litter in order to enable science-based definitions of threshold levels for GES;

(ix) evaluation of direct costs of marine litter to the maritime industry, fishing industry, local authorities and governments and in terms of impacts on ecosystems goods and services;

(x) development of automated monitoring systems (ship-based cameras, microlitter quantification etc.) and impact indicators (aesthetic impact, effects on human health, and harm to the environment); and

(xi) optimization of monitoring (standards/baselines, data management/quality assurance, extension of monitoring protocols to all MSFD regions/subregions).

Conclusions

The EU Marine Strategy Framework Directive (MSFD) establishes a framework for EU Member States to achieve or maintain GES for their marine waters by 2020. The Directive lists marine litter in Annex I as one of the qualitative descriptors associated with achieving GES, and therefore is a key instrument for addressing this kind of contamination of the marine environment and needs to be tackled urgently. Plastics are a major part of the problem of marine litter. As plastic is completely unnatural in the marine environment, the ultimate goal should be plastics without any effects in the marine environment. In the process of implementing the MSFD with regard to marine litter, policy makers, managers and scientists face the complexity and diversity of Marine Litter. Questions arise associated with harmonizing monitoring tools and strategies, defining harm to the marine environment, assessing land- and sea-based sources from which marine litter enters the sea, and developing a common understanding of the application of appropriate operational/environmental targets. In order to support EU Member States in taking the required implementation steps for the MSFD, the TSG ML is tasked with working on those questions and with providing monitoring protocols and further technical and procedural recommendations. This support for EU Member States will help in combating marine litter while providing a strong scientific and technical foundation for the implementation of Descriptor 10 of the MSFD.

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