Chapter 6
Litter in the Mediterranean Sea

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Abstract In the Mediterranean Sea human activities generate considerable amounts of waste, and quantities are increasing, although they vary between countries. To support actions to be taken in order to minimize impacts on the marine environment, the European Commission included recently marine litter as one of the descriptor of the Marine Strategy Framework Directive (MSFD), establishing a framework within which Member States must take action to achieve or maintain Good Environmental Status (GES). Beside, the Barcelona convention with its Regional Action is coordinating the monitoring of marine litter and support the implementation of reduction measures. As necessary steps, a better management will then need to (i) increase our knowledge and further development of data analysis in all regions, enabling to map areas at risk and sources, (ii) develop supporting tools for larger scale assessments, including harmonized databases, (iii) a better definition of thresholds, baselines and targets, to better understand harm and finally (iv) a coordinated monitoring. Research, supported by many institutions has then become critical and priorities include (i) a better definition of standardized/harmonized protocols, (ii) research on nanoparticles at sea, (iii) a better understanding of circulation and transport (iv) an increased knowledge of the ecology of microbial life on plastic and consequences on degradation, species dispersion and release of chemicals, and (v) a better understanding of the interactions between plastic and marine organisms. Using some examples, the process of the implementation of monitoring is described and discussed in the context of reduction measures.

Keywords Mediterranean sea · Marine litter · Microplastics · Monitoring

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6.1 Introduction

Because of (i) large cities, rivers and shore uses, (ii) some of the largest amounts of Municipal Solid Waste that are generated annually per person (208–760 kg/Year), (iii) because of tourism, (iv) 30% of the world's maritime traffic and (v) a closed basin, the Mediterranean has been described as one of the most affected areas by marine litter in the world. Plastic, mainly bags and fishing equipment, is the largest part of debris and they may physically degraded into smaller fragments, the so-called microplastics. Most existing surveys of microplastics on the surface, worldwide, have found average densities lower than in the NW Mediterranean Sea (80–250000 items/km^2) and microplastics have been also found on beaches and sediments, including deep sea, reaching concentrations of 1000 pellets/m^2.

Research demonstrated (i) the importance of hydrodynamics, (ii) the impact of plastic at sea that include entanglement, physical damage and ingestion, the release of chemicals, the transport of species and the alteration of benthic community structures, and (iii) social and economic harm.

In fact, the issue of marine litter and related information on the amounts and types in the Mediterranean is rather complicated, as it is addressed principally by scientific institutions and sub-regional and local authorities in most countries on the one hand and by NGOs on the other.

6.2 Source and Distribution

Sources of marine litter are traditionally classified as either land-based or sea-based, depending on where the litter enters the water. Other factors, such as ocean current patterns, climate, tides, and proximity to urban centers, waste disposal sites, industrial and recreational areas, shipping lanes, and commercial fishing grounds, influence the type and amount of marine litter found in open ocean areas or collected along beaches and ocean, including underwater areas.

Studies on land based source pollution indicated inputs of the Po river only at a level of 50 billons particles every year (Vianello et al. 2015). Another study on this river (Tweehyusen 2015), demonstrated that 677 tons of microplastics were entering the Mediterranean Sea every year. Uncontrolled discharges also act as main sources of litter in the Mediterranean Sea as in some countries, a reduced percentage of coastal cities are controlling their waste discharges in adapted structures. Ocean-based sources for marine litter include merchant shipping, liners, fishing vessels, military fleets, and offshore installations. It is expected that garbage coming from ships to the Mediterranean may be in the range of 1 million tons.

Assessments of the composition of beach litter in different regions show that synthetic materials (bottles, bags, caps/lids, nets, unidentifiable plastic and polystyrene) make up the largest proportion of overall litter pollution, mostly from recreational/tourism activities. Smoking related wastes and litter from fishing in general is also a significant problem in the Mediterranean.

Circulation is the primary driver of marine litter transport. As a semi-enclosed sea surrounded by developed areas, the Mediterranean Sea has particularly high concentration of marine debris. There, studies have already documented the beaching of litter, its transport on the surface and its accumulation on the sea floor (review in UNEP/MAP 2015).

The variability of the surface circulation is very high as the basin has many constraints. Some scenarios could be hypothesized to evaluate a realistic distribution through simulations based on homogeneous and continuous deployment of litter. Only few large sub-basins appear as possible retention areas (the north-western and the Tyrrhenian sub-basins, the southern Adriatic, and the Gulf of Syrt) but no permanent gyres, lasting longer than a few months, are occurring because seasonal and inter-annual variability alter the water movements and the distribution of litter.

On the sea floor, compilation of data from 16 studies covering the entire basin of the Mediterranean Sea confirmed the importance of plastic, at 62.7% ± 5.47 of total debris (Pham et al. 2014). The study showed that in canyons, plastic was the dominant litter items (50%) followed by fishing gear (25%), On slopes, the dominant litter items recovered was fishing gear (59%), followed by plastic (31%). This was also confirmed by an analysis of data from regular monitoring of litter on the sea floor in the gulf of Lion (Fig. 6.1).

In deep analysis finally detected that the "Distance to the coast" variable accounted for less than 20% of the variance in the distribution of litter between

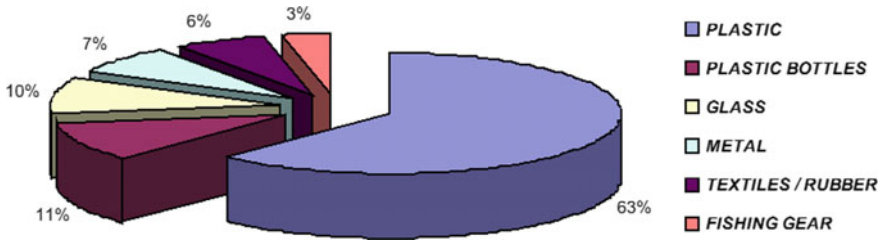

Fig. 6.1 Typology of debris collected between 30 and 800 m in the Gulf of Lion, France (MEDITS cruises, average from 70 stations/year and 15 years monitoring, 1994–2009, Galgani et al. 2011a, b)

canyons (see UNEP/MAP 2015). In some areas, fishing gears may account for the largest part of debris, depending on fishing activity. As an example dominant type of debris (89%) consisting of fishing gear were found on rocky banks in Sicily and Campania (Angiolillo et al. 2015)

Only a few studies have been published on the abundance of floating macro and mega debris in Mediterranean waters and the reported quantities measuring over 2 cm range from 0 to over 600 items per square kilometer (review in UNEP/MAP 2015).

On the sea floor, Counts from 7 surveys and 295 samples in the Mediterranean Sea and Black Sea (2,500,000 km^2, worldatlas.com) indicate an average density of 179 plastic items/km^2 for all compartments, including shelves, slopes, canyons, and deep sea plains (Pham et al. 2014).

In the Gulf of Lions, only small amounts of debris were collected on the continental shelf. Most of the debris was found in canyons descending from the continental slope and in the bathyal plain, with high amounts occurring to a depth of more than 500 m (Table 6.1, Fig. 6.2).

In the Mediterranean, static gear is an important part of ghost fishing and fishing can continue for years. Estimated ghost catches are generally believed to be well under 1% of landed catches and was estimated annually, for hake, between 0.27% and 0.54% of the total commercial landings.

In addition to large debris, there is growing concern with regards to Micro plastics, a very heterogeneous group, varying in size, shape, color, chemical composition, density and other characteristics. Most of them are resulting from the breakdown of larger plastic materials into increasingly small fragments rather from precursors (virgin resin pellets) for the production of polymer consumer products. Mean sea surface plastic was found in concentrations up to 100,000–200,000 particles/km^2 in the NW Mediterranean Sea (maximum 4,860,000 particles per km^2), giving an estimated weight over 1000 tons for the whole basin. Beach surveys revealed also an abundance of pellets on all Mediterranean beaches.

Table 6.1 Distribution of debris in the Gulf of Lion in relation to the depth (After Galgani et al. 2011a, b)

Depth (m)	Tows	Total area (km^2)	Total debris	Plastics	Debris (km^{-2})
<200	57	3.03	337	229 (68%)	111.2
200–1000	21	0.816	568	483 (85%)	696
>1000	10	0.17	631	537 (85%)	3712

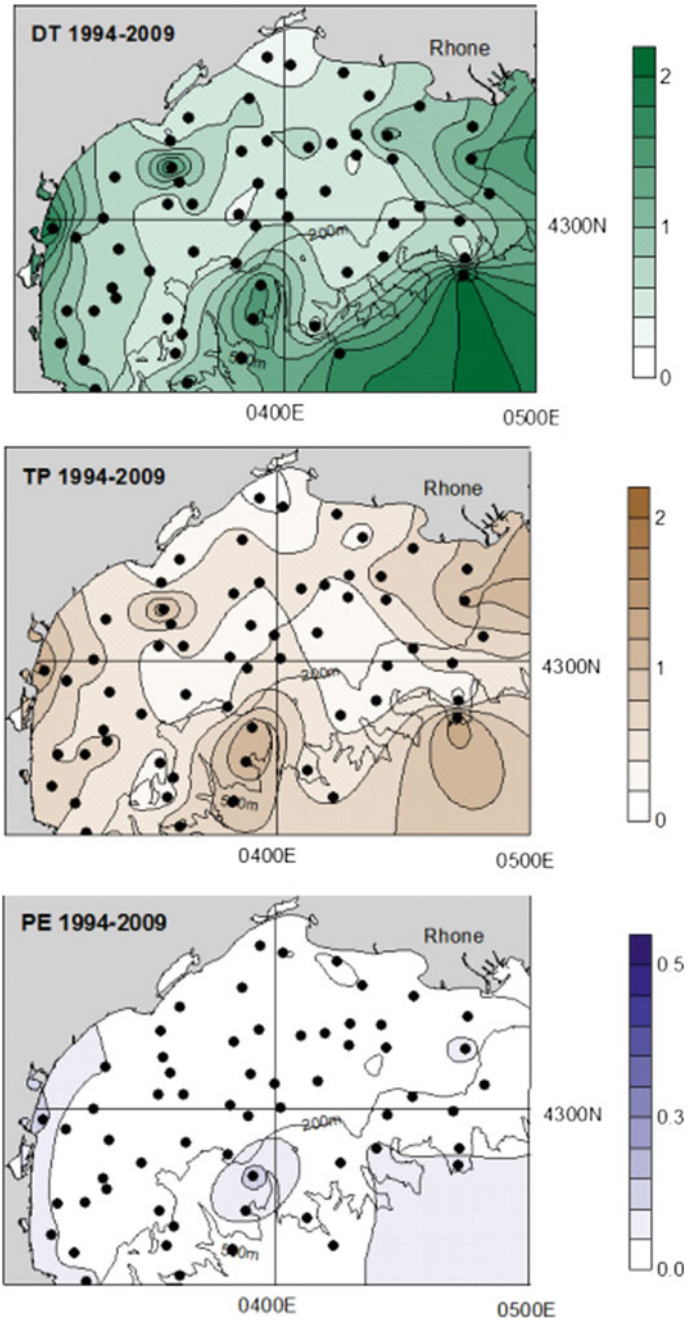

Fig. 6.2 Mean annual litter densities on the sea floor from the Gulf of Lion for a period of 15 years of sampling (1994–2009). Results are extrapolated densities expressed in items per hectare of the following categories: total Debris (DT), total plastics (TP) and fishing gears (PE). Data were from MEDITS cruise. (After Galgani et al. 2011a, b)

6.3 Impacts

As marine litter affects different ecological compartments, the study of its impact on marine biota of all trophic levels on the same temporal and spatial scale is of increasing importance. With regard to biodiversity, it is essential to focus research on sensitive species such as turtles, marine mammals, seabirds, and filter feeders, invertebrates or fish that may be ingest micro plastics. So far, 79 studies have investigated the interactions of marine biota with marine litter (mainly plastics) in the Mediterranean basin (Deudero and Alomar, in CIESM 2014). These studies cover a wide range of depths (0–850 m) and a large temporal scale (1986–2014), unveiling a vast array of species that are affected by litter, ranging from invertebrates (Polychaeta's, ascidians, bryozoans, sponges …), fish, and reptiles to cetaceans.

Effects from the studies are usually classified into entanglement, ingestion, and colonization and rafting.

About entanglement, there is a general lack of available data on marine wildlife in the Mediterranean but factors that may contribute to the entrapment of organisms in ghost gears have been described and include (i) the presence of organisms in the nets or in their proximity, (ii) the water turbidity, making the fishing gear less visible; (iii) the capability of organisms to detect the net filaments, (iv) the age, and for cetaceans (v) the ambient noise.

For ingestion, with more than 62 million of debris items estimated to be floating in the Mediterranean, these may affect a large number of species. Moreover, some species that are feeding on bottom may also ingest litter directly from the sea floor. Sub-lethal effects caused by marine litter ingestion may greatly affect populations in the long term because of possible reduced growth rates, longer developmental periods at sizes most vulnerable to predation, reduced reproductive output, and decreased survivorship. Highly affected fish species include *Boops boops*, myctophids, *Coryphaena hippurus, Seriola dumerilii,* (Deudero and Alomar, in CIESM 2014). Recently (Romeo et al. 2015), tunas and swordfish from the Mediterranean Sea were identified as targets species with occurrence of micro, meso, and larger plastics in more than 18% of the samples. Invertebrates such as *Mytilus galloprovincialis, Arenicola marina, and holothurids* are good indicator of harm due to their feeding habits as detritivorous or filter feeders.

The loggerhead sea turtle (*Caretta caretta*) may ingest plastic bags mistaken for jellyfishes (review in Galgani 2015) when they feed in neritic and offshore habitats. This is a very sensitive species to marine litter and one of the most studied.

In most cases, organisms are shown to utilize the debris items in oceans as habitats to hide in, adhere to, settle on, and move into new territories. The 250 billion microplastics floating in the Mediterranean Sea are then all potential carriers for alien, harmful species and so-called "invasive" species. However, because the Mediterranean Sea is a closed basin, species could potentially use litter to further expand their range (secondary invasion) after entering the basin by other means.

By sinking, debris may also have an impact on the deep sea environment, providing solid substrates and new habitats, impacting the distribution of benthic species even in remote areas (Pham et al. 2014).

Typically, large sized debris may affect humans from molecular (toxicity) to individual levels. Pieces of glass, discarded syringes, and medical waste all present possible harms to beach users. Moreover, plastic debris is now an abundant substrate for microbial colonization, physically and chemically distinct from natural substrates, and could support distinct microbial communities with a question of the transport of pathogens has now become crucial and may potentially support impact on human health. In recent years, secondary pollution from the leaching of pollutants from litter has been extensively studied. The transfer or enhanced bioaccumulation of persistent organic pollutants (POPs) may also occur as a consequence of the high sorption capacity of many plastics for lipophilic compounds. High concentrations of Di-(2-ethylhexyl) phthalate (DEHP) and nonylphenol have been also measured in small planktivorous fish, posing a long term risk to the environment. Beaches located downstream from industries and/or port facilities showed higher quantity of plastic debris and microplastics as well as higher concentrations of POPs (PAH, PCB and DDT).

Litter in the marine environment gives rise to a wide range of economic and social impacts, most often on small-scale, relying on anecdotal evidence, and negative environmental effects are often also interrelated and frequently dependent upon one another (Ten Brink et al. 2009). For the European commission, the total costs of marine litter is estimated at 263 million euros (Arcadis 2014), with a value for the closed Mediterranean Sea likely even more important due to the population in the region, maritime traffic, and tourism. In this basin, there is little or no reliable data on what the exact costs are. Furthermore, the loss of tourism and related revenues due to marine litter both on the beaches and in the sea, although recognized and considered, has not been quantified in detail. Economic impacts are most often described as including the loss of aesthetic value, impacts on fishing, the loss of non-use value, public health and safety impacts (extent and frequency of incidents), navigational hazards that are often unreported, and finally Ecosystem degradation, an extremely complex cost to evaluate.

6.4 Monitoring

Marine debris monitoring generally consists of various approaches, such as beach surveys, at-sea surveys, and estimates of the amounts entering the sea and impacts. Beach surveys are widely viewed as the simplest and the most cost effective, but they may not relate to true marine pollution and, because they may be affected by weather, the stranded debris may not necessarily provide a good indicator of changes in overall abundance.

There is actually no regular monitoring of micro particles in the Mediterranean Sea. Another approach to monitoring is to look at impacts directly. Entanglement

data does suffer from not always being expressed as a proportion of the population, and the distinction between active gears and litter when sampling stranded organisms is too difficult to enable regular and consistent monitoring. Ingestion sampling provides consistent data but is restricted to deceased and stranded individuals as opposed to a sample from the population at large. Moreover, species that can be considered for monitoring purposes must meet a number of basic requirements, like (i) sample availability (adequate numbers of beached animals, by-catch victims or harvested species), (ii) regular plastic consumption (high frequency and amounts of plastic over time in stomachs), and (iii) feeding habits (stomach contents should only reflect the marine environment).

In the Mediterranean Sea, there is very little coverage of any marine compartment other than beach and stranded debris, the most mature indicator and the one for which most data is available because

Regular surveys on beaches have been made in many areas, often over a number of years, by various NGOs. Valuable information about the quantity and composition of marine litter found on beaches has been available in most of the countries, giving an overview of debris found in the Mediterranean countries. However, there is a lack of official statistics for most of the countries. The challenges in dealing with this problem are not due to lack of awareness or data from various regions but rather are due to the lack of standardization and compatibility between methods. If many programs that exist or have existed in most Mediterranean countries involve (d) NGOs, the institutional MEDITS survey program (International Bottom Trawl Survey in the Mediterranean, http://www.sibm.it/SITO%20MEDITS/principaleprogramme.htm) is sampling benthic and demersal species between 80 and 800 m, through systematic bottom trawl surveys and with a common standardized sampling methodology and protocols at a global Mediterranean scale. The recent collection of sea floor litter data on a regular basis will provide assessments at the basin scale, with a potential of 1280 sampling stations to be considered.

The use of sea turtles for monitoring ingested litter in the Mediterranean Sea was first suggested in 2010 by a MSFD task group after many years of research. Protocols were then implemented (Matiddi et al. 2011; Galgani et al. 2013a, b) providing support to monitoring. Only with sub regional experiments performed to date, reinforced coordination, capacity building, quality assurance, and harmonization are however still needed.

Due to the poor differences between the Mediterranean sub-regions in terms of litter densities, the unequal spread of available data-sets, and some countries belonging to two or more sub-regions (Italy, Greece), it was suggested that common baselines for the various litter indicators (beaches, sea surface, sea floor, microplastics, ingested litter) must be considered at the level of the entire basin (Mediterranean Sea) rather than at the sub-regional level. Definitive baselines may be adjusted after monitoring programs could provide additional data. It is also quite important to harmonize the monitoring programs with other Regional Seas Conventions (e.g. OSPAR) as much as possible.

Environmental targets are qualitative or quantitative statements that are important for management as they will enable regions to (i) link the aim of achieving

objectives such as Good Environmental Status (GES) to the measures and effort needed, (ii) measure progress towards achieving the objective by means of associated indicator(s), and (iii) assess the success or failure of measures enacted to prevent marine litter from entering the seas and to support management and stakeholder awareness (Interwies et al. 2013). This author provided an overview of potential aspects to set targets on marine litter. They may consider (i) Location (Beaches, floating, estuaries, marine life, etc.), (ii) Composition or type (Plastic bags, cigarette bugs, microparticles, sanitary wastes, etc.), (iii) Sources and pathways (rivers, ship-based litter, landfills, etc.), (iv) Sectors (fisheries, recreation, industrial pellets, etc.), and (v) Measures (reduce urban waste production, improve waste collection of land-based sources/sectors, improve collection of ship-based waste in the port reception facilities, improve waste water treatment, reduce consumer littering, and improve inspections at sea, etc.). The Marine litter MEDPOL regional Plan also provides for strategic and operational objectives and lists a series of prevention and remediation measures that should be considered and implemented by the concerned actors. The establishment of both "state" and "pressure" complementary targets can then better reflect and support the effectiveness of specific operational objectives.

The different types of targets must be relevant to different types of information gaps (at-sea targets for improving the state of information about abundance, operational targets such as estuarine monitoring for improving information on pathway, source, and regional differences). However, due to a large set of factors affecting the quantities and distribution of marine litter in a certain area, it can be very challenging to detect clear reduction trends in the sea that can be associated to the implementation of measures in a particular area.

In regards to the coordinated monitoring strategy in the Mediterranean Sea and technical or scientific considerations, accessible targets were proposed (UNEP/MAP 2015) considering baselines that may be optimized after the 2015/2016 first results from monitoring. Targets may focus on the total amount of marine litter first, with some specific targets on individual items after impacts of reduction measures can be evaluated. For floating and sea floor litter, a significant decrease in amount requires overcoming the constraints of diffuses and uncontrolled sources (transboundary movements, influence of currents) and permanent accumulation processes on the sea floor. Targets on ingested litter in sea turtles will then focus on the number of affected animals and the amount of ingested debris by number or weight.

6.5 Management and Reduction Measures

Attempts to prevent marine litter require the inclusion of a vast amount of activities, sectors, and sources that cannot be addressed by a single measure.

Poor waste management, limited awareness of the public and inadequate interventions from industry and policy-makers are the main causes of the presence of litter at sea (Oosterhuis et al. 2014). As a result of the complexities caused by the

diverse origin of marine litter, a wide range of instruments have been proposed to deal with it across multiple sectors

The Mediterranean MLRP and the Berlin Conference on Marine Litter, 2013, Berlin, Germany (http://www.marine-litter-conference-berlin.info/) provided the following guiding principles as well as an umbrella structure that serves as a guiding framework for any of the following marine litter measures:

- The principle of prevention establishes that any marine pollution measure should primarily aim at addressing the prevention at the source, as removal of already introduced waste is very costly and labour intensive, especially compared with prevention measures.
- The polluter-pays principle has a preventive function in that externalities from polluting activities should be borne by the polluter causing it, which puts more pressure on potential polluters to make better attempts to avoid polluting. However, the application of this principle is limited by the difficulty in determining the polluter and also the extent of (environmental) damage.
- The precautionary principle is based on the understanding that measures must not be postponed in the light of scientific uncertainties. This principle plays an important role in setting targets and addressing the issue of micro-particles, despite an incomplete scientific knowledge on the specific sources and consequences of marine litter.
- The ecosystem-based approach is an approach that ensures that the collective pressures of human activities are considered.
- The principle of public participation is an important aspect of creating awareness for the problem of marine litter.
- The principle of integration means that environmental considerations should be included in economic development. This principle constitutes a key element of the Protocol on Integrated Coastal Zone Management in the Mediterranean.

Then, measures and actions taken should respond to the major sources and input pathways, but they should also take into consideration feasibility and the specificity of this pollution in the Mediterranean Sea. The main groups of items found on beaches in the Mediterranean are sanitary items, cigarette butts, as well as packaging items and bottles, all related to coastal-based tourism and recreation. This indicates direct disposal, intentionally or negligently, on the beaches or inland (river banks, dumpsites, etc.) as the main input pathways.

The fishing and shipping industries are also considered major sources of marine litter. In the Mediterranean Sea, specific measures in specific areas must be most effective in tackling the problem, including “Fishing for Litter”, one of the most important measures that would lead to the reduction and removal of marine litter from sea.

Further implementation is being considered within the Mediterranean Regional Action Plan, developing best practices adapted to the context of the basin (Gallego 2015).

Some of reduction measures are regulatory policy instruments that focus on adopting relevant legislation to help minimize marine litter, such as the EU Directive 2000/59/EC on port reception facilities for ship-generated waste and cargo residues. Other instruments, more economic in nature, influence the amount of marine litter through taxes, charges, or subsidies.

Effectiveness is a key determining factor for economic instruments. The cost of implementation is another important factor that influences which instrument to opt for, and it focuses on how to allocate scarce resources (e.g. public funds) to meet a certain environmental objective. This is the case in the cost of ghost gears.

Unfortunately for the Mediterranean Sea, there is no unique economic instrument, and the choice of an appropriate intervention is case specific, largely depending on the source and nature of pollution, the country's institutional characteristics and infrastructure, consumer preferences, perception and habitual behavior, and the economy's overall sectorial composition.

6.6 Setting Priorities

UNEP/MAP-MEDPOL (2015), MSFD (Galgani et al. 2011a, b), the European project STAGES (http://www.stagesproject.eu), and CIESM (2014) recently reviewed the gaps and research needs of knowledge, monitoring, and management of marine litter. This requires scientific cooperation among the parties involved prior to reduction measures due to complexity of issues.

Typically, more valuable and comparable data could be obtained by standardizing our approaches. In terms of distribution and quantities, identification of litter (size, type, etc.), evaluation of accumulation areas (bays, gyres, canyons, etc.), and identification of sources (rivers, diffuse inputs, etc.) need additional research prior to develop GIS and mapping systems to locate hotspots and to better understand transport dynamics. Further development and improvement of modelling tools must be considered for the evaluation and identification of both the sources and fate of litter.

A better understanding of rates of degradation and the development of appropriate methodologies to quantify degraded materials, including nanoparticles will be an important step.

Pilot-scale monitoring is now an important step towards monitoring litter harm in terms of determining baselines and/or adapting the strategy to local areas. A better understanding of entanglement (lethal or sub lethal) and of how litter is ingested by marine organisms are key questions. A more precise definition of target (GES) and the identification of Parameters/biological constraints and possible bias sources must be considered when defining the good environmental status. Work on other "sentinel" species (fishes and invertebrates) is also important, as it may provide additional protocols supporting the measurement of impacts. The (i) increase in the probability of translocation of species due to floating litter, (ii) the identification of species (including pathogens for both marine organisms and

human) in the Mediterranean that settle on marine litter, (iii) the nature of constraints for the colonization of floating plastic, are also key questions to consider for a better understanding of harm.

Knowledge about the extent of ghost fishing is still very limited due to the costs and practical difficulties of underwater survey work and partial knowledge about fish stocks losses. There are actually no overall estimates of the extent of the problem for the Mediterranean as a whole.

Harmonization of sampling protocols for the water surface and for microplastics is highly recommended. Moreover, the comparability of available data remains highly restricted, especially with respect to different size class categories, sampling procedures, analytical methods, and reference values. From the economic/management point of view (UNEP 2015) it is clear that (i) the lack of international legal instruments (except for IMO/MARPOL Annex V), (ii) the lack of coordination between actors, (iii) the poor management of coastal waste and (iv) the problems that are encountered in the application of economic instruments must be solved prior to implementation of measures. This must be based on the development of common methodologies to collect social and economic data, an assessment of socially acceptable levels of marine litter to the public and industry, the development of social and economic impact indicators and the education of the public.

In terms of measures, the development of tools to assess the effectiveness of monitoring, the implementation of measures intended to reduce the amount of marine litter and/or effectiveness programs, the development of port reception facilities (taking into consideration the Mediterranean maritime traffic), and the consideration/elimination of trans border marine litter, including the intervention in case of critical situation, are the main priorities in the management of marine waters that have to complement management measures to reduce inputs.

In conclusion, marine litter in the Mediterranean has become a critical issue. Management and reduction still need to be developed, implemented and coordinated. However, a number of points need to be addressed in order to better understand the issue. A number of key issues will have to be considered in order to provide a scientific and technical background for a consistent monitoring, a better management system, and science based reduction measures. For this, the improvement of basic knowledge, the support of monitoring and management has become critical.

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