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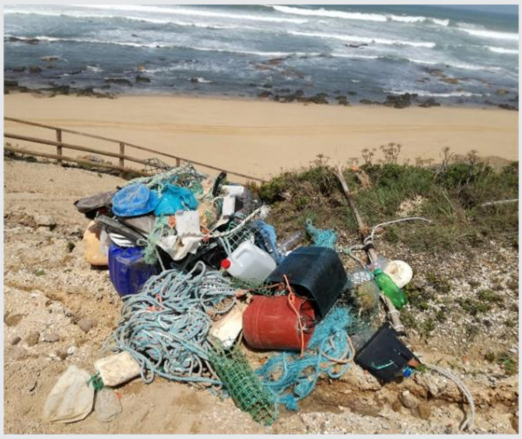
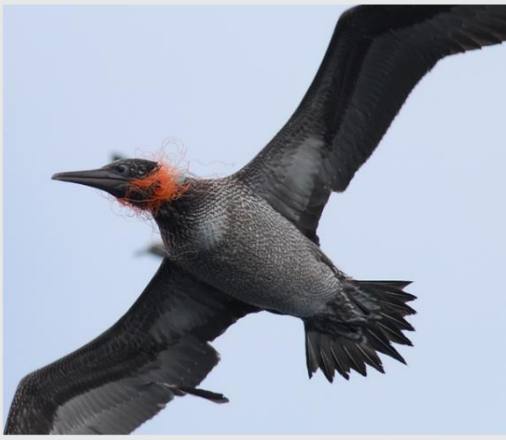
Guidance on the Monitoring of Marine Litter in European Seas

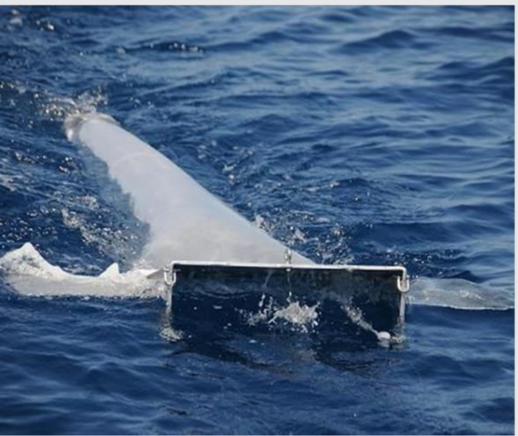
An update to improve the harmonised monitoring of marine litter under the Marine Strategy Framework Directive

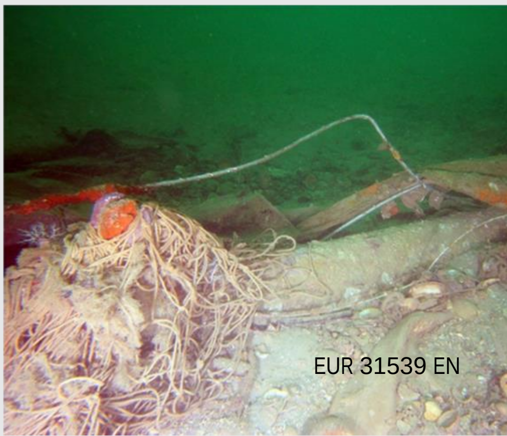
MSFD Technical Group on Marine Litter

2023









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5 Seafloor macro litter

5.1 Introduction

Criterion D10C1 (‘The composition, amount and spatial distribution of litter on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment’) of D10 includes the amount of litter deposited on the seafloor, with analysis of its composition, spatial distribution and, where possible, source, according to Commission Decision (EU) 2017/848 (replacing Decision 2010/477/EU).

Comparable data and baselines are needed to establish trends and compare current data against threshold values. The existing methods for monitoring litter on the seafloor reflect the difficulties associated with applying compatible and harmonised methods and their limitations. Any location is characterised by different depths, and the nature of the bottom may be sandy, muddy or rocky. As a consequence, different methods are applied to monitor litter on the seafloor (e.g. trawling, diving, imagery) (GESAMP, 2019). Moreover, monitoring litter on the seafloor may be challenging for some Member States and coastal areas because of limited resources; therefore, there is a need to set up a list with priority areas to monitor.

Coordinated national or regional monitoring programmes for litter on the seafloor within Europe started in 2013 through experimental monitoring. The most common approaches to evaluating seafloor litter distribution use opportunistic sampling during trawling surveys. This type of sampling is usually coupled with regular fisheries surveys (marine reserve, offshore platforms, etc.) and programmes on biodiversity monitoring, since methods for determining seafloor litter distribution (e.g. trawling, diving, video) are similar to those used for benthic and biodiversity assessments.

Monitoring programmes for demersal fish stocks, undertaken as part of the Data Collection Framework (DCF), provide data using harmonised protocols, which may support the monitoring of litter at the European scale. Data are collected regularly through existing International Bottom Trawl Surveys in the North Sea (NS-IBTS), the Atlantic Ocean (IBTS, North-East Atlantic Surveys), the Baltic Sea (Baltic International Trawl Survey (BITS)), the Mediterranean Sea (Mediterranean International Trawl Survey (MEDITS)), and the Adriatic Sea (Solea monitoring project (SOLEMON)), according to MSFD requirements.

5.2 Background and the state of the art

The seafloor, from inter-tidal to abyssal depths, has been identified as an important sink for marine litter (Ramirez-Llodra et al., 2011). Data have been obtained from varying locations and depths using different methodologies (divers, video footage, or sampling by bottom trawls).

Both abundance and spatial distribution of seafloor litter show considerable variability. The distribution of litter on the seafloor is strongly influenced by hydrodynamics, geomorphology and human factors. In general, the abundance of marine litter is much greater in shallow coastal areas than on the deeper parts of the continental shelf. For instance, near metropolitan areas, densities may exceed 100000 items per km^2 (Galgani et al., 2015). In these coastal areas, activities related to fishing and tourism significantly contribute to the littering of the seafloor with notable temporal, particularly seasonal variations, while dumping activities that pre-date the introduction of international regulations (e.g. the London Convention) influence the offshore litter distribution. Considering existing data, the Mediterranean Sea may be the most affected European sea (Galgani et al., 2015; Canals et al., 2021).

Long-term monitoring of litter on the seafloor has been performed regularly in some EU countries such as Germany, Spain, France and Italy, and non-EU countries such as the United Kingdom. In the United Kingdom, the results from the plastic caught in nets have not changed since 1999 (Maes et al., 2018). Consistent results were also obtained at several sites in the Spanish Mediterranean Sea in a study carried out between 2007 and 2017, with 1 323 hauls on shelves, except for the Alboran Sea, where a decrease was measured (García-Rivera et al., 2018).

Other studies indicate an increase in litter amounts. For example, at the margins of the Gulf of Lion (France; Gerigny et al., 2019), trend studies (70 stations, depth 40-800 m) have determined a slight but statistically significant increase since 2013.

In the Baltic Sea, a survey performed by seven countries conducting 2 377 hauls (53 cruises between 2012 and 2017) also showed an increase in the occurrence of plastic in the last 2-years; however, no trend for fishing-related litter was detected (Zablotski and Kraak, 2019). A weak but statistically significant increase in seafloor litter representing non-natural materials in the Baltic Sea was also seen between 2012 and 2016 (HELCOM, 2018).

In contrast, a significant decrease in the total litter quantity (kg/km^2) between 2011 and 2016 was found in the north-central Adriatic Sea (Strafella et al., 2019).

However, the evaluation of trends may be challenging when the aim is to detect slight changes. A power analysis of IBTS-related sampling by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) indicated that detecting a 10 % change over 5 or 10 years is unlikely without massive sample sizes (Maes et al., 2015). However, a 50 % change over 5 or 10 years looks readily detectable with current designs based on fish stock surveys such as the IBTS. Annual variations in litter transport, such as seasonal changes in the flow rate of rivers and related turbidity currents, further complicate the interpretation of temporal trends. Other seasonal factors include the intensity of currents, swell and downwelling/upwelling.

Due to the persistence of many litter materials, monitoring litter on the seafloor must consider accumulation processes over past decades. Timescales for observations should therefore be adapted, for example by requiring pluriannual deep seafloor surveys. Finally, seafloor litter assessments need to be planned with defined protocols, including the definition and specification of the survey location; the choice of sampling units; the methodology for collection, classification and quantification of litter; and the process for data integration, analysis and reporting of results.

Research activities focusing on evaluating litter on the seafloor have suggested some priority topics (Canals et al., 2021). These include (i) the evaluation of the catching and detecting potentials of different possible approaches and gear, (ii) the localisation of accumulation areas and supporting tools, such as modelling or seabed maps of sedimentation, to identify areas to be targeted by reduction measures, and to enable the backtracking of transportation schemes and sources, (iii) an analysis of existing data to characterise the most important sources, and (iv) the improvement of imaging tools (automated analysis, image resolution, etc.) for video protocols. A combined approach using both trawl surveys and visual/imaging surveys may be the best set-up for future monitoring of seafloor macro litter.

5.3 Scope and key questions to be addressed

This chapter evaluates existing methods for monitoring litter on the seafloor with respect to their capacity to fulfil the requirements of the MSFD. It proposes harmonised methods that can be applied to assess litter in regional seas, ensuring the comparability of seafloor assessments of litter within and between regions and at the European scale. A strategy is proposed, listing criteria, sites of interest and constraints. Complementary methodologies are also proposed for specific questions. Finally, it addresses data QA/QC requirements. An outlook for the needs of developments and research is provided.

Because of limited resources, the monitoring of litter on the seafloor is determined by each Member State at the national level, depending on the priority areas to be monitored. The strategy to be employed may consist of regularly monitoring selected areas, comparable to the approach used in beach litter surveys to identify and report litter trends over time (Hanke et al., 2019).

Opportunistic approaches may be used to minimise monitoring costs. Valuable information can be obtained from ongoing monitoring of benthic species in marine protected areas, during pipeline camera surveys, the cleaning of harbours and diving activities. Additional monitoring might have to be put in place to cover all areas and create a consistent monitoring network. The sampling strategy should enable the generation of detailed data in order to allow the assessment of the most likely sources of litter, the evaluation of trends and pressure/impact (ingestion, entanglement, and contaminants) relationships and the possibility of evaluating the effectiveness of measures.

The TG ML proposes using protocols based on existing trawl surveys and two protocols based on diving and imagery, which fit the MSFD requirements and will support harmonisation at the European level if applied transnationally. The monitoring strategy for the seafloor can partly be based on ongoing monitoring already developed at the European level. Indeed, existing fishery stock assessment programmes cover most European seas annually, facilitating harmonisation across Member States and data management. Key information on seafloor litter typology, sources, localisation and trends can be obtained. Trawling (otter or beam trawl) is an efficient method for large-scale evaluation and monitoring of seafloor litter, but a much better understanding of how different fishing trawls catch litter from the seafloor is needed. However, when the same gear is used, seafloor data from trawling represent a resource that can be used as a base for marine litter assessments at the transboundary level.

Nevertheless, it must be noted that trawling is a destructive monitoring method, and some sampling locations in rocky areas are incompatible with trawling. Indeed, potential litter accumulation areas (e.g. trenches, seamounts and canyons) cannot be covered by trawling approaches. Designing and developing an adequate monitoring programme will have to consider these limits and consider non-destructive imagery approaches. In a combined approach, protocols based on imaging techniques are efficient approaches to monitoring, particularly in deep-sea areas. These protocols are based on the use of submersibles, remotely operated vehicles (ROVs), AUVs and towed underwater cameras (TUCs). Only some countries will have to consider deep-sea areas in terms of monitoring seafloor litter. The strategy is to be determined by each Member State at the national level, depending on affected areas, but previous scientific results indicate that priority should be given to coastal canyons (e.g. Pierdomenico et al., 2019; Canals et al., 2021).

In this chapter, guidelines are provided for the following:

- visual surveys,
- trawl surveys,
- image-based surveys.

5.4 Visual surveys

Underwater visual surveys are the most common method of estimating marine litter density in shallow areas (GESAMP, 2019). The shallow seafloor is considered separately from other compartments, as it requires a dedicated monitoring strategy, and the approach can differ from those applied to other seafloor depths. The depth limit here is defined as 30 m, which is within the limits of recreational diving and provides enough bottom time to perform safe surveys. Underwater visual surveys are well adapted to monitoring marine protected areas and may address the lack of data where other methods, such as trawls, cannot be employed. As the shallow seafloor is the more accessible seafloor area, there are additional opportunities for data gathering through participatory science with non-scientific communities (e.g. Consoli et al., 2020); these opportunities are not available for the deep seafloor. The abundance of marine litter in shallow coastal waters is generally high in bays, where litter disposed of locally is more likely to accumulate on the bottom because of weaker currents (Katsanevakis, 2008; Stagličić et al., 2021). Furthermore, wave or upwelling-induced cleaning of the seafloor is less important in small bays, where there is usually much less transport. As the logistics related to scientific diving are demanding, opportunistic monitoring – that is, the add-on of litter monitoring to surveys performed for other purposes, such as biodiversity assessments – might provide a cost-effective approach.

Although the most commonly used method to estimate marine litter density in shallow coastal areas is to conduct underwater visual surveys by scuba diving, snorkelling has also been used in very shallow waters (usually < 10 m depth) and for larger items of marine litter (nets/fishing gear). The most common methodology is to perform strip transects, where the observer travels along the centre line searching for litter and counting all items within the strip (e.g. Fortibuoni et al., 2019, Pasternak et al., 2019).

5.4.1 Technical requirements

Knowledge of temporal variation is used to choose the sampling frequency. The minimum sampling frequency for any site should be annual, and at a similar time of the year. Ideally, it is recommended that locations are surveyed every three months (allowing an interpretation in terms of seasonal changes). Sites should be selected that have flat and uniform substrates without risks of wrecks, munitions and/or endangered or protected species.

The easiest methodology for underwater visual surveys with scuba diving is to perform 'strip transects'. The observer travels along a line searching for litter and counting all items within a predefined strip. The transect length (L) must be measured. All litter items within 2 m or 4 m (w) on both sides of a nylon line are recorded and removed, if possible. The strip area (A) is defined as $A = 2 * w * L$. It has to be considered that underestimations of the abundance might occur, especially when counting small items or in the case of high turbidity.

Surveys should be conducted through a minimum of two transects for each site (GESAMP, 2019). Unbiased design-based inference requires allocating transects randomly in the study area or on a grid of systematically spaced lines randomly crossing each other. However, with a model-based approach such as density surface modelling (DSM), it is not required that the transects are located according to a formal and restrictive survey sampling scheme, although good spatial coverage of the study area is desirable. Transects may be defined with a nylon line, marked every 5 meters with resistant paints, and deployed using a diving reel while scuba diving. This way, the transect is well-defined, and its length is easily and accurately measured. Another option might be to not physically define the line but move along an imaginary line using a compass. However, when no real line is deployed, there are difficulties in accurately estimating transect length. A vessel with a GPS may help to assess the transect length in this case by measuring the distance between the start and endpoint of the dive or by summing the lengths for a sequence of positions along the line (in which case, the divers could display their position, for example by towing a buoy) (Katsavenakis, 2009).

The nature of the bottom/habitat is also recorded. The length of the transects may vary between 20 m and 200 m, depending on the depth, the depth gradient, the turbidity, the habitat complexity and the litter density (Katsanevakis, 2009). Results are expressed as litter density (e.g. items/km^2 or items/100 m^2).

5.4.2 Use of volunteers in shallow water surveys

Recreational scuba divers can provide valuable information on seafloor litter in shallow waters. They can access and have the skills and equipment needed to collect, record, and share information about the litter they encounter underwater. Many dive clubs and shops organise underwater clean-ups, often in partnerships with NGOs or local governments. For some Member States, the involvement of volunteer divers might be a good opportunity for litter monitoring in shallow waters, but standardisation and conformity with the common methodologies, protocols and tools proposed here should be achieved.

For example, the Dive Against Debris (DAD) project run by the Professional Association of Diving Instructors (PADI) AWARE Foundation provides a harmonised methodology, field protocol and data reporting process for scuba divers to remove and report marine litter found on the seafloor. As such, data are directly comparable between survey sites globally. Data acquisition can be further harmonised by considering the effort of the survey (e.g. Consoli et al., 2020; Scotti et al., 2021). As the DAD project encourages divers to also report debris-free sites, it yields also presence-absence data. Divers are encouraged, but currently not required, to conduct surveys at the same dive site on a regular (monthly) basis to build data identifying temporal trends in seafloor litter. All resources are freely available to download from the DAD project website (https://www.diveagainstdebris.org/) and the PADI AWARE Foundation has numerous data sharing agreements with various entities to provide bespoke datasets at the local, national and regional levels. Volunteers submit their data to the global data set via the free mobile app or the online submission form. Every DAD survey submitted undergoes and internal quality review process to ensure data integrity. The DAD project and similar projects provide a cost-effective monitoring tool that Member States can implement nationally to build quantitative baselines regarding the types and quantities of seafloor debris and facilitate ongoing assessment.

5.5 Trawl surveys

Trawling (otter and beam) has been employed for large-scale seafloor litter evaluation and monitoring (e.g. Goldberg, 1995; Galgani et al., 2000; Maes et al., 2018; Spedicato et al., 2019). There are some restrictions in rocky areas and soft sediment, as the method may not be suitable and/or may underestimate the litter quantities present.

General strategies to investigate seabed litter are similar to the methodology for benthic ecology. The occurrence of international surveys of bottom trawls such as the IBTS (Atlantic Ocean), the BITS (Baltic Sea), MEDITS (Mediterranean Sea) and SOLEMON (Adriatic Sea) provides useful and valuable means for monitoring marine litter. These use standard gears, depending on the region (GOV and BACA nets in the Atlantic, TVL and TVS nets in the Baltic Sea, GOC73 nets in the Mediterranean and a modified beam trawl in the Adriatic Sea) and provide some harmonised and common conditions for sampling (mesh size, duration of tows, large sampling surface covered) and hydrographical and environmental information (surface & bottom temperature, surface & bottom salinity, surface & bottom current direction & speed, wind direction & speed, swell direction and height). Moreover, specific equipment is used to calculate the swept area of the net. In some cases, when the horizontal opening of the trawl is not evaluated for each tow, surfaces can be calculated by estimating the opening of the trawl (e.g. Fortibuoni et al., 2019). The TG ML recommends using these ongoing and continuous programmes to collect data on marine litter on the seafloor in combination with other visual and imaging methods. However, bottom trawling has a significant impact on benthic ecosystems. Thus, creating a new monitoring programme to monitor seafloor litter may not be justified from an environmental perspective when other methods are available (GESAMP, 2019).

Data on seafloor litter should be reported as items/km^2 before further processing and reporting according to Commission Decision (EU) 2017/848.

5.5.1 Technical requirements

5.5.1.1 Atlantic Ocean, North Sea and Baltic Sea

Litter data collection using trawl surveys started in the 1990s in the north-east Atlantic Ocean (within the IBTS programme; Maes et al., 2018). The International Council for the Exploration of the Sea (ICES) Working Group on Marine Litter (WGML) has recently developed a unique protocol for marine litter assessment using trawling programmes; its application is mandatory for ICES surveys (ICES, 2022). This protocol harmonises the procedures for collecting and reporting marine litter data during existing fish stock surveys. It has been discussed within the TG ML and modified to provide an accurate methodology applicable to MSFD monitoring (facilitating the evaluation of sources, trends, data analysis, etc.).

In the North Sea, the sampling grids are based on statistical rectangles of 1° longitude × 0.5° latitude (30 × 30 nautical miles). Each rectangle is usually fished by ships of two different countries (two hauls per rectangle) or a single country fishing more than once in every rectangle (e.g. in the Skagerrak and the Kattegat, Sweden). In the Baltic Sea, the station allocation is different and stratified by depth intervals, and only one country covers each area. All countries have a standard haul duration of 30 minutes (defined as starting at the moment when the vertical net opening and door spread are stable), using the same 36/47 GOV demersal trawl in the North Sea (ICES/IBTS, 2017), BACA nets in the Bay of Biscay and on the Iberian coast, and TV-3 (TVS and TVL) bottom trawl in the Baltic sea (ICES/BITS, 2017), sampling at 3.5-4 knots (2.3-2.73 knots in the BITS) between 20 m and 200 m depth with 20 mm mesh nets (3 knots in the IBTS between 15 m and 800 m).

5.5.1.2 Mediterranean Sea

Litter data collection using trawl surveys started in the 2010s in the Mediterranean Sea (within the MEDITS programme; Spedicato et al., 2019). The protocol is derived from the MEDITS survey (see the protocol manual (MEDITS working group, 2017)). It is also a reference for associated countries, including Bulgaria and Romania in the Black Sea. The hauls are positioned following a depth-stratified sampling scheme with a random drawing of the positions within each stratum. The number of hauls in each stratum is proportional to the surface of these strata, and the hauls should be made in the same position from year to year. The depth strata (10–50 m, 50–100 m, 100–200 m, 200–500 m and 500–800 m) are fixed in all areas. The total number of hauls for the Mediterranean Sea is approximately 1300 every year, covering the shelves and slopes from 10 countries in the Mediterranean (MEDITS working group, 2017). The haul duration (defined as starting at the moment when the vertical net opening and door spread are stable) is fixed at 30 minutes at depths of less than 200 m and 60 minutes at depths of over 200 m, using the GOC73 trawl with a mesh size of the cod end of 10 mm of mesh side, which corresponds to about 20 mm of mesh opening and sampling between May and July, at 3 knots (MEDITS working group, 2017). The length of the mesh side is defined by the International Organization for Standardization as ‘the distance between two sequential knots or joints, measured from centre to centre when the yarn between those points is fully extended’ (ISO 1107:2017 (2022)).

5.6 Image-based surveys

Seafloor image-based surveys are increasingly used to study the abundance and distribution of litter on the seafloor and its interactions with marine organisms (Canals et al., 2021). The most commonly used platforms for image acquisition of marine litter are submersibles, ROVs, AUVs and TUCs. Visual surveys can be performed at all depths and on all sea bottoms, including those not accessible to bottom trawls, such as steep slopes, rocky bottoms, and ultra-deep areas, down to the oceanic trenches (e.g. Galgani and Lecornu, 2004; Bergmann and Klages, 2012; Miyake et al., 2011; Ioakeimidis et al., 2015; Tekman et al., 2017; Chiba et al. 2018), and allow the precise geo-referencing of each litter item. In addition, these methods enable small-scale observations, which are essential for identifying litter–biota interactions and accumulation areas. Furthermore, image-based systems are harmless to organisms. Two disadvantages of the image-based approaches to seafloor litter quantification are that the minimum size of litter that can be identified depends on the resolution achievable by the cameras and that items covered by sediment or entrapped within seagrass, coral reefs or fine-scale rocky structures cannot be detected. The ability to physically sample and bring litter items onboard for examination is also severely limited. As a result, seafloor-imaging surveys may easily underestimate litter items, and some objects (e.g. fragments) could barely be identified by conventional imagery.

There are some available protocols where litter is counted on routes and expressed as items/km^2, especially when using TUCs, ROVs, and submersibles at variable depths above the deep seafloor (Galgani et al., 1996). These technologies enable the evaluation of the densities through standardised approaches (transect lengths and widths, sampling units, etc.). Considering the improvement in visual sampling, there is a need to develop a data management approach for data acquired through direct observations, such as on the shallow seafloor, or through imagery techniques. This requires identifying essential metadata sets and agreeing on common reporting formats. This area is underdeveloped and will be considered within the EMODnet data management system for the next MSFD cycle.

5.6.1 Shallow seafloor

In some circumstances, diving may be unsuitable, difficult or impossible because of inadequate conditions, such as heavy boat traffic and cold water temperatures, because the legal requirements for diving are very strict, because the costs are high or because there is a lack of diving personnel with the proper scientific/technical requirements. Imaging-based approaches to seafloor monitoring (e.g. ROVs or TUCs) may also be employed for shallow surveys. The shallow depth can allow the use of simple equipment and thus reduce monitoring costs. Recording videos during the monitoring enables data analysis using appropriate software, thus improving data collection.

Towed low-cost camera set-ups (Fakiris et al., 2022) or sledges (Lundqvist, 2013) can be also employed for shallow seafloor macro litter monitoring.

The types of litter should then be recorded using the categories defined by the MSFD Joint List (Fleet et al., 2021).

5.6.2 Deep seafloor

The deep sea includes waters and sediment below depths of approximately 200 m (Danovaro et al., 2010). Only some areas/countries (e.g. France, Greece, Ireland, Italy, Norway, Spain and Portugal) are concerned with the deep seafloor along the European coasts, including submarine canyons, seamounts, cold seeps, open slopes and deep basins. Sampling difficulties and costs largely restrict monitoring in those deep-sea areas. Litter that reaches the seabed may already have been transported for considerable distances, only sinking when weighed down, for example, by fouling. The consequence is an accumulation in canyons that tunnel litter, often around large cities, rather than in the open sea (Chiba et al., 2018). These high litter densities result from residual ocean circulation patterns and, more locally, from the morphology of the seabed (around rocks and/or in depressions or channels) and the deep submarine extensions of coastal rivers (Pierdomenico et al., 2019). Specific equipment is necessary for slopes and rocky bottoms, including ROVs, AUVs and/or submersibles, which may be very expensive to operate, especially in deep-sea areas. Data collection is usually performed irregularly, using protocols based on existing seafloor monitoring and research activities to study seafloor litter and benthic biodiversity through opportunistic approaches (e.g. Enrichetti et al., 2020, Canals et al., 2021). ROVs, which are less complicated than submersibles and generally cheaper, are recommended for litter surveys of the deep seafloor.

For the monitoring, video transects should be linear and at least 200 m long. If there is a deviation from the initial track, it is essential not to count the same items several times. Three video transects for each area surveyed are recommended. The start of the dive is defined as the moment at which the ROV (or other cameras/vehicles) dives into the seawater. The end of the dive is defined as when ROV is at the surface / on the deck. The start of the transect is defined as the moment at which the ROV is at the bottom, and the end of the transect is when the ROV leaves the bottom (i.e. is off the bottom). The area surveyed is calculated by multiplying the transect length by the visual field (width) of the video. When possible, two laser beams can be used to measure the size of objects and distances on the seafloor. Altimeters are necessary to evaluate the altitude, and then, depending on the focus of the camera, the surface of the area sampled during surveys can be estimated (GESAMP, 2019). ROVs (or other cameras/vehicles) should be in continuous recording mode at a constant slow speed (e.g. 0.5-2 knots) and a constant height from the bottom (e.g. < 1.5 m). Each object observed along the transect (within the constant field of view of the camera) has to be recorded and counted to obtain information about litter abundance and occurrence. Each item has to be classified based on the type of object, according to the list of main categories provided in the MSFD Joint list (Fleet et al., 2021). Data must be annotated in a data sheet, which should be completed for each dive. Results are usually expressed as items/km^2 when the explored surface measurement is possible, and items/km (or items/100 m) when the surface cannot be measured. Site information should be recorded, such as location, date, time, geographical coordinates, depth, substrate types, speed, distance from the coast and other relevant observations.

Adopting a common protocol will lead to a significant standardisation level among the countries that apply it as their sampling strategy. Usually, transect routes are strategically distributed to delineate surveys along canyon heads, floors and flanks at various depths to obtain a visual picture of the overall distribution. Images are also referenced on navigation logs, providing the time of observation, water depth and geographical position along a given transect route. Single frames may be extracted from video records for further analysis and identification (GESAMP, 2019).

Given that surveys might be performed by ROV classes with different equipment, or other more sophisticated instruments, it is very important to record any extra equipment and the characteristics of the instrumentation to harmonise these among the teams performing surveys. Technological instruments should provide controlled sampling, precise data on geographical position and depth, high-definition video or photos, and reference points (e.g. laser beams) to use as a metric scale for measuring the width of the visual field. The video survey should allow the recording of the precise position of litter items.

5.7 Data recording and management

It is necessary to combine different methodologies according to the requirements of the various seafloor types and depths, and approaches designed to ensure comparable assessments. For trawling surveys, templates for data recording sheets based on this system have been integrated into the ICES ([19]), MEDITS ([20]) and SOLEMON ([21]) manuals. Data on litter should be collected using these templates and the items categories listed for the seafloor. Site information and trawl sampling characteristics such as the date, the position and type of trawl, the speed, the distance, the sampled area, the depth and the hydrographical and meteorological conditions, should be recorded. Data sheets should be filled out for each trawl and compiled by survey. If multiple counts (transects/observers) are run at any given site, then a new sheet should be used for each trawl shot. After each survey, data must be processed for analysis and reporting. Furthermore, for litter items, the weight, a picture and a note of attached organisms may further complement the classification of objects.

Monitoring litter on continental margins must be co-organised and coordinated within two groups: (i) the ICES / the IBTS (north-east Atlantic Ocean and Baltic Sea) and (ii) MEDITS (Mediterranean Sea). The inclusion of litter monitoring through the IBTS/MEDITS programmes has been organised within the EU through the Scientific, Technical and Economic Committee for Fisheries (STECF) and its Subgroup on Research Needs (SGRN), with the support of the Data Collection Framework (DCF) from the Directorate-General for Maritime Affairs and Fisheries. Litter data management has been organised at the regional institution level through the OSPAR Commission (ICES Database of Trawl Surveys (DATRAS)), HELCOM (ICES-DATRAS) and MEDITS data management systems.

EMODnet Chemistry, a pan-European network of organisations supported by the EU, developed a central database for seafloor litter in 2017. A common infrastructure for managing all the data is well adapted to address protocols and reporting heterogeneity. It was modelled following the ICES-DATRAS approach and considering the European TG ML and MEDITS requirements. Using a single data model and common data formats based on consolidated monitoring initiatives has allowed the collation of multiple data streams in a uniform and standardised way. It will also the creation of a basic dataset from which to compute seafloor baselines.

Furthermore, the EMODnet visualisation products will provide an easy tool to display available litter data and allow partial comparison of homogenised European data. They are a straightforward way to promote access to interesting data for a wide variety of stakeholders. For example, data from the north-east Atlantic Ocean and the Baltic Sea are directly collected by EMODnet from the OSPAR/ICES-DATRAS database. The temporal coverage of the seafloor litter collection is from 2006 to 2018, with a total of 3 600 seafloor surveys. Up to now, this can be considered the most comprehensive collection of homogenised data available at the pan-

([19]) https://ices-library.figshare.com/articles/report/ICES_Manual_for_Seafloor_Litter_Data_Collection_and_Reporting_from_Demersal_Trawl_Samples/21435771
([20]) https://archimer.ifremer.fr/doc/00832/94436/
([21]) https://podaci.ribarstvo.hr/files/SOLEMON-Handbook_2019_Ver_4.pdf

European level (Molina Jack et al., 2019). EMODnet's visualisation products provide an accessible way to display the available data and allow their partial comparison. The products provide information such as total abundances, litter composition or abundances of relevant litter types. Marine litter formats and instructions for data gathering, raw litter data, and aggregated collections and visualisation products are accessible through the EMODnet Chemistry web portal (http://www.emodnet-chemistry.eu/) (Galgani et al., 2017, 2022). Aggregated marine data collections and the visualisation products are in the public domain and freely available for all users with acknowledgement of the source (https://www.emodnet-chemistry.eu/marinelitter). The methodology used in the generation of visualisation products is described by Le Moigne et al. (2019).

5.8 Seafloor litter categories

Because marine litter degradation is increased by light, oxygen and wave action, the persistence of marine litter is increased on the seafloor and deep seafloor, generating variable outcomes for the nature of litter found. Moreover, the gear types and their ground contact used in different areas may affect the types of litter caught, making a comparison between areas and surveys more complex. Another important factor influencing the composition of benthic litter is related to the source of litter. Typically, the analysis of sources must indicate the importance of and differences between sea- and land-based litter, but also the differences between different activities or sectors. Although marine litter is strongly affected by processes affecting transport, fishing has been shown as a main source of litter in some fishing or aquaculture grounds (e.g. Fortibuoni et al., 2019). Similarly, specific types of marine litter were also found in areas affected by tourism, for example around beaches, such as those in the Mediterranean Sea (Stagličić et al., 2021). This may affect the selection of monitoring sites, such as shallow waters.

A standardised litter classification system has been defined and adopted by Member States for use in MSFD implementation (i.e. the MSFD Joint List; Fleet et al., 2021) in accordance with the types of litter found at the regional level, providing common main categories for all regions. This list allows for assessments with comparable categories across marine environmental compartments. The list main categories provide the basis for a hierarchical system, including subcategories. It considers nine main categories of material (artificial polymer materials, chemicals, cloth/textiles, metals, rubber, glass/ceramics, processed/worked wood, paper/cardboard and organic food waste) and 183 subcategories.

5.9 Interactions with criterion C4 of Descriptor 10

As litter is widely distributed on the seafloor and interacts with / affects marine biota in different ways, through entanglement, providing new substrates, or covering/smothering marine fauna (e.g. Anastasopoulou and Fortibuoni, 2019), some of these interactions can be easily measured through seafloor visual surveys (e.g. by diving or using ROVs). The imagery technology provides a well-adapted platform for documenting the entanglement of marine fauna, especially on seafloor areas dominated by sessile suspension feeders, structuring coralligenous assemblages, mesophotic and deep-sea sponge and coral aggregations, termed 'animal forests' (Galgani et al., 2018). Because of their branching and massive morphology, these habitat-forming species have strong potential for monitoring temporal and spatial trends of entanglement events caused by marine litter, especially by abandoned, lost or otherwise discarded fishing gear (ALDFG) (Galgani et al., 2018; Angiolillo and Fortibuoni, 2020).

Considering the importance of this type of data on litter for a better understanding of interactions with marine organisms, it is necessary to perform litter surveys using videos (deep waters) and by diving (shallow waters) that simultaneously allow the assessment of MSFD primary (D10C1) and secondary (D10C4) criteria.

No specific database exists for this approach, but future work, within the next MSFD cycle, will need to consider merging databases on seafloor images/pictures and interactions to facilitate the evaluations of interactions between litter and organisms, especially in fishing grounds where ALDFG are most often present and abundant.

5.10 Quality assurance / quality control

While assuring the quality of data employed for assessments in a policy context is important, the implementation of practical QA/QC measures for seafloor litter monitoring is challenging. The use of agreed and harmonised monitoring protocols and the provision of relevant agreed metadata sets are crucial.

Several contracting parties from OSPAR and the programme for the assessment and control of marine pollution in the Mediterranean (MEDPOL) use their fish stock surveys for seafloor litter monitoring, an approach that is already adopted as a common indicator in the OSPAR, Barcelona Convention and HELCOM regional plans. Adopting a common protocol will lead to significant standardisation among the countries that apply it as their sampling strategy. This is considered an adequate approach, although litter quantities are probably underestimated when using GOV fishing nets due to their limited bottom contact and given the restrictions in rocky or hard bottom areas. How to compare the data collected during trawl surveys with data gathered using different methodologies remains an open question. A conversion factor between beam trawling and GOV trawling would help compare data from different surveys.

Data recording and management should be undertaken through an online, relational database system under the quality control and direction of skilled managers. Regional/country coordinators should review and approve the uploaded data. This would ensure a high level of consistency within each region and create a hierarchy of quality assurance on data acquisition. For the IBTS, the BITS and MEDITS, sampling data are collected in the DATRAS and MEDITS databases together with data on hydrographical and environmental conditions. This process may also support quality insurance for data on litter. The ICES is considering data for OSPAR and HELCOM areas, while MEDITS has included litter data to be analysed within a specific subgroup of experts. The occurrence of WISE/EMODnet with modules dedicated to MSFD indicators may also be considered to develop a specific module for criteria from Descriptor 10, including litter on the seafloor.