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A Mediterranean Focus Overview of EU Marine Litter Data Management Performed in the Framework of the European Marine Observation and Data Network Chemistry

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Abstract: The Mediterranean Sea is an almost completely closed basin connecting several countries. Its configuration leads to its peculiarity and richness, but the intensive activities within the basin and along the coast aggravate the ecological conditions. The existing regulatory European Framework for environmental protection has already been in place through a series of legal instruments for almost 20 years. In this context, open science could play a fundamental role. The existing data must become findable, accessible, interoperable, and reusable (FAIR) to provide stakeholders and decision-makers with the instruments to understand how to improve the available information and support decisions based on the best set of existing information. Since 2009, the European Marine Observation and Data Network, EMODnet, has provided access to high-quality marine information supporting research and stakeholders' mission and objectives. Data related to pollution are collated, validated, and published using standard protocols, formats, and vocabularies, thus becoming FAIR. For marine litter, a detailed and qualified data management system for macro- and microlitter in diverse compartments was structured. Some of these data and metadata were already used to calculate the first coastline litter baselines based on harmonized and FAIR datasets (2012–2016). The availability of these data related to the Mediterranean area is relevant, but additional work is required.

Keywords: marine litter; data management; FAIRness; open science; metadata; data and data products; data accessibility; Mediterranean

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1. Introduction

The Mediterranean Sea is an almost completely closed basin, except for its three exchange points with the Atlantic Ocean, the Black Sea, and the Red Sea. It connects several countries with different cultures, religions, economic development, and relevant habitats. Its configuration leads to its peculiarity and richness, but the intensive activities within the basin and along the coast aggravate the ecological conditions. The numbers pretty much speak for themselves: the coastal population is expected to grow steadily (from about 100 million in 1980 to 150 million in 2005), potentially reaching 200 million by 2030; maritime traffic in the Mediterranean represents more than 20 percent of the global one [1]; it ranks first among tourism destinations [2]; and it is the second largest market for cruising [1].

The existing regulatory framework for environmental protection is very broad: in the European Framework, the protection of waters, and in particular marine waters and oceans, has already been in place for almost 20 years through a series of legal instruments such as the Integrated Maritime Policy, the Water Framework Directive, and the Marine Strategy Framework Directive (MSFD). In addition, Mediterranean countries have accepted the United Nations' call (2015) to take action to promote wealth while protecting the planet through the Mediterranean Strategy for Sustainable Development (2016–2025). Furthermore, the Regional Seas Programme of the United Nations Environment Programme (UNEP MAP), the Programme for the Assessment and Control of Marine Pollution in the Mediterranean, and the Regional Plan for Marine Litter are among the regulatory instruments established in the Mediterranean to prevent and combat the effects of eutrophication, chemical pollution, marine litter, marine noise, and much more.

Plastic pollution is a burning issue worldwide, not to mention in the Mediterranean [3–5]. It is estimated that around 730 tons of plastic waste are dumped into the Mediterranean Sea every day, mainly from land-based sources [6]. Macro-, micro-, and nanoplastics threaten the Mediterranean's species and ecosystems [7–10]. Despite representing only 1% of the world's water volume, this sea has become the sixth-largest gathering area for marine debris, containing 7% of the world's microplastics [11]. The Mediterranean, a semi-enclosed body of water, is exceptionally susceptible to plastic pollution. Plastics make up over 85%, whether floating on the sea surface or lying on the seabed [11]. Notably, while plastics are observed along shorelines, in surface waters, and dispersed throughout the water column, most of this pollution accumulates on the seafloor [12–14], predominantly in microplastics within deep-sea sediments [15].

Plastic production and plastic waste are increasing faster than efforts to rationalize use and production, though different policies are taking small steps to turn the tide [16]. Research and monitoring efforts are still project-based in some cases, making it difficult to establish consolidated monitoring protocols and long-term data series that can lead to comparable data and consistent assessments [3]. However, great efforts have been made toward the harmonization of monitoring programs at the EU and regional sea convention levels, as well as globally (e.g., the G20 Implementation Framework for Actions on Marine Plastic Litter or the UN Global Partnership on Marine Litter).

The specificity of the Mediterranean Sea lies in the co-existence of several management frameworks. One includes the EU member states within MSFD [17], and the other includes the IMAP (Integrated Monitoring and Assessment Programme) related to the UNEP MAP, addressing the basin-scale assessments of marine litter with non-EU countries by means of Ecological Objective 10 (marine and coastal litter do not adversely affect coastal and marine environments) and the related Common Indicators 22, 23, and 24 [18]. These two main data management processes in the Mediterranean basin require further harmonization and interconnection that would lead to a win–win situation for both of them. In addition, some countries are involved in multiple other Regional Action Plans, such as France and Spain, which participate in MSFD monitoring, the program of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), and the UNEP MAP program. Similarly, Turkey is involved in both the Mediterranean Action Plan and the Black Sea Commission Action Plan. For data and databases, this implies more elaborated data harmonization schemes between the different databases associated with the different action plans.

In this context, open science could play a fundamental role. Scarce existing data must become findable, accessible, interoperable, and reusable (FAIR) to provide stakeholders and decision-makers with the instruments to evaluate and understand how to improve the available information and support decisions based on the best set of existing information [19]. Since 2009, the European long-term initiative EMODnet Chemistry has provided access to marine data and products from various disciplines to provide high-quality information supporting research and stakeholders' mission and objectives. Data related to pollution (eutrophication, hazardous substances, or marine litter) are collated,

validated, and published using standard protocols, formats, and vocabularies developed by the SeaDataNet infrastructure so that the data can be FAIR. When data fairness is promoted, larger spatio-temporal datasets are available to enable further assessments and studies to be conducted (e.g., [20]).

In relation to marine litter, standard formats and common vocabulary services have been developed based on existing best practices and guidelines for marine litter monitoring and research (e.g., [17]), structuring a detailed and qualified data management system focused on coastline macrolitter, seafloor macrolitter from trawling and floating, and sediment microlitter [21]. Some of these data and metadata were used to calculate the first beach litter baselines based on harmonized and FAIR datasets (2012–2016). The direct involvement in the data management of the monitoring efforts, as performed currently through EMODnet for microlitter, might bring even better results. All steps taken to ensure fairness and data quality are crucial to providing high-quality information for environmental assessment and evaluation of the mitigation measurements. At the same time, the analysis of data for map generation is an important post-ingestion mechanism to further improve the quality of data and the discrepancies in data values.

The existence of a well-structured data management system for marine litter, dealing with data from all European seas and coastlines, seems to be an optimal context for FAIR data availability in the Mediterranean basin that would contribute to research, policy implementation, and pollution prevention. However, in the Mediterranean, data availability is scarce due to various reasons.

In this article, we aim to explain how EMODnet has contributed to FAIR data availability in the Mediterranean, the weak points in data accessibility, and the opportunities for further improvement.

2. Materials and Methods

Over the years, EMODnet Chemistry has consolidated a workflow to provide access to marine chemistry data sets and derived data products on eutrophication, ocean acidification, contaminants, and litter [22]. The selected parameters are relevant to the MSFD, particularly for descriptors 5, 8, 9, and 10.

Descriptor 10 sets criteria to ensure that marine litter does not harm the coastal and marine environment within the European Union. It includes four criteria for the assessment of the Good Environmental Status (GES) of European waters, i.e., "composition, amount, and spatial distribution of litter on the coastline, in the surface layer of the water column, and on the seabed" (D10C1), "the composition, amount, and spatial distribution of microlitter on the coastline, in the surface layer of the water column, and in seabed sediment" (D10C2), "the amount of litter and microlitter ingested by marine animals" (D10C3), and "the number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects" (D10C4). Commission Decision (EU) 2017/848 laid down the criteria and methodological standards for determining GES and for assessing the status of marine waters. It requires for D10C1 that litter on the coastline be monitored, while litter in the surface layer of the water column and on the seabed may also be monitored. For D10C2, the microlitter must be monitored in the surface layer of the water column and in the seabed sediment and may be additionally monitored on the coastline [23].

In particular, EMODnet Chemistry hosts data regarding litter on the coastline (called "beach litter" hereafter) and the seabed (only from trawl surveys) and data on microlitter in the surface layer of the water column and in the sediment, contributing specifically to criteria D10C1 and D10C2 of the MSFD.

Litter data formatting follows the specifications outlined in the guidelines and forms that are available in the section of the EMODnet portal (https://emodnet.ec.europa.eu/en/marine-litter, accessed on 25 October 2023) and are regularly revised and updated. These specifications are the basis of the efficient data stream (Figure 1) to turn data FAIR-compliant and improve their quality thanks to the internal and external feedback circuits.

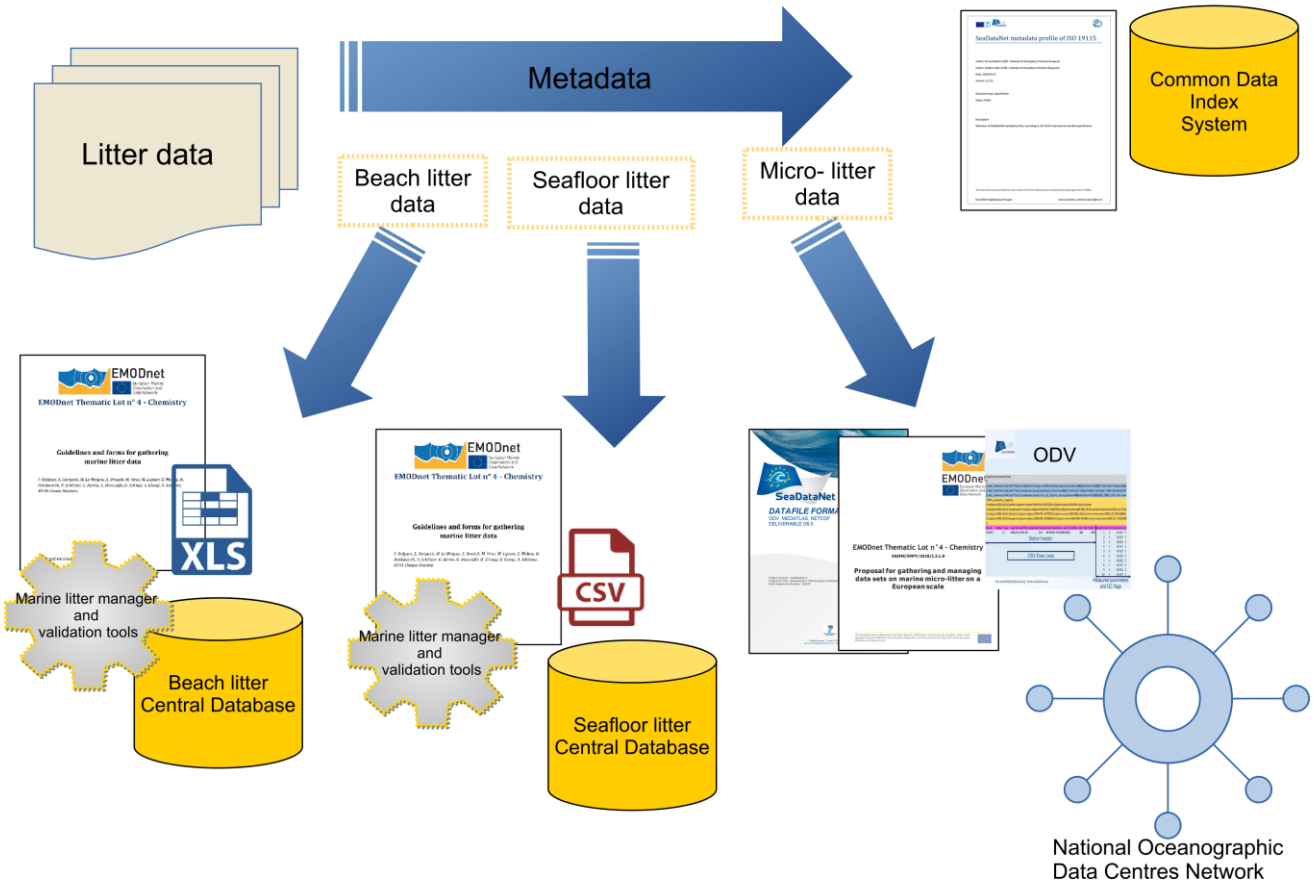

Figure 1. EMODnet marine litter data workflow (adapted from Partescano et al. [21]).

2.1. Marine Litter Data Workflow

The format allows for the inclusion of relevant information for monitoring and assessment purposes. Some of these fields are mandatory to include all the necessary details for data users (e.g., originator, coordinates, sampling effort); the lack of these details would avoid reproducibility or correct data reusability. The use of standard vocabularies has been implemented, paying attention both to the different monitoring initiatives, gathering the diverse particularities of the monitoring conventions, and harmonizing the terms used to describe the information. To perform this, the EMODnet infrastructure relies on the SeaDataNet vocabularies (https://vocab.seadatanet.org/search, accessed on 25 October 2023) and, for seafloor litter data, also on the ICES vocabularies (https://vocab.ices.dk/, accessed on 25 October 2023). Finally, the description of the data is based on the common data index metadata format, which is based on the ISO19139 XML schema to be compliant with the Infrastructure for Spatial Information in Europe (INSPIRE). Using common formats and vocabularies allows for the provision of homogeneous datasets that can be used to derive analyses and assessments.

To facilitate the correct format generation of beach and seafloor litter data, an open-source data formatting tool was developed in Python (Marine Litter Manager (https://github.com/nodc-it/marine-litter-manager, accessed on 25 October 2023)). The tool follows the specifications of the official guidelines mentioned above. It is available for Linux and Windows, and video tutorials are provided to facilitate its use.

After the formatting process, the data are ready to be checked with the online validation service on the EMODnet Chemistry website (https://emodnet.ec.europa.eu/en/marine-litter#beachlitter-formatvalidator, https://emodnet.ec.europa.eu/en/marine-litter#seafloorlitter-formatvalidator, accessed on 25 October 2023) before ingesting data in the centralized database.

A centralized PostgreSQL database was developed in 2018 for beach and seafloor litter data. The PostGIS spatial extension has allowed for the inclusion of several additional pieces of information regarding maritime spatial delimitations (e.g., marine MSFD regions and subregions). The development of a web service in Java code using Spring and Hibernate technologies has made it possible to implement a useful input data validation service through checks that verify syntactic and semantic correctness [21]. Through the mapping of the entities and relationships of the database in an object language, it was also possible to automate the insertion and extraction of data effectively and efficiently. The web service is able to manage HTTP requests (GET/POST), which allow the data present in the database to be retrieved and updated, making the contents of the database more easily accessible to the user; this simplifies the work and prevents most of the more frequent errors. This procedure allows for making specific extractions to fulfill the requests of stakeholders (e.g., Baltic beach litter assessment based on data collated by EMODnet or EU marine beach litter baseline and threshold calculations).

Data are loaded into the central Marine Litter Database (MLDB) after a semi-automated pre-ingestion validation phase, as described in the previous paragraph. Once loaded, a data analysis is performed in order to check for consistency. The potential errors are corrected thanks to a feedback loop with data originators.

Conversely, for microlitter data, the management system is distributed. This means that data assembly and preservation are carried out on an individual basis by each one of the National Oceanographic Data Centers from 45 research and monitoring institutes that work together to provide access to standard oceanographic data [24,25]. Currently, microlitter data entered into EMODnet Chemistry complies with formats and vocabularies' requirements, using the instruments and tools (https://www.seadatanet.org/Software, accessed on 25 October 2023) developed over time by the SeaDataNet infrastructure. Stakeholders' requirements and the desire to improve data quality push EMODnet to improve the instruments and upgrade the existing ones (e.g., spatial filter by MSFD regions available in the Ocean Data View software v.5 (https://odv.awi.de/en/software/download/, accessed on 25 October 2023)).

All data are accessible through the EMODnet Chemistry Data and Discovery Access Service (https://cdi-chemistry.seadatanet.org/search, accessed on 25 October 2023).

Based on data collection, delivered approximately every two years, EMODnet Chemistry has the additional objective of providing aggregated datasets and thematic visualization services to show the data collected in the infrastructure. All products (maps and unrestricted parts of the aggregated collections) are described by specific metadata published in the Sextant (https://sextant.ifremer.fr/eng/Data/Catalogue#/search?isTemplate=n&from=1&to=30&any=EMODnet%2520Chemistry, accessed on 25 October 2023) metadata catalog based on the Geonetwork open source, which provides essential information as the institutions that contribute to the collection as originators of data to enable appropriate credit.

2.2. Aggregated Collections

Aggregated datasets are extremely useful resources from several points of view. For users, it is an easy way to have all available data in a single file with the same format and codified using the same standard terminology. It also provides stakeholders with objective information on the spatial and temporal coverage and data comparability. Finally, the use of these datasets allows for the improvement of the quality control of the data thanks to the data analysis and feedback from users and stakeholders.

Data policy allows for the regulation of access to data to protect the rights of researchers while giving access to data, metadata, and data products. In this way, from each data collection, the unrestricted part is published as an aggregated data collection.

For beach litter, the data available in the system are brought together into a standardized, harmonized, and validated dataset provided as the generic EMODnet beach litter data format, which is a spreadsheet composed of 4 sheets: beach metadata, survey metadata,

animals, and litter. It contains litter data from monitoring, research, and citizen science. A relevant part of the monitoring data has been considered for assessment purposes by the European institutions and, therefore, is tagged as "MSFD_monitoring". Litter items are described using 5 different reference classifications: Joint List of Litter Categories for Marine Macrolitter Monitoring [26], OSPAR guidelines for beach litter monitoring [27,28], TSG-ML Guidance on Monitoring of Marine Litter in European Seas [29], UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter [30], MARLIN—litter monitoring and raising awareness [31], and an Italian reference list according to the monitoring program for the marine strategy of the Italian Ministry of Environment (Programmi di Monitoraggio Per la Strategia Marina Art. 11, D.lgs. 190/2010). The last published one (https://doi.org/10.13120/7f2da2d4-3e14-4925-804e-d6b12e240f3a, accessed on 25 October 2023) contains unrestricted data from 1384 beaches, and the time span is up to 2022.

The seafloor litter aggregated dataset contains harmonized data in the EMODnet seafloor litter data format, which is a csv file with tab-delimited values that provide information related to data sources, sampling protocols, and reference lists used. The non-restricted set (https://doi.org/10.13120/d98b57be-e6b5-4081-9464-da773d3209b9, accessed on 25 October 2023) contains data up to 2022 and includes data collected using several protocols and reference lists of litter items: International Council for the Exploration of the Sea manual for Seafloor Litter Data Collection and Reporting from Demersal Trawl Samples [32], International Bottom Trawl Survey in the Mediterranean (MEDITS) [33], TSG-ML Guidance on Monitoring of Marine Litter in European Seas [29], and DeFishGear Methodology for Monitoring Marine Litter on the Seafloor (continental shelf) [34].

Regarding floating microlitter, the aggregated dataset contains harmonized and validated data on floating microlitter. The parameters (e.g., sampling effort, depth, count) are described using the SeaDataNet parameter usage vocabulary (https://vocab.seadatanet.org/p01-facet-search, accessed on 25 October 2023) (P01), while the categories of microlitter properties (morphology, size, material, color, transparency) are consistent thanks to the use of "H" vocabularies (https://vocab.nerc.ac.uk/search_nvs/H01/; https://vocab.nerc.ac.uk/search_nvs/H03/; https://vocab.nerc.ac.uk/search_nvs/H04/; https://vocab.nerc.ac.uk/search_nvs/H05/; https://vocab.nerc.ac.uk/search_nvs/H06/, accessed on 25 October 2023) that define the different properties in a standard way. Each measurement value has a quality flag indicator. A harmonization process was performed with the Ocean Data View (ODV) software v.5 to express variable values with a limited number of measurement units and to standardize parameter names and reporting properties. The latest version (https://doi.org/10.13120/6621ec8c-a825-47cd-8cd8-4f7b990241be, accessed on 25 October 2023) of the public dataset is based on information up to 2021. It can be downloaded as an ODV collection and spreadsheet (txt format, tab-separated values) that can be opened with the ODV software for visualization.

Each collection is described through a metadata record that allows for the proper acknowledgment of the source data. These metadata descriptions are available through the Products Catalog (https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search, accessed on 25 October 2023), which is a Catalog Service for the Web (CSW).

2.3. Visualization Products

EMODnet marine litter visualization maps are built on the aggregated collections and designed to attempt a homogeneous representation of the data within the limits of compatibility of data sampling methodologies. Furthermore, this exercise works as an additional data review and analysis method, improving data quality by detecting errors or missing information. If any anomalies are detected during the map generation (e.g., coordinate or unit errors), they are reported to the author, who will update the data if necessary.

The aggregated collections are imported into a PostgreSQL database to generate a specific view for each product using queries in SQL (structured query language).

Once each view has been generated in the database, it can be published with Mapserver OGC services: Web Map Services (WMSs) for product visualization with the associated graphic semiology (symbology, labeling, legend, etc.) and Web Feature Services (WFSs) to download the current version of the data available in the specific product. These web services are produced using Mapserver. Maps can be visualized through a map viewer (https://emodnet.ec.europa.eu/geoviewer, accessed on 25 October 2023), and the associated metadata descriptions are in the Products Catalog (https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search, accessed on 25 October 2023). The whole process is diagrammed out in Figure 2.

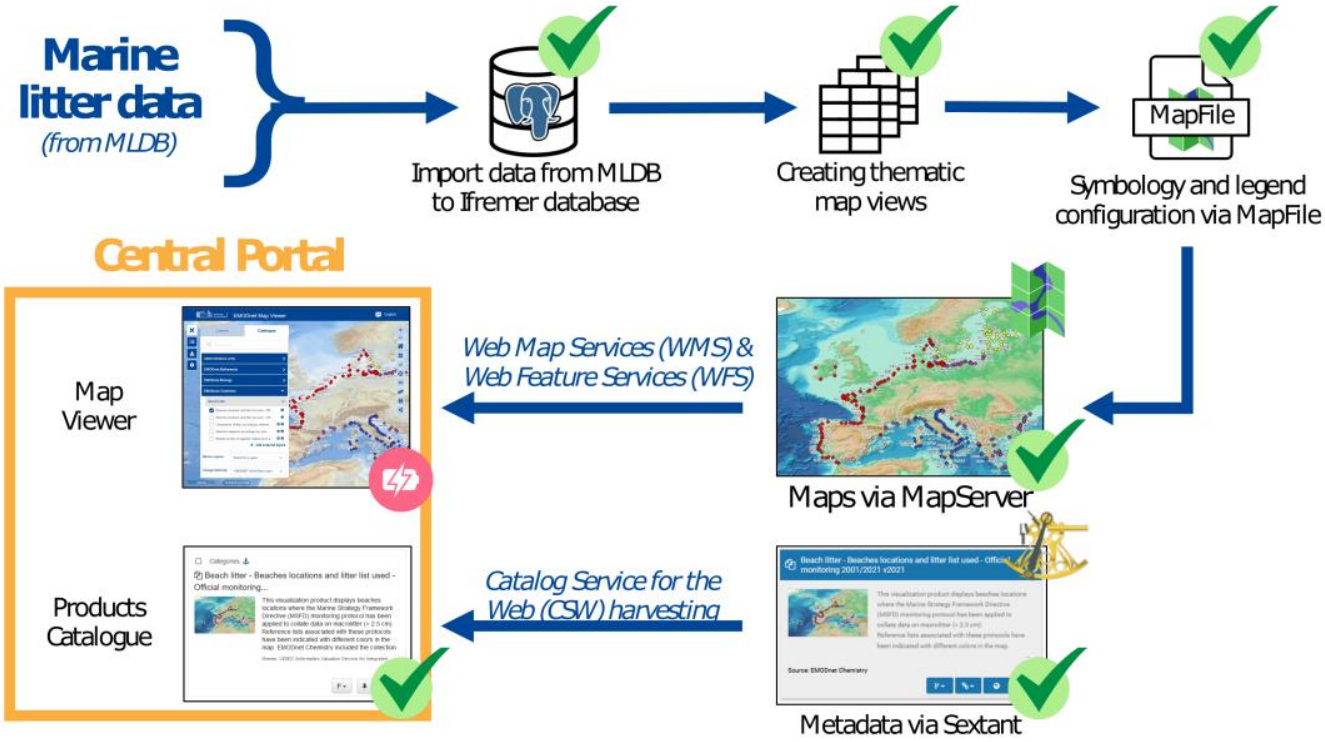

Figure 2. Visualization products' development procedure.

For beach litter, products are mainly related to the following: total abundances of litter per beach and year; percentage of material categories per beach and year; and specific thematic products related to some litter macrocategories, i.e., smoking-related items, fishery- and aquaculture-related litter items, plastic bag-related items, and single-use plastics-related items. To facilitate the identification of data from MSFD monitoring, a distinction was made in relation to other types of surveys (research, cleaning, and other monitoring protocols). In all the products, data were normalized, and certain assumptions were needed, but the methodologies to develop the products are public and accessible through specific metadata.

The maps regarding seafloor litter concern the location of the trawling and the gear used, the percentage of material categories in the trawling, the density of seafloor litter per trawl per year (total and for the above-mentioned specific thematic macrocategories), and spatial distribution density maps using a grid of 30 km × 30 km. Partially based on the methodology of Garcia-Rivera et al. [35], this gridded spatial distribution density is calculated using the weighted mean of seafloor litter densities in each cell. The cell size has been defined to provide a representation adapted to the European scale while maintaining a relatively high resolution.

The microlitter maps are the most recent ones and, up to now, show the sampling location and mesh size used, the density of microlitter per sampling device considering the different reporting units (i.e., number of items per km^2, in grams per km^2, or in number of

items per litter), the distribution of the classes of the microlitter properties (type, size, color, and transparency), and the spatial distribution of microlitter total abundance density per year (using a similar methodology as described for seafloor).

3. EMODnet Chemistry Contribution to Litter Data Availability in the Mediterranean

Thanks to the whole workflow presented above (Figure 1), there is a reasonable amount of FAIR litter data collected in the Mediterranean available in the EMODnet Chemistry infrastructure (Figure 3).

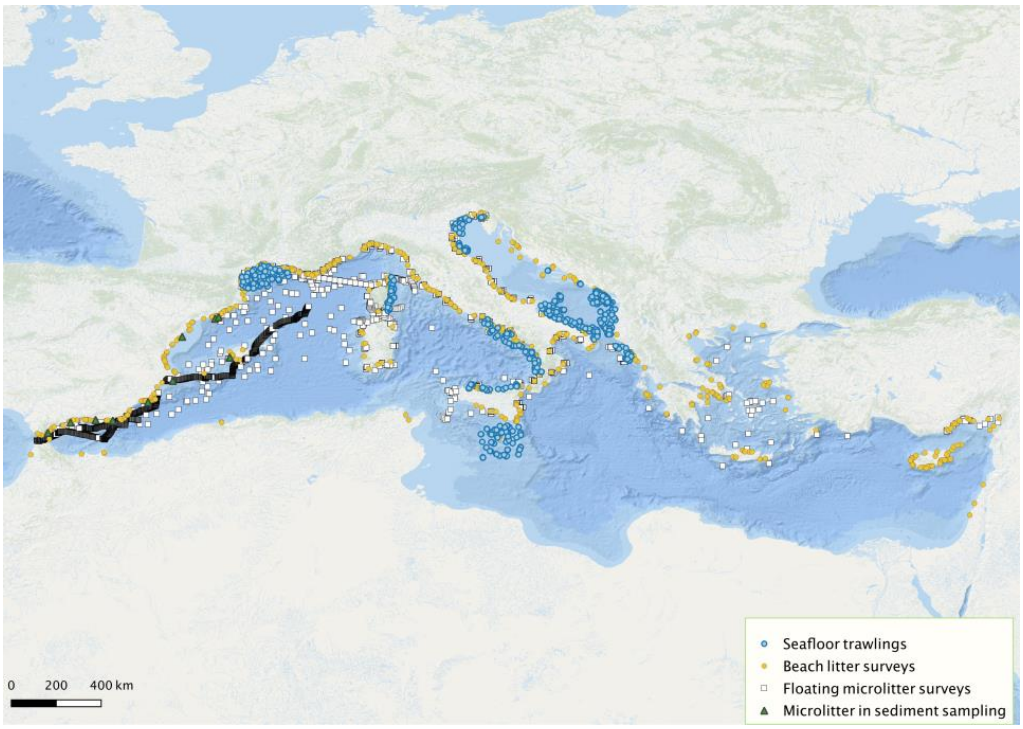

Figure 3. Data distribution of litter data in the Mediterranean basin accessible through the EMODnet Chemistry infrastructure.

At the moment of writing this work, the database hosts around 4000 beach litter surveys from 8 EU countries along the Mediterranean coastline that span from 2001 to 2022, representing almost 30% of the whole database. Around 80% of the data are part of the official monitoring programs and are used for assessment purposes. The additional 20% are mainly from research institutions and non-governmental organizations that have carried out surveys for research, non-official monitoring, or cleaning purposes.

As described before, the EMODnet data format for beach litter is quite extensive. Specific metadata fields to accommodate metadata regarding the beaches and the surveys were included to facilitate the inclusion of detailed information regarding the sampled sites, which is very useful for the assessments. However, this information is not always provided. The Mediterranean data cover 615 beaches, but only about half indicate the topography, orientation, urbanization degree, or material composition.

Microlitter data in EMODnet Chemistry is by far the youngest topic. In addition, it is a complex topic (similar to data on contaminants), where all the subjects, from the methodological aspects to the monitoring protocols, are evolving exponentially, which means that formats and vocabularies require the same degree of evolution. Up to now, the floating microlitter dataset in EMODnet comprises around 3000 surveys in the Mediterranean, collected between 2011 and 2021 and provided by institutions from five different EU countries (France, Germany, Greece, Italy, and Slovenia). Monitoring, research, and data from citizen science initiatives converge in EMODnet, contributing 37% of the data to the whole microlitter dataset. The data report microlitter features as material or polymer type

when known, morphology, color, or transparency. Information concerning the sampling device is frequently indicated. In more than half of the data, the instrument is a manta trawl, which is, at present, the most used device for floating microlitter samplings [36].

Unlike beach litter, the number of data points related to seafloor litter present in the EMODnet Chemistry database is very poor for the Mediterranean area. It hosts around 1500 hauls from EU countries, from a time range of 2012–2022, representing around 6% of the data held in the whole database. These data mainly belong to the DeFishGear project and the International Bottom Trawl Survey in the Mediterranean (MEDITS) initiative and have been made available to EMODnet thanks to the particular support of some EU institutions and countries (Croatia, France, Greece, Italy, Malta, and Slovenia). The data have been collected following MEDITS [37] and DeFishGear [38] protocols, using different gear types (GOC73 and commercial bottom trawl nets), with different litter reference lists of items (MEDITS and TSG-ML), and different methods for calculating sampling effort (trawled area). This makes collation and data harmonization ambitious but also provides the opportunity to put existing data together under the same conditions, giving the same background level of homogenization to the whole dataset.

4. Results

Despite its recent arrival at EMODnet, data information management for marine litter has rapidly evolved. Thanks to the combined efforts of the EMODnet network, the Joint Research Centre, and the European member states since 2017, marine litter information data management has picked up incredible steam.

Beach litter datasets mainly come from consolidated fit-for-purpose monitoring. The harmonization of the data for the period 2012–2016 was challenging, considering the heterogeneity of the data sources, the sampling protocols, and reference lists used at the European level (only for the Mediterranean data, items are reported over time using five different lists). Nevertheless, this step has been essential to highlight data features, strengths, and weaknesses and identify the reasons that hinder data from being comparable.

In 2021, a significant milestone in data harmonization occurred with the release of the "Joint List of Litter Categories for Macrolitter Monitoring" [26], referred to as the Joint List. The Joint List was developed by the MSFD Technical Group on Marine Litter in close collaboration with member states, regional sea conventions, non-governmental organizations, and the European Environmental Agency. This comprehensive list encompasses various litter types present in coastal and marine environments. The Joint List builds upon the foundation laid by the "Master List", published in 2013 by the TSG-ML [29]. The "Master List" successfully merged litter types from different marine litter monitoring lists (OSPAR, ICES, UNEP, etc.) into a unified resource. Benefiting from the insights gained through the Master List within the MSFD implementation context, the Joint List has been meticulously crafted, resulting in an updated, refined, and finely tuned inventory of litter items found in the coastal and marine environments.

A further step toward data harmonization is represented by the recent update of the "Guidance on Monitoring of Marine Litter in European Seas" (under publication at the moment of writing this work). This updated guidance aims to assist member states in meeting new decision requests by providing a comprehensive overview of state-of-the-art methodologies for monitoring marine litter. It includes a dedicated chapter focused on beach macrolitter monitoring, proposing a standardized approach to evaluating beach litter across all European regional seas. This harmonized method ensures that monitoring data from coastal litter assessments remains consistent, compatible, and comparable within and across different regions.

Seafloor litter data for the Mediterranean, available through the EMODnet platform, are scarce at the moment and derive from project-based monitoring (the DeFishGear project) and fishery surveys (MEDITS), which do not specifically addressing marine litter [13,39]. Theoretically, the existence of a widespread monitoring campaign (MEDITS, see [37]) using the same type of gear should provide a good basis for data comparability. Unfortunately,

so far, the data collected have not been shared with EMODnet or other platforms, with just a few exceptions, leaving a large set hidden from becoming FAIR.

Microlitter is the newest and most difficult topic. The properties for characterizing microparticles using the EMODnet format have been established based on consolidated monitoring and research protocols, covering features such as morphology, size, color, transparency, and material. Analytical methodologies are evolving and require adaptations in formats and vocabularies (e.g., the description of each particle's properties instead of describing data aggregated into categories). Data are not currently comparable due to differences in sampling and measurement procedures and data reporting [36]. The comparisons with harmonization initiatives, like the EuroQcharm project, and already existing initiatives aiming to operate at a global level, like the microlitter portal prototype developed by the Ministry of Environment of Japan, are providing crucial insights to understand the minimum metadata requirements to be able to make an efficient data comparison.

5. Discussion and Conclusions

Marine litter monitoring status and the related data management experience are quite heterogeneous from different points of view.

For beach litter, there are already consolidated national and regional programs with agreed protocols and litter item lists describing what is monitored, providing quite significant and available time series of data. In this case, the efforts of these and future years are more focused on how to use the already existing information for analysis that can be significant at the EU level.

For some other topics, like seafloor litter from trawl surveys, there are also well-established monitoring programs in some areas, while in others, there are less consolidated large-scale monitoring programs, like in the south of the Mediterranean. For the seafloor, the challenges are more linked to the heterogeneity and scarcity of data. Furthermore, recent research suggests that the data on seafloor litter collected through trawling in fishery surveys may not accurately reflect the actual extent of litter on the seafloor. These studies also underscore notable variations in catch rates among different types of fishing gear (e.g., [40,41]). Among the gear types, one key distinction is the degree of interaction with the seafloor. The MSFD Technical Group on Marine Litter has been tasked with establishing baselines and threshold values for marine litter, including seafloor litter. A comprehensive approach is necessary to achieve this environmental threshold for seabed litter and ensure compliance with the MSFD. This approach includes the development of a mutually agreed methodology, the establishment of a sustainable monitoring system, and consensus on the threshold values [42].

Besides the comparability of data from trawling, spatial coverage is another hindrance to this kind of monitoring [13]. Trawling is limited to rather restricted areas, and interpolation might not be representative as litter distribution is heterogeneous due to multiple reasons [38]. Additional technologies based on images are already in place, both exclusively [43–45] or in combination with trawling surveys [46].

The quick development of new monitoring techniques based on images might improve data availability and comparability, especially for seafloor litter monitoring. It is important, though, that the new monitoring approaches are designed to take into account metadata, data, and reporting units to promote the comparability of data. Imaging technologies can be used for multidisciplinary purposes, making the use of the same surveys for biological and marine debris studies possible [45,47,48]. Some imaging technologies can be considered quite cheap, like shallow water monitoring with scuba divers or tow cameras, while the use of ROVs and AUVs for deep environments is really expensive. In addition, the interpreting tools are still quite far from being optimized. The already existing proposal to gather this new type of data, available in EMODnet (https://emodnet.ec.europa.eu/en/tools-guidelines, accessed on 25 October 2023), and the involvement in the present activities of a collaborative framework [13] to establish a monitoring system based on images constitute

the starting point in EMODnet for the development of a new data format for collecting litter data from images and the appropriate management system that might be implemented in the medium term to allow for the management of this new data type.

For microlitter monitoring, the situation is still not so consolidated and is under active discussion due to the youth of the topic and the complex and evolving situation of the measurement methods to ensure the generation of comparable data. The involvement of data management in this early stage might bring even better results by trying to refine in parallel the monitoring methods and the related data management formats and tools.

The peculiarity of the Mediterranean basin, where several data management processes converge (e.g., one related to the EU member states within MSFD, where EMODnet is highly involved, and another one to address basin-scale data on marine litter with non-EU countries, correlated to IMAP (http://imappilot.info-rac.org/app/#/, accessed on 25 October 2023), urgently requires a joint effort for interoperable and harmonized data processing that would benefit all actors.

This article provides a broad view of marine litter data management in EMODnet Chemistry, with a focus on the Mediterranean area. The availability and accessibility of these data are very significant. In the Mediterranean basin, there is consistent activity on litter research [49], and there are multiple small-scale studies conducted on project-based initiatives [37,38,50,51], research based on the existing limited-scale studies [52,53], and even online databases (https://litterbase.awi.de/, accessed on 25 October 2023) of marine litter studies. However, the number of regional studies based on the existing available data is really scarce [52], reporting in some cases the difficulties in finding data [54]. The contribution to long-term data infrastructures provides fertile ground for better research and assessments, increasing the data and their quality thanks to the principle of "collecting once and use many times". Information from these assessments will assist in developing local and global policies as well as devising management strategies to reduce and prevent marine pollution.

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Abbreviations

AUV	Autonomous Underwater Vehicle
CSW	Catalog Service for the Web
EMODnet	European Marine Observation and Data Network
EU	European Union
FAIR	Findable, Accessible, Interoperable, and Reusable
HTTP	Hypertext Transfer Protocol
ICES	International Council for the Exploration of the Sea
IMAP	Integrated Monitoring and Assessment Programme
INSPIRE	Infrastructure for Spatial Information in Europe
MEDITS	International Bottom Trawl Survey in the Mediterranean
MLDB	Marine Litter Database
MSFD	Marine Strategy Framework Directive
ODV	Ocean Data View
OGC	Open Geospatial Consortium
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
ROV	Remotely Operated Vehicle
SQL	Structured Query Language
TSG-ML	MSFD Technical Group on Marine Litter
UN	United Nations
UNEP	MAP Regional Seas Programme of the United Nations Environment Programme
WFS	Web Feature Service
WMS	Web Map Service

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