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Citizen Science approaches for beach litter monitoring

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Index

PREFACE 2

THESIS SUMMARY 3

1. INTRODUCTION 4

2. AIM OF THE STUDY 7
2.1 Summary of the studies 7

3. MARINE STRATEGY and EUROPEAN CONTEXT 9

4. MAC EMERSO CITIZEN SCIENCE PROTOCOL 13
4.1 The role of Citizen Science 13
4.2 The MAC-Emerso protocol 14

5. MAIN RESULTS and DISCUSSIONS 17
5.1 Scientific knowledge on marine beach litter: A bibliometric analysis 17
5.2 Marine beach litter monitoring along Mediterranean coasts 18
5.3 Field activities: the MAC-E pilot campaign 20

6. SCIENTIFIC PAPERS 25
6.1 Cesarano et al., 2021 – *Marine Pollution Bulletin*, 173, 113102 25
6.2 Cesarano et al., 2022 – submitted to *Marine Pollution Bulletin* 45

7. CONCLUDING REMARKS 84

ADDITIONAL PRODUCTS 86

REFERENCES 87

PREFACE

This research thesis was submitted to the Università Politecnica delle Marche for the Doctor Philosophy Degree (PhD) in "Life and Environmental Sciences", PhD Curriculum: Civil and environmental protection. The research project was carried out at Università Politecnica delle Marche and along the Campania region coast, where the Citizien Science activities were realized in collaboration with the no-profit association "Progetto Terra". The PhD project not received financial support.

The principal aim of this PhD thesis, entitled "Citizen Science approaches for beach litter monitoring", was to examine how and to what extent the scientific world is addressing the issue of marine beach litter monitoring and how much Citizen Science can be useful to this purpose.
In this framework, an innovative Citizen Science method was also applied to beach litter monitoring, i.e. the Mac Emerso protocol. A pilot campaign was realized in Ascea Marina, in the Cilento National Park, training and involving several children and teen-agers as volunteer young scientists. Unfortunately, during the COVID-19 pandemic, the planned monitoring activities were severely limited by national and regional regulations. Thus, the pilot activities were not followed by the expected regular, repeated, seasonal surveys.

This PhD project has been possible thanks to the support of many people who have contributed to this activity of research. In particular, I would like to express my sincere gratitude to my main supervisor Dr. Stefania Puce and my co-tutor Dr. Carlo Cerrano for their continuous guidance and useful knowledge.
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Sincerely,
Cinzia Cesarano

THESIS SUMMARY

This thesis entitled "Citizen Science approaches for beach litter monitoring" focuses on Marine Beach Litter (hereafter MBL).
MBL represents a huge problem that concerns scientific, economic, and social areas. During the first year of my PhD, a pilot citizen science activity was organized and realized for monitoring beach environment with primary and secondary school students, using the MAC-Emerso protocol. The collected observations were included in the official MAC-Emerso database. During the second year, a bibliometric analysis on the MBL topic has been completed and the achieved results have been organized for publication in a peer-reviewed journal. Furthermore, a preliminary analysis of the available national MAC-Emerso database was carried out. The third year was devoted to compile previous studies and programs focusing on MBL monitoring and clean-up campaigns along the Mediterranean coastline. All the methodologies applied to date have been analysed and compared in detail to identify strengths and weaknesses of current protocols, citizen involvement, and existing gaps.

The present thesis consists of eight chapters and two papers and opens with a general introduction describing Marine and Beach Litter (***Chapter 1***). ***Chapter 2*** discusses the overall aim of the PhD research, and summarizes the papers included in the PhD thesis. ***Chapter 3*** examines in detail the Marine Strategy, while ***Chapter 4*** focuses on Citizen Science and the MAC-Emerso protocol. ***Chapter 5*** describes the main results achieved, including the pilot citizen science activity organized and realized for monitoring beach environment with primary and secondary school students using the MAC-Emerso protocol. ***Chapter 6*** includes the collection of the two scientific papers on MBL realized during the PhD activities. The first paper (Cesarano et al., 2021) has been published in *Marine Pollution Bulletin* (with Q1 ranking), while the second paper has been recently submitted to the same journal. The former explores the global scientific literature on MBL through an accurate bibliometric analysis. The latter presents a systematic review of current literature concerning MBL monitoring along the Mediterranean coasts. Together, they do provide a comprehensive review of the scientific knowledge on MBL in the Mediterranean region and offer interesting insights to understand where current gaps lie, and what would be needed to develop a basin-scale more efficient monitoring in support of our efforts to tackle the MBL challenge.
Finally, a concluding remark of the overall results achieved in the present study is elaborated in ***Chapter 7.*** A note about the other products not included in this thesis, but performed during my PhD period, follows. Then, a reference list of the studies mentioned through the thesis ends this document.

1. INTRODUCTION

The global oceans cover more than 70% of the planet surface, collecting about 97% of the Earth's water. Considering their volume, they also offer 99% of the habitable space on the planet, hosting an uncountable richness in terms of biodiversity. From a different perspective, they also offer, and support, vital services for humans, such as food provision, climate regulation, transport pathways and recreation. They provide habitat for marine organisms that produce more than half of the oxygen we breathe and absorb one quarter of the annual human-induced CO_2 emissions into the atmosphere, being the greatest reservoir of actively cycled carbon on Earth (about 50 times larger than the atmosphere). Therefore, protecting the marine environment is not only crucial for the conservation of biodiversity but also for the survival and wellbeing of humans and the planet itself. It is also crucial for the economy and for avoiding the increase of social disparities in different places of the world. Nevertheless, the marine environment and its ecosystems are still subject to multiple pressures from human activities (e.g., fishing, pollution, global warming), whose impacts are dramatically increasing in the last decades. As a response to this global threat, the EU designed the Marine Strategy Framework Directive (MSFD), a holistic policy to protect the marine environment of the seas around Europe and to support the sustainable use of marine natural capital and services.

Sandy beaches and dunes are iconic environments that dominate the open ocean shorelines (Rodil et al., 2022). Their attractive natural environment facilitates human settlement and favours economic activities such as recreation and tourism, fishing and transportation (Schlacher et al. 2008), so that they end up hosting higher densities of human settlement compared to inland areas (Small and Nicholls, 2003). Therefore, beaches have been particularly linked to human history and activities due to the provision of ecosystem services from which people obtain many benefits (Rodil et al., 2022), including income-generating services that can strengthen local and national economies (Stronge, 2005; Houston, 2013). From a natural perspective, beaches and coastlines host a large variety of organisms that perform numerous supporting and regulating services, e.g., water filtration and nutrient cycling (e.g., Lastra et al., 2008; Dugan et al., 2011; Rodil et al., 2019). On the other hand, it is important to remark that the delivery of these beach ecosystem services is largely related to the ecological condition of this environment, and that the value of some of these services is sometimes difficult to quantify in economic terms, especially where the benefits are intangible (Rodil et al., 2022). Unfortunately, they have also been recognized as ecosystems only recently (McLachlan and Erasmus, 1983), so that their management has been historically built on a poor understanding of their ecological importance. All these factors combine into management policies that frequently result inappropriate or self-defeating. This commonly happens when shoreline management neglects one or more critical ecological processes that connect systems across the ecotone (Rodil et al., 2022), eventually causing cumulative impacts to the shore as a consequence of natural (e.g., extreme weather events, sea level rise) or anthropic (e.g., waste spill, touristic overexploitation) stressors.

One of the most common and widespread human stressors is probably marine litter. Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (Cheshire et al., 2009; MSFD GES Technical Subgroup on Marine Litter, 2013). It includes items or fragments that have been directly discarded on the beaches (e.g., coastal and beach tourism, recreational activities), those that have been somehow transported from land to the sea (e.g., households, agriculture, illegal dumping, input by rivers, wind and land run-off) and those coming from ocean-based sources (e.g., storm water overflows, off-shore industries, commercial shipping, fisheries, port activities and boating). It can also be transported over long distances by ocean currents before being deposited, so that it is found in all marine compartments such as beaches, on the shallow and deep seafloor, in the sea surface layer and in the water column, in sediments and seaice, in the biota (Law, 2017; Addamo

et al. 2017). Thus, the marine environment can be considered as a sink in which anthropogenic litter accumulates (Van Acoleyen et al., 2013) coming from land-based and offshore sources (Veiga et al., 2016).
This implies that marine beach litter (MBL) found in a given area can be of local origin, can arrive from inland or can be transported from distant regions via ocean currents and the prevailing wind. Source and origin identification is usually very difficult, especially when the litter items are fragments resulting from the disintegration of larger items that spent long time along the pathways system. This is the case of microplastics (i.e., small pieces of plastic litter < 0.5 cm in diameter, Arthur et al., 2009) that represent a serious global problem causing harm to marine wildlife, coastal communities, and maritime activities (Veiga et al., 2016).
Due to their persistent nature and their potential to cause undesirable effects, MBL has detrimental impact on marine biota at different levels of biological organisation and habitats, environment, human health, as well as economy (Gall and Thompson, 2015; Schneider et al., 2018; Agamuthu et al., 2019). Marine litter can also act as a vector for spread of invasive species altering or modifying assemblages of species (Kiessling et al., 2015; Werner et al., 2016) or as vehicles for chemicals and contaminants, which may be absorbed on to their surface (e.g., phthalates, polycyclic aromatic hydrocarbons (PAH), brominated flame retardants (BFR), polychlorinated biphenyl (PCB), dichlorodiphenyltrichloroethane (DDT) – see Cole et al., 2011) and become bioavailable accumulating along the biological food chain (Li et al., 2016; Fossi et al., 2018). Finally, MBL is eyesore and aesthetically unpleasant causing landscape degradation and leading to a decline in tourism, and subsequent income loss, when washed ashore on beaches (Keswani et al., 2016; Pasternak et al., 2017). Therefore, whatever is our perspective, marine litter, including plastic debris, pose a serious threat to marine life, human health, and coastal economies (e.g., tourism, fisheries, etc.), causing harm to the environment and generating adverse economic, health and aesthetic impacts (Cesarano et al., 2021).

Generally, MBL monitoring constitutes a cost-effective methodology and its results can be considered someway representative of new litter entering the coastal environment. In particular, this is true for urban beaches and those geographically under the influence of specific activities and discharges (Van Acoleyen et al., 2013). Moreover, information on the temporal and spatial distribution of marine litter found stranded on beaches can be effectively provided by NGO and participatory science campaigns (UNEP/MAP, 2015; Hidalgo-Ruz and Thiel, 2015) that also encourage communities to take up action and fill in the knowledge gaps (Figueiredo Nascimento et al., 2016; Hanke et al., 2019; Vlachogianni et al., 2020).
From a historical perspective, the first studies on marine beach litter (MBL) were reported in the scientific literature in the 1970s (e.g., Gregory, 1977, 1978). Since then, several studies have aimed to quantify beach litter through monitoring programmes providing classifications based on items typology and abundance. Despite the growing interest in the last decade, also supported by international policy, different estimation approaches and methods have been applied which has led to vastly different results (Addamo et al., 2018; Schneider et al., 2018; Schulz et al., 2015, 2017; Williams et al., 2016; Vlachogianni et al., 2018). To reduce its impact, MBL collections such as beach clean-ups have been frequently conducted through government and citizen science initiatives in many countries (Agamuthu et al., 2019; Hidalgo-Ruz and Thiel, 2013, 2015).

Unfortunately, initiatives organized in different parts of the world have applied different methodologies and criteria for the collection and classification of MBL information (Cesarano et al., 2021). Several differences in how surveys are carried out exist, including: where data are collected (sample site), survey protocol, and survey effort (number of people participating and how much of an area is surveyed). Results collected by different organizations often fail to match and combining them is a challenge because data requires accurate standardization to be interpreted correctly (Hardesty et al., 2017; Vlachogianni et al., 2020).
In recent years a considerable effort has been made to create shared protocols to harmonize data collection in different areas of the globe (e.g., Jack et al., 2019) and improve the accuracy of information collected by

several organizations during volunteer beach cleaning events. In Europe, the Marine Litter Watch (MLW) mobile app, for example, aims to aid marine litter data collection on beaches, supporting official monitoring for MSFD, with the help of motivated volunteers. It was built by the European Environmental Agency (EEA) using the MSFD monitoring guidelines developed by the Technical Group on Marine Litter, a group of experts established to support the MSFD implementation. MLW provides methodologies and tools to support data collection events on beaches and other stretches of coastline, including un-official initiatives such as clean-ups, favouring the homogeneity of in situ observations between different areas. Many other national and local initiatives exist promoted by non-governmental organization (NGOs). For instance, the Italian NGO Reef Check Italia promotes in primary and secondary schools and Marine Protected Areas (MPAs) the application of a protocol based on random quadrats to quantify MBL along with beached natural products (Cerrano et al., 2011). Nevertheless, additional efforts are still needed to improve shared worldwide guidelines for MBL monitoring, removal and management activities and support the cooperation between academic and citizen science (Cesarano et al., 2021).

In this framework, even if no clear evidence of permanent garbage patches has been reported so far (Cózar et al. 2015), the Mediterranean Sea has been recognized as one of the most vulnerable areas in the world by MBL (e.g., Suaria et al., 2016; Grelaud and Ziveri, 2020). It is a semi enclosed basin whose coasts are threatened by critical anthropogenic pressures that sum up with intensive fishing and shipping, and slow waters turnover. Reducing litter in the Mediterranean coastal and marine environment is recognised as a priority challenge to preserve the ecosystem and human health, and avoid adverse economic and aesthetic impacts (Addamo et al., 2018). Specific measures have already been suggested for preventing further inputs and reducing the abundance of litter items. However, they strongly need the determination of marine litter composition and distribution patterns, as well as sources and, possibly, pathways (Addamo et al., 2017; European Commission, 2018a; 2018b). In the last decades, several scientific and participative initiatives have been conducted to study, monitor and clean-up the Mediterranean shorelines. Unfortunately, these studies were generally characterized by differences in timing and frequency of the surveys, as well as in litter sampling, classification and analysis. This issue has been widely analysed in the framework of this thesis and is discussed in the following chapters. The involvement of citizens in the monitoring of beaches resulted an economic and efficient strategy to collect useful data and improve our knowledge of the current state of coastal environments. Again, citizen participation was often limited to litter collection because of intrinsic difficulties in sharing protocols' methodologies and scientific approaches. Also, these aspects are addressed in the following sections.

2. AIM OF THE STUDY

The interest in MBL contamination and beach monitoring has increased considerably since the implementation of the MSFD. Accumulation, abundance, concentration, sources, as well as the possible effects on living organisms are complex phenomena that deserve further studies to be fully understood and characterized.
The overall objective of this study is to carefully analyse the state of the art on MBL and increase knowledge on which factors exert the greatest influence on its monitoring, then offering useful insights about existing gaps and pressing needs to tackle the MBL challenge.

To this aim, the following questions have been taken into account:
Is MBL an emerging problem? (Paper 1 and Paper 2)
How long has it been a problem for the attention of the scientific community? (Paper 1)
How active is the scientific world in this topic? (Paper 1)
In which parts of the world is the scientific community more attentive to these issues? (Paper 1)
How many studies are there in the Mediterranean region that address this issue? (Paper 2)
How homogeneous are the monitoring protocols used in the Mediterranean? (Paper 2)
What is the contribution of Citizen Science in Europe and the Mediterranean? (Paper 2)

During my PhD research activities a deep analysis on the discrepancies and similarities of the methodologies applied to date for monitoring MBL has been carried out. Scopus indexed studies have been analysed to identify existing protocols, understand where current gaps lie, and point out what would be needed to develop a basin-scale efficient monitoring for the Mediterranean Sea. The aim is to identify strengths and weaknesses of current protocols towards the goal of developing a homogenous methodology for MBL monitoring. This would help considerably statistical comparison between data collected in different areas and periods and could better support local, regional, national and international efforts to combat this threat. Although the COVID-19 pandemic, unfortunately, conditioned the completion of all the aspects of the planned work, most of the expected activities have been indeed successfully carried out during my PhD studies, as reported in this thesis. Among them, a pilot monitoring campaign using the Mac Emerso Protocol was planned and realized during summer 2019 (see details in ***Chapter 7***). This experiment involved several primary and secondary school students and was realized with the help of young trained volunteers of a no-profit association.

2.1 Summary of the studies

Marine litter is a growing problem for environmental and human health and policies have included monitoring as an important tool to evaluate both trends and the efficiency of reduction measures. The first objective of this paper is to present the work done so far, why it is important and which are the expectations for the future. This sub-section summarizes the two papers included in my PhD thesis which address this goal.

Paper 1: Scientific knowledge on marine beach litter: A bibliometric analysis
Litter reduction in the coastal and marine environment represents a major challenge but must be prioritized to preserve biodiversity and ecosystems, as well as the goods and services that humans derive from seas and oceans. This paper reviews the available global scientific literature focusing on marine beach litter and tracks its evolution and trends by combining social network analysis and bibliometrics. The relationships and co-

occurrences among authors, countries and keywords retrieved from the Scopus abstract and citation database are presented. A total of 1765 publications are analysed, the majority being journal articles. Results reveal the notable worldwide increase in scientific interest in beach litter in the last decade, as well as its multidisciplinary perspectives. This information could be beneficial for the processes that support the improvement of international efforts for beach litter monitoring, removal, and management activities.

Paper 2: Marine beach litter monitoring along Mediterranean coasts

Marine beach litter represents a serious issue for marine life, coastal ecosystems, human health and several economical activities. The Mediterranean Sea is a semi enclosed basin particularly vulnerable to this problem. Its coasts are threatened by critical anthropogenic pressures that sum up with intensive fishing and shipping, and the slow turnover of its waters. In the last decades, several scientific and participative initiatives have been conducted to study, monitor and clean-up shorelines. Unfortunately, these studies were generally characterized by differences in timing and frequency of the surveys, as well as in litter sampling, classification and analysis. This paper presents a systematic review of current literature concerning MBL monitoring along the Mediterranean coasts. Discrepancies and similarities among Scopus indexed studies are analysed to identify existing protocols, understand where current gaps lie, and point out what would be needed to develop a basin-scale efficient monitoring for the Mediterranean Sea.

3. MARINE STRATEGY and EUROPEAN CONTEXT

To understand the issue of MBL and coastal environment monitoring over the Mediterranean basin, it is necessary to deepen the European policy framework. The European MSFD has given a breakthrough to international scientific research by focusing attention on 11 descriptors capable of determining the main issues related to marine pollution.

The MSFD has been in force since 2008. It requires Member States to set up national marine strategies to achieve, or maintain where it exists, 'good environmental status' (hereafter GES) by 2020. The GES means that the marine waters are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is sustainable, thus safeguarding the potential for uses and activities by current and future generations. In addition, GES means that:

- Ecosystems, including their hydro-morphological (i.e. the structure and evolution of the water resources), physical and chemical conditions, are fully functioning and resilient to human-induced environmental change;

- The decline of biodiversity caused by human activities is prevented and biodiversity is protected;

- Human activities introducing substances and energy into the marine environment do not cause pollution effects. Noise from human activities is compatible with the marine environment and its ecosystems.

The MSFD is implemented in a six-year cycle with three major stages. First of all, Member States had to report in 2012 and 2018 on the status of their marine waters and set targets to achieve GES based on the 11 descriptors which cover the health of ecosystems, as well as the human pressures and impacts affecting them. Secondly, in 2014, Member States had to set up monitoring programmes to collect data in order to assess progress in achieving good environmental status and reaching targets. Thirdly, in 2016 Member States had to set up programmes of measures that would help them to deliver their objectives, whilst in 2018 they had to report on their progress in implementing these programmes.

To help Member States interpret what GES means in practice, the MSFD set out, in Annex I, eleven qualitative descriptors which describe what the environment will look like when GES has been achieved, as follows:

Descriptor 1. Biodiversity is maintained

Descriptor 2. Non-indigenous species do not adversely alter the ecosystem

Descriptor 3. The population of commercial fish species is healthy

Descriptor 4. Elements of food webs ensure long-term abundance and reproduction

Descriptor 5. Eutrophication is minimised

Descriptor 6. The sea floor integrity ensures functioning of the ecosystem

Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem

Descriptor 8. Concentrations of contaminants give no effects

Descriptor 9. Contaminants in seafood are below safe levels

Descriptor 10. Marine litter does not cause harm

Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Thus, the GES must be determined at regional or sub-regional level on the basis of these 11 qualitative descriptors. In this context, Descriptor 10 focuses on marine litter, stating that GES is achieved only when "properties and quantities of marine litter do not cause harm to the coastal and marine environment".

As a consequence, marine litter, directly linked to the occurrence of litter in the terrestrial and riverine environment, has received increasing attention and, based on assessments made through the MSFD and the regional sea conventions, has led to a swift preparation of legislative actions at EU level against single-use plastics and fishery-related litter, as well as a revision of the Directive on Port Reception Facilities for the delivery of waste from ships. As expected, the presence of litter has been confirmed in all compartments of the marine environment (shoreline, water column and seafloor), also confirming that plastic items represent the most abundant component of marine litter.

Unfortunately, progress in reaching GES has not been fast enough to cover all MSFD descriptors over the EU waters by 2020. Several factors may have contributed to this debacle. Among them, a prominent role can be ascribed to the complexity of monitoring, analysing, and managing the marine environment. In addition, missing, or limited, political efforts have been responsible of an inadequate economical and technical support to the positive completion of this process. Public funding was not relevant to the MSFD goals, whilst private sectors were only sporadically involved. The second cycle of MSFD implementation is now operative, with the responsibility of providing better regulation guidelines for reviewing the directive and favour the implementation of the European Green Deal, including its 2030 biodiversity strategy and zero pollution ambition. In this scenario, improving our knowledge on marine litter is fundamental. To this goal, further studies are necessary, including the development of appropriate and shared monitoring strategies to optimize the increasing efforts provided by scientific research and participative initiatives.

Actually, article 11 of the MSFD, regarding monitoring programmes from Member States, provides legally binding requirements for establishing and implementing coordinated monitoring programmes for assessment of EU waters environmental status. The monitoring indications for Descriptor 10 require measuring techniques of demonstrated accuracy. This must deliver relevant, reliable data on marine litter, at affordable costs, for assessing the environmental status, such as temporal and spatial trends; environmental target achievement levels; source identification; effectiveness of measures. A list of seven key requirements for monitoring programmes was then elaborated by MSFD in 2013, including:

- All protocols suggested are aimed mainly at assessing environmental status and environmental targets. They must supply quantitative data and allow the assessment of trends. The beach litter protocol is also designed to identify sources by using a detailed list of identifiable items

- The monitoring programmes have to be "coordinated", "compatible", "coherent", "consistent" and "comparable"

- Although difficult, build upon and integrate already established monitoring programmes already established.

- Data and information, resulting from the monitoring programmes, should be made available for interoperable use.

- Monitoring programmes need to adapt with appropriate reaction to changes in the marine environment and understanding of emerging issues.

- Monitoring must be linked to assessment needs, including the use of risk-based approach as a basis for flexible monitoring design. A complete analysis of risk should ideally include quantitative knowledge of harm

or assess where the amounts of litter are likely to be highest or the type of litter has the largest impact (e.g., microplastics).

- Differences in scientific understanding for each descriptor in the monitoring programmes must be considered and precautionary principle applied.

The Final Report "Guidance on Monitoring of Marine Litter in European Seas", the output of the work of the TSG-ML between 2012 and 2013, received these recommendations and provided useful information to commence the monitoring of the MSFD Descriptor 10 on the base of clear and well-defined guidelines (MSFD GES Technical Subgroup on Marine Litter, 2013). It describes specific protocols and considerations to collect, report and assess data on marine litter, in particular beach litter, floating litter, seafloor litter, litter in biota and microliter.

As for MBL, the report suggests that it is a well-developed monitoring tool to determine composition, amount and trends of litter in the environment, and provide an indication of its main sources and the potential impact of measures. It also stresses the importance of data harmonization and further development of standard statistical analyses methods for the identification sources. Although the type of survey often depends on the objectives of the assessment and on the magnitude of the pollution on the coastline, it also provides some basic indications about the characteristics of a valid monitoring protocol, its applicability and limitations (Table 3.1). A "master list" of item categories for identifying and assessing macro-litter (G-code) is also provided. It has been recently improved, especially for plastics (Fleet et al., 2021).

Table 3.1. *Marine beach litter monitoring protocol characteristics (MSFD GES Technical Subgroup on Marine Litter, 2013)*

SUMMARY OF MONITORING PROTOCOLS									
Environ. matrices	Method/ protocol	Level of maturity	Technical/ Equipment	Expertise needed	Cost	Level of detail generated	Geographic applicability	Limitations	Opportunities to reduce costs
Beach	Visual/ Collection	HIGH Extensively applied in NEA and Baltic but further R&D needed on statistical analysis	LOW	LOW/ MEDIUM	L/M	HIGH Size ≥ 2.5 cm	HIGH but depending on site availability (*e.g.* problems with remote or inaccessible beaches)	Great variability among sites; Amount of items deposited can be affected by weather/sea conditions	Potential to make use of (trained) volunteers

The potential to make use of trained volunteers in MBL monitoring is also clearly assessed in this report, as a valid innovative and cost-efficient strategy. To support Citizen Science monitoring activities, a mobile tool to collect MBL data, i.e., the Marine Litter Watch (MLW), was also developed in 2014 by European Environment Agency (EEA). It mainly consists in a mobile application built on the TSG-ML guidelines and the proposed master list litter items (G-code). MLW includes a public central database hosted by EEA from which data can be retrieved and used in other databases and/ or further disseminated into a wider range of products. The initial results showed that the mobile application was well suited for both scientific surveys and clean-up initiatives. Nevertheless, even though it is the only pan-European platform that members of the public can use to coordinate clean-ups and record MBL in an official and useful way, its use was quite limited and does not appear in scientific publications, as shown by the results of this thesis presented in the following chapter.

As stated above, the variety of sampling methods that differ in the indicator of marine litter (e.g., total abundance, weight, surface density), reference list used to classify the marine litter, or spatial and temporal distribution of the sampling units, leads to a large fragmentation of the data. This heterogeneity make them

difficult to compare. In this context, the use of a common structure for managing all the data is very relevant to have a comprehensive understanding of the available data, their comparability and which are the core requirements to address the heterogeneity of protocols and reporting in order to work at the European, or Mediterranean, level. A robust, homogeneous marine litter datasets at the European scale was actually developed within the existing European Marine Observation and Data Network (EMODnet). Generally, the network serves to collect, homogenise and provide access to standardised datasets, and derived products, that may be used as a basis for marine litter assessment at pan-European scale. It is a European initiative divided into seven thematic areas, each focused on a specific topic (e.g., geology, physics, chemistry or human activities). Among them, EMODnet Chemistry started in 2009, intending to support the MSFD implementation with a data management plan aiming to unlock the fragmented and inaccessible environmental chemical monitoring datasets (Galgani et al., 2017a, 2017b). The EMODnet database for MBL was modelled following the OSPAR Beach litter database approach and taking into account the MSFD TG-ML and UNEP/MAP recommendations. Data enters the EMODnet network through direct contact with data providers or EMODnet Ingestion (https://www.emodnet-ingestion.eu/). The possibility of having a central gate to sparse data, with a unique access procedure, represents itself an innovation for litter management. In this sense, it challenge the heterogeneity of the source data that represents a considerable issue both in terms of standardization of the data management procedures and comparison of the data. Visualization products make it also a useful tool for earlier evaluation of the database content, as well as for education, communication and gap-analyses purposes. Nevertheless, surprisingly, its use is never mentioned in the Scopus publications focusing on the existing Mediterranean MBL collections which have been analysed in this thesis (see *Chapter 6*).

4. MAC EMERSO CITIZEN SCIENCE ACTIVITIES

4.1 The role of Citizen Science

The term “Citizen Science” was formulated and spread during the second half of the 90s, developing contemporary, and independently, in the United Kingdom and in the United States of America (Benetton, 2020). The term "citizen science" was officially coined in 1995 by the British scientist Alan Irwin, highlighting the need to open the world of science to the public (Irwin, 1995). In the same period, the American scientist Rick Bonney highlighted the important contribution to science provided by non-expert participants, stressing its importance to develop scientific research projects that produce an increase in knowledge and awareness (Hecker et al., 2018). Nowadays, Citizen Science is also considered as a valid tool for involving a community on a specific topic of interest, capable of initiating a decision-making process based on scientific evidence (Eitzel et al., 2017). The citizen scientists can thus become an integral part of the scientific process, favouring informal science education and dissemination of scientific knowledge and skills (Bonney et al., 2009). In fact, Citizen Science requires an energetic involvement of the public, promoting continuous training in both the technical and scientific fields, expanding public support for scientific research activities, and driving the attention of society towards a specific issue (Robinson et al., 2018). Of course, volunteer citizens must be adequately introduced and trained. They must be made aware of the methods for collection and use of the data, and of the effects that the achieved results could have on scientific research, political decisions and society. At the same time, citizen scientists should also receive feedback and updates on the project carried out and have open access to the data collected and the results obtained.

Citizen Science projects can be differentiated according to the level of involvement required from the citizens, such as depending on practical skills, availability of time and equipment to be dedicated (Benetton, 2020). According to the level of skills and abilities, as well as interest and motivation, citizen scientists can be grouped in different levels of participation. The “crowdsourcing”, for example, only requires participation to science through financial support, whilst “set and forget” demands citizen make available their computational resources or simple monitoring sensors for a scientific project. The "web-based” Citizen Science requires participants to access a website and take part in the identification, analysis or interpretation of data. The "app-based” and “get-outdoor” Citizen Science", instead, involves the citizens in the direct collection of data for the specific monitoring of a territory or of living organisms. Finally, some participatory science experiences can also include volunteers in scientific research projects from its initial design. Generally, the best way to make the citizens understand and appreciate science is through direct participation. A citizen scientist may have various motivations that initially lead him to take part in a scientific research experience, such as passion for a discipline, awareness of its importance, desire to acquire new skills. The wide accessibility of technical and IT tools necessary for the dissemination of information and the collection of data by the citizens helped this process.

On this basis, the applications of Citizen Science can concern any field of scientific research, such as medicine, climate change, air quality, ecology, biology, astronomy. In the last two decades, it has been used to tackle research questions that would otherwise not have been addressed due to lack of resources, time or geography (van der Velde et al., 2017). Volunteer participants, from school-aged children to adults, have been involved in a variety of roles contributing to our understanding of large-scale environmental or conservation problems. Of course, the degree of replicability and success of Citizen Science project depends on the ability of researchers to plan and carry out the scientific activity maintaining the same levels of rigor and accuracy that are required for a particular scientific process. Validation of collected data is also critical (Boudreau and Yan, 2004), thus a subset of citizen scientist collected data should always be compared with

correspondent data collected by expert researchers (Van der Velde et al., 2017). Additional problems may concern the use of data, the free work of volunteers, the exaggerated expectations. Planning, coordination and management from expert scientists can tackle these threads, together with clear and easy to use protocols, training and constant support from project leaders.

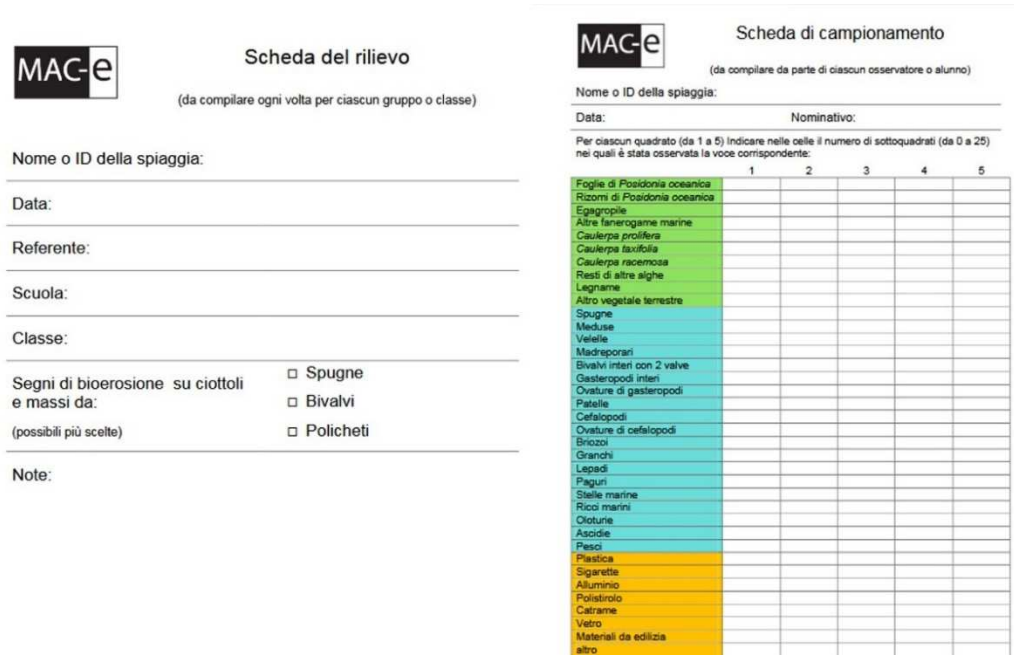
4.2 The MAC-Emerso protocol

In this scenario, trained citizen scientists may have great potential to contribute on widespread monitoring of environmental issues such as marine litter. Actually, in the last decade the role of Citizen Science in the scientific research devoted to marine litter is quickly improving (e.g., Hartley et al., 2015; Bergman et al., 2017; Ballard et al., 2017; Burgess et al., 2017). An increasing number of people pay specific attention to ecological issues and feel the need to take part actively in marine conservation (McKinley et al., 2017). Solid waste in the world's waters and solid waste that accumulates on the shorelines of waterways (MBL) were recognized as a form of pollution for nearly 50 years and represent nowadays a concern for the general public. Despite international and national legislation is improving to prevent at-sea dumping, marine litter continues to be a major pollution issue. However, not all debris found on the beaches comes from the ocean; accidental or intentional land-based (washed from the land) litter, stormwater run-off and discharges affect beaches as well. Their management often focuses on apparent visual results much more than on rational conservation strategies, so aesthetic reasons prevail over environmental safety and human health (Jambeck et al. 2015). On the other hand, MBL also affects income generated from tourism industry, especially the eco-tourism industry, and from commercial fishing due to habitat degradation and destruction (Krelling et al., 2017). Citizens are more and more aware about these threats and feel an increasing impulse to take part in the monitoring and protection of shorelines. Nevertheless, although beach ecosystems are among the most popular sites, their systemic importance is still little known and/or underestimate. So, both classifying MBL and identifying its sources are essential for the conservation of coastal environment. And it is fundamental to involve citizens in these activities in order to promote their perception and collaboration.
Among the existing Citizen Science strategies developed for the marine and coastal environment monitoring (e.g., OSPAR, NOAA Marine Debris Program, SEACleaner, Ocean Conservancy International Coastal Clean-up), we opted for the use of the MAC Emerso (hereafter MAC-E) protocol. This beach monitoring protocol, developed in the framework of the Reef Check project for the Mediterranean Sea, represents an extraordinary opportunity to take part in an ambitious project of scientific research and to empower the people to save our oceans through education, research and conservation. The MAC-E is part of an Italian national educational project that aims to enhance the natural wealth of the marine areas, develop knowledge on the beach environment, foster aware and responsible attitudes and behaviors of pupils, inform them on the advantages of sustainable management of coastal areas, form an environmental awareness and educate to respect for rights of future generations; promote the dissemination of the activities practiced in order to obtain a cascade effect of involvement and awareness of other people. The MAC-E project is divided into the following stages:

- evaluate the starting situation of the different classes through individual and/or group activities;
- involve pupils in didactic activities aimed at enhancing their curiosity;
- guide the pupils to observation, intentional discovery and elaboration of hypotheses;
- provide new knowledge through theoretical lessons;
- stimulate dialogue on the proposed issues;
- guide the pupils, during the practical exercise, to collection and census of beached material;
- verify the level of competence achieved;
- evaluate if pupils adopt attitudes and behaviors aware and responsible during practical activities.

These characteritics make the MAC-E really appropriate for the involvement of primary and secondary school pupils, together with their teachers and parents. In addition, the MAC-E protocol is really intuitive and easy to carry out. Because of its simplicity it can be easily replicated over time in order to appreciate the dynamism of these environments and provide valuable data to monitor the ecosystem. The materials required for the execution of the protocol are also cheap and easy to find. On the field, the surveyors need only:

- the MAC-E manual or any other valid manual to identify natural and antropogenhic items;
- 1 data sheet for each participant (Figure 4.1a);
- 1 survey form for each group of participants (Figure 4.1b);
- Several 50 × 50 cm sampling squares divided into 25 sub-squares (e.g., at least one for every 3-4 participants). The sampling squares can be easily made by hand with strips of wood or plastic pipes from electrical channels (see Figure 4.2).



MAC-e

Scheda del rilievo

(da compilare ogni volta per ciascun gruppo o classe)

Nome o ID della spiaggia:

Data:

Referente:

Scuola:

Classe:

Segni di bioerosione su ciottoli e massi da: (possibili più scelte)

- ☐ Spugne
- ☐ Bivalvi
- ☐ Policheti

Note:

MAC-e

Scheda di campionamento

(da compilare da parte di ciascun osservatore o alunno)

Nome o ID della spiaggia:

Data: Nominativo:

Per ciascun quadrato (da 1 a 5) indicare nelle celle il numero di sottoquadrati (da 0 a 25) nei quali è stata osservata la voce corrispondente:

	1	2	3	4	5
Foglie di *Posidonia oceanica*					
Rizomi di *Posidonia oceanica*					
Egagropile					
Altre fanerogame marine					
Caulerpa prolifera					
Caulerpa taxifolia					
Caulerpa racemosa					
Resti di altre alghe					
Legname					
Altro vegetale terrestre					
Spugne					
Meduse					
Velelle					
Madreporari					
Bivalvi interi con 2 valve					
Gasteropodi interi					
Ovature di gasteropodi					
Patelle					
Cefalopodi					
Ovature di cefalopodi					
Briozoi					
Granchi					
Lepadi					
Paguri					
Stelle marine					
Ricci marini					
Oloturie					
Ascidie					
Pesci					
Plastica					
Sigarette					
Alluminio					
Polistirolo					
Catrame					
Vetro					
Materiali da edilizia					
altro					

Figure 4.1. *Data sheet (a) and survey form (b) for MAC-E protocol survey.*

Figure 4.2. *An example of 50 × 50 cm MAC-E sampling square divided into 25 sub-squares.*

Before starting the monitoring activities, it is necessary to identify the accumulation band of the beached material that coincides with the water level reached by the previous high tide or with that reached by the last storms. If there are multiple bands of accumulation it is preferable to analyze the one closest to water, because it represents the most recent. Living organisms or remains could be best preserved there. Then, squares must be arranged randomly along the identified accumulation band. For each square an entire column of the data form (Figure 4.1b) must be filled, reporting for each item the number of sub-squares (from 0 to 25) in which it can be identified. Every participant repeats the operation for 5 times. Once the field operations are completed, all collected data must be entered in the online MAC-E archive as soon as possible on the website www.progettomac.it. Each survey is identified by a numerical code (ID survey), automatically assigned by the system.

All these characteristics meet the aim of my PhD study, that is involving pupils and citizens to explore good practices for monitoring beach ecosystems in order to limit habitat damages and increase the awareness of the danger of MBL, as well as of the role of trophic sources.

5. MAIN RESULTS AND DISCUSSIONS

In this chapter, the main results and discussions of the papers included in the PhD thesis are reported, as well as the results of the pilot campaign carried out during the PhD research activities using the MAC-E ptotocol.

5.1 Scientific knowledge on marine beach litter: A bibliometric analysis

The second year of my research activities has been devoted to compile previous studies and programs focusing on MBL monitoring and clean-up campaigns, also taking advantage of social network analysis (SNA). The achieved results have been organized for publication in *Marine Pollution Bulletin* journal (Cesarano et al., 2021).

Bibliometric network analysis has proved to be a useful tool for assessing trends and patterns of scientific literature, helping identify trends and gaps. Coupling bibliometric data and social network analysis (SNA), the relationships among researchers, organizations, countries, and keywords dealing with a given topic can be explored, which also allows further identification of research gaps. The VOSviewer software (version 1.6.16) based on SNA was used to implement and analyse relationship networks based on Scopus indexed MBL scientific publications.

The analysed Scopus database included 579 products among articles, conference proceedings and technical reports. The analysis of their geographical distribution suggests that Europe produced the majority of the existing documents (56%), while Asia, North and South America provided together one third of indexed studies; Africa and Oceania represent about 5% of the database each. UK is the main country publishing on MBL, followed by US, Spain and Italy respectively. The co-authorship authors network results (Figure 5.1) show that consistent collaborations exist within different clusters/groups, but it is lower if compared to general marine litter studies. Furthermore, setting a minimum of 10 occurrences, 153 keywords were selected, grouped in 6 clusters (Figure 5.2). As expected, the term “beach” is the keyword with the largest TLS, followed by “plastic”, “marine pollution”, “seashore”, “environmental monitoring” and “litter”. The size of their nodes reflects the importance and relationship of the top keywords listed. The six clusters are well defined and identify specific aspects of the existing research activities. A key role is played by the “environmental monitoring” yellow cluster in the centre of the map. The other four clusters indeed are more specific.

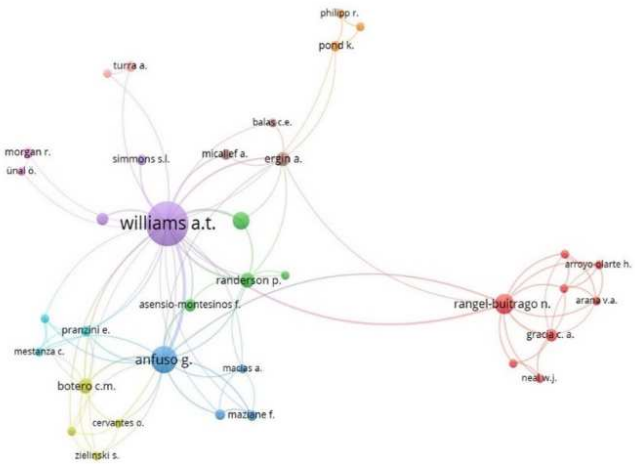


Figure 5.1. *Scopus indexed MBL publications co-authorship authors network*

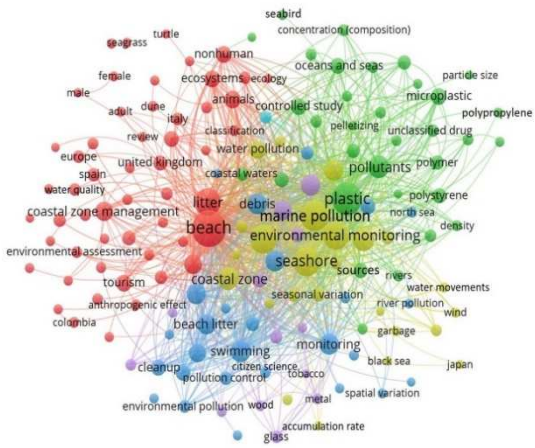


Figure 5.2*. Scopus indexed MBL publications keywords co-occurrence network*

5.2 Marine beach litter monitoring along Mediterranean coasts

A special attention has been then dedicated to the systematic review of current literature on MBL monitoring along the Mediterranean coasts through bibliometric and content analyses, in order to compile information about existing monitoring protocols. Data collection took advantage of the Scopus scientific database from which 58 publications were selected. The discrepancies and similarities in the applied monitoring methodologies were analysed to identify where current gaps lie and point out what would be needed to progress in developing a basin-scale efficient monitoring of the Mediterranean Sea.

The achieved results showed that several commendable initiatives have been taken globally, regionally and nationally by governments, scientific organisms and non-scientific communities in order to monitor and/or remove debris from the beaches and the marine environment (Figure 5.3a). Unfortunately, these efforts resulted in a complex and heterogeneous collection of protocols, criteria and methodologies (Figure 5.3b) that make the available datasets difficult to compare and share from region to region. In fact, the exisiting MBL monitoring activities follow different approaches, which someway rely on the UNEP/IOP, OSPAR, NOAA and MSFD guidelines but miss harmonization in the strategy of survey, as well as in the analysis and presentation of the collected observations. The type of survey selected often depends on the objectives of the assessment, on the magnitude of the pollution, and on the typology of the coastline. Thus, the comparison of MBL data between different assessment programmes is still difficult due to the use of different methods, different spatial and temporal scales, different size scales of litter items, and different lists or categorisation of litter items recorded on beaches. Consequently, even though some similarities can be found, giving indications for intercomparison studies, the lack of standardization of the monitoring protocols limit the integration of MBL data and the efforts to provide a pan-Mediterranean MBL temporal and spatial analysis. However, MBL monitoring confirmed to be a cost-effective methodology whose results can be considered someway representative of new litter entering the coastal environment. Moreover, it emerges that information on the temporal and spatial distribution of marine litter found stranded on beaches can be effectively provided by NGO and participatory science campaigns that also encourage communities to take up action and fill in the knowledge gaps.

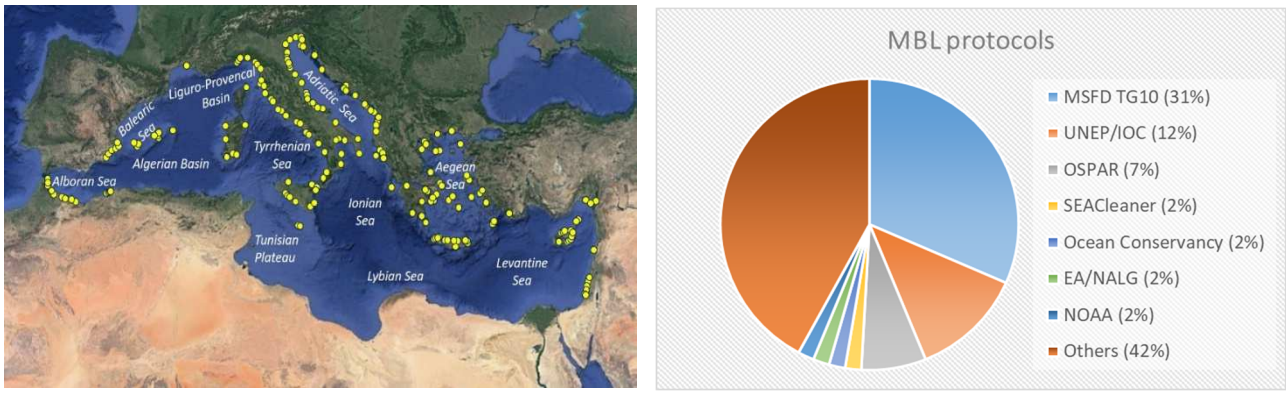


Figure 5.3. *a) Geographical distribution of analysed MBL collections in the Mediterranean Sea and its main sub-basins. Yellow dots indicate the beaches where single or multiple surveys were realized. b) MBL protocols used in the analysed MBL collections.*

In conclusion, this analysis suggests that a unique and easy-to-use protocol for providing homogenous data over time and regions is still missing but urgently needed. It also reaffirms the necessity of improving international collaboration between Mediterranean countries, including the harmonization of directives and protocols between European and North African countries, to provide a complete picture of the MBL pollution status over this basin. This is essential to make easier a direct comparison of information collected by

different groups/initiatives and over different regions and to create a valid communication channel between the world of research and policy makers. To the goal of a drastic MBL reduction, it is also necessary to better identify its main sources, so that effective intervention strategies can be developed to prevent litter from entering the marine environment. The allocation of likelihoods of MBL (e.g., through the Matrix Scoring Technique) resulted a useful approach to this aim. Again, this process needs shared guidelines, central coordination, local knowledge and stakeholders collaboration. A summary of the strengths and weakness emerging from this analysis is reported in the SWAT analysis below (Table 5.1).

Table 5.1. *SWOT analysis of Mediterranean Sea MBL collections reported in Scopus indexed publications.*

Strengths	**Weaknesses**
• Existence of a "Guidance on Monitoring of Marine Litter in European Seas", providing recommendations to plan and realize MBL monitoring activities. • Rising scientific interest in MBL since 2012. • Collections repeated seasonally and annually can identify trends and accumulation rates • 72% of available studies concern exclusively (40%) or not-exclusively (32%) sandy beaches. • 42% of available studies provide beach typology information (urban, rural, remote, natural, touristic); 12% provide also additional details (lagoon, wetland, river estuary). • 18% of monitoring collections is in protected areas. • 79% of monitoring collections include MBL removal. • Visual inspection is cost-effective and can easily involve trained volunteers. • Standard codes exist to identify litter items and allow temporal and spatial comparison.	• Few monitoring activities before 2012. • No guidelines along African coastline. • Sampling frequency is not homogeneous (not repeated, seasonal, annual, monthly, weekly). • Rocky, gravel, pebbles, cobbles and cliff beaches are less monitored. • No information about beach typology in 46% of available studies. • 42% of available studies do not use standard monitoring protocols making result comparison difficult. • Only 10% of available studies involve volunteers. • Sampling units and data representation are not homogeneous. • Few projects also involve the monitoring of other environmental aspects. • Statistical analyses are not homogeneous.
Opportunities	**Threats**
• Strengthen international platforms to collect and disseminate MBL dataset (e.g., Emodnet). • Develop and disseminate methods to standardize collected data with different measurement units and sampling details. • Making the data collected public and easily accessible, to scientific community, policy makers and stakeholders. • Improve collaborations between the Mediterranean countries. • Create synergy between marine litter research in all environmental compartments (seafloor, water column, sea surface, coast). • Involve more volunteers (associations, schools, and citizens) in MBL monitoring through Citizen Science projects. • Strengthen interventions to increase "structural resilience" on beaches and ports (buckets for waste collection, extra containers for cigarette butts, sea-bins, etc.). • Strengthen awareness-raising interventions to improve "social resilience" and study its effects. • Identify the degree of waste decomposition and improve its treatment. • Identifying the main brands of some categories of waste to get proxy information on sources and possible intervention strategies. • Create a communication channel between the world of research and policy makers.	• Existing MBL information represent a fragmented and not homogeneous database. • Not homogenous data make spatial and temporal comparison among available MBL data difficult. • Citizen Science activities have inner limitations due to safety and training of volunteer surveyors. • Academic and volunteer monitoring need to be followed by effective political initiatives to serve their reliability. • Avoid the exploitation of scientific commitment by the political world.

5.3 Field activities: the MAC-E pilot campaign

During the first year of PhD activities, a pilot campaign using the Italian Reef Check MAC-E protocol was planned and realized in collaboration with Progetto Terra, an Italian no-profit association that promotes environmental protection and science dissemination. MBL data collection was organized in the summer period when the beaches are most frequented, the anthropic pressure is more evident and the massive presence of both locals and tourists has a great impact on the cleanliness of the public beach. One of the public beaches of the municipality of Ascea (Campania, Italy) was chosen in the area of the Cilento, Vallo di Diano and Alburni National Park (Figure 5.4).

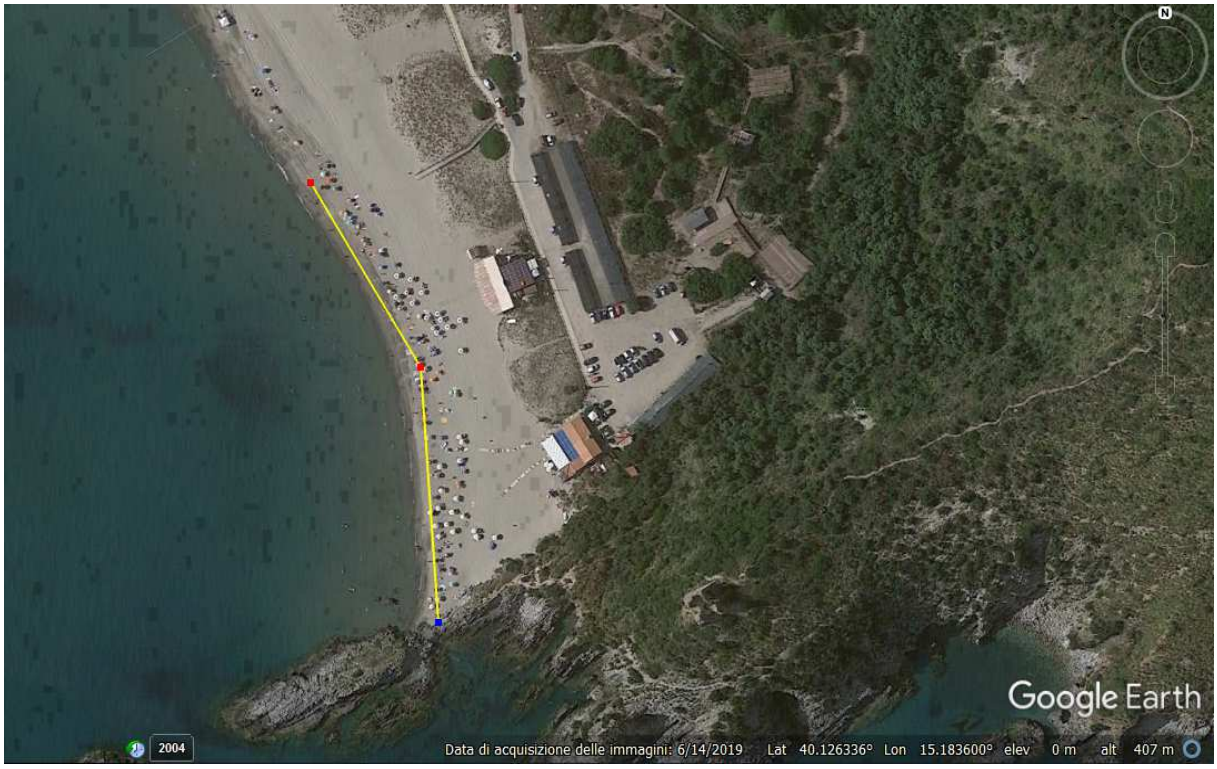


Figure 5.4. *MAC-E pilot campaign sampling site at "La Scogliera", Ascea Marina (Campania, Italy).*

As suggested by MAC-E guidelines, the monitoring activity was carried out the day after a storm in order to have greater reliability on the data collected. The monitoring experiment was carried out by 23 students between 9 and 14 years old (Figure 5.5). Each small work group (3 to 5 young scientists) operated under the supervision of a trained naturalist from Progetto Terra (see Figure 4.2). Data recorded during the 20 surveys included both marine litter (e.g., plastics, cigarettes, glass) and living/dead biotic material (e.g., seagrasses, rhizomes, algae, invertebrates, eggs), representing the 17% and 83% of the observed items, respectively. Remains of *Posidonia oceanica* (31%) and pieces of glass (5%) were the most frequently sampled among biotics and abiotics categories, respectively (Figure 5.6).

Figure 5.5. The 23 students (9-14 years old) and the Progetto Terra volunteers involved in the pilot campaign in proximity of the *Caretta caretta* nest discovered during the MAC-E monitoring activities.

After collecting in situ data, the young scientists informed tourists and locals present on the beach about the importance of the monitoring actions and the advantages of Citizen Science. They explained that beach monitoring could allow to plan a more appropriate management of the coast and, therefore, to preserve the ecosystem function of the beaches over time and make them usable also for future generations. The synergy of dissemination, science and tourism resulted extremely successful and attracted numerous people which were informed, during the children's surveys, about how beaches, being transitional areas, constitute a trophic exchange node between the sea and the land. In fact, the organic materials of marine origin that are stranded on the coast represent one of the primary trophic resources of the entire ecosystem. So, the preservation of the beaches is important because they perform functions of accumulation and re-elaboration of sediments, reduction of levels of organic substance and pollution, mineralization and recycling of nutrients. They also serve as nursery areas, and it actually happened in Ascea with *Caretta caretta* turtles that were nesting exactly along the shoreline monitored during the experiment (Figure 5.5).

Data collected in the framework of the Citizen Science experiment promoted and realized during summer 2019 were also useful to test and confirm the usability of MAC-E as a tool for participative monitoring of coastal environmental systems. The collected observations have been organized and analysed, and then uploaded in the Italian Reef Check onlus web archive including all the data previously collected (2008-2020) along the Italian coasts through the use of MAC-E protocol (https://www.progettomac.it).

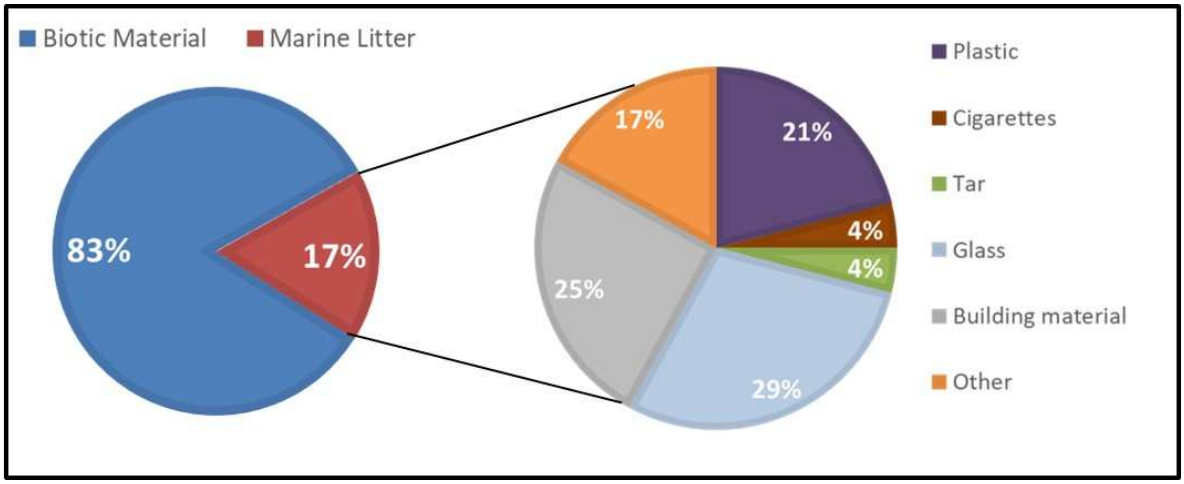


Figure 5.6. *Percentage of data recorded during the 20 surveys of the pilot campaign in Ascea.*

As reported above, unfortunately, the additional MAC-E field campaigns in the framework of the planned Citizen Science initiatives, to be performed in sites of particular interest of both Adriatic (Marche) and Tyrrhenian (Campania) coasts, were not realized due to the difficulties of managing children and teen-agers groups in such unexpected health situation due to the Covid-19 pandemic.

Nevertheless, a preliminary comprehensive analysis of all MBL data collected between 2008 and 2020 along Italian beaches through the MAC-E protocol was carried out. A total of 140 surveys completed along Italian (and Croatian) coasts were explored. Metadata and basic details were analysed to provide a general picture of the existing MAC-E observations and their temporal and geographical distribution (Figures 5.7 and 5.8). Results show that many sites were monitored only through one-time surveys, on single or multiple beaches (Figure 5.9). Despite the MAC-E project useful suggestions and guidelines, a common strategy for repeated monitoring activities (e.g., timing and frequency of campaigns) does not emerge for the initiatives repeated over two or more years. A general coordination for improving these aspects would be desirable. A deeper discussion of strengths, weakness, opportunities, and threats of the MAC-E protocol are summarized in the SWOT analysis reported in Table 5.2.

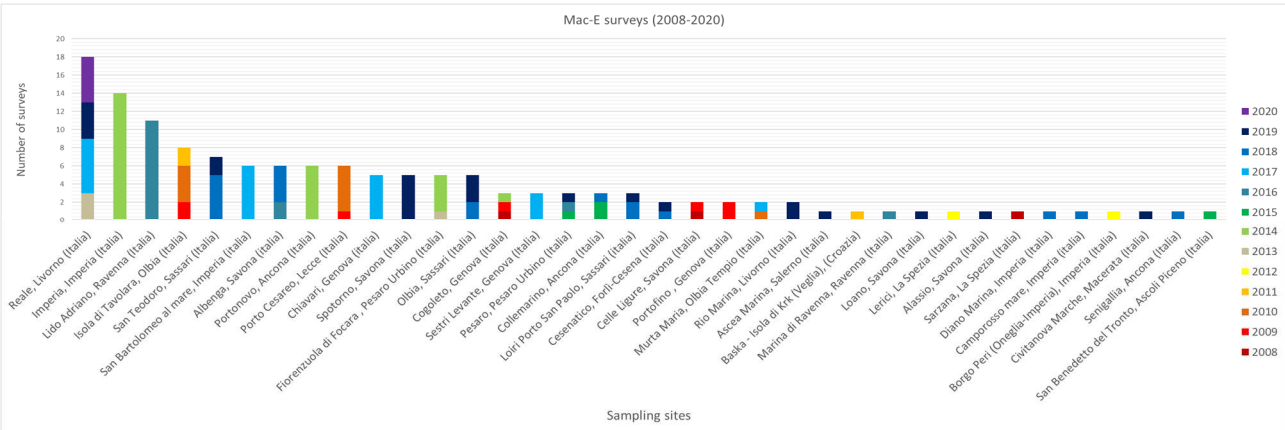


Figure 5.7. *Temporal and geographical distribution of existing surveys using the MAC-E protocol for MBL monitoring.*

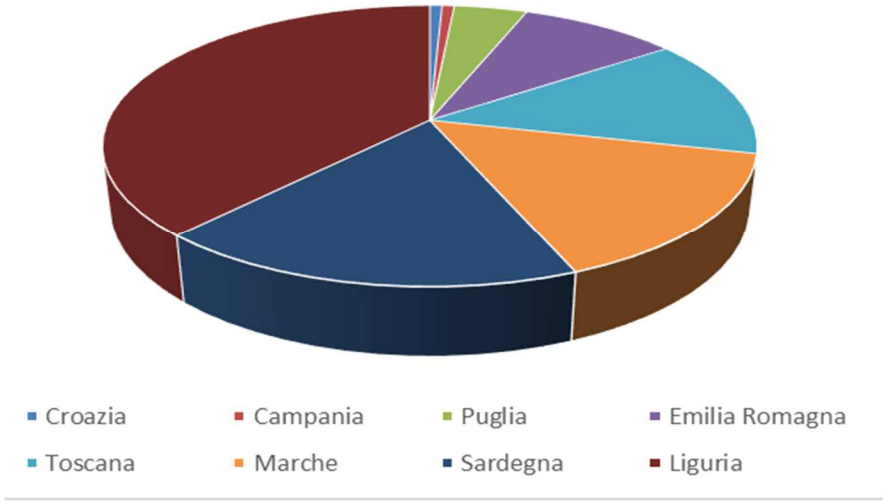


Figure 5.8. *Geographical distribution of existing field surveys using the MAC-E protocol for MBL monitoring among Italian regions and Croatia.*

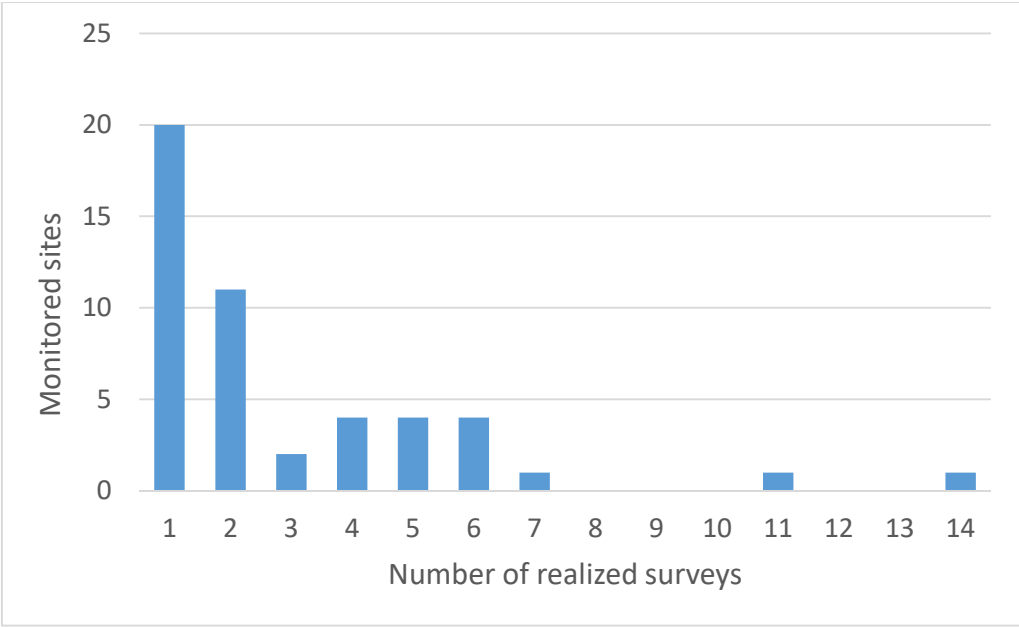


Figure 5.9. *Frequency distribution of monitored sites as a function of the number of realized field surveys in a single site using the MAC-E protocol for MBL monitoring.*

Finally, I would like to express my regret for the impossibility to complete the rich plan of field activities with young citizen scientists. However, although my PhD activities will be completed at time, during next years I expect to recommence, and systematically repeat, the MAC-E monitoring activities in Ascea, and possibly in additional sites of the Campania coast. To this aim, several primary and secondary schools, as well as other no-profit associations, already asked information to be involved in. Of course, if surveys will be realized, all the results will be progressively uploaded on the MAC-E website to enrich the available MBL database.

Table 5.2. *SWOT analysis of MAC-E protocol for MBL monitoring*

Strengths	**Weaknesses**
• Classification and registration of biotic material of marine and terrestrial origin; • Classification of waste based on material typology; • Registration on standardized forms; • Scientific research; • Outreach and Education advantages; • Cost-effective method; • Squares easily constructed with inexpensive hardware materials; • Involvment of small or large groups of children and teenagers; • By creating a network between university and school, it is possible to act on teacher training with benefits for students; • Safety, waste is not handled; • Promotion of outdoor activities; • Sand and other natural material not removed from the beach.	• Difficultly comparable with data collected by other methods; • Waste is not removed; • Not frequent seasonal repetitions; • Data are not public; • Few scientific publications using data collected with this method; • No awareness program for boaters and touristic ports (Goode Mate); • No involvment in proposing bills to tackle the problem and seek solutions; • No single association, university or organization that coordinates all the activities; • Almost exclusively national (Italian).
Opportunities	**Threats**
• The reef check includes also an underwater monitoring protocol that could also include waste census in the future; • A seasonal calendar with a series of national and international events can be created; • Positive effects on tourism; • Positive effects on knowledge of environmental issues and on the sense of belonging of young people, families, stakeholders; • The categories could be standardized and made comparable with those proposed by the MSFD guidelines; • Medium and long-term projects in schools can contribute to oceanic literacy that aligns with the environmental education objectives defined by UNESCO; • The coordination of events at the regional level could be entrusted to associations operating for environmental issues; • Social organizations could be involved to propose this initiative to groups of disadvantaged children who, through group activity in contact with nature, could find opportunities for integration and rehabilitation; • Underpinned by meaningful collaborations between scientists and formal education institutions to achieve the outcomes of conservation research and management as well as conservation learning and action; • Involvement in all aspects of science beyond data collection, including the analysis and interpretation of the data, the dissemination of scientific findings, and the development of new hypotheses to substantially enhance validation, pride and environmental science agency among youth; • Favouring the engagement of youth coming from different socio-cultural backgrounds and include both coastal and inland communities.	• Health safety: being a group activity, they have limitations related to the restrictions due to Covid 19 pandemic; • By not removing the waste it may be demotivating not to see immediate improvement; • Without data processing, it might seem like a sterile and useless job; • Local administrations or political parties and/or organizations could exploit and manipulate events; • The reliability of the data depends on the preparation of the teachers and the motivation of the students; • Sampling may be too sporadic to spot trends.

6. SCIENTIFIC PAPERS

6.1 Cesarano et al., 2021 – *Marine Pollution Bulletin*, 173, 113102

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Scientific knowledge on marine beach litter: A bibliometric analysis

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Abstract

Litter reduction in the coastal and marine environment represents a major challenge but must be prioritised to preserve biodiversity and ecosystems, as well as the goods and services that humans derive from seas and oceans. This paper reviews the available global scientific literature focusing on marine beach litter and tracks its evolution and trends by combining social network analysis and bibliometrics. The relationships and co-occurrences among authors, countries and keywords retrieved from the Scopus abstract and citation database are presented. A total of 1765 publications are analysed: the majority being journal articles. Results reveal the notable worldwide increase in scientific interest in beach litter in the last decade, as well as its multidisciplinary perspectives. This information could be beneficial for the processes that support the improvement of international efforts for beach litter monitoring, removal, and management activities.

1. Introduction

Marine litter, or debris, is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (Cheshire et al., 2009; MSFD GES Technical Subgroup on Marine Litter, 2013). The marine environment can be considered as a final sink in which, sooner or later, every kind of anthropogenic litter accumulates (Van Acoleyen et al., 2013) coming from both land-based and offshore sources (Veiga et al., 2016). Marine litter is found in all marine environments: beaches, shallow and deep-sea bottoms, the sea surface layer and throughout the water column.

Marine litter, including plastic debris, pose a serious threat to marine life, human health, and coastal economies (e.g., tourism, fisheries, etc.), causing harm to the environment and generating adverse economic, health and aesthetic impacts. It is recognised as a worldwide concern by the European Union (EU) and global initiatives such as the United Nations Environment Programme (see Sustainable Development Goal 14), the G7 and the G20.

The Marine Strategy Framework Directive (MSFD) provides the EU legal framework for the protection of the European Seas and requires EU Member States to ensure that, by 2020, "properties and quantities of marine litter do not cause harm to the coastal and marine environment" (European Parliament & Council of the

European Union, 2008). Marine litter is also included as one of the Descriptors for the Good Environmental Status (GES) of the European Marine Waters and the European Commission provides details for the assessment of litter in the environment (European Commission, 2017a).

Great efforts have been made by EU member States to adapt their established environmental monitoring activities and to plan new monitoring programmes to fulfil the requirements of this ambitious policy. An interesting analysis of the reports for the monitoring programme, which are updated every 6 years, is presented by Palialexis et al. (2021) highlighting the reports role as a primary source of information to harmonise the policy's implementation, to fill knowledge and data gaps, and to share good practices. Although MSFD lacks a dedicated financing instrument, it resulted in the creation and the attraction of new funding opportunities to support the measures derived from its legislation (e.g., PERSEUS project, http://www.perseus-net.eu/site/content.php; STAGES project, https://www.stagesproject.eu/). MSFD has encouraged international collaboration between experts across Europe and beyond, to develop joint cost-efficient monitoring programmes (e.g., Danovaro et al., 2016; OSPAR, 2017; Borja et al., 2021). Time is needed to adopt and apply the outcomes and recommendations all over Europe and overcome institutional barriers that will ensure a robust and ecologically unequivocal GES for EU marine biodiversity (Palialexis et al., 2021).

The implementation of the directive also raises questions requiring increased scientific knowledge and understanding and/or further survey and monitoring data. To meet this aim, the recent commission background document accompanying the Report from the Commission to the European Parliament and the Council on the implementation of the MSFD (European Commission, 2020) identifies several key priorities. These include: furthering our understanding of acceptable levels of environmental impact and cumulative effects on the state of the marine environment; developing more quantifiable determinations of GES, based on specific scientific indicators; identifying long-term ecosystem changes that need updated GES thresholds; and distinguishing wider climate-change effects from more local effects caused by other anthropogenic pressures. The report clearly states that a considerable amount of scientific knowledge has already been obtained and can be used to start effectively supporting the MSFD implementation and decision-making processes (European Commission, 2020).

Overseas, the NOAA Marine Debris Program (MDP) represents the United States' main initiative as the Federal government's lead for addressing marine debris through the Marine Debris Act, which was signed into law in 2006 and amended in 2012, 2018 and 2020 (https://marinedebris.noaa.gov/about-our-program/marine-debris-act). The MDP achieves its mission through five main pillars: Removal, Prevention, Research, Regional Coordination, and Emergency Response (NOAA, 2020). The U.S. Environmental Protection Agency (EPA) also provides technical and financial support for projects designed to reduce aquatic litter.

In 2011, organizations from around the world announced "The Declaration of the Global Plastics Associations for Solutions on Marine Litter", also informally known as the Global Declaration. Since then, 80 plastics organizations and allied industry associations in 40 countries have voluntarily signed and operate as the Global Plastics Alliance providing proactive ideas and innovative solutions from all parts of the globe (Global Plastics Alliance, 2020).

Despite these international efforts, disparity in collection and classification methods, and the lack of scientific research means we do not have a complete global picture of the composition and distribution patterns of marine litter which allow us to fully understand its origin and optimize mitigation strategies. The identification of top marine litter items is essential to understand what needs most attention and to prioritise specific measures to prevent further inputs and reduce their abundance in marine ecosystems (Addamo et al., 2017; United Nations Environmental Programme, 2017; MSFD GES Technical Subgroup on Marine Litter, 2011).

From a historical perspective, the first studies on marine beach litter (MBL) were reported in the scientific literature in the 1970s (e.g., Gregory, 1977; 1978). Since then, several studies have aimed to quantify beach litter through monitoring programs providing classifications based on items typology and abundance. Despite the growing interest in the last decade, also supported by international policy, different estimation approaches and methods have been applied which has led to vastly different results (Addamo et al., 2018; Schneider et al., 2018; Schulz et al., 2015, 2017; Williams et al., 2016; OSPAR Commission, 2017; Vlachogianni et al., 2018).

To reduce its impact, MBL collections such as beach clean-ups have been frequently conducted through government and citizen science initiatives in many countries (Agamuthu et al., 2019; Hidalgo-Ruz and Thiel, 2013, 2015). Reviewing 132 studies, Schneider et al. (2018), estimate that up to 2016 over 250 thousand tonnes of MBL was removed. An interesting example of research into the sources, distribution and fate of marine debris that involves multiple actors was provided by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). Using volunteers' data from 86 countries between 2011 and 2018, they compared the proportion and density of both total debris and specific items across 19,428 coastal land and seafloor sites from International Coastal Clean-ups and Dive Against Debris surveys, demonstrating an overall global mismatch between debris types and densities on land and the seafloor from nearby areas (Roman et al., 2020).

Unfortunately, initiatives organized in different parts of the world have applied different methodologies and criteria for the collection and classification of MBL information. Several differences in how surveys are carried out exist, including: where data are collected (sample site), survey protocol, and survey effort (number of people participating and how much of an area is surveyed). Results collected by different organizations often fail to match and combining them is a challenge because data requires accurate standardization to be interpreted correctly (Hardesty et al., 2017; Vlachogianni et al., 2020). A significant example is provided by the analysis of marine debris along the U.S. coasts carried out by CSIRO in collaboration with NOAA MDP and the Ocean Conservancy (OC). NOAA MDP implements a comprehensive sampling regime across a relatively small set of representative beaches, at regular time intervals, with trained volunteers that collect litter and quantify the debris type per unit area. In contrast, the OC's International Coastal Clean-up is an annual (typically in September) citizen science event held at thousands of sites each year during which people with no formal training clean-up an area of shoreline and count the individual items of litter collected. CSIRO's approach differs again, focusing on stratified designed surveys conducted by trained professionals at sites selected by a random sampling design (Hardesty et al., 2016; 2017).

In recent years a considerable effort has been made to create shared protocols to harmonize data collection in different areas of the globe (e.g., Jack et al., 2019) and improve the accuracy of information collected by several organizations during volunteer beach cleaning events. In Europe, the Marine Litter Watch (MLW) mobile app, for example, aims to aid marine litter data collection on beaches, supporting official monitoring for MSFD, with the help of motivated volunteers. It was built by the European Environmental Agency (EEA) using the MSFD monitoring guidelines developed by the Technical Group on Marine Litter, a group of experts established to support the MSFD implementation. MLW provides methodologies and tools to support data collection events on beaches and other stretches of coastline, including un-official initiatives such as clean-ups, favouring the homogeneity of in situ observations between different areas. Many other national and local initiatives exist promoted by non-governmental organization (NGOs). For instance, the Italian NGO Reef Check Italia promotes in primary and secondary schools and Marine Protected Areas (MPAs) the application of a protocol based on random quadrats to quantify MBL along with beached natural products (Cerrano et al., 2011). Nevertheless, additional efforts are still needed to improve shared worldwide guidelines for MBL monitoring, removal and management activities and support the cooperation between academic and citizen science.

In this study, we explore the global scientific literature on MBL to track its evolution and obtain a systematic review of its temporal developments, geographical distribution, and connections between different fields of research. A network analysis applied to bibliometric science is presented which made use of VOSviewer software. The final aim of this work was to provide useful information for assessing trends and identifying the gaps in MBL research which could support the development of improved strategies for future studies and initiatives.

2. Materials and Methods

2.1 Bibliographic research and data collection

The publications included in the bibliometric analysis were collected through Scopus, Elsevier's abstract and citation database. This approach is strongly dependent on both the searching string and the analytical criteria, as reported in Table 1 and discussed in Section 3. A preliminary analysis was developed using three search strings: << marine AND litter >>, << beach AND litter >>, << beach AND litter AND marine >>. Several interesting studies dealing with beach litter that used synonyms in the title, abstract and keywords were missing in the resulting datasets. We therefore opted for a more inclusive query: << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >>. All Scopus searches queried the "Article title", "Abstract", "Keywords" database for all the publication types published in the English language available up to December 31st, 2020. The dataset was exported as .csv files including "Citation Information", "Bibliographic Information", "Abstract", "Keywords" and "References" on February 28th, 2021.
To further refine the data, a close-up inspection was carried out manually to exclude off topic publications, i.e., studies that did not focus on MBL. The analyses described below were then performed starting from the year of the first publication indexed in Scopus (1971).

2.2. Bibliometric network analysis

Bibliometric network analysis has proved to be a useful tool for assessing trends and patterns of scientific literature (e.g., Buonocore et al., 2018; Appolloni et al., 2020; Sorensen and Jovanovic, 2020), helping identify trends and gaps. Coupling bibliometric data and social network analysis (SNA), the relationships among researchers, organizations, countries, and keywords dealing with a given topic can be explored (Reutters et al., 2008), which also allows further identification of research gaps. The VOSviewer software (version 1.6.16) is based on SNA and allows us to implement and analyse relationship networks based on data from scientific publication databases. In this study we focus on the relationships among countries, journals, authors, and keywords through the selection of co-authorship and co-occurrence analyses to exploit the scientific literature on MBL monitoring and collection. The main terms in VOSviewer software and a description of VOSviewer analyses used in this study are reported in Van Eck and Waltman (2020).
The software generates network graphs that highlight main authors, countries, and keywords related to a given topic. In the cluster plots, the size of items (e.g., authors, countries, and keywords) is a function of "Total Link Strength" (TLS) (i.e., the cumulative strength of the links of an item with others) and number of publications and number of citations. Connections among clusters are represented by curved lines whose thickness is related to the "link strength". In the case of co-authorship, the link strength is the number of publications that two researchers, organizations or countries have "co-authored", while in the case of co-occurrences, it represents the number of times that two keywords are paired. Finally, the map resolution determines the number of clusters, thus the higher the detail, the higher the number of displayed clusters. This value can be set to visualize an appropriate number of clusters in the maps (Van Eck and Waltman, 2020). In this study, it was set to 1 for all the analyses.

We restricted the co-authorship analysis to articles with a maximum of 25 authors per publication, as suggested in the default settings of VOSviewer and previous studies (e.g., Pauna et al., 2019; Appolloni et al., 2020). Among these we only selected authors and countries with at least three publications. As for keywords, we only processed terms which occurred in at least 10 of the selected publications.

3. Results and discussion

3.1 Bibliometric research and data collection

The bibliometric analysis started with the comparison of the Scopus indexed publications obtained through the different search strings applied. The number of available publications and their time frame were considered at this stage, as summarized in Table 1. The number of open access publications is also reported, even though it does not represent a selective criterion in the following analyses.

The << "beach litter" >> query points out that the scientific interest on this topic is relatively recent. Figure 1 shows only a few publications available before 2000 and suggests that this terminology was not used before 1989 when Scopus registers three studies focusing on the Gulf of Mexico beaches that belong to the Proceedings of the Symposium on Coastal and Ocean Management held in Charleston, USA between 11 – 14th of July 1989.

Table 1. Summary of the publications results obtained through the different search strings applied

Search string	Number of publications	Time frame	Open Access
TITLE-ABS-KEY ("Beach litter")	184	1989-2020	42
TITLE-ABS-KEY ("Marine litter")	743	1975-2020	260
TITLE-ABS-KEY (beach* AND litter)	686	1978-2020	172
TITLE-ABS-KEY (marine AND litter)	1650	1961-2020	541
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic))	2077	1858-2020	459
Final refined dataset	1765	1971-2020	425

Moving the search criteria to << "marine litter" >>, the temporal coverage of existing studies goes back to 1975 (Figure 1). Over 700 Scopus publications exist, presenting an exponential increase over the last 45 years. Nevertheless, the analysis of these publications' abstracts shows that the majority of the older "marine litter" publications deals with open ocean, focusing on plastic, debris transport and water column pollution. On the other hand, the subset of studies including the beach and shoreline pollution as an important component of marine waste was not completely covered by the << "beach litter" >> string results.

Of course, we had to consider that several studies, especially in the past, might not have clearly used "beach litter" and/or "marine litter". Thus, we searched the strings << beach* AND litter >> and << marine AND litter >>, which include both keywords in the article title, the abstract and/or the keywords, but not necessarily as adjoining words. Moreover, although spelling and plurals are included in standard searches, we included the use of the asterisk wildcard (i.e., *) to ensure the inclusion of derived words (e.g., beached from beach*, coastal from coast*, microplastics and/or macroplastics from *plastic).

The << beach AND litter >> and << marine AND litter >> queries allowed us to obtain a dataset of 686 and 1650 publications on several disciplines, respectively (Table 1). Even though the "beach litter" terminology only appeared as recently as 1989 (Figure 1), our searches suggest that several publications focusing on the

presence of marine shoreline waste were being published from the early '70s. Much more importantly, is that they clearly point out the worldwide increased interest within the scientific community on beach and marine litter in the last decade (Figure 2). This could be a consequence of the 2008 MSFD and other similar initiatives.

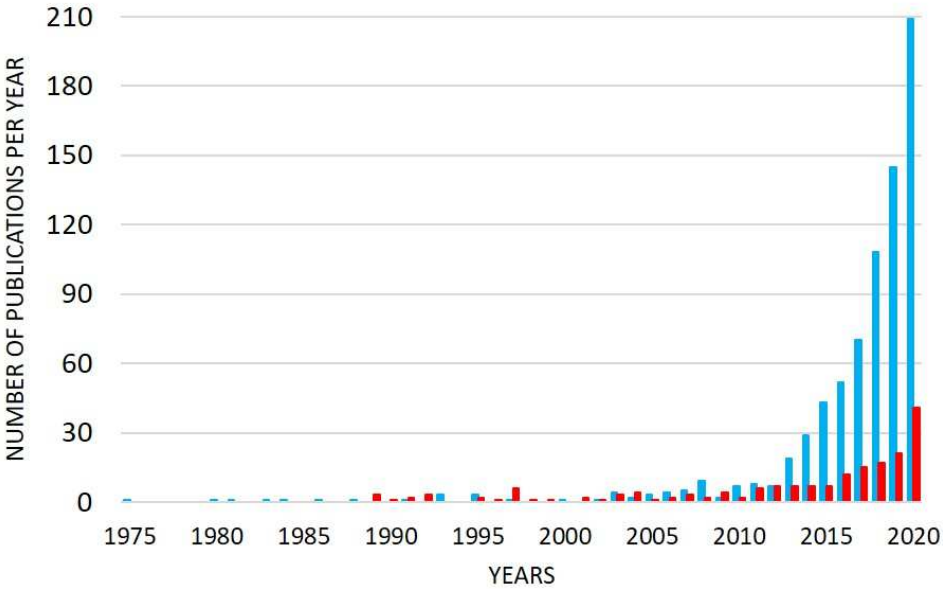

Figure 1. Number of publications indexed in Scopus including the string "marine litter" (blue) or "beach litter" (red).

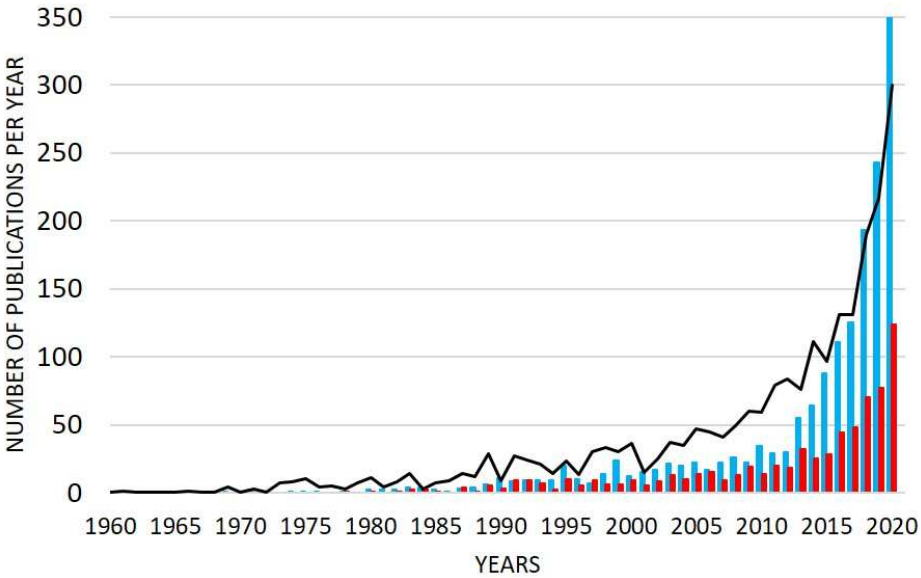

Figure 2. Number of publications indexed in Scopus (1960-2020) dealing with << marine AND litter >> (blue), << beach* AND litter >> (red), in comparison with the final refined dataset used in the bibliometric network analysis (black line).

Nevertheless, this search excluded several Scopus indexed publications which used a different terminology for discussing marine plastic debris and other waste impacts on marine coastal ecosystems, as well as the scientific and governmental efforts for their monitoring, conservation, and management. Conversely, several studies that did not focus on seashore (i.e., focused on open ocean or inland lakes and rivers) were included.

Thus, the << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >> query was used to obtain a more complete collection of existing MBL literature. This search resulted in 2077 publications published between 1858 and 2020 (Table 1).
Finally, the resulting data were inspected manually to remove off-topic products and provide a complete and coherent dataset including, hopefully, the entire Scopus indexed bibliography dealing with MBL. Most of the excluded products referred to marine geology, sedimentology, and engineering (71%); a smaller part to veterinary, pharmaceutics and toxicology (19%) or other disciplines (10%).
A total of 1765 publications since 1971 were retained in the final dataset which was then subjected to the following bibliometric analysis (Figure 2). A preliminary qualitative analysis of the queried publications suggests that 55% of the papers dealt with MBL monitoring, as well as with its collection and removal in different regions of the planet. A smaller subset (about 10%) focused on coastline management, tourism and other economic aspects linked to MBL, including the costs of beach cleaning (e.g., Araújo et al., 2018; Zielinski et al., 2020). The urgent need to remove beach and marine litter from the natural environment is widely assessed. In recent papers, the need for international guidelines and protocols of best practices for MBL monitoring, removal and management activities is highlighted. This information should be shared by different communities/governments to facilitate the comparison of data collected in different areas and time intervals (e.g., Roman et al., 2020). An interesting initiative to overcome these hindrances is represented by the first pan-European Marine Litter Database (MLDB) developed by EMODnet, following the advice of the MSFD Technical Group on Marine Litter (Jack et al., 2019). The MLDB contains data for beach and seafloor litter from a variety of very different sources, including existing international heterogeneous datasets published in project specific databases (e.g., OSPAR), which are processed and gathered in a new common format based on existing monitoring protocols and data reporting formats, to synchronise the available information at the European level (Addamo et al., 2018).
Concerningly, we observe that little or no information is available about how this waste should be analysed, treated, or used post collection (Iñiguez et al., 2016; Williams-Wynn and Naidoo, 2020; Ronkay et al., 2021), and about the potential damages to the ecosystems due to the accidental removal of organic biomass during waste collection.

3.2 Dataset bibliometric analysis

After a few pioneering studies during the 70s and 80s (e.g., Dillon, 1971; Gregory, 1977, 1978; Dixon and Cooke, 1977; Merrell, 1980), the temporal distribution of the 1765 publications analysed points out that the research interest in MBL was modest during the 90s and 2000s, then began to grow substantially since 2008 and continued to increase exponentially through 2020 (Figure 2).
A total of 123 countries published articles on MBL. The geographical distribution of the analysed Scopus database (Figure 3.a) shows the USA to be the country leading publications on MBL with 452 publications indexed. The UK follows with more than 219 publications, then Spain (154), Brazil (148) and Italy (133). The top fifteen ranked countries included other European countries (Germany, France, Portugal, and the Netherlands), three Asian countries (India, Japan and China) and Canada. Africa and Oceania are represented by South Africa and Australia, respectively. The geographical distribution per continent confirms that Europe produced most of the existing publications (42%), North America (20%), Asia (18%) and South America (10%) which together made up almost half of the Scopus indexed studies; Africa and Oceania together represented about 10% of the database (Figure 3.b).

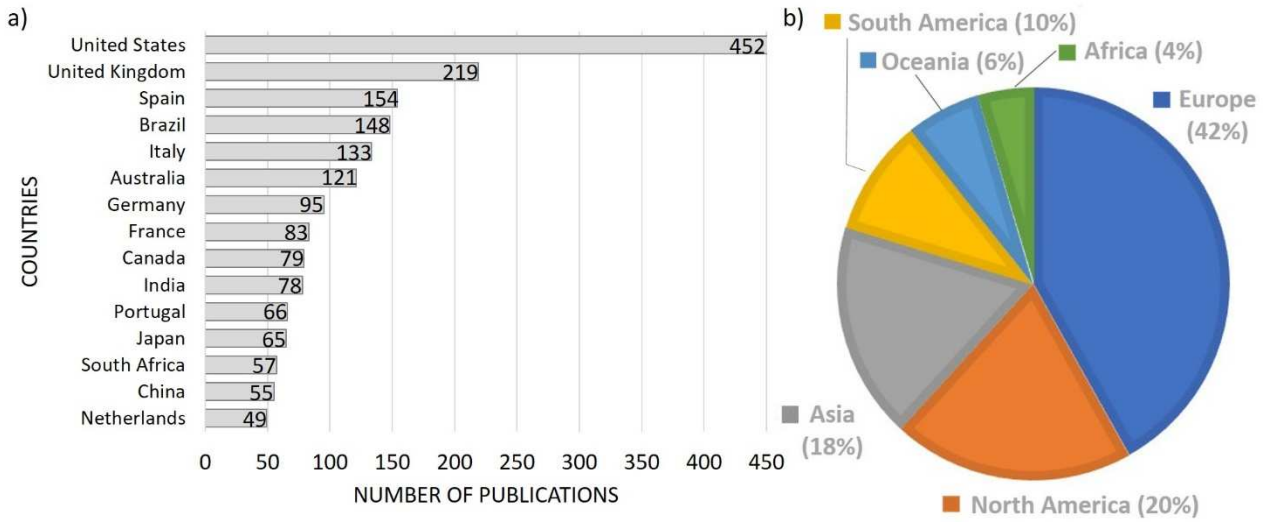

Figure 3. Geographical distribution of MBL publications indexed in Scopus a) per country (top fifteen countries) and b) per continent.

Figures 4 and 5 report the main institutions and scientists involved in these studies representing the top fifteen affiliations and the top eighteen authors occurrence in MBL publications indexed by Scopus, respectively. Thanks to the remarkable efforts provided since 2009 (Ogata et al., 2009), the University of Plymouth has a leading role in this field of scientific research with 30 contributions. Among scientists, Prof Allan Thomas Williams was found to have the most productive voice with 49 MBL studies published since 1993 with over 1233 citations (updated on 31 December 2020).

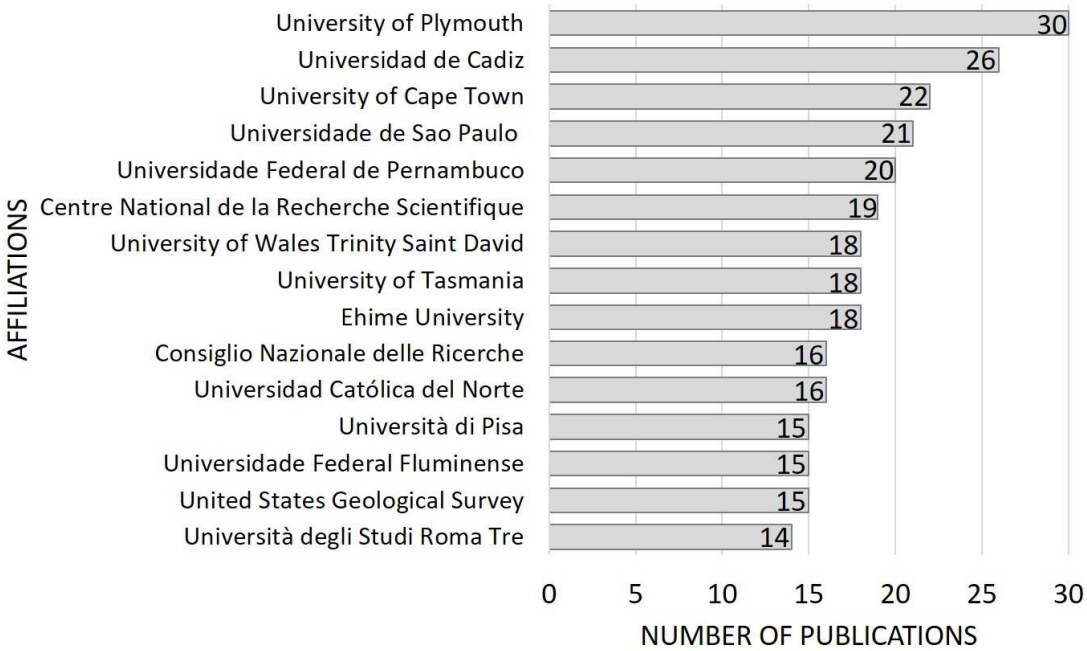

Figure 4. Top fifteen affiliations associated with MBL publications indexed in Scopus.

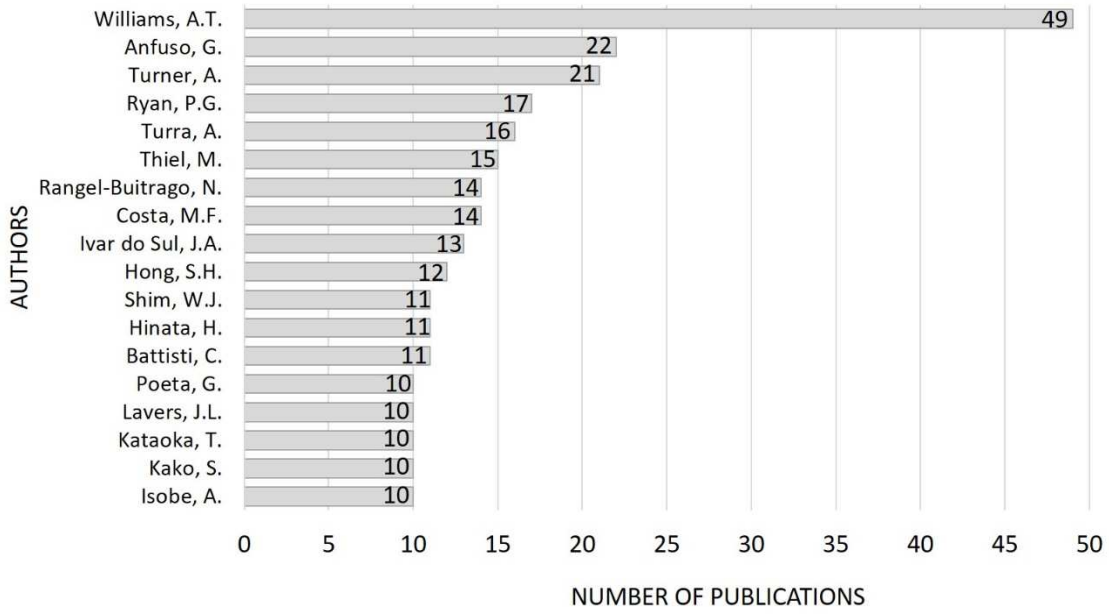

Figure 5. Top eighteen authors publishing on MBL indexed in Scopus.

The Scopus database also allowed us to investigate other bibliometric features, i.e., the types, the scientific areas, and the sources of the indexed publications. As expected, articles represent most of the selected publications (82%) while conference papers, reviews and book chapters represent 11%, 3% and 3% respectively; the remaining 1% includes letters, notes, data papers, short surveys, editorials, and erratum (Figure 6).

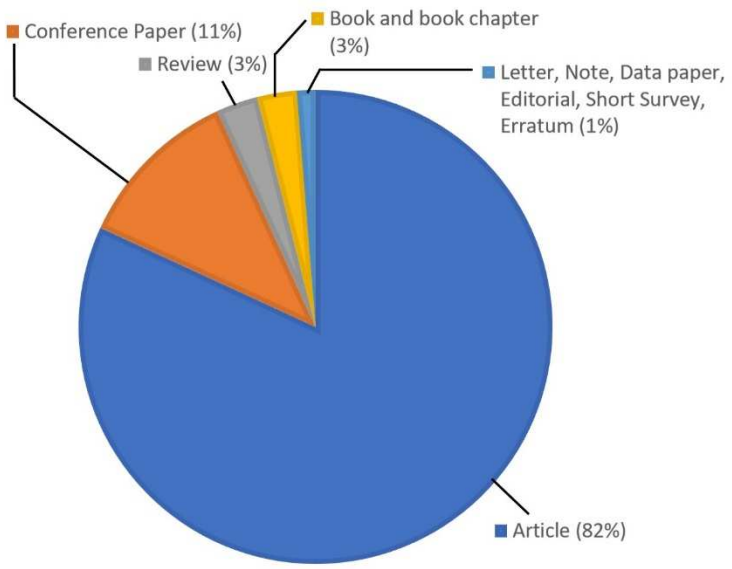

Figure 6. Occurrence of MBL publications indexed in Scopus by a) type (in percentage).

The main sources of these products are reported in Table 2 where top journals publishing MBL studies are summarized. The "Marine Pollution Bulletin" journal was found to be the first-ranked with 440 publications (24.9% of total publications). This is also an outcome of the increase of space devoted to MBL studies by this journal in the last decade, as shown in Figure 7 that illustrates the temporal evolution of Scopus indexed MBL publications published by the top five journals identified in Table 2.

Table 2. Top ten MBL publication sources (number of publications indexed in Scopus).

Source	Publications	Percentage of total publications
Marine Pollution Bulletin	440	24.9 %
Journal of Coastal Research	72	4.1 %
Environmental Pollution	57	3.2 %
Science of the Total Environment	56	3.2 %
Ocean and Coastal Management	35	2.0 %
Water Science and Technology	27	1.5 %
Environmental Monitoring and Assessment	21	1.2 %
Estuarine Coastal and Shelf Science	21	1.2 %
Marine Environmental Research	20	1.1 %
Environmental Science and Pollution Research	16	0.9 %

Table 3. Occurrence of MBL publications indexed in Scopus by subject area (in percentage)

Subject area	Percentage of total publications
Environmental Science	31.7 %
Earth and Planetary Sciences	25.6 %
Agricultural and Biological Sciences	20.3 %
Engineering	5.7 %
Social Sciences	2.8 %
Pharmacology, Toxicology and Pharmaceutics	2.0 %
Biochemistry, Genetics and Molecular Biology	1.6 %
Chemistry	1.5 %
Medicine	1.3 %
Energy	1.1 %
Multidisciplinary	1.0 %
Materials Science	0.8 %
Computer Science	0.8 %
Chemical Engineering	0.7 %
Arts and Humanities	0.6 %
Immunology and Microbiology	0.5 %
Physics and Astronomy	0.5 %
Business, Management and Accounting	0.4 %
Mathematics	0.3 %
Economics, Econometrics and Finance	0.3 %
Veterinary	0.2 %
Decision Sciences	0.1 %
Psychology	0.1 %

The source analysis results also indicate that a clear ecological perspective has not yet been prioritized within the research with a larger interest coming from journals mainly focusing on pollution and coastal management.

Although the largest number of them fall under the "Environmental Science" (31.7%), "Earth and planetary Science" (25.6%) and "Agricultural and Biological Science" (20.3%) subjects, we can generally observe that a broad number of multidisciplinary categories is represented, from Social Sciences to Engineering, Business and Management disciplines and many others (Table 3). This diversity demonstrates the vastness of the scientific community publishing on MBL is. These aspects point out that a multidisciplinary approach is mandatory in MBL studies and emphasizes that a plurality of stakeholders should always be involved in monitoring, collection, and management activities.

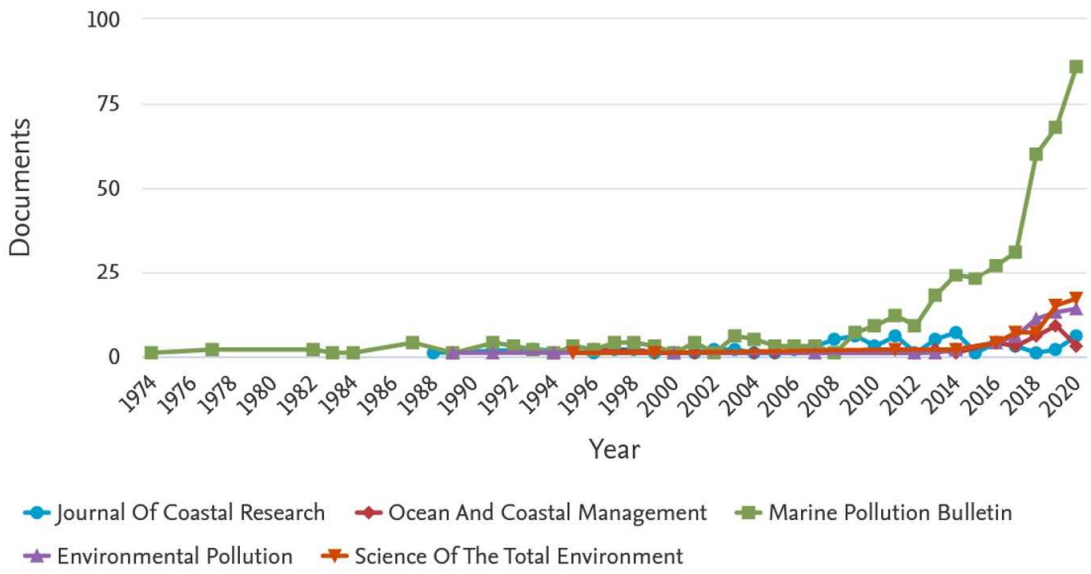

Figure 7. MBL publications indexed in Scopus per year by source since 1971: top five journals.

3.2. Bibliometric network analysis

The bibliometric network analysis was carried out on the refined Scopus dataset described in the previous section.

3.2.1 Authors

The authors, co-authorship analysis, included 6246 scientists. When analysing only authors with at least three publications, the number was reduced to 316 authors, which can be grouped in 13 main clusters. The top ten authors are summarized in Table 4 where TLS, links, publications, and citations are reported. As expected, the TLS ranking mostly respects the list per number of publications presented in Figure 5. Nevertheless, the resulting network map (Figure 8) points out that even though consistent collaborations exist within different clusters/groups, they are less impressive if compared to marine litter studies that include both beach and seawater pollution (Pauna et al. 2019). In fact, only 114 out of 316 scientists are interconnected among the different clusters. Still, some of the authors ranked in Table 4 show strong collaborations within their cluster, but not among other clusters. A high commitment on the issue of MBL by scientists specialized in oceanography, geomorphology and marine biology is evident while less interest seems to come from toxicology and chemistry which are indeed much more common in the study of microplastics and other waste present in the oceans (Pauna et al., 2019; Sorensen and Jovanovic, 2021).

Table 4. Summary of the top ten authors per total link strength (TLS) in Scopus indexed MBL publications.

Author	Specialization	TLS	Links	Publications	Citations
Williams, A.T.	Geomorphology	62	20	49	1373
Hong, S.H.	Oceanography	51	9	12	963
Shim, V.J.	Oceanography	49	9	11	909
Anfuso, G.	Geomorphology	43	12	22	552
Song, Y.K.	Oceanography	41	9	8	734
Turra, A.	Marine biology	40	15	16	626
Lee, J.	Oceanography	34	12	8	539
Thiel, M.	Marine biology	29	7	15	2566
Ryan, P.G.	Environmental Science	28	7	17	1040
Ivar do sul, J.A.	Environmental Science	27	7	13	1022

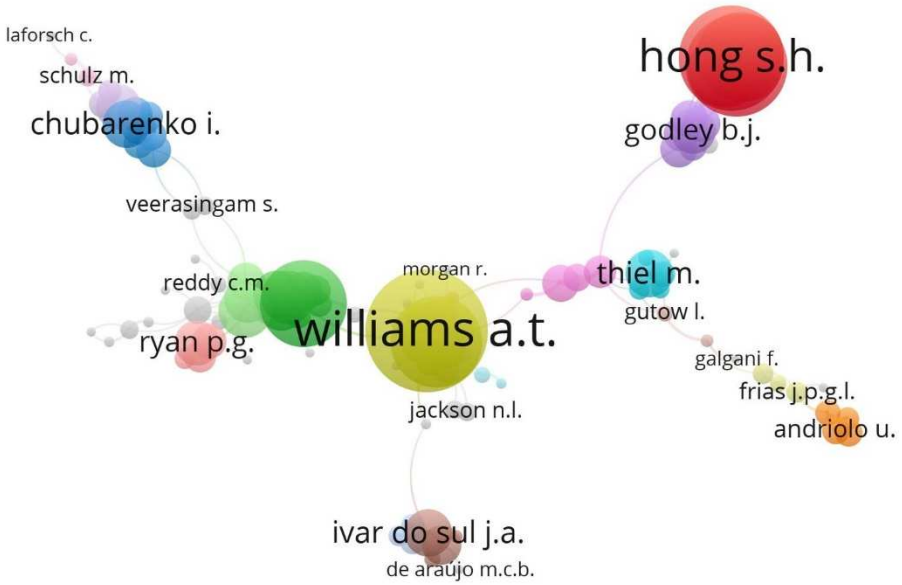

Figure 8. Co-authorship network map of authors based on total link strength. Colours refer to different clusters. The bigger the circle size the greater total link strength the author has. The closer the circles are the more often the authors are found in the same publications.

3.2.2 Countries

The co-authorship countries network only includes 76 publications, which meet the threshold of having at least three publications on MBL, grouped in 6 clusters. The role of EU countries is extremely relevant, with the UK having the highest TLS on MBL research and seven EU countries in the top ten (Table 5). The network map (Figure 9) gives a representation of how countries and clusters are connected. The proximity of their nodes demonstrates a strong collaborative relationship between several countries that are grouped in the same cluster. The main role of the UK and US is emphasized by their position in the centre of the figure and by the high number of existing links with the other countries. The UK is well connected with all the other clusters and leads a small one (purple network) which also includes eastern Mediterranean countries (e.g., Israel, Greece, Turkey). The second cluster in terms of TLS is the one led by the US (red network) which is strongly interconnected with the UK and includes Canada, South Africa, and several Asian countries (e.g., South Korea, China, India, Japan). Another interesting cluster (blue network) is the one that groups Spain and Portugal with Central and South American (e.g., Mexico, Colombia, Uruguay) as well as North African (e.g.,

Morocco) countries. A proximity is also shown by the geographically focused cluster (green network) that includes central and north European countries (e.g., Germany, Belgium, the Netherlands, Poland, Scandinavia, and the Russian federation). Conversely, the yellow network clusters several countries (e.g., Italy, Australia, New Zealand, Brazil, and Chile) which cannot be grouped based on typical geographic or language criteria, but which share common topic interests in the framework of the MBL scientific research which were not prominent in other clusters (e.g., beach management, tourism, and recreation perspectives). Finally, despite the high TLS score, France appears less interconnected with the rest of the world, being directly related only with Indonesia and Saudi Arabia in the presented network map (cyano network). On the other hand, its location in the middle of the map suggests that it tends to collaborate with several other countries whilst also developing independent research activities and possessing solid exclusive collaborations within its own small cluster.

Table 5. Top ten countries per total link strength (TLS) in Scopus indexed MBL publications.

Country	TLS	Links	Publications	Citations
United Kingdom	187	48	219	8452
United States	164	45	452	15515
Spain	146	33	154	3325
Germany	103	38	95	5868
Portugal	94	28	66	2308
Italy	87	31	133	2913
Australia	85	31	121	4104
France	74	27	83	2635
Netherlands	71	32	49	1901
Brazil	57	20	148	3685

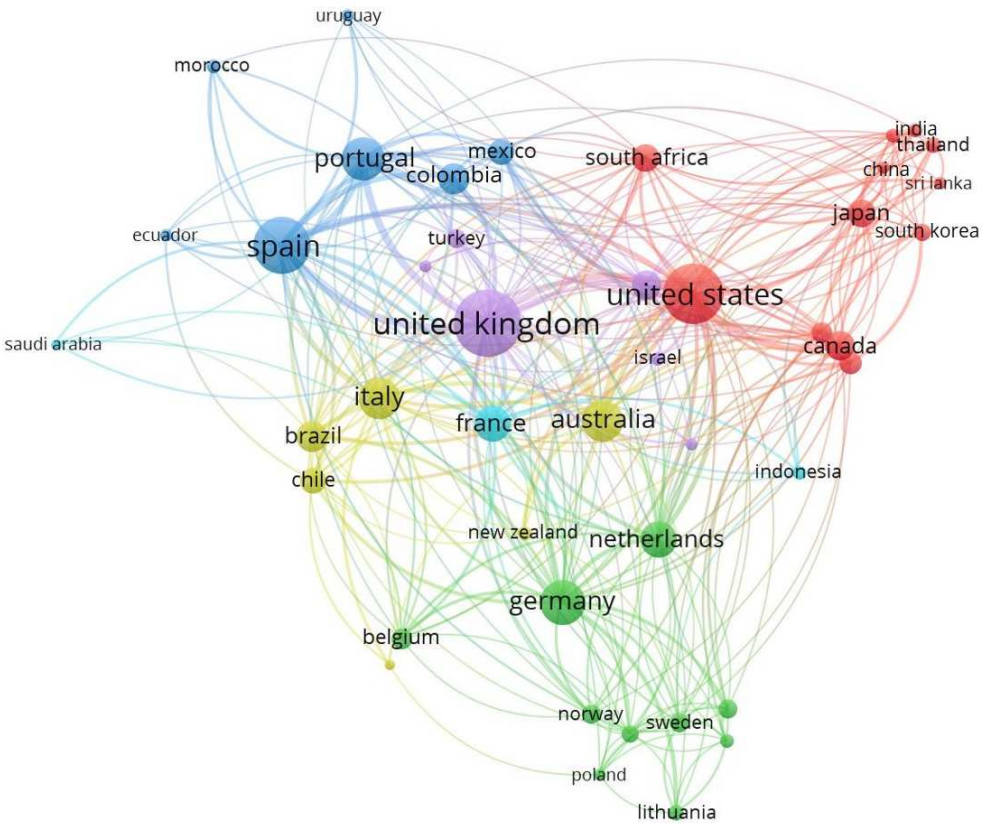

Figure 9. Co-authorship network map of countries based on total link strength. Colours refer to different clusters. Circle size indicates a countries publication frequency. Circle proximity indicates increased occurrence of two countries being found in the same publication.

3.2.3 Keywords

The analysis of the co-occurrence of keywords with a minimum number of 10 occurrences included 683 publications, grouped in five clusters of closely related keywords. As expected, the term "beach" is the most frequent keyword, followed by "plastic", "marine pollution", "environmental monitoring", "seashore" and "waste" (Table 6). Figure 10 reflects the importance and the relationships of the keywords. The size of the circles demonstrates how frequently a term was used as a keyword in the different MBL publications. Node proximity indicates how the research topics are highly related to each other, i.e., the frequency of two terms occurring together in either the abstract, title or keyword listing of the publications.

The network map also reflects the way in which the MBL issue is investigated. The five clusters are well defined and identify specific aspects of existing research activities. A key role is covered by the "environmental monitoring" cluster (in blue) that is positioned in the centre of the map and partially overlaps the others. It includes main keywords like *waste*, *debris*, *marine litter*, *beach litter* as well as terms directly linked to monitoring activities (e.g., *survey*, *citizen science*, *cleanup*, *education*, *questionnaire*, *marine strategy framework directive*) and MBL classification (e.g., *glass*, *cigarette butts*, *wood*). The cluster also includes frequent keywords related to coastal management and human activities (e.g., *coastal zone management*, *economics*, *fishing*, *shipping, tourism*). Nevertheless, these keywords are often associated with terms such as *ecosystem restoration*, *biodiversity* and *environmental quality* which have relevance in this cluster. This suggests that the human interest in conservation of beaches and coastlines is no longer devoted exclusively to its use for recreation and that people recognize more the environmental aspects as a significant value.

Natural keywords (e.g., *coastal zone*, *season*) mark the border with the "geophysical" cluster (in red) that mainly includes geomorphology and physical terms (e.g., *beach*, *seashore*, *dune*, *sand*, *vegetation*, *debris flow*, *sea level*, *tides*, *ocean currents*, *storms*, *wave runup, tsunami*) together with geographical locations (e.g., *Mediterranean Sea*, *Europe*, *Florida*).

On the opposite side of the map, topic keywords such as *waste* and *debris* connect the "environmental monitoring" cluster to the "chemistry" cluster (green). The joining link is represented by the *plastic* and *pollutants* keywords. This cluster groups all the terms which address the study of the MBL components that compromise the beach and coastal water ecosystems, from *microplastic* and other *petroleum* derivatives (e.g., *nylon*, *polystyrene*, *polyethylene*, *polypropylene*, *polycyclic aromatic carbons*) to *heavy metals* (e.g., *mercury*, *zinc*, *copper*, *chromium*) and *chemical analysis* (e.g., *mass fragmentography*, *density*, *concentration*).

As expected, the "chemistry" cluster is directly related with the "biology" one (in purple) which mainly includes terms dealing with the bioaccumulation and the pollutants effects (e.g., *ingestion rate*, *animal tissue*, *nesting*, *diet, physiology, population abundance, metabolism, food chain*) on *marine species* and ecosystems (e.g., *biota, turtles*, *seabirds*, *crabs*, *decapoda*, *Caretta caretta*). A central role is played by the *environmental impact* keyword placed in the middle of the map that bridges this cluster with the others, and with the "microbiology" one (yellow).

In fact, the yellow cluster is more focused on *water quality* and *anthropogenic sources* which foster the presence of MBL and the degradation of the coastal environment. This cluster group refers to the quality of *coastal waters* (e.g., *Escherichia coli*, *faecal pellets*, *contamination*, *bioindicator*) and the potential sources (e.g., *rivers*, *estuaries*, *discharge*, *waste waters*, *sewage*, *urban areas*). Several links connect these terms with the red cluster through keywords (e.g., *storms*, *tsunami*, *flooding*, *sea level*, *numerical modelling*) that provide a direct connection between the coastal water characteristics and the litter presence on the beaches.

Generally, even though a strong relationship to the blue cluster can be detected, this analysis points out that all the keyword clusters are clearly sector-based and identify recognizable scientific areas, suggesting that

the multidisciplinary nature of several studies is often limited to particular and specific aspects of the MBL issue. This hypothesis is confirmed by the small number of interdisciplinary studies available in the analysed database and by the prevalence of sectorial scientific products.

Table 6. Top ten keywords per occurrence in Scopus indexed MBL publications

Keyword	Occurrence	Percent of total publications	TLS
Beach	896	50.8 %	15723
Plastic	677	38.4 %	13533
Marine pollution	644	36.5 %	13609
Environmental monitoring	566	32.1 %	13940
Seashore	531	30.1 %	12360
Waste	445	25.2 %	9023
Pollutants	415	23.5 %	10566
Debris	376	21.3 %	6889
Coastal zone	327	18.5 %	5581
Microplastic	262	14.9 %	5952
Nonhuman	241	13.7 %	5744

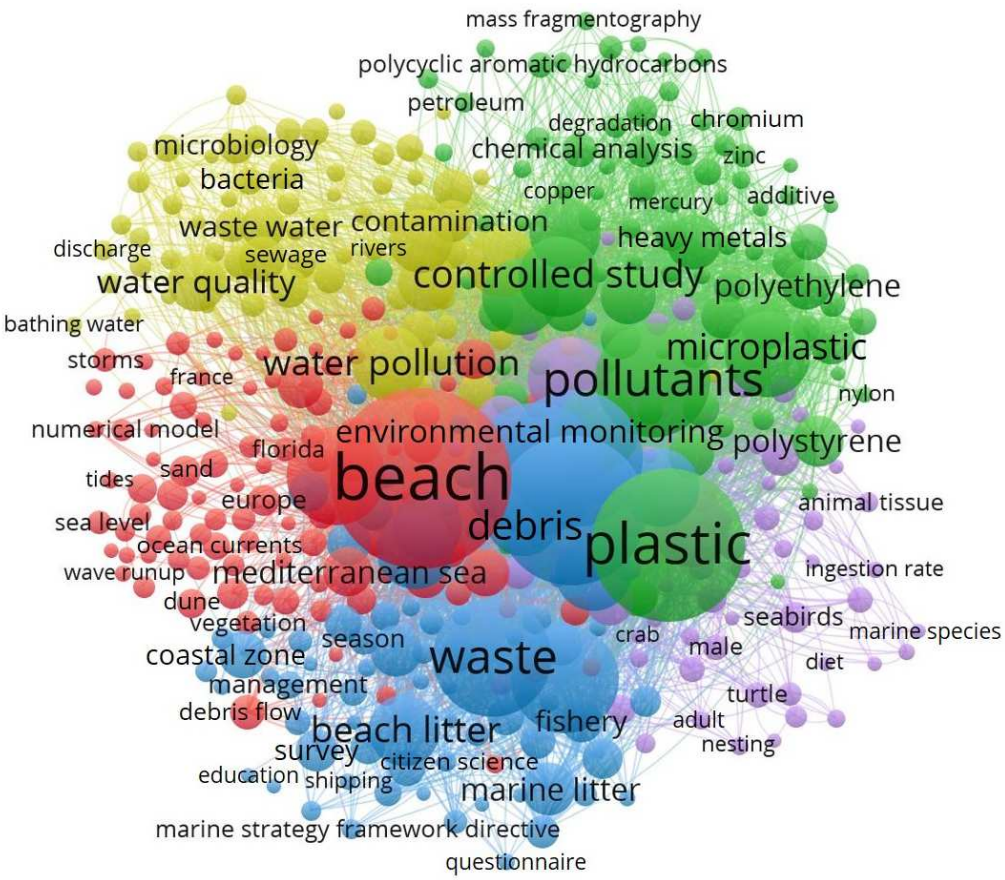

Figure 10. Co-occurrence network map of keywords based on total link strength. Colours refer to different clusters according to the specific aspects of the MBL included (i.e., blue for “environmental monitoring”, red for “geophysics”, green for “chemistry”, yellow for “microbiology”, purple for “biology”). Circle size indicates keyword frequency. Circle proximity indicates the frequency of two keywords being found in the same publication. The size of the keyword label is proportional to its total link strength.

4. Concluding remarks

In this study, we explored the global scientific literature on MBL. Although several studies have been published since the 1970s, only in the last decade has the scientific interest on this issue obtained a consistent impact within Scopus indexed journals. The number of scientific articles published on this subject after 2010 (1373 out of a total of 1765) revealed that this relatively new field of research is now growing exponentially. An increasing trend of publications focusing on MBL is also expected in the near future. Considering the broad implications of this issue on human and ecosystem health, as well as on tourism and other economic activities, it is necessary that future research further explores this subject adopting a larger interdisciplinary perspective.

The combined use of social network analysis and bibliometrics proved to be useful for understanding the published literature (e.g., on MBL) by applying systems thinking in bibliometric science. Even though the analysis of the co-occurrence of keywords pointed out that the MBL issue has been examined from several different points of view, the results obtained showed that weak connections exist between different fields of research. A more holistic approach could help combine and integrate the technical and scientific competences gained over the last decades to improve i) our understanding of the risks caused by visible MBL and microscopic pollution, and ii) our capability to prevent, monitor and remove micro- and macro-litter from seashores.

A whole-system quantitative assessment for the monitoring and collection of beach litter, as well as for the creation of shared protocols and open access data, is also necessary to encourage future analyses and comparisons among different countries and different areas within each single country (e.g., to be used during different lab experiments, sampling and clean-up activities, impact modelling and environmental quality evaluation). The existing literature (e.g., Hardesty et al., 2017; Jack et al., 2019) points out that important efforts are finally on the way for providing common guidelines, good practices and indexes that could help data comparison and integration between different regions and scientific groups.

On the other hand, a preliminary analysis of the queried publications shows that only a few studies have been devoted to other important aspects, e.g., the impact of coastal currents on MBL transport and deposition. In this context, dedicated studies are needed to create multiplatform observatories able to provide physical and biogeochemical information at different spatio-temporal scales useful for in situ MBL data analyses, numerical model assimilations and connectivity investigations (Aulicino et al., 2016; 2018; 2021; Cotroneo et al., 2021). Still, little or no information is available regarding how beach waste is treated or used post collection (e.g., Williams-Wynn and Naidoo, 2020; Ronkay et al., 2021). Although a few studies (e.g., Zielinsky et al., 2019) focus on the aspect of beach cleaning from both the conservation and intensive tourism use perspectives, a lack of understanding remains as to how this waste presence/removal can affect the biodiversity and the functioning of marine ecosystems, and indirectly the provisioning of ecosystem services, as observed by Pauna et al. (2019) who focused on marine microplastics.

Finally, it is important to note that the results of this study are strongly dependent on the applied searching string and analytical criteria. Studies such as this would benefit from additional detailed research, e.g., through a comprehensive and formal qualitative content analysis. Nevertheless, this study provides a useful piece of information about the existing global scientific literature on MBL. As more and more countries have begun to adopt initiatives to reduce MBL presence, this study is also expected to be useful to regulators that need information about the past and the present scientific research on this topic. It also represents a general basis for future studies that may be carried out to focus on peculiar MBL sub-topics using specific keywords and criteria.

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6.2 Cesarano et al. 2022 – Submitted to *Marine Pollution Bulletin*

Marine beach litter monitoring and collection along Mediterranean coasts. A methodological review

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Abstract

Marine beach litter (MBL) represents a serious issue for marine life, coastal ecosystems, human health and several economical activities. The Mediterranean Sea is a semi enclosed basin particularly vulnerable to this problem. Its coasts are threatened by critical anthropogenic pressures that sum up with intensive fishing and shipping, and the slow turnover of its waters. In the last decades, several scientific and participative initiatives have been conducted to study, monitor and clean-up shorelines. These studies were generally characterized by differences in timing and frequency of the surveys, as well as in litter sampling, classification and analysis. This paper presents a systematic review of current literature concerning MBL monitoring along the Mediterranean coasts. Discrepancies and similarities among Scopus indexed studies are analysed to identify existing protocols, understand where current gaps lie, and point out what would be needed to develop a basin-scale efficient monitoring for the Mediterranean Sea.

1. Introduction

Beaches were only recently recognized as ecosystems (McLachlan and Erasmus 1983) but the public perception is very far from this awareness (Rodil et al., 2022). Marine litter, particularly plastic pollution, are paradoxically helping in the valorisation of coastal habitats, being visible along the coast and triggering a strong perception that is important to take action to limit this kind of pollution (Lucrezi and Digun-Aweto, 2020). Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (MSFD GES Technical Subgroup on Marine Litter, 2013). It includes items or fragments that have been directly discarded on the beaches (e.g., coastal and beach tourism, recreational activities), those that have been somehow transported from land to the sea (e.g., households, agriculture, illegal dumping, input by rivers, wind and land run-off) and those coming from ocean-based sources (e.g., storm water overflows, off-shore industries, commercial shipping, fisheries, port activities and boating). Marine litter can also be transported over long distances by ocean currents before being deposited, so that it is found in all marine compartments such as beaches, on the shallow and deep seafloor, in the sea surface layer and in the water column, in sediments and sea ice (Law, 2017; Addamo et al. 2017). Thus, the marine environment can be considered as a sink in which anthropogenic litter accumulates (Van Acoleyen et al., 2013) coming from land-based and offshore sources (Veiga et al., 2016).

This implies that marine beach litter (MBL) found in a given area can be of local origin, can arrive from inland or can be transported from distant regions via ocean currents and the prevailing wind. Source and origin identification is usually very difficult, especially when the litter items are fragments resulting from the disintegration of larger items that spent long time along the pathways system. This is the case of microplastics (i.e., small pieces of plastic litter < 0.5 cm in diameter, Arthur et al. 2009) that represent a serious global problem causing harm to marine wildlife, coastal communities and maritime activities (Veiga et al., 2016).
Due to their persistent nature and their potential to cause undesirable effects, MBL has detrimental impact on marine biota at different levels of biological organisation and habitats, environment, human health, as well as economy (Gall and Thompson, 2015; Schneider et al., 2018; Agamuthu et al., 2019). Marine litter can also act as a vector for spread of invasive species altering or modifying assemblages of species (Kiessling et al., 2015; Werner et al., 2016) or as vehicles for chemicals and contaminants, which may be absorbed on to their surface (e.g., phthalates, polycyclic aromatic hydrocarbons (PAH), brominated flame retardants (BFR), polychlorinated biphenyl (PCB), dichlorodiphenyltrichloroethane (DDT) – see Cole et al., 2011) and become bioavailable accumulating along the biological food chain (Li et al., 2016; Fossi et al., 2018). Finally, MBL is eyesore and aesthetically unpleasant causing landscape degradation and negative public perception leading to a decline in tourism, and subsequent income loss, when washed ashore on beaches (Keswani et al., 2016; Pasternak et al., 2017; Forleo and Romagnoli, 2021).

Although no evidence of permanent garbage patches has been reported so far (Cózar et al. 2015), the Mediterranean Sea has been recognized as one of the most vulnerable areas in the world by MBL (e.g., UNEP/MAP, 2015; Suaria et al., 2016; Fossi et al., 2019; Grelaud and Ziveri, 2020). It is a semi-enclosed basin characterized by complex anti-estuarine circulation (Pinardi and Masetti, 2000; Cotroneo et al., 2021), slow water overturning and the presence of intense gyres and mesoscale eddies (Aulicino et al., 2016; 2018) that favour the potential accumulation of floating plastic debris (Suaria and Aliani, 2014; Zambianchi et al., 2017; Compa et al., 2020). In addition, coastal population of nearly 150 million inhabitants and an intensive growing tourism pressure, estimated in about one third of the world tourist presences (World Tourism Organization, 2018), make its coasts densely populated. Also, the Mediterranean Sea hosts about 15 to 30% of the global shipping activity (UNEP/MAP, 2012) and represents an area of intense commercial fishing. This potential high contamination goes hand to hand with a stream of adverse effects to marine ecosystems, public health and socio-economic costs at local, regional and basin scales (Thompson et al., 2009; Wilcox et al., 2016; Solo-Gabriele et al., 2016; Brouwer et al., 2017; Angiolillo and Fortibuoni, 2020).

In this scenario, reducing litter in the Mediterranean coastal and marine environment is recognised as a priority challenge to preserve the ecosystem and human health, and avoid adverse economic and aesthetic impacts (Addamo et al., 2018). Specific measures aimed at preventing further inputs and reducing the abundance of litter items need the determination of marine litter composition and distribution patterns, as well as sources and pathways (Addamo et al., 2017; European Commission, 2018a; 2018b). A guidance document produced by the MSFD Technical Group on Marine Litter (MSFD TG-ML) suggested five comparts for monitoring marine litter in European Seas, i.e., beach litter, sea floor litter, floating litter, litter in biota and micro-litter (MSFD GES Technical Subgroup on Marine Litter, 2013). Of these, MBL was expected to be the most mature indicator and the one for which the most data could be easily available (Van Acoleyen et al., 2013). The Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast (IMAP), adopted by all Mediterranean countries in 2016, also includes indicator 22, which deals with litter deposited on the coastline (UNEP/MAP, 2016).

Even though it is more representative of land-based sources than that which is deposited far offshore, and the ratio between sea-based and land-based sources may vary considerably between the regional seas, MBL

accumulation may be easier monitored and estimated than along water column or onto seabed (Schneider et al., 2018). Generally, MBL monitoring constitutes a cost-effective methodology and its results can be considered someway representative of new litter entering the coastal environment. In particular, this is true for urban beaches and those geographically under the influence of specific activities and discharges (Van Acoleyen et al., 2013). Moreover, information on the temporal and spatial distribution of marine litter found stranded on beaches can be effectively provided by non-government organizations (NGOs) and participatory science campaigns (UNEP/MAP, 2015; Hidalgo-Ruz and Thiel, 2015) that also encourage communities to take up actions toward responsible behaviours and fill in the knowledge gaps (Figueiredo Nascimento et al., 2016; Hanke et al., 2019; Vlachogianni et al., 2020).

Nevertheless, the increasing efforts to survey offshore areas aimed to improve the knowledge of marine litter dispersal, concentration and type (e.g., MedSeaLitter EU Project, 2019), have not been always accompanied in the Mediterranean by an equally increasing interest in the homogenization of the protocols and methodologies devoted to the collection of reliable, coherent and comparable data of the composition and distribution of MBL (Merlino et al., 2020). The number of MBL studies published to-date in peer-review journals remains limited and often dedicated to specific coastal areas (Vlachogianni et al., 2020). Additionally, these studies are generally characterized by differences in timing and frequency of the surveys, as well as by discrepancies in litter sampling and classification, data analysis and waste disposal (e.g., Galgani et al., 2013; Wenneker and Oosterbaan, 2010; Papachristopoulou et al., 2020; Grelaud and Ziveri, 2020; Vlachogianni et al., 2020; Fortibuoni et al., 2021; Simon-Sanchez et al., 2022). It is extremely difficult to understand to what extent the data produced are comparable or limited by the different methods.

In this context, the present study reviews current literature relating to the monitoring and collection of MBL over the Mediterranean coasts through bibliometric and content analyses, in order to compile information about the monitoring strategies. Data collection takes advantage of the Scopus scientific database. Based on this dataset, the discrepancies and similarities in the methods are analysed to identify where current gaps lie and to point out what would be needed to progress in developing a basin-scale efficient monitoring for the Mediterranean Sea. Moreover, we reaffirm the necessity of improving international collaboration between Mediterranean countries, including the harmonization of directives and protocols between European and North African countries, to provide a complete picture of the MBL pollution status in this basin.

2. **Methods**

2.1 Literature search

A systematic literature review was conducted to compile the MBL studies along the Mediterranean Sea coasts, and the associated methods. In the first step, the Scopus, Elsevier scientific database (www.scopus.com) was consulted, integrating logical operators, through specific string search. The search was limited to English peer-reviewed articles published before 31st December, 2021.

To identify a proper search string, the information about MBL queries provided by the same authors in Cesarano et al. (2021) were considered. In that study, the authors pointed out that several documents, especially in the past, might have used also a different terminology than “beach litter” and/or “marine litter” as adjoining words for discussing marine plastic debris and other waste impacts on coastal areas. Thus, the search string was set to << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >> in conjunction with << Mediterranean >> in the “Article title”, “Abstract” or “Keywords” fields (see Table 1) to obtain a more complete collection of existing MBL literature. Since spelling and plurals are often used in title, abstract and keywords, we included the use of the asterisk wildcard (i.e., *) to ensure the inclusion of derived

words (e.g., beached from beach*, coastal from coast*). This query resulted in 202 documents focusing on several disciplines published between 1978 and 2021.

A broader analysis was also carried out to make sure that relevant papers were not missed, using additional regional terms referring to the main Mediterranean sub-basins (Novi et al., 2021), i.e., << Alboran >>, << Balearic >>, << Ligur* >>, << Tyrrhenian >>, << Adriatic >>, << Tunisi* >>, << Ionian >>, << Aegean >>, << Levantine >>, << Algerian >>, << Israel* >>. When considering in the query these regional names the number of the selected documents increased the review list to 255 items (Table 1). This final dataset was exported as .csv file including all the information provided by Scopus, i.e., "Citation Information", "Bibliographic Information", "Abstract", "Keywords" and "References".

The resulting collection is clearly dependent on the string taken for the literature search, so that an additional check is preferable. Thus, in the second step, the documents were further screened by reading the titles and abstracts followed by the exclusion of those that were irrelevant to our objective (Afghan et al., 2020).
In the third and last step, the documents were thoroughly screened (i.e., through full-text reading) to identify those eligible for our study. The meeting criteria for inclusion in the following content analysis (see Section 2.2) was that the study must be clearly addressing the data collection and/or analysis of macro-MBL (i.e., items ≥ 0.5 cm) over the Mediterranean shoreline, and providing details about the protocols and the methodologies applied.
According to these criteria, the documents relating exclusively to micro-MBL were excluded at this stage.
A stepwise sketch of the searching strategy is given as Figure 1.

Table 1. Summary of the publications results obtained through the different search strings applied.

Search string	Number of publications	Time frame	Open Access
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (mediterranean))	206	1978-2021	51
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (tyrrhenian))	14	1991-2020	2
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (aegean))	19	2000-2021	3
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (adriatic))	29	2000-2021	7
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (algerian))	2	2018-2021	1
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (balearic))	8	2001-2021	4
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (ligur*))	5	2008-2021	0
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (israel*))	17	1978-2021	1
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (alboran))	1	2021	1
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (ionian))	10	2006-2021	0
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (levantine))	3	2018-2019	0
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (tunisi*))	10	1998-2021	82
TITLE-ABS-KEY (beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) AND (mediterranean OR tyrrhenian OR balearic OR aegean OR adriatic OR ionian OR levantine OR alboran OR israel* OR ligur* OR tunisi* OR egypt* OR algerian))	255	1978-2021	58

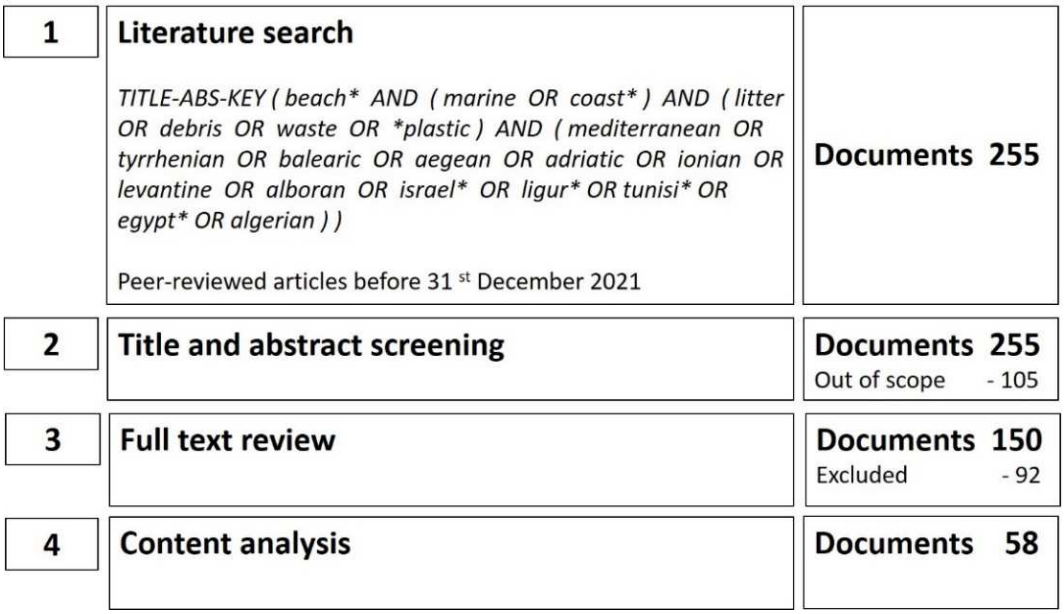

Fig. 1. Flow diagram illustrating the selection process and systematic review of the published literature.

2.2 Content analysis

After the full-text review, the dataset containing Scopus indexed documents was explored to analyse the studies focusing on macro-MBL data collection over the Mediterranean shoreline. To this aim, a content analysis was carried out extracting from each included study, and bringing together, information about the surveyed area, the sampling timing and the applied methodologies. In particular, the data concern: the locations, dates and frequency of the monitoring campaign; the number and characteristics (i.e., coastal type and beach typology) of surveyed sites; the description of the applied protocols and classification strategy (e.g., sampling unit and methodology, macro-litter definition size, number of examined categories); the total surveyed area and the total number/weight of the collected items; the performed statistical analysis.

This analysis provides a fairly comprehensive overview of the MBL data collections published in Scopus indexed scientific articles, allows the identification of the most (and least) investigated areas, enlist the applied strategies used for sampling activities and their occurrence. It also offers a quantitative snapshot of the abundance and weight of the collected items, and of the statistical analysis eventually carried out.

3. **Results**

3.1. Bibliometric research and data collection

The bibliometric analysis started with the comparison of the Scopus indexed publications obtained through the different search strings applied (i.e., step 1 in Figure 1). The number of available publications and their time frame were considered at this stage, as summarized in Table 1. Although it does not represent a selective criterion in the following analyses, the number of open access publications is also reported.
From this first set of articles, 105 were discarded after the title and abstract screening (i.e., step 2 in Figure 1), because out of the scope of this review. The high number of documents discarded at this step was because they were related to different environmental compartments (i.e., water surface, seafloor, sediment, biota), study areas, or disciplines, as summarized in Table 2.

Finally, the full text review (i.e., step 3 in Figure 1) further reduced the eligible documents to 58 articles that were included in the following bibliometric and content analyses. Tables are presented in the following sections bringing together data from these publications, specifying the locations, dates, frequency, and main sampling details of each monitoring campaign (see Tables 3 to 6).

Table 2. Occurrence of documents indexed in Scopus excluded after the title and abstract screening by category (in percentage).

Category	**Percentage of total excluded documents**
Environmental compartments (water surface, seafloor, sediment, biota)	33.7 %
Geology and paleogeology	28.8 %
Technology and biotechnology	13.5 %
Health and water quality	9.6 %
Coastal and landscape management	8.6 %
Different study area	5.8 %

3.2. Temporal analysis

The bibliometric analysis draws data from 58 documents published between 1991 and 2021 (see Table 3). The leading journal is *Marine Pollution Bulletin* that hosted about 42% of the Scopus indexed publications on the Mediterranean macro-MBL data collection. The temporal distribution of these documents indicates a consistent increase of the interest in this topic over the last decade (Figure 2). After a few pioneering studies focused on pellets, dated to late 70s and 80s (Shiber, 1979; 1982; 1987), the first articles on this topic appeared in the early 90s (e.g., Shiber and Barrales-Rienda, 1991; Gabrielides et al., 1991; Golik and Gertner, 1992). Nonetheless, the research interest in macro-MBL over the Mediterranean coasts was extremely modest during the 90s (Bowman et al., 1998) and 2000s (Tudor et al., 2002; Martinez-Ribes et al., 2007) and mostly devoted to specific regions (e.g., Israeli and Spanish beaches). The number of available scientific studies began to grow substantially since 2013 and continued to increase considerably through 2021. This is possibly a response to the overall rise of awareness towards the problem following the long-term accumulation of litter in the ocean and along the shoreline (Petry and Benemann, 2017; Schneider et al., 2018), and to the release of the MSFD guidance on monitoring of marine litter in European seas (Galgani et al., 2013). For example, the high number of studies published in 2021 (Figure 2) sum up the sampling efforts of the previous years when several projects were carried out in the framework of the Marine Strategy activities 2015-2020.

A deeper analysis of the information reported in the selected publications shows that MBL scientific collection projects are typically conducted over a limited and short period of time covering two years or less (Table 3). The majority were collection activities and/or experiments that were started and completed within the same year. Actually, a third of the publications (19 of 58) reports about single-day surveys. Only 9 publications deal with macro-MBL monitoring activities characterized by a seasonal revisit time, as advised by international methodological indications (e.g., UNEP/MAP, 2016). A similar fraction, indeed, opted for monthly repetitions, while three monitoring projects were performed on a 15-days basis but over a shorter time period (i.e., four months). Other research activities are organized following different temporal strategies according to specific criteria, for example to have an overview of marine debris characteristics and distribution before/after the touristic season (e.g., Grelaud and Ziveri, 2020), the periods in which beach cleaning operations are (are not) carried out (e.g., Nachite et al., 2019), or the realization of citizen awareness programmes.

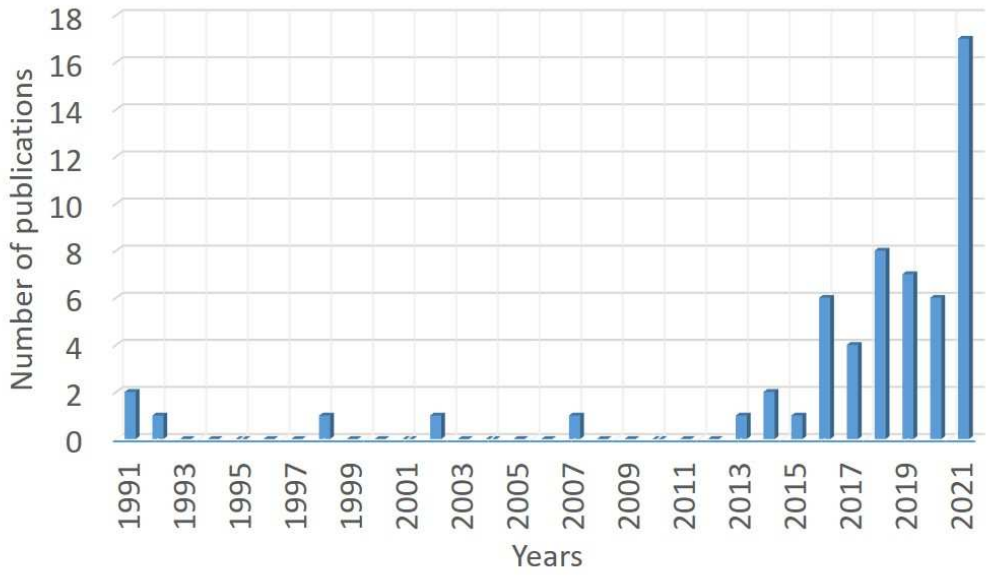

Fig. 2. Number of publications indexed in Scopus per year (1991–2021) dealing with macro-MBL monitoring.

Table 3. Extracted temporal and geographical data from enquired Scopus indexed scientific collections. Countries are reported through the ISO 3166-1 alpha2 code.

ID	Reference	Time period	Frequence and timing	Location	Country	Journal
1	Shiber and Barrales-Rienda, 1991	1978 - 1978	Twice per week (Jul)	Beirut	LB	Environmental Pollution
2	Shiber and Barrales-Rienda, 1991	1988 - 1988	Three times (Mar, Apr)	Beirut	LB	Environmental Pollution
3	Golik and Gertner, 1992	1988 - 1989	Monthly (May - May)	Israeli coast	IL	Marine Environmental Research
4	Gabrielides et al., 1991	1988 - 1989	Monthly (May - May)	Spain, Italy, Turkey, Cyprus, Israel	ES, IT, TR, CY, IL	Marine Pollution Bulletin
5	Bowman et al., 1998	1990 - 1991	Monthly (Jul - Oct)	Israeli coast	IL	Journal of Coastal Research
6	Tudor et al., 2002	1998 - 2000	Single/multiple surveys per beach site	Turkey, Malta, Spain, Tunisia	TR, ES, MT, TN	Journal of Coastal Research
7	Martinez-Ribes et al., 2007	2005 - 2005	Monthly (Apr, Jun - Sep)	Balearic Islands	ES	Scientia Marina
8	Kordella et al., 2013	2006 - 2007	Once	Greece	GR	Aquatic Ecosystem Health and Management
9	Poeta et al., 2014; Poeta et al., 2016a	2012 - 2012	Once (Apr, May)	Lazio coast	IT	Marine Pollution Bulletin; Estuarine, Coastal and Shelf Science
10	Laglbauer et al., 2014	2012 - 2012	Once (Jul)	Slovenia	SI	Marine Pollution Bulletin
11	Pasternak et al., 2017	2012 - 2015	14 to 19 surveys per beach site	Israeli coast	IL	Marine Pollution Bulletin
12	Gonulal et al., 2016	2013 - 2015	Once	Gokceada Island	TR	Aquatic Ecosystem Health and Management
13	Camedda et al., 2021	2013 - 2016	Twice a year (autumn, spring)	Sardinia	IT	Water Air and Soil Pollution
14	Karkanorachaki et al., 2018	2014 - 2014	Summer (Apr - Jun), winter (Nov - Mar)	Northern Crete	GR	Marine Pollution Bulletin
15	Aydin et al., 2016	2014 - 2014	Once (Apr)	Cilician Basin	TR	Turkish Journal of Fisheries and Aquatic Sciences
16	de Francesco et al., 2018	2014 - 2015	Spring	Abruzzo e Molise	IT	Rendiconti Lincei. Scienze Fisiche e Naturali
17	Prevenios et al., 2018	2014 - 2015	Every ~15 days (Jul - Oct)	Corfu Island	GR	Marine Pollution Bulletin
18	Poeta et al., 2016b	2014 - 2015	Spring, summer, autumn, winter	Montalto Marina	IT	Marine Pollution Bulletin
19	Giovacchini et al., 2018	2014 - 2015	Spring, summer, autumn, winter	Pelagos sanctuary (Ligurian Sea)	IT	Marine Pollution Bulletin
20	Vlachogianni et al., 2018	2014 - 2016	Autumn, winter, spring, summer	Adriatic Sea	AL, BA, HR, GR, IT, MO, SL	Marine Pollution Bulletin
21	Alshawafi et al., 2017	2015 - 2015	Spring, summer, autumn, winter	Martil	MA	Marine Pollution Bulletin
22	Maziane et al., 2018	2015 - 2015	Once (Nov - Dec)	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
23	Munari et al., 2016	2015 - 2015	Once (May - Jun)	North-western Adriatic coast	IT	Waste Management

24	Munari et al., 2017	2015 - 2015	Once (May)	North-western Adriatic coast	IT	Waste Management
25	Nachite et al., 2019	2015 - 2017	Twice a year (autumn, spring)	Alboran Sea	MA	Ocean and Coastal Management
26	Fortibuoni et al., 2021	2015 - 2017	Twice a year (spring, autumn)	Italy	IT	Environmental Pollution
27	Portman and Brennan, 2017	2016 - 2016	Every ~15 days (Apr - Jul)	Jisr-Az-Zarqa	IL	Waste Management
28	Loizidou et al., 2018	2016 - 2017	Once (May - Aug)	Island of Cyprus	CY	Environmental Monitoring and Assessment
29	Papachristopoulou et al., 2020	2017 - 2018	Summer, autumn, winter, spring	Western Saronikos Gulf	GR	Marine Pollution Bulletin
30	Ozden et al., 2021	2017 - 2019	Monthly (Jan - Jan)	Northern Cyprus	CY	Marine Pollution Bulletin
31	Grelaud and Ziveri, 2020	2017 - 2019	Monthly (Feb - Nov 2017, Aug - Sep 2019)	Mallorca, Sicily, Rab, Malta, Crete, Cyprus, Mykonos, Rhodes,	ES, IT, HR, MT, GR, CY	Scientific Reports
32	Silc et al., 2018	2017 -2017	Once (May)	Velika plaža	ME	Marine Pollution Bulletin
33	Taibi et al., 2021	2017 -2017	10 - 21 replicates per beach site (Feb - Jul)	Western Algerian coast	DZ	Marine Pollution Bulletin
34	Gundogdu and Cevik, 2019	2018 - 2018	Once (May)	Iskenderun Bay	TR	Environmental Pollution
35	de Francesco et al., 2019	2018 - 2018	Once (Apr – May)	Abruzzo e Molise	IT	Sustainability
36	Gjyli et al., 2020	2018 - 2018	Once (Apr)	Albanian coastline	AL	Ocean and Coastal Management
37	Asensio-Montesinos et al., 2019a	2018 - 2018	Once (Mar)	Alicante coast	ES	Marine Pollution Bulletin
38	Asensio-Montesinos et al., 2019b	2018 - 2018	Twice (Mar, Aug)	Alicante coast	ES	Ocean and Coastal Management
39	Mokos et al., 2019	2018 - 2018	Once (Mar - May)	Croatian Adriatic Sea	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
40	Vlachogianni et al., 2020	2018 - 2018	Twice (autumn, winter)	Croatia, Cyprus, France, Greece, Italy	HR, CY, FR, GR, IT	Science of the Total Environment
41	Mo et al., 2021	2018 - 2018	Twice (spring, autumn)	Ligurian Sea, Tuscany	IT	Marine Pollution Bulletin
42	Battisti et al., 2019	2018 - 2018	Once (Mar)	Torre Flavia wetland	IT	Environmental Science and Pollution Research
43	Mandic et al., 2021	2018 - 2019	Three times (autumn, winter, spring)	Montenegrin coast	MO	The Montenegrin Adriatic Coast: Marine Chemistry Pollution
44	Mokos et al., 2020	2018 - 2019	Summer, autumn, winter, spring	Vodenjak cove	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
45	Bozzeda et al., 2021	2019 - 2019	Once (Apr)	Aquatina	IT	Marine Pollution Bulletin
46	Asensio-Montesinos et al., 2021a	2019 - 2019	Monthly (Feb - Apr)	Ceuta	ES	Water MDPI
47	Romiti et al., 2021	2019 - 2019	Monthly (Apr - Jun)	Ionian coast of the Calabria	IT	Journal of Insect Conservation
48	Fanini and Guittard, 2021	2019 - 2019	Weekly (Apr - Sep), twice (Nov - Dec)	Island of Crete	GR	Marine Pollution Bulletin

49	Mghili et al., 2020	2019 - 2019	Winter, spring, summer, autumn	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
50	Cesarini et al., 2021	2019 - 2019	Once (Nov)	Torre Flavia wetland	IT	Marine Pollution Bulletin
51	Benaissa et al., 2021	2019 - 2019	Once (Mar - Apr)	Aïn el Turk Bay	DZ	Geo-Eco-Marina
52	Ertas, 2021b	2019 - 2020	Summer, autumn, winter, spring	Adana Akyatan Lagoon Coast	TR	Marine Pollution Bulletin
53	Ertas, 2021a	2019 - 2020	Winter, spring, summer, autumn	Homa Lagoon coast	TR	Estuarine, Coastal and Shelf Science
54	Asensio-Montesinos et al., 2021b	2020 - 2021	Every ~15 days (Dec - Mar)	Alicante province	ES	Marine Pollution Bulletin
55	Cresta and Battisti, 2021	2021 - 2021	Twice (Apr, May)	Torre Flavia wetland	IT	Marine Pollution Bulletin
56	Merlino et al., 2021	2021 - 2021	Once (May)	Migliarino, Massacciuccoli and San Rossore park	IT	Water
57	Katsanevakis, 2015	NA	NA	Lesvos Island	GR	Mediterranean Marine Science
58	Battisti et al., 2016	NA	NA	Torre Flavia wetland	IT	Environmental Practice

3.3. Beach distribution and typology

At present there is no agreed statistical method for recommending a minimum number of sites that may be representative for a certain length of coast. This depends greatly on the purpose of the monitoring, on the geomorphology of the coast and how many sites that meet the sampling criteria are available (Galgani et al., 2013).

Figure 3 positions the reviewed macro-MBL collections. Generally, scientific efforts tend to focus on the European Mediterranean Sea. Information about the African coasts are largely missing, with the exception of Morocco (e.g., Maziane et al., 2018; Nachite et al., 2019; Mghili et al., 2020) and Algeria (Benaissa et al., 2021). Additional investigation is needed to determine whether those areas have been surveyed but not reported in scientific publications. Italy and Greece undertake major efforts, but also Israel, Cyprus and the Balkan countries are largely represented (Table 3). Consequently, Tyrrhenian, Adriatic and Aegean coasts are the most surveyed among the Mediterranean sub-basins (Figure 3). Conversely, several monitoring activities promoted by France, Spain and Turkey, which actually cover a larger fraction of their long coastline, are missing in scientific literature and do not appear in this bibliometric research.

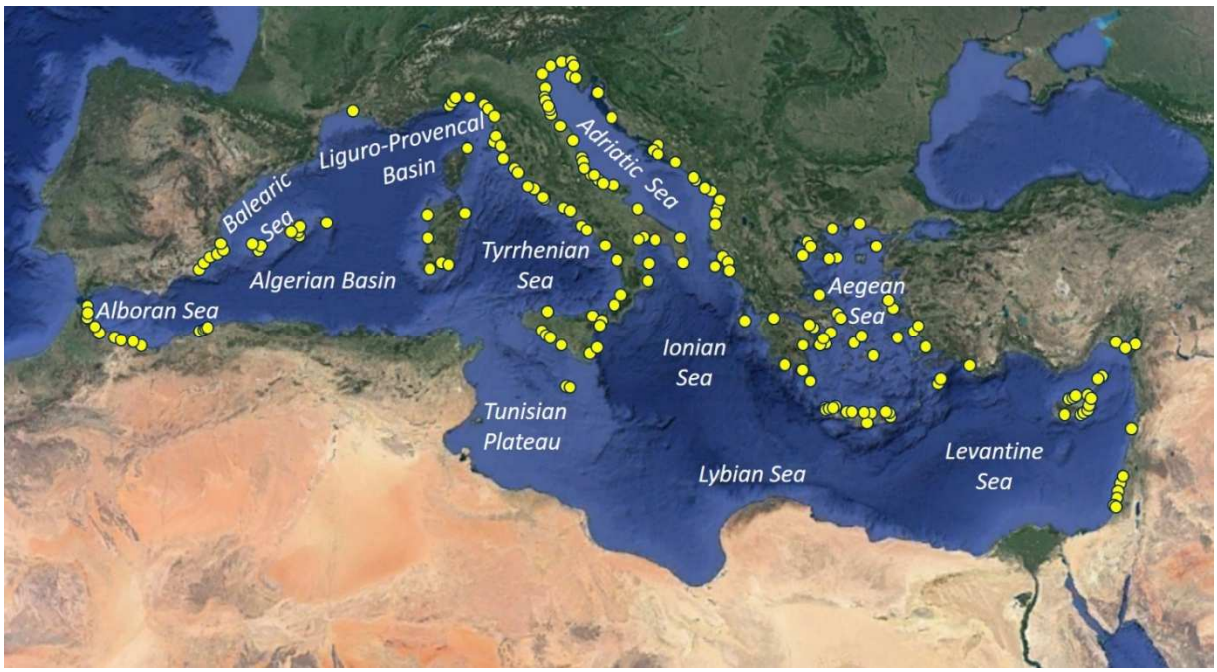

Fig. 3. Geographical distribution of macro-MBL collections in the Mediterranean Sea and its main sub-basins. Yellow dots indicate the beaches where single or multiple surveys were realized.

The amount and the composition of MBL can vary over geographical scales and reflects the geomorphological and hydrographical characteristics of the coast (Ansari and Farzadkia, 2022). Different criteria drive the selection of the surveyed areas according to the objectives of each monitoring campaign. The majority of the projects consider specific factors and often aim at covering different exposure to natural and anthropogenic drivers of litter deposition (e.g., Prevenios et al., 2018). Among these factors, the most represented are i) distance from urban areas, harbour, river outflow, shipping lane; ii) prevailing meteorological conditions (e.g., sea currents and winds); iii) beach characteristics (e.g., length, orientation, substrate and slope); iv) usage of the beach and/or of the surrounding area (e.g., tourism, agriculture, industrial activities). Sometimes, surveyed areas distribution is arbitrarily selected to uniformly cover the whole length of an investigated coastline (e.g., Asensio-Montesinos et al., 2019a). Only a few studies (17%) focus on natural

reserves and marine protected areas (e.g., Giovacchini et al., 2018; de Francesco et al., 2021). This is possibly due to the MSFD and UNEP guidelines suggesting that survey activities should be conducted so as not to impact on any endangered or protected species (Cheshire et al., 2009; Galgani et al., 2013).

Beach typology information is provided in 59% of the publications (Table 4). Nevertheless, only one third of the publications follow the Bathing Area Registration and Evaluation (BARE) system (see chapter 9 in Williams and Micallef, 2009) that classifies coastal sites into four beach types (remote, rural, village, urban), according to the difficulty of access, level of coastal occupation and community services. Thus, criteria are not completely homogenous. Several authors, in fact, only indicate the main destination of the area, e.g., touristic/non-touristic (Lagalbauer et al., 2014); very touristic/low touristic/remote (Grelaud and Ziveri, 2020); industrial/agricultural/urban/rural (Gundogdu and Cevik, 2019); or its geographical characteristics, such as wetland (Alshawafi et al., 2017; Battisti et al., 2019), river estuary (e.g., Romiti et al., 2021). As stated above, a few publications report more detailed information about beach selection, including parameters such as minimum length or width, slope range, access, presence of vegetation, dunes, road, fence or other anthropogenic structures (e.g., Vlachogianni et al., 2020).

As for coastal characteristics, 78% of analysed papers report information about the beach typology (Table 4). As expected, sandy beaches represent the majority of the surveyed sites. However, rocky areas, cobbles and pebbles beaches, and less frequently cliffs and artificial coasts, have been also studied.

Table 4. Surveyed sites information from scientific collections identified by ID numbers, as in Table 3. In parenthesis, the exact number of sites falling into a given category, if explicitly stated in the analysed documents.

ID	Number of sites	Beach typology (sites)	coastal type (sites)	Protected area
1	5		sandy, rocky	
2	3		sandy, rocky	
3	6		sandy, cobbles, rocky	
4	13			
5	6		sandy (5), gravel (1)	
6	7			
7	32			
8	80			
9	5		sandy	
10	6	touristic / non-touristic		
11	8	urban, semi-urban, semi-rural	sandy	
12	14		sandy, rocky	
13	7	exposed (3), sheltered (4)	sandy	
14	4		sandy	
15	13		sandy (12), small gravel (1)	
16	3		sandy	yes
17	4	urban (1), remote (2), semi-rural (1)	sandy (3), pebbles and cobbles (1)	
18	3	natural	sandy	
19	11	natural, urbanized, urban	sandy	yes
20	31	urban, semi-urban, semi-rural, remote		
21	1	wetland		
22	14	urban, village, rural, remote	cliffed, sandy	
23	5		sandy	

24	5		sandy	
25	14	urban (6), village (2), resort (2), rural (4)	cliffed, sandy	
26	64		sandy, gravel	
27	3	urban	sandy	
28	9			
29	62	remote		
30	8	natural, semi-urban	sandy, rocky	
31	35	very touristic, used by locals, remote		
32	1	urban	sandy	
33	9		sandy	
34	13	agricoltural (5), industrial (3), urban (3), rural (2)	sandy (11), gravel (2)	
35	7		sandy, rocky, pebbles	yes
36	5	semi-urban (2), urban (2), semi-rural (1)		
37	56	remote and rural (19), village (17), urban (20)	sandy, gravel, pebbles, rocky, low cliff, artificial	
38	56	remote (9), rural (10), village (17), urban (20)	sandy (31), gravel (14), boulders (14), rocky (8), banquettes (6), artificial (1)	
39	3	semi-urban, semi-rural, remote/natural	sandy, gravel, pebbles	
40	23	urban, semi-urban, semi-rural, remote/natural		
41	3	remote/natural	sandy	
42	1	wetland	sandy	yes
43	2	urban	stones, sandy	
44	1	semi-rural	rocky	
45	1		sandy	yes
46	12	urban (7), rural (2), remote (3)	sandy (2), gravel (2), sandy and gravel (7), pebbles (1)	
47	2	river estuary	sandy	
48	2			
49	5	urban (3), village (2)	sandy	
50	1	Wetland	sandy	yes
51	10	Urban	sandy (8), boulders and cliffs (2)	
52	1	Lagoon	sandy	yes
53	1	Lagoon	sandy	
54	5	rural (2), remote (3)	cobbles	
55	1	Wetland	sandy	yes
56	1		sandy	yes
57	2		pebbles	
58	1	Wetland	sandy	yes

3.4. Sampling methodologies and data analysis

Depending on how they are designed and realized, MBL counts and collections can reflect the presence, amounts and types of marine debris, and the long-term balance between inputs (e.g., land-based sources, storms, tides) and export (e.g., degradation, clean-up) over a coastal area (Portman and Brennan, 2017). However, the evaluation of fluxes between beaches and nearshore marine waters is usually difficult. Surveys mostly represent a valid tool for tracking minor changes in overall abundance and accumulation rates, as well as for monitoring evident changes in the composition of litter (Galgani et al., 2013). These goals imply an appropriate logical temporal and spatial organization of surveys and the choice of criteria (e.g., parameters,

standard sampling units, replications) that allow the inter-comparison between observations collected by different operators in different moments over the same (or different) areas.

The sampling strategies to assess the occurrence of MBL include a wide range of methodologies/approaches, depending on many factors, including the main goal of a given study (Velander and Mocogni, 1999; Romiti et al., 2021) and the costs associated to the application of different protocols. The latter include, for example, labour in different phases of monitoring, equipment, specialized personnel and other running costs (MSFD, 2013).

Table 5 summarizes surveys information for scientific collections analysed in this study. The compiled information shows a large variety of applied methodologies and criteria. Firstly, the standard unit was very different among the collections. Only for half of them (29 of 58) it consisted of a 100 m long coastal sector. Some authors opted for 50 m or for full length of the surveyed beach (about 18%). Other sampling activities (20%), indeed, opted for quadrats instead of linear transects. Again, quadrats dimensions vary from site to site (see Table 5). The remaining publications present customized sampling units due to specific research interests or to the absence of standardized protocols (e.g., for studies dating to the '80s). The different strategies, of course, imply manual collections of litter items during some surveys (about 80 %), and only visual inspection during others (about 20%). Among all of them, in some cases (20%) the observer recorded litter data whilst moving along separated transects parallel to the coastline (usually 5 m wide) in order to cover the entire usable beach, from the shoreline up to its landward limits (e.g., Asensios Monteisons, 2019a). Conversely, 30% of the surveys were performed along transects normal to the coastline, from the strandline to the back of the beach (e.g., Grelaud and Ziveri, 2020).

Another important difference lies in the size of MBL surveyed during monitoring activities. Different definitions can be found in the analysed publications. Generally, there are no upper size limits and classes of items. On the other hand, the lower limit of detection varies considerably from survey to survey. A few collections (10%) set the MBL size lower limit at 0.5 cm (e.g., Taibi et al., 2021). As generally recommended (Galgani et al., 2013), most of the analysed collections (41%) opt indeed for a lower limit of 2.5 cm in the longest dimension (e.g., Giovacchini et al., 2018). This ensures, for example, the inclusion of caps and lids and cigarette butts in any counts (Galgani et al., 2013). Other surveys use different lower limits (28%), such as 2 cm (12%) or 1 cm (5%), or do not provide clear information about size limits (21%).

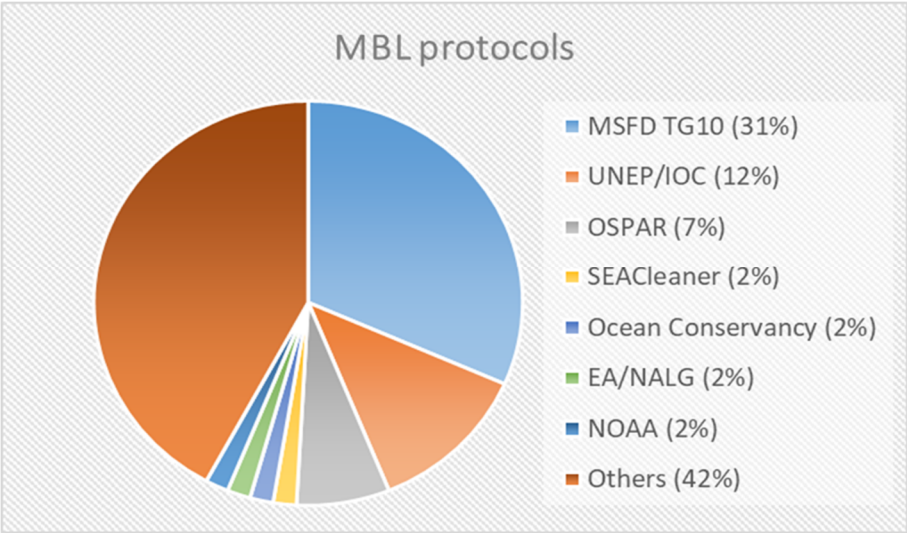

Fig. 4. Percentage distribution of sampling protocols used in MBL data collections indexed in Scopus.

All these differences are the results of the application of different protocols providing specific guidelines for MBL sampling. Figure 4 summarizes information reported in Table 5 through the percentage distribution of the official protocols applied in the analysed studies. Since their release in 2013, the guidelines suggested by the MSFD technical group on marine litter (MSFD Technical Support group on marine litter, 2013) represent the most used protocol (31%). These recommendations are based on the OSPAR Commission Guidelines for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area (OSPAR, 2010a), UNEP Operational Guidelines for Comprehensive Beach Litter Assessment (Cheshire et al., 2009) and the NOAA Marine Debris Shoreline Survey Field Guide (Opfer et al., 2012).
Similar differences can be found in the existing approaches for identification and classification of information about the observed MBL typology. Most of the analysed studies firstly group MBL items into macro-categories according to the basic material they are made of (e.g., plastics, wood, metal, glass, paper, organic matter, etc.), then divide them into specific typologies. Although several detailed international guidelines exist (e.g., EA/NALG, 2000; Cheshire et al., 2009; OSPAR, 2010a; Opfer et al., 2012; Galgani et al., 2013), scientists are often dealing with specific interests and needs, so they categorize litter into personalized groups (e.g., Battisti et al., 2019; Fanini and Guittard, 2021) or combine different litter classification schemes (Asensio-Montesinos et al., 2021a). Sometimes, very detailed information, such as the specific type or even brand of single items, are also used to support specific analyses, such as source attribution (e.g., Golik and Gertner, 1992; Renzi and Blaskovic, 2018). Among the selected publications, the most used classification scheme (31%) is the master list suggested by MSFD GES Technical Subgroup on Marine Litter (Galgani et al., 2013). This reference list was developed as part of a technical (non-legally binding) guidance document with recommendations for monitoring marine litter in accordance with the MSFD (Portmann and Brennan, 2017). It considers 213 categories referring to MBL grouped into eight material classes and permits to assign each litter item to a standard General Code (G-Code). However, several studies that use G-code only consider a subset of 165 relevant categories, among the 213 available for MBL classification, excluding categories for micro-litter (i.e., G103-123) or other residual types of items which are not applicable to monitoring marine macro-litter on beaches. G-code was derived in order to move towards harmonised monitoring, but different lists have been and are still being used in parallel, such as the OSPAR Items List for 100-metre sampling, which contains 121 MBL categories divided into 11 groups of classes, or the UNEP/IOC items list, which includes 77 typologies grouped in 10 material classes.

Furthermore, different studies count and report MBL amount in different ways. The unit in which litter is assessed range among number, weight or volume. A combination of these units can be also used (see Table 6). Generally, count of items is recommended as the easiest way to assess its presence along the coastline. The assessment of weight of litter, instead, can be more difficult because it is dependent on MBL items conditions (e.g., wet or dry, covered or plenty of sand or gravel, too big for being weighted on site; Jambeck and Farfour 2011). The assessment of the volume of litter is also problematical because it depends on the level of compression of the litter involved. Among the analysed collections, just two studies do not consider items abundance preferring to assess MBL through its weight (Alshawafi et al., 2017) and percentage coverage (Mo et al., 2021). Conversely, 33 studies report only MBL abundance, while the others focus on abundance and weight or a combination of different parameters including abundance (19 and 5 documents, respectively). It is also interesting to notice that 19% of the available documents do not mention if/how MBL was removed during/after beach monitoring, or they adopt methodologies that include visual census without waste removal (Merlino et al., 2021). Moreover, as for the Mediterranean Sea, only six studies declare a direct participation of volunteers. However, as stated above, non-scientific initiatives are usually characterized by a massive use of websites and outreach reports, thus appearing in scientific publications only at later stages, frequently after several years.

Whatever is the applied collection methodology, scientists usually convert their abundance, weight or volume information into density, opting for per beach length unit (m) rather than per beach area unit (m^2) in order to facilitate the comparability of MBL on a temporal, local, or global level (Papachristopoulou et al., 2020). Still, differences exist among available studies estimating density per m (m^2) or 100 m (100 m^2) of beach face length (Table 6). Most of the analysed studies reporting MBL abundance densities express them in items/m^2 or items/100 m^2 (66%), while a lower percentage of collections use per length units (21%) or both (13%). Statistical analyses are always very useful when processing and interpreting these data. Table 6 shows that a variety of univariate and multivariate analyses have been used in the selected publications. Opting for a specific statistical tool seems to be generally driven by the research objectives more than the typology of the collected dataset. Mathematical formulas and coefficients can be used for providing an evaluation of beach quality, for example through common shared indices, and litter sources. Only 34% of the analysed studies reports this kind of information, using different indices, i.e., clean cost index (15 studies), litter grade (3), pollution density index (1), index of environmental spoil (1), accumulation index (1), Chao's Sørensen index (1). The clean cost index, for example, provides an aggregate indicator that translates the quality of the beaches in terms of potential and direct damage to the health of marine organisms, and it results very useful for spatial (e.g., beaches with different characteristics) and temporal (e.g., seasonal or interannual) comparisons.

Finally, it is noteworthy that 81% of available Scopus indexed documents deal, someway, with litter source analysis. To this goal, a variety of methods have been used, from simple counts of items believed to originate from a given source to more complex mathematical methods, such as the Matrix Scoring Technique.

Table 5. Surveys information for scientific collections identified by ID numbers, as in Table 3.

ID	Sampling unit	Transect details	Units	Tot area or length	Methodology	MBL size	Protocol	MBL classification
1	customized	area included the zone between the low and high water marks	7	1500 m^2	visually	> 2 cm	NA	type (e.g., metal, plastic, glass, paper)
2	customized	area included the zone between the low and high water marks	1	NA	manually	> 2 cm	NA	type (e.g., metal, plastic, glass, paper)
3	customized	5 m wide, normal to the coastline, from the waterline to the back of the beach	472	NA	visually or manually	> 1 cm	NA	NA
4	customized	normal to the coastline, from the waterline to the back of the beach	64	NA	manually	> 2 cm	NA	7 groups (plastics, wood, Styrofoam, fishing gear, glass, metal, other)
5	50 m		NA	NA	visually	NA	NA	7 groups (plastic, metal, glass, paper, wood, cloth, other)
6	100 m		15	1500 m	manually	NA	EA/NALG	45 litter types
7	customized	2 m wide, normal to the shoreline, 15 m apart, upper few cm	NA	NA	manually	> 0.1 cm	NA	7 groups (plastics, wood, metal, glass, paper, organic matter, other)
8	full beach		NA	NA	manually	≥ 1 cm	NA	8 groups (glass, plastic, paper, aluminum, other metals, rope, building materials, other materials)
9	2 x 2 m^2		153	612 m^2	visually	> 2.5 cm	NA	165 categories in 8 groups (G-code)
10	50 m	parallel to the shoreline	6	300 m	manually	≥ 2 cm	UNEP/IOC (Cheshire et al., 2009)	59 categories in 8 groups
11	100 m	12 m wide	146	33,790 m^2	visually	NA	UNEP/IOC (Cheshire et al., 2009)	87 categories
12	customized	normal to the coastline, from the action of waves limitation up to territorial plants	NA	209,220 m^2	manually	> 2.5 cm	NA	10 groups about material (plastic, nylon, fibres, polystyrene, glass, metal, paper, wood, synthetic material, cigarette butts/package) and 11 about usage (drink packaging, food packaging,

								packaging, fishing material, rope, recreational, cleaning supplies, medical supplies, cigarette, cloth/shoes, others)
13	*100 m*	*parallel to the shoreline*	*3*	*300 m*	*manually*	*NA*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
14	*0.4 x 0.4 m^2*	*5 m apart, from the back of the beach to the waterline, 10 cm depth*	*75*	*12 m^2*	*sieved by a 2mm mesh*	*> 2.5 cm*	*NA*	*165 categories in 8 groups (G-code)*
15	*100 m*		*NA*	*NA*	*manually*	*> 2 cm*	*MSFD TG10*	*8 groups (cloth, foamed plastic, glass and ceramics, metal, paper and cardboard, plastic, rubber, wood)*
16	*customized*	*parallel to the coastline, from the shoreline to the dune habitats*	*NA*	*NA*	*manually*	*> 0.5 cm*	*OSPAR*	*6 groups (plastic, polystirene, glass, paper, mixed, other)*
17	*100 m*	*perpendicular to the coastline, from waterline to the back of the beach*	*144*	*595,200 m^2*	*manually*	*> 2.5 cm*	*MSFD TG10*	*213 categories in 8 groups (G-code)*
18	*100 m*	*perpendicular to the coastline, from sea line to back dune's woody vegetation*	*15*	*112,500 m^2*	*manually*	*> 2 cm*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
19	*100 m*	*perpendicular to the coastline, from waterline to the back of the beach*	*33*	*32,154 m^2*	*manually*	*NA*	*SEACleaner Protocol*	*33 categories in 9 groups (plastic, polystyrene, wood, foam/sponge, textiles, multimaterial, rubber, glass, metal)*
20	*100 m*	*perpendicular to shoreline, 50 m apart*	*180*	*33,200 m^2*	*manually*	*all items*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
21	*100 m*		*NA*	*NA*	*manually*	*> 2 cm*	*NOAA (Ioakeimidis et al., 2016)*	*6 categories (plastic, lumber and paper, cloth and fabric, glass, metal, rubber)*
22	*100 m*	*parallel to shoreline, 5 m apart between shoreline and beach landward*	*17*	*108,051 m^2*	*manually*	*> 2.5 cm*	*UNEP/IOC (Cheshire et al., 2009)*	*7 groups (artificial polymers, rubber, textile, paper, metal, wood, glass and ceramics)*
23	*50 m*	*perpendicular to the beach, from waterline to the back of the beach*	*10*	*12,000 m^2*	*manually*	*> 2.5 cm*	*UNEP/IOC (Cheshire et al., 2009)*	*76 categories in 9 groups*
24	*0.5 x 0.5 m^2*	*10 m wide along shoreline*	*30*	*7.5 m^2*	*manually*	*NA*	*NA*	*fragments, pellets, films*

25	*100 m*	*parallel to shoreline, 5 m apart from the strandline to the beach landward*	*56*	*408,204 m^2*	*manually*	*> 2.5 cm*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
26	*100 m*	*perpendicular to the coast, no more than 50 m apart*	*192*	*19,200 m*	*manually*	*> 0.4 cm*	*MSFD TG10*	*59 categories in 10 groups*
27	*100 m*		*21*	*5476 m^2*	*manually*	*> 2.5 cm*	*MSFD TG10*	*165 categories in 9 groups (G-code)*
28	*full beach*		*NA*	*20,980 m^2*	*manually*	*NA*	*Ocean Conservancy*	*41 categories (Ocean Conservancy)*
29	*full beach*		*NA*	*31,461 m^2*	*vessel-based photography*	*≥ 2.5 cm*	*MSFD TG10*	*213 categories in 8 groups (G-code)*
30	*50 m*		*104*	*26,000 m^2*	*manually*	*> 2.5 cm*	*MSFD TG10*	*8 groups (OSPAR, 2010a)*
31	*100 m*	*perpendicular to the beach, from waterline to the back of the beach*	*147*	*14,700 m*	*manually*	*> 2.5 cm*	*OSPAR*	*9 groups (artificial polymer materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics, unidentified and chemicals)*
32	*2 x 2 m^2*	*random quadrats*	*120*	*480 m^2*	*manually*	*all items*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
33	*0.5 x 0.5 m^2*	*perpendicular to the coastline, 20 m apart along highest waterline; 5 cm depth*	*110*	*27.5 m^2*	*sieved by a 1mm mesh*	*≥ 0.5 cm*	*NA*	*fragments, pellets, films*
34	*1 x 1 m^2*	*high strandline, mid line, backshore line; 5 cm depth*	*117*	*117 m^2*	*sieved by a 5 mm mesh*	*> 2.5 cm*	*adapted from Losh (2015), Frias et al. (2018)*	*5 groups of plastics (filament, film, foam, fragments, pellets)*
35	*2 x 2 m^2*	*random quadrats*	*180*	*720 m^2*	*manually*	*> 2.5 cm*	*OSPAR, UNEP/MAP*	*6 groups about material (plastic, polystyrene, glass, paper, aluminum, mixed waste) and 5 for usage (containers, fishing and boating, food and beverage, packaging, other)*
36	*100 m*	*perpendicular to the coast, 50 m apart*	*10*	*24,000 m^2*	*manually*	*> 2.5 cm*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
37	*100 m*	*parallel to coastline, 5 m apart*	*NA*	*201,686 m^2*	*visually*	*> 2.5 cm*	*UNEP/IOC, NOAA, OSPAR*	*116 categories in 8 groups (UNEP code)*
38	*100 m*	*parallel to coastline, 5 m apart*	*NA*	*201,700 m^2*	*visually*	*> 2.5 cm*	*EA/NALG, UNEP/IOC,*	*129 categories in 8 groups (UNEP code)*

							OSPAR, NOAA	
39	100 m	10 m wide along shoreline	3	2800 m^2	manually	> 0.5 cm	MSFD TG10	165 categories in 8 groups (G-code)
40	100 m	perpendicular to the coastline, at least 50 m apart	62	113,780 m^2	manually	> 2.5 cm	MSFD TG10	165 categories (G-code) in 3 groups (single-use plastics, non-single use plastics, non-plastics)
41	4 x 4 m^2	random quadrats, with nested 1 x 1 m^2 plots	22	352 m^2	visually	> 2.5 cm	NA	213 categories in 8 groups (G-code)
42	full beach		NA	15,000 m^2	manually	> 3 cm	NA	fishing lines and hooks
43	100 m	perpendicular to the coastline, from the strandline to the back of the beach	18	16,500 m^2	manually	all items	MEDPOL	11 categories (plastic, rubber, textile, glass, ceramics, processed wood, metal, paper, sanitary waste, medical waste, paraffin/wax)
44	100 m	10 m wide	4	4000 m^2	manually	> 2.5 cm	MSFD TG10	165 categories in 8 groups (G-code)
45	0.3 x 0.3 m^2	random quadrats, from the shoreline to the base of the dune; 10 cm depth	9	0.81 m^2	box corer	> 3 cm	allometric models	plastic items
46	100 m	parallel to the shoreline, 5 m apart	NA	63,645 m^2	visually	> 2.5 cm	UNEP/MAP	207 categories in 9 groups (UNEP code)
47	full beach	wet beach, dry beach, fore dune, hind dune	NA	48,000 m^2	manually	container	Poeta et al. 2015	3 groups (plastic, glass, aluminium) in 5 categories of shape/volume (small bottles (< 1.5 l), large bottles (≥ 1.5 l), tanks (≥ 5 l), jars (0.3-1 l), cans (0.3–0.5 l))
48	400 m		NA	400 m	manually	> 2.5 cm	NA	2 groups (traws, wraps litter)
49	100 m	20 m wide	19	38,000 m^2	manually	NA	MSFD TG10	165 categories in 8 groups (G-code)
50	0.2 x 0.2 m^2	parallel to the coastline, 30 m from the water's edge, 50 m apart	32	1.28 m^2	manually	> 2.5 cm	customized	vegetal wrack and plastic litter (Hanke et al., 2013)
51	100 m	parallel to shoreline, from the water line to the beach backshore	10	NA	manually	> 5.0 cm	UNEP/IOC (Cheshire et al., 2009)	5 groups (bottles, bags, packaging, tyres, other)
52	100 m	from the landward beach limit to the shoreline, garbage bins	5	500 m	manually	> 2.5 cm	MSFD TG10	165 categories in 8 groups (G-code)

53	*100 m*	*from the landward beach limit to the shoreline, garbage bins*	*8*	*800 m*	*Manually*	*> 0.5 cm*	*MSFD TG10*	*165 categories in 8 groups (G-code)*
54	*full beach*	*perpendicular to the coastline, 2 m apart from the strandline to the backshore area*	*35*	*73,451 m^2*	*Manually*	*> 0.5 cm*	*Williams and Tudor, 2001*	*183 categories*
55	*90 m*	*along the dunes, backdunes, channels in wetland*	*13*	*1170 m*	*sieve by a 8 mm mesh*	*> 1 cm*	*customized*	*total litter and expanded polystyrene subcategory (EPS)*
56	*3 x 3 m^2*		*100*	*900 m^2*	*unmanned aerial vehicle, visually*	*> 0.5 cm*	*OSPAR*	*43 tipologies divided in 6 groups (fragments, containers, packaging, sanitary, clothing, others)*
57	*100 m*	*perpendicular to the coastline, from the tide line to the back border of the beach*	*2*	*1600 m^2*	*manually/visually*	*> 5 cm*	*NA*	*28 categories*
58	*Customized*		*NA*	*3000 m^2*	*Manually*	*> 2.5 cm*	*NA*	*7 groups (bottle cap, cotton buds, expanded polystyrene, cigarette butts, generic fragments, bottles, other containers)*

Table 6. MBL collection details for surveys identified by ID numbers, as in Table 3.

ID	Measurements	Total litter	Litter density estimation	litter removal	Volunteers participation	Statistical analysis	indices	Sources analysis
1	abundance		g cm^{-3}					yes
2	abundance		g cm^{-3}					yes
3	abundance	17,355 items		yes		Wilcoxon test, Duncan test		yes
4	abundance and weight		g m^{-1}	yes				yes
5	abundance		items 100 m^{-2}				pollution density index, index of environmental spoil	
6	abundance			yes		PCA, cluster analysis		yes
7	abundance and weight		items m^{-1}	yes		PCA, multivariate analysis, redundancy analysis, univariate analysis of variance		yes
8	abundance	110,423 items		yes	yes	R-mode factor analysis, cluster analysis		yes
9	abundance					Shapiro–Wilk test, Kruskal–Wallis test, generalized linear mixed-effects model, Pearson correlation test		yes
10	abundance and weight	5,870 items	items m^{-2} g m^{-2}	yes		multidimensional scaling	clean coast index	
11	abundance	69,122 items	items 100 m^{-2}	yes				yes
12	abundance	1,445 items	items 100 m^{-2}	yes				yes
13	abundance	39,972 items	items 100 m^{-1}	yes		PERMANOVA		
14	abundance and weight	12,263 items 0.734 kg	items m^{-2} g m^{-2}	yes				
15	abundance and weight		items m^{-2} g m^{-2}	yes		multivariate adaptive regression splines	clean coast-index	yes
16	abundance	6,100 items		yes				yes
17	abundance and weight	41,617 items	items 100 m^{-1} items m^{-2}	yes		PCA, Kruskal-Wallis test, Dunn's test, PCA with Varimax rotation, PERMANOVA, Kaiser-Meyer-Olkin test		yes
18	abundance	31,739 items	items m^{-1}	yes		PERMANOVA, SIMPER		yes
19	abundance	34,027 items	items m^{-2}	yes	yes	PCA, cluster analysis	clean coast index	yes

20	*abundance*	*70,581 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*			*clean coast index*	*yes*
21	*weight*	*12.855 kg*		*yes*	*yes*	*PCA, cluster analysis*		*yes*
22	*abundance and weight*	*8,021 items* *198 kg*	*items m^{-2}* *g m^{-2}*	*yes*				*yes*
23	*abundance*	*2,502 items*	*items m^{-2}*	*yes*		*PERMANOVA, regression analysis, Shannon's diversity index, UPGMA sorting, Bray-Curtis index, SIMPER*	*clean coast index*	*yes*
24	*abundance and weight*	*1,345 items* *13.491 kg*	*items m^{-2}* *items kg^{-1}*	*yes*		*PERMANOVA, Bray-Curtis index, SIMPER*		
25	*abundance*	*21,943 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*			*clean coast index*	*yes*
26	*abundance*		*items 100 m^{-1}*	*yes*		*PERMANOVA, SIMPER*		*yes*
27	*abundance*	*3,305 items*	*items m^{-2}*	*yes*		*Pearson's Chi-Square test*	*clean coast index*	
28	*abundance*	*7,658 items*		*yes*	*yes*			*yes*
29	*abundance*	*17,620 items*	*items 100 m^{-1}*			*regression analysis*		*yes*
30	*abundance and weight*	*59,556 items* *697 kg*	*items m^{-2}* *items m^{-1}* *g m^{-2}* *g m^{-1}*	*yes*				*yes*
31	*abundance*	*162,320 items*	*items m^{-2}*	*yes*		*accumulation rate*	*accumulation index*	*yes*
32	*abundance*	*585 items*	*items m^{-2}*	*yes*		*univariate statistics, SIMPER, PCA*		*yes*
33	*abundance, weight, colour*	*356 items*	*items m^{-2}* *g m^{-2}*	*yes*		*Mann-Whitney test, Kruskal-Wallis test, NDWD test*		*yes*
34	*abundance and weight*	*1,424 items*	*items m^{-2}* *g m^{-2}*	*yes*		*Mann-Whitney test, Kruskal-Wallis test, PERMANOVA, PCA, Bray-Curtis index*		*yes*
35	*abundance*	*1,492 items*	*items m^{-2}*	*yes*		*PCA, Mann-Whitney test*		*yes*
36	*abundance*	*3,321 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*		*cluster analysis*		*yes*
37	*abundance*	*10,101 items*	*items m^{-2}*			*multivariate analysis, nMDS, cluster analysis*	*litter grade*	*yes*
38	*abundance*	*30,941 items*	*items m^{-2}*			*nMDS, PCA, cluster analysis*	*litter grade*	*yes*
39	*abundance and weight*	*6,010 items*	*items m^{-2}*	*yes*			*clean coast index*	*yes*

40	*abundance*	*37,991 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*	*yes*	*cluster analysis*		*yes*
41	*percentage coverage*					*Kruskal-Wallis test, PERMANOVA, diachronic analyses, Shapiro-Wilk test, Levene test*		
42	*abundance, length of the lines, density of hooks*	*243 fishing lines* *88 skeins* *33 hooks*	*cm m^{-2}* *mg m^{-2}* *items ha^{-1}*	*yes*				
43	*abundance and weight*	*133,4 kg*	*items m^{-2}*	*yes*			*clean coast index*	
44	*abundance*	*11,024 items*	*items m^{-2}*	*yes*			*clean coast index*	*yes*
45	*abundance and weight*			*yes*		*nMDS*		
46	*abundance*	*31,571 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*		*Kolmogorov–Smirnov test, Bartlett's test, Tukey's test, ANOVA*	*litter grade, clean coast index*	*yes*
47	*abundance*	*2,177 containers*	*items 100 m^{-2}*				*chao's sørensen index*	
48	*abundance, shape, colour*		*items m^{-1}*	*yes*		*Spearman rank correlation*		*yes*
49	*abundance and weight*	*7,839 items* *231 kg*	*items m^{-2}* *g m^{-2}*	*yes*			*clean coast index*	*yes*
50	*abundance and weight*		*items m^{-2}*	*yes*		*Mann-Whitney test, Pearson or Spearman correlation test*		
51	*abundance*	*14,537 items*	*items m^{-2}*	*yes*				*yes*
52	*abundance and weight*	*2,324 items* *105.44 kg*	*items m^{-2}* *g m^{-2}*	*yes*		*one-way ANOVA*	*clean coast index*	*yes*
53	*abundance and weight*	*10,717 items* *229.29 kg*	*items m^{-2}* *g m^{-2}*	*yes*		*one-way ANOVA*	*clean coast index*	*yes*
54	*abundance*	*2,410 items*	*items 100 m^{-1}* *items m^{-2}*	*yes*		*nMDS, cluster analysis, Bray–Curtis index*	*clean coast index*	*yes*
55	*abundance*	*2,120 items*		*yes*		*Kruskall-Wallis test, Mann-Whitney test*		
56	*abundance and colour*	*332 items*			*yes*	*Kendall's coefficient of concordance*		*yes*
57	*abundance and weight*	*810 items* *1641.25 kg*						*yes*
58	*abundance and weight*	*6,700 items,* *10.717 kg*		*yes*				

4. Discussion

The Final Report "Guidance on Monitoring of Marine Litter in European Seas" (Galgani et al., 2013), realized by MSFD TSG-ML, provides recommendations and information needed for an effective monitoring of the MBL. Much of the information included is taken from some of the most comprehensive and useful overviews for monitoring methods on the coast, i.e., the UNEP (Cheshire et al., 2009), the OSPAR (OSPAR, 2010a), and the NOAA (Opfer et al., 2012) guidelines. This is probably one of the reasons of its success (Portman and Brennan, 2017).

MSFD TSG-ML suggests that when designing marine litter surveys, it is necessary to differentiate between standing-stock surveys, where the total load of litter is assessed during a one-off count, and the assessment of accumulation and loading rates during regularly repeated surveys of the same stretch of beach with initial and subsequent removal of litter (Galgani et al., 2013). This distinction between the assessment of flux rate rather than standing crop is generally reflected in the differences between the comprehensive and rapid assessment protocols. Both types of survey provide information on the amount and types of litter, however, only the accumulation surveys provide information on the rate of deposition of litter and trends in litter pollution. The amount of litter arriving on a given length of beach over a given period of time can be expressed as [unit quantity of litter] per [unit length of beach] per [unit time]. Conversely, the amount of material standing on the beach is usually determined as [unit quantity of litter] per [unit length of beach] (Cheshire et al., 2009). The accumulation periods should be approximately of the same length. To this aim, the minimum sampling frequency of a given beach should be annually, roughly on the same day each year. Ideally, beach site should be surveyed every three months through seasonal collections at regular intervals in time. Thus, at least four surveys per year (i.e., in spring, summer, autumn and winter) are recommended by MSFD (Galgani et al., 2013).

Nevertheless, the information reported in the selected publications shows that MBL scientific collection projects are typically conducted over a limited and short period of time, i.e., covering two years or less. Actually, almost one third of the analysed studies focus on single-day surveys. This implies that only few studies can effectively assess the temporal variation in the amount of litter present on a given beach, or several beaches. Additionally, also the collection characterized by seasonal repetitions are significantly affected by seasonal variation that might partly mask long-term variability (Schulz et al., 2013). This makes rather impossible the estimation of trends. As a consequence, in the existing literature the assessment of the MBL temporal and spatial variability in a surveyed areas is generally obtained through the comparison with data published in previous studies. Normalized variables (e.g., density and/or weight per m^{-2}) help this task but a direct comparison often neglects that collections carried out in the framework of different projects may have been realized taking advantage of different protocols and guidelines. On the other hand, it is possible that several projects could be still in progress and that the available publications represent only a preliminary piece of information about monitoring activities designed for the long-term. Similarly, non-scientific initiatives (e.g., citizen science and clean-ups events) typically have no fixed end-date, and the results of their collection efforts, which are disseminated regularly on websites and outreach reports, appear in scientific publications after several years when scientific conclusions can be finally retrieved (Schneider et al., 2018). The surveys, indeed, should be repeated on exactly the same site as strongly recommended by OSPAR (OSPAR, 2010b) and MSFD (Galgani et al., 2013). Still, the site should not be subject to any other litter collection activities except the monitoring survey; alternatively, the frequency and timing of the other beach cleaning (e.g., those carried out every morning at dawn during the summer to please tourists) should be well known and documented such that their influence on the litter flux rates can be determined. This information is generally missing in the analysed scientific production.

The selection of costal sites for the monitoring of MBL can significantly influence the achieved results due to the different demographic and geographical conditions of beaches (e.g., in urban areas, touristic areas, rural or remote areas). Therefore, as for basic beach selection criteria, geomorphological and sedimentary characteristics, river presence, meteo-oceanographic regimes, main beach usage (i.e., recreational, fishing, surfing, boat access), should be always considered and reported. Year-round accessible beaches with low to moderate slope (15 – 45°) should be preferred, better if free of barriers such as breakwaters or jetties that can alter local water dynamics (Afghan et al., 2020). Litter exposure (i.e., urban sites, rural coasts, marine protected area) should be evaluated too. Nevertheless, a few publications clearly define all these aspects among those analysed in this study.

A basic monitoring criterion is the MBL sampling unit, that is a fixed section (length) of beach from which measurements of litter number of items, weight or volume are made periodically (Galgani et al., 2013). Both MSFD and OSPAR guidelines suggest a minimum length of 100 m (i.e., sufficient to fit the recommended smallest sampling unit, 100 m transect). This length can be reduced to 50 m for heavily littered beaches. Any case, a repetition of at least two sections on the same beach is always recommended. Even though most of the considered studies follow these recommendations, a large number of collections opted for quadrats (of different sizes) and customized criteria, instead of linear transects (Table 5). Inhomogeneity also exists in the use of transects. Different studies are carried out parallel rather than perpendicular to the coast, at a different distance between each other, and covering determined or variable beach width. Some of them do not report this information, providing quantitative litter estimation that can be hardly comparable to other collections. This issue sums to the fact that the observed data are sometimes expressed per beach length unit (m) rather than per beach area unit (m^2) in different MBL collections. Although per length unit can be more easily related to floating litter fluxes washed ashore, most of the analysed studies do report MBL densities per beach area. However, when the whole width of the beach is sampled, for equal litter counts, one must consider that per area densities can increase as the width of the beach decreases, resulting in higher values for narrow beaches data, and viceversa (Prevenios et al., 2018). Additionally, these quantitative estimates can refer to abundance or weight (or even to volume in a few cases). This generates additional problems because estimations obtained through weight-based surveys (in kg) cannot be directly compared to those based on the number of items. A comparison between the two methodologies can be attempted when estimates of average weights of the counted litter items are known. However, this would not be always possible since litter items of the same materials occur on beaches in a wide range of sizes and weights.

Furthermore, even though no upper size limits are applied to litter recorded on beaches, the analysed studies shows that lower size limits can be very different from survey to survey. Actually, the lower limit should be determined by the possibility of detection by the naked eye, thus being dependent on the surveyor's visual perception (eyesight) and on the conspicuousness of the MBL items. This actually depends on litter abundance, size, colour and form. The MBL size lower limit is often identified around 0.5 cm. However, it is doubtful that such small items can be monitored effectively during beach surveys in different locations and by differently experienced personnel, e.g., trained scientists, volunteers (OSPAR, 2010a). In this sense, a lower limit of 2.5 cm in the longest dimension seems more recommendable (Galgani et al., 2013), as applied by the majority of the Mediterranean studies carried out in the recent years.

The assessment of litter composition is one of the great strengths of coastal monitoring. A detailed assessment can provide information on potential harm to the environment and, potentially, on the source of the litter found (Ansari and Farzadkia, 2022). To this aim, the assessment and analysis of MBL composition must follow commonly agreed categories in order to provide results which are comparable over larger

regions and different periods. Thus, the attribution of litter categories plays an important role, as do different interpretations of monitoring guidance. Generally, this composition is estimated by grouping the items into different predetermined categories. However, this classification can be based on different codes, as reported in Table 5. Of course, different classification schemes allow to report a different detail of information, from the raw material to the specific type, or even brand, of single items, that can differently support additional litter analyses, such as source attribution (e.g., Golik and Gertner, 1992; Renzi and Blaskovic, 2018). In addition, the existence of shared reference lists for the descriptive identification of items is of crucial importance for comparability and compatibility of available observations. Comparing information collected in different areas/seasons/years, by different groups, is essential to identify priorities for action or effectiveness of mitigation measures. However, MBL data should be considered as a valuable proxy for the amount of litter present in the coastal environment that requires careful interpretation. Scopus indexed documents show that the reported data are usually not accompanied by uncertainties and deserves metadata to be carefully interpreted to evaluate data accuracy and reliability.

Nevertheless, several studies attempt of determine top litter items over a specific region. The identification of top MBL items is essential for the prioritisation of measures to prevent further inputs and reduce the abundance of litter items (Addamo et al., 2017). Previous studies provided interesting information in this sense. The final report of the EU ARCADIS project, for example, lists the top fifteen MBL items for the Mediterranean Sea from 33 OSPAR screenings (Van Acoleyen et al., 2013). Among them, plastic cutlery/trays/straws represent the dominant fraction (17%) with an average frequency of 131 items per 100m, followed by cigarette butts (14%), plastic caps/lids (14%) and plastic drink bottles (12%). The report on Marine Litter Assessment in the Mediterranean, instead, states that the main groups of items found on beaches in the Mediterranean are sanitary items (mostly cotton bud sticks), cigarette butts and cigar tips, as well as packaging items and bottles, all likely related to coastal-based tourism and recreation (UNEP/MAP MEDPOL, 2015). Several other surveys confirm that smoking related waste are a significant problem in the Mediterranean, representing the most frequent items found on beaches, with abundances ranging from 35-62% of the total items recorded (e.g., Martinez-Ribes et al., 2007; UNEP/MAP MEDPOL, 2011; Öko-Institut, 2012). Items related to uncontrolled discharges and inadequately managed waste also represent an important problem in several Mediterranean countries (Makhoukh, 2012; Jambeck et al., 2015; UNEP/MAP MEDPOL, 2015). Unfortunately, the top items calculation modes were different, as well as the category lists and the top items ranking length. Consequently, even if data enable the ranking of items according to their abundance, in many cases they cannot be directly compared with rankings from other collections due to the different monitoring techniques used. These issues add to the above-mentioned differences in MBL sampling and reporting of the results, so that the aggregation of different studies proved to be often unfeasible. Nevertheless, obtaining comparable data and sampling strategies remains a priority to provide the basis for reliable litter abundance rankings.

The identification of the MBL source and pathway is another crucial step in determining the actions and measures to reduce its impact in a given area. The above-mentioned protocols provide useful master lists that relate item categories with potential sources of litter. Nonetheless, source identification is relatively easy only for some items (e.g., fish box/nets; glass bottle in proximity of a beach bar). For the majority of items, especially those fragmented or altered by long stay in the natural environment, it is much more difficult to assign a source with a robust level of accuracy. First of all, a preliminary distinction between sea-based and land-based input is necessary. Sea-based items include litter that is accidently or purposely released into the sea by maritime activities (e.g., by shipping, fishing, aquaculture, offshore activities); land-based items include litter generated on the coast (e.g., by beach users) or behind (e.g., by towns, industrial

sites), that is blown or washed into the sea (Veiga et al., 2016). The analysed Scopus dataset shows that several methodological approaches have been used to determine where litter is coming from, but few information are provided about value and limitations of the attribution of sources per type of item. Several studies, for example, assume that all occurring items from a certain category originate from a particular source/pathway. This is based on the assumption that certain items are typically or widely used by particular sectors (e.g., fishing, shipping, medical) and are conventionally released into the environment via specific pathways. Such approaches can provide a preliminary indication of contribution of key sources. On the other hand, they dismiss potential contributions from other sources (and/or pathways) and the importance of multiple sources. To overcome these issues, a number of statistical techniques exist, such as the Matrix Scoring Technique developed by Tudor and Williams (2004) and further developed by ARCADIS (Van Acoleyen et al., 2013) for use with the OSPAR MBL data.

This technique considers the level of likelihood of the origin of each litter item evaluating all potential sources. A qualitative score (e.g., from "very likely" to "very unlikely" or “not considered”) is assigned to each potential source and then translated to a scoring system (i.e., using weighted numerical values). The attribution of likelihoods is based on the type of litter, distance from each source, impact of a specific activity in the area and any other local factor that can affect litter contribution (Veiga et al., 2016). Several MBL collections over the Mediterranean Sea coastline do made use of attribution of sources based on likelihoods. Its popularity is also based on the fact that it considers the possibility that specific items originate from more than one source. Nonetheless, a reliable likelihood analysis always deserves an accurate knowledge of the survey sites and its surroundings to determine in advance a number of possible local and regional litter sources (e.g., tourism, fishing, shipping, general littering, inadequate waste management, etc.). Numeric modelling, based on Eulerian processes, can be also useful for understanding (and sometimes predicting) MBL distribution in a specific region. However, their application deserves additional knowledge and efforts (e.g., water circulation patterns, meteorological conditions).

Another important problem is represented by litter removal during/after beach surveys, and the consequent waste treatment. Among the analysed studies, several collections rely on counting litter items without removing them from the coastline, or do not mention if/how MBL was removed during/after beach surveys. Actually, removal of litter should be carried out at the same time as monitoring the litter. This is important to ensure better accuracy of reporting, to allow the comparison of litter accumulation over time, to reduce MBL impact on the ecosystems, and to leave a clean coastline to beach users (Galgani et al., 2013). In this context, it is also very important limiting the quantity of sand and living organisms that could be removed during manual/mechanical MBL collections (Zielinski et al., 2019). To this goal, MBL assessment programmes should always include specific efforts to recruit, and train, field staff (Galgani et al., 2013). This is essential to ensure data quality and prevent environmental damages. This is even more important when citizens and volunteers are involved in the beach monitoring during clean-up activities or citizen observation-based initiatives. In this case, some protocols (e.g., Ocean Conservancy’s National Marine Debris Monitoring Program) also requires a percentage of monitored locations to be re-surveyed by expert staff after the volunteers monitoring. Generally, although several studies deal with MBL impact on the aesthetic value of beaches (Zielinsky et al., 2019), the effectiveness and cost-effectiveness of manual and mechanical cleaning remain largely unknown. There are very few studies that consider the impact of beach cleaning as a factor for loss of species abundance and changes to the beach natural conditions (Defeo et al., 2009). For example, the removal of anthropogenic litter can rake and sieve the upper layer of beach sand, causing the removal of beach wrack (e.g., algae, *Posidonia oceanica*, etc.) that is a source of food and habitat for many organisms (Dugan et al., 2003). This may affect beach ecosystems’ food chains (Del Vecchio et al., 2017; Schneider et

al., 2018). Thus, more studies that compare manual and mechanical methods of litter removal on intensively used beaches are required.

Still, waste disposal and treatment also represent a tackling issue that deserves careful specific discussion. Almost no information about waste treatment is available in the analysed publications, so that it is impossible to evaluate the potential efforts in terms of reuse, recycle, energy recovery and landfill. Conversely, previous projects demonstrated that, even if challenging, it is possible to reuse or recycle macro-litter, such as fish nets, metals, lead line, polystyrene buoys (e.g., Northwest Straits Foundation, 2015; National Fish and Wildlife Foundation, 2016; Iñiguez et al., 2016), turn them into art (Olive Ridley Project, 2017), or use them to recover energy (Iñiguez et al., 2016).

Finally, it is important to notice that the analysed publications do not mention the inclusion of the collected observations in Mediterranean, or pan-European, comprehensive databases (e.g., EMODnet) that allows the processing of datasets based on different protocols and reference systems. This kind of shared databases could help to group the relevant information collected during both scientific monitoring activities and no profit initiatives (e.g., citizen science activities, clean-up events) along the surveyed Mediterranean beaches, to define what is available to the scientific community, and to highlight gaps and hindrances. Of course, an extensive effort to MBL data gathering and compilation has to tackle carefully the incompatibility of data formats, the spatial-temporal heterogeneity, the inconsistencies in the different litter identification lists, and the eventual variability in the survey protocols. To date, this is not an easy task, as demonstrated by the analysed Scopus indexed documents. Nevertheless, such an effort could considerably favour the harmonisation and comparability of information collected over the Mediterranean Sea and, consequently, support the EU strategies to tackle marine pollution and reduce waste impact on coastal environment.

5. Conclusions

In the last decades scientists, citizens and policy makers recognized MBL as a serious issue for coastal ecosystems, human health and economical activities. Due to high anthropogenic pressure, intensive economical exploitation and slow turnover of its waters, the Mediterranean Sea is particularly vulnerable to this problem. A systematic review of current literature concerning MBL monitoring along its coasts shows that increasing efforts have been realized to monitor, study, and clean-up shorelines in the last two decades.

Despite the ongoing efforts and initiatives to harmonize MBL monitoring over Mediterranean coasts, the heterogeneity of the source data still represents a major challenge in terms of standardization of the data management procedures and of data comparison. The presented extensive literature review points out that these studies were generally characterized by significant differences in timing and frequency of the surveys, in litter sampling and classification methodologies, as well as in the analysis and presentation of the collected data. A large number of protocols for MBL monitoring exists, originally developed from a number of campaigns over a thirty-year period. On the impulse of the MSFD, they are on the way to evolve into a standardized monitoring tool. However, this task has not been achieved yet. Current MBL monitoring activities follow different approaches, which someway rely on the UNEP/IOP, OSPAR, NOAA and MSFD guidelines, but they still miss harmonization in the strategy of survey, as well as in the analysis and presentation of the collected observations. The choice of a particular type of survey often depends on the objectives of the assessment, on the magnitude of the pollution, and on the typology on the coastline. Thus, the comparison of MBL data between different assessment programmes is still difficult due to the use of different methods, different spatial and temporal scales, different size scales of litter items, and different lists or categorisation of litter items recorded on beaches. Consequently, even though some similarities can

be found, giving indications for intercomparison studies, the lack of standardization of the monitoring protocols limit the integration of MBL data and the efforts to provide a pan-Mediterranean MBL temporal and spatial analysis.

Nevertheless, the monitoring of MBL in Mediterranean Sea can be still considered a valid and important tool for coastal environment conservation. Pressing research needs must be addressed as soon as possible. First of all, it is essential to make easier a direct comparison of information collected by different groups/initiatives and over different countries. Adopting consistent and harmonised criteria and methodological standards, would ensure consistency of data and the possibility of meaningful comparison. To this goal, coordination at a regional/national/Mediterranean level is urgently needed. Differently, an efficient monitoring system for MBL cannot be permanently maintained. In this framework, it would be warmly welcome the improvement and support to the use of shared platforms to collect and disseminate MBL dataset. Surveys and clean-up activities carried out along the southern Mediterranean coasts, for example, are rarely reported in scientific publications (Figure 2), but they do exist. Strengthening international collaborations across the Mediterranean would help this process. Similarly, it is necessary to favour synergy between marine litter research in all environmental compartments (i.e., seafloor, water column, sea surface, coast, biota). Making the data collected, raw and processed, public and easily accessible, and having them available not only to the scientific community but also to policy makers and stakeholders, would be important as well. To this goal, the shared methods of spatial and temporal monitoring of Mediterranean beaches should be easy to follow by both scientists and volunteers. Collections that can be conducted as part of the normal human presence in the marine environment, such as beach clean-ups, appear interesting cost effective and environmentally friendly solutions (Schneider et al., 2018). Involving more trained volunteers in MBL monitoring (e.g., through associations, schools, Citizen Science projects) would, at the same time, arise the ecological awareness and support the scientific monitoring efforts. This could also help create a communication channel between the world of research and policy makers.

Actually, a consistent increase in MBL monitoring efforts does not necessarily mean a significant reduction of the overall stock of MBL (Schneider et al., 2018). A growing and much larger amount of new waste, in particular plastics, is added to the marine environment every year (Jambeck et al., 2015). A drastic input reduction is indeed necessary to tackle the challenge of MBL effectively. Recognize the degree of waste decomposition, and improve its treatment, as well as identifying the main sources is essential to design effective intervention strategies to prevent litter from entering the marine environment. The allocation of likelihoods of MBL (e.g., through the Matrix Scoring Technique) can provide a useful picture of sources and their relative importance in a certain area. However, a number of indispensable factors must be enquired to characterize correctly a given region (local topography and geography, human activities and their intensity, proximity to potential litter sources or pathways). Again, this process needs shared guidelines, central coordination, local knowledge and stakeholders' collaboration.

In conclusion, despite the progresses recently achieved through several research activities, there is still an urgent need to promote broad international collaboration in order to improve and harmonize scientific and politics efforts to produce quality, open, and comparable MBL data over the Mediterranean basin (Sanchez-Simon et al., 2022). Quality science is fundamental to engage and inform policy makers, stakeholders and society to the goal of implementing effective measures, actions and regulations to tackle the challenging MBL threats.

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7. CONCLUDING REMARKS

The analysis of the existing literature shows that the increasing efforts to survey global shorelines aimed to improve the knowledge of MBL concentration and type, have not been always accompanied (e.g., in the Mediterranean) by an equally increasing interest in the homogenization of the protocols and methodologies devoted to the collection of reliable, coherent, and comparable data of its composition and distribution. Generally, MBL monitoring constitutes a cost-effective methodology, and its results can be considered someway representative of new litter entering the coastal environment. Nevertheless, the number of MBL studies published to-date in peer-review journals remains limited and often dedicated to specific coastal areas. Additionally, differences in timing and frequency of the surveys emerge from the analysed scientific literature, as well as discrepancies in litter sampling and classification, data analysis and waste disposal. For this reason, it is extremely difficult to understand to what extent the data produced are comparable and integrable, or are limited by the variety of different monitoring methods. At the state of the art, it seems extremelt difficult to provide a reliable and accurate pan-Mediterranean MBL temporal and spatial quantitative analysis. This is a main step to be addressed in order to provide national and local government, as well as other stakeholders, with clear and easy-to-use information to tackle marine litter challenge.

On the other hand, in the last decade Citizen Science progressively proved its capability to facilitate the scientific process through the collection of reliable data by volunteers over extended spatial and temporal scales. The marine litter data collected by citizen scientists, including school pupils, are increasingly recognized as valid and meeting or even exceeding quality standards. Moreover, Citizen Science also demonstrated its positive effects on society providing direct (e.g., better attitudes towards science and scientific thinking, awareness of various environmental issues) and derived (e.g., improved ability to use science to solve daily problems, personal growth, social learning, stewardship and proactivity, social democratization through public participation in policy processes) achievements. With these assumptions, Citizen Science can really inspire action for change and strengthen the relationship between science and society. Furthermore, school participation in scientific research represents a unique opportunity for children to develop environmental awareness and ecological sensibility, indispensable prerequisites for future responsible actions, particularly among coastal communities. This aligns with environmental education objectives defined by UNESCO in the framework of Ocean Literacy, which include awareness of the global environment and its problems, positive attitudes towards the environment, an agency in conservation, and participation in environmental problem-solving.

In this context, the MAC-E protocol represents a valid opportunity for disseminating scientific knowledge and promoting Citizen Science. The collaboration with Progetto Terra no-profit association and the direct involvement of the children and teenagers in the MBL monitoring activities proved to be useful and profitable. The volunteer naturalists, duly trained, were able to organize the data collection activities and brilliantly manage the groups of children. The protocol was easy-to-use for students and trainers and the observations were suitable for an appropriate scientific analysis. The pilot campaign also proved to be especially useful for its social value. The meeting with tourists and the awareness campaign directly realized by the young citizen scientists added great value to the simple collection of scientific data.

Finally, concluding remarks can be summarized through the following bullet points:

- The achieved results showed that several commendable initiatives have been taken globally, regionally and nationally by governments, scientific organisms and non-scientific communities in order to monitor and/or remove litter from the beaches.

- Unfortunately, these efforts resulted in a complex and heterogeneous collection of protocols, criteria and methodologies that make the available datasets difficult to compare and share from region to region.
- The number of MBL studies published to-date in peer-review journals remains limited and often dedicated to specific coastal areas. Additionally, differences in timing and frequency of the surveys emerge from the analysed dataset, as well as discrepancies in litter sampling and classification, data analysis and waste disposal.
- It is often extremely difficult to understand to what extent the data produced are comparable or useful to provide spatial and temporal trends as needed to develop correct strategies to tackle MBL.
- MBL monitoring confirmed to be a cost-effective methodology whose results can be considered someway representative of new litter entering the coastal environment.
- Information on the temporal and spatial distribution of MBL can be effectively provided by NGO and participatory science campaigns that also encourage communities to take up action and fill in the knowledge gaps.
- In the last decade the role of Citizen Science in the marine scientific research is quickly improving. An increasing number of people pay specific attention to marin litter and other ecological issues and feel the need to take part actively in ocean conservation.
- Citizen science has good potential to contribute improving science and environmental protection and to reduce lack of data and cost of surveys in MBL monitoring.
- On the other hand, previous studies showed that data quality and projects results are affected by motivation of volunteers and correct organization of field activities. This means that Citizen Science can help, but it needs standard, easy to follow, protocols and specific organization for providing homogenous data over time and regions.
- The MAC-E is a valide cost-effective method for collecting MBL information through Citizen Science initiatives along the Mediterranean coasts but deserves additional efforts in terms of central co-ordination and international diffusion.
- The development of MAC-E medium and long-term projects in schools may also contribute to Ocean Literacy environmental education objectives defined by UNESCO.

ADDITIONAL PRODUCTS

This is a brief note about the other products not included in the research activities on MBL but performed during my PhD period:

- Aulicino, G., Cotroneo, Y., Olmedo, E., **Cesarano, C.**, Fusco, G., Budillon, G. In Situ and Satellite Sea Surface Salinity in the Algerian Basin Observed Through ABACUS Glider Measurements and SMOS Enhanced Products. Remote Sens. 2019, 11, 1361, doi:10.3390/rs11111361.

- Aulicino, G., **Cesarano, C.**, Zerrouki, M., Ruiz, S., Budillon, G., Cotroneo, Y. On the use of ABACUS high resolution glider observations for the assessment of phytoplankton ocean biomass from CMEMS model products, Ecol. Modell. 2021, 455, 109619, doi:10.1016/j.ecolmodel.2021.

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