Marine beach litter monitoring strategies along Mediterranean coasts. A methodological review

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Corresponding Author:	Giuseppe Aulicino, Ph.D. ITALY
First Author:	Cinzia Cesarano
Order of Authors:	Cinzia Cesarano
	Giuseppe Aulicino, Ph.D.
	Carlo Cerrano
	Massimo Ponti
	Stefania Puce
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Suggested Reviewers:	Anna Maria Addamo am.addamo@gmail.com
	Antonio Sanchez Roman asanchez@imedea.uib-csic.es
	Valentina Pauna valentinahpauna@gmail.com
	Giuseppe Suaria giuseppe.suaria@sp.ismar.cnr.it
	Vincenzo Donnarumma v.donnarumma.v@gmail.com
	Ivan Franco Rodil ivan.franco@uca.es
	Giorgio Anfuso giorgio.anfuso@uca.es
	Mohsen Ansari mohsen.ansari90@yahoo.com

Marine beach litter monitoring strategies along Mediterranean coasts. A methodological review

Cinzia Cesarano [a], Giuseppe Aulicino [b,*], Carlo Cerrano [a,d,e,f,g], Massimo Ponti [c,d,g], Stefania Puce [a]

[a] Dipartimento di Scienze della Vita e dell'Ambiente, Università Politecnica delle Marche, Ancona, Italy

[b] Dipartimento di Scienze e Tecnologie, Università degli studi di Napoli Parthenope, Napoli, Italy

[c] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Ravenna, Italy

[d] Reef Check Italia onlus, Ancona, Italy

[e] Fano Marine Center, Fano, Italy

[f] Stazione Zoologica Anton Dohrn, Napoli, Italy

[g] Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), Roma, Italy

* Corresponding author. *E-mail address:* giuseppe.aulicino@uniparthenope.it (G. Aulicino).

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 strategies along the Mediterranean coasts. Scopus indexed studies are analysed to identify discrepancies and similarities among the applied 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 applied 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 monitoring strategies. 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.

Taking advantage of the information about MBL queries provided by the same authors in Cesarano et al. (2021), the search string was set to << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >>, in conjunction with << Mediterranean >> and the main regional terms referring to its main sub-basins, in the “Article title”, “Abstract” or “Keywords”. This query resulted in 255 documents published between 1978 and 2021 (see details in Supplemental material, Table S1). This dataset was exported as .csv file including all the information provided by Scopus, i.e., “Citation Information”, “Bibliographic Information”, “Abstract”, “Keywords” and “References”. To refine this dataset, the documents were further screened by reading the titles and abstracts followed by the exclusion of those that were irrelevant to the objective of this study (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 the present analysis. The meeting criteria for inclusion in the following content analysis (see Section 2.2) was that the study must be 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.

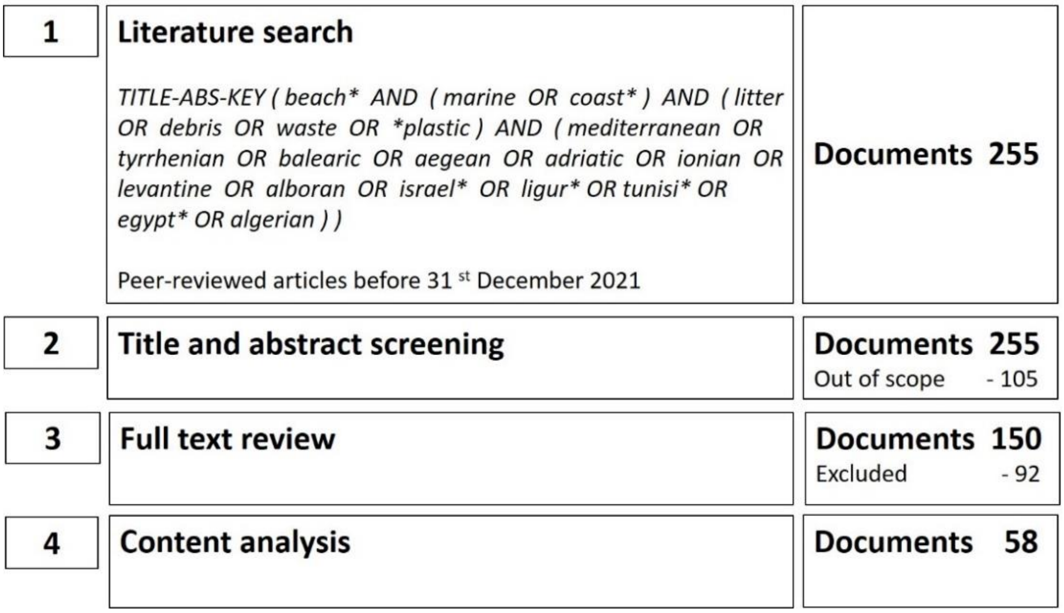

Fig. 1. Flow diagram illustrating the selection process and systematic review of the published literature.

2.2 Content analysis

After the full-text review, 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 strategies adopted for monitoring macro-MBL along the Mediterranean coast as reported in Scopus indexed scientific articles, the occurrence of the sampling activities and the identification of the most (and least) investigated areas.

3. **Results**

3.1. Bibliometric research and data collection

The bibliometric analysis started with title and abstract screening of the selected articles (i.e., step 2 in Figure 1). Among them, 105 documents were discarded because out of the scope of this review since they were related to different environmental compartments (i.e., water surface, seafloor, sediment, biota), study areas (e.g., Atlantic Ocean), or disciplines (see details in Table S2). 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 survey (see Tables 1 to 3).

3.2. Temporal analysis

The bibliometric analysis draws data from 58 documents published between 1991 and 2021 (Table 1). The leading journal is *Marine Pollution Bulletin* that hosted about 42% of the Scopus indexed publications on the Mediterranean macro-MBL data monitoring activities. 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.

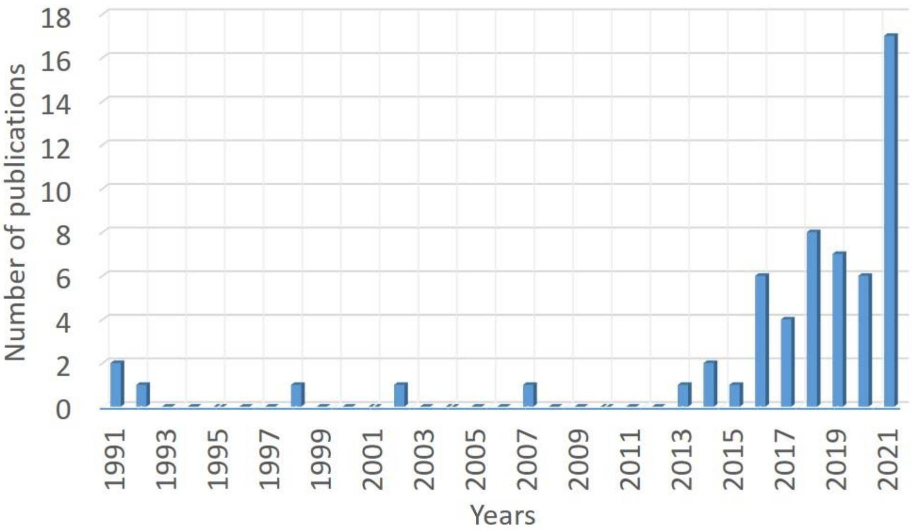

Fig. 2. Number of publications indexed in Scopus per year (1991–2021) dealing with macro-MBL monitoring.

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 1). 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.

Table 1. Extracted temporal and geographical data from enquired Scopus indexed scientific surveys. Countries are reported through the ISO 3166-1 alpha2 code. Sites located in protected areas are indicated in cyano. Colours identify publications reporting information about beach typology (blue), coastal types (green) or both (red). Sites located in protected areas are indicated in blue (additional details in Table S3).

ID	**Reference**	**Time period**	**Frequence and timing**	**Number of sites**	**Location**	**Country**	**Journal**
1	Shiber and Barrales-Rienda, 1991	1978 - 1978	Twice per week (Jul)	5	Beirut	LB	Environmental Pollution
2	Shiber and Barrales-Rienda, 1991	1988 - 1988	Three times (Mar, Apr)	3	Beirut	LB	Environmental Pollution
3	Golik and Gertner, 1992	1988 - 1989	Monthly (May - May)	6	Israeli coast	IL	Marine Environmental Research
4	Gabrielides et al., 1991	1988 - 1989	Monthly (May - May)	13	Spain, Italy, Turkey, Cyprus, Israel	ES, IT, TR, CY, IL	Marine Pollution Bulletin
5	Bowman et al., 1998	1990 - 1991	Monthly (Jul - Oct)	6	Israeli coast	IL	Journal of Coastal Research
6	Tudor et al., 2002	1998 - 2000	Single/multiple surveys per beach site	7	Turkey, Malta, Spain, Tunisia	TR, ES, MT, TN	Journal of Coastal Research
7	Martinez-Ribes et al., 2007	2005 - 2005	Monthly (Apr, Jun - Sep)	32	Balearic Islands	ES	Scientia Marina
8	Kordella et al., 2013	2006 - 2007	Once	80	Greece	GR	Aquatic Ecosystem Health and Management
9	Poeta et al., 2014; Poeta et al., 2016a	2012 - 2012	Once (Apr, May)	5	Lazio coast	IT	Marine Pollution Bulletin; Estuarine, Coastal and Shelf Science
10	Laglbauer et al., 2014	2012 - 2012	Once (Jul)	6	Slovenia	SI	Marine Pollution Bulletin
11	Pasternak et al., 2017	2012 - 2015	14 to 19 surveys per beach site	8	Israeli coast	IL	Marine Pollution Bulletin
12	Gonulal et al., 2016	2013 - 2015	Once	14	Gokceada Island	TR	Aquatic Ecosystem Health and Management
13	Camedda et al., 2021	2013 - 2016	Twice a year (autumn, spring)	7	Sardinia	IT	Water Air and Soil Pollution
14	Karkanorachaki et al., 2018	2014 - 2014	Summer (Apr - Jun), winter (Nov - Mar)	4	Northern Crete	GR	Marine Pollution Bulletin
15	Aydin et al., 2016	2014 - 2014	Once (Apr)	13	Cilician Basin	TR	Turkish Journal of Fisheries and Aquatic Sciences
16	de Francesco et al., 2018	2014 - 2015	Spring	3	Abruzzo e Molise	IT	Rendiconti Lincei. Scienze Fisiche e Naturali
17	Prevenios et al., 2018	2014 - 2015	Every ~15 days (Jul - Oct)	4	Corfu Island	GR	Marine Pollution Bulletin
18	Poeta et al., 2016b	2014 - 2015	Spring, summer, autumn, winter	3	Montalto Marina	IT	Marine Pollution Bulletin
19	Giovacchini et al., 2018	2014 - 2015	Spring, summer, autumn, winter	11	Pelagos sanctuary (Ligurian Sea)	IT	Marine Pollution Bulletin

20	Vlachogianni et al., 2018	2014 - 2016	Autumn, winter, spring, summer	31	Adriatic Sea	AL, BA, HR, GR, IT, MO, SL	Marine Pollution Bulletin
21	Alshawafi et al., 2017	2015 - 2015	Spring, summer, autumn, winter	1	Martil	MA	Marine Pollution Bulletin
22	Maziane et al., 2018	2015 - 2015	Once (Nov - Dec)	14	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
23	Munari et al., 2016	2015 - 2015	Once (May - Jun)	5	North-western Adriatic coast	IT	Waste Management
24	Munari et al., 2017	2015 - 2015	Once (May)	5	North-western Adriatic coast	IT	Waste Management
25	Nachite et al., 2019	2015 - 2017	Twice a year (autumn, spring)	14	Alboran Sea	MA	Ocean and Coastal Management
26	Fortibuoni et al., 2021	2015 - 2017	Twice a year (spring, autumn)	64	Italy	IT	Environmental Pollution
27	Portman and Brennan, 2017	2016 - 2016	Every ~15 days (Apr - Jul)	3	Jisr-Az-Zarqa	IL	Waste Management
28	Loizidou et al., 2018	2016 - 2017	Once (May - Aug)	9	Island of Cyprus	CY	Environmental Monitoring and Assessment
29	Papachristopoulou et al., 2020	2017 - 2018	Summer, autumn, winter, spring	62	Western Saronikos Gulf	GR	Marine Pollution Bulletin
30	Ozden et al., 2021	2017 - 2019	Monthly (Jan - Jan)	8	Northern Cyprus	CY	Marine Pollution Bulletin
31	Grelaud and Ziveri, 2020	2017 - 2019	Monthly (Feb - Nov 2017, Aug - Sep 2019)	35	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)	1	Velika plaža	ME	Marine Pollution Bulletin
33	Taibi et al., 2021	2017 -2017	10 - 21 replicates per beach site (Feb - Jul)	9	Western Algerian coast	DZ	Marine Pollution Bulletin
34	Gundogdu and Cevik, 2019	2018 - 2018	Once (May)	13	Iskenderun Bay	TR	Environmental Pollution
35	de Francesco et al., 2019	2018 - 2018	Once (Apr – May)	7	Abruzzo e Molise	IT	Sustainability
36	Gjyli et al., 2020	2018 - 2018	Once (Apr)	5	Albanian coastline	AL	Ocean and Coastal Management
37	Asensio-Montesinos et al., 2019a	2018 - 2018	Once (Mar)	56	Alicante coast	ES	Marine Pollution Bulletin
38	Asensio-Montesinos et al., 2019b	2018 - 2018	Twice (Mar, Aug)	56	Alicante coast	ES	Ocean and Coastal Management
39	Mokos et al., 2019	2018 - 2018	Once (Mar - May)	3	Croatian Adriatic Sea	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
40	Vlachogianni et al., 2020	2018 - 2018	Twice (autumn, winter)	23	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)	3	Ligurian Sea, Tuscany	IT	Marine Pollution Bulletin
42	Battisti et al., 2019	2018 - 2018	Once (Mar)	1	Torre Flavia wetland	IT	Environmental Science and Pollution Research

43	Mandic et al., 2021	2018 - 2019	Three times (autumn, winter, spring)	2	Montenegrin coast	MO	The Montenegrin Adriatic Coast: Marine Chemistry Pollution
44	Mokos et al., 2020	2018 - 2019	Summer, autumn, winter, spring	1	Vodenjak cove	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
45	Bozzeda et al., 2021	2019 - 2019	Once (Apr)	1	Aquatina	IT	Marine Pollution Bulletin
46	Asensio-Montesinos et al., 2021a	2019 - 2019	Monthly (Feb - Apr)	12	Ceuta	ES	Water MDPI
47	Romiti et al., 2021	2019 - 2019	Monthly (Apr - Jun)	2	Ionian coast of the Calabria	IT	Journal of Insect Conservation
48	Fanini and Guittard, 2021	2019 - 2019	Weekly (Apr - Sep), twice (Nov - Dec)	2	Island of Crete	GR	Marine Pollution Bulletin
49	Mghili et al., 2020	2019 - 2019	Winter, spring, summer, autumn	5	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
50	Cesarini et al., 2021	2019 - 2019	Once (Nov)	1	Torre Flavia wetland	IT	Marine Pollution Bulletin
51	Benaissa et al., 2021	2019 - 2019	Once (Mar - Apr)	10	Aïn el Turk Bay	DZ	Geo-Eco-Marina
52	Ertas, 2021b	2019 - 2020	Summer, autumn, winter, spring	1	Adana Akyatan Lagoon Coast	TR	Marine Pollution Bulletin
53	Ertas, 2021a	2019 - 2020	Winter, spring, summer, autumn	1	Homa Lagoon coast	TR	Estuarine, Coastal and Shelf Science
54	Asensio-Montesinos et al., 2021b	2020 - 2021	Every ~15 days (Dec - Mar)	5	Alicante province	ES	Marine Pollution Bulletin
55	Cresta and Battisti, 2021	2021 - 2021	Twice (Apr, May)	1	Torre Flavia wetland	IT	Marine Pollution Bulletin
56	Merlino et al., 2021	2021 - 2021	Once (May)	1	Migliarino, Massacciuccoli and San Rossore park	IT	Water
57	Katsanevakis, 2015	NA	NA	2	Lesvos Island	GR	Mediterranean Marine Science
58	Battisti et al., 2016	NA	NA	1	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 1). 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 analysed 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 1 and Table S3). 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 shoreline characteristics, 78% of analysed papers report information about the coastal type (see Table 1 and Table S3). 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.

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 2 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 (i.e., the fixed section (length) of beach from which measurements of litter number of items, weight or volume are made periodically - Galgani et al., 2013), is usually 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 (Table 2). 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%). 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, 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%).

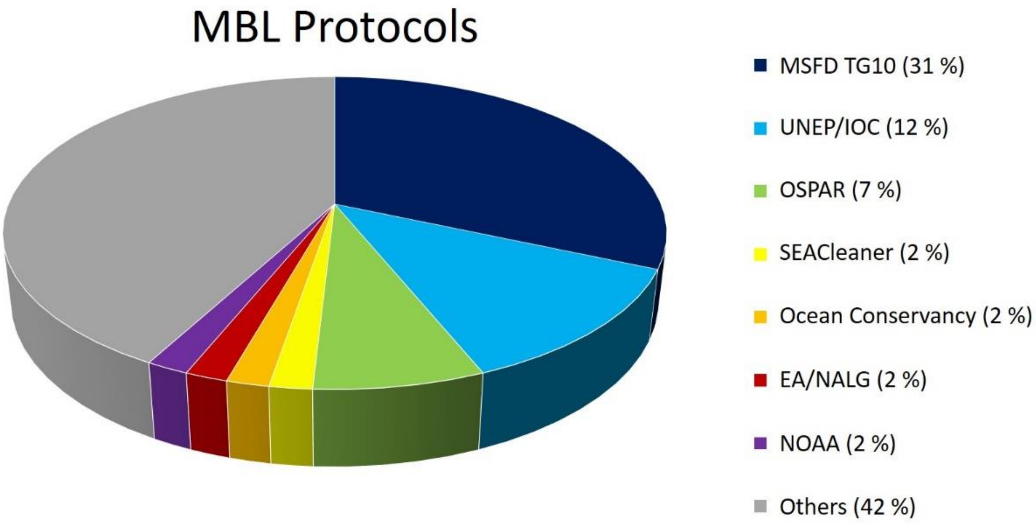

Fig. 4. Percentage distribution of sampling protocols used in MBL data collections indexed in Scopus.

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 2 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 3). 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 surveys, or they adopt methodologies that include visual census without waste removal (Merlino et al., 2021). Moreover, only six studies declare a direct participation of volunteers. However, as stated above, non-scientific initiatives usually have no fixed end-date and are characterized by a massive use of websites and outreach reports, thus appearing in scientific publications only at later stages, frequently after several years, when scientific conclusions can be finally retrieved (Schneider et al., 2018).

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 3). 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 3 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. 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. Nevertheless, 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).

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 proposed 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).

Table 2. Surveys information for scientific collections identified by ID numbers, as in Table 1.

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 3. MBL collection details for surveys identified by ID numbers, as in Table 1.

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 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 must follow commonly agreed methodologies in order to provide results which are comparable over larger regions and different periods.

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.

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). 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 analysed Scopus indexed publications shows that MBL monitoring activities are typically conducted over a limited and short period of time (e.g., covering two years or less, or even including only 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 collections characterized by seasonal repetitions are significantly affected by seasonal variation that might partly mask long-term variability (Schulz et al., 2013). Still, the surveys should be repeated on exactly the same site (Galgani et al., 2013) that should not be subject to any other litter collection activity 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. All these aspects make 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 different collections may have been realized taking advantage of different protocols and guidelines.

The selection of a specific costal sites for the monitoring activities is another factor that can significantly influence the comparability of the achieved results. Geomorphological and sedimentary characteristics, river presence, meteo-oceanographic regimes, litter exposure (e.g., urban sites, rural coasts, marine protected area), demographic and geographical conditions, main beach usage (i.e., recreational, fishing, surfing, boat access) should be always considered and reported. Unfortunately, only few publications clearly define these characteristics.

Even more important is the choice of the MBL sampling unit. Both MSFD and OSPAR guidelines suggest a minimum length of 100 m, which can be reduced to 50 m for heavily littered beaches, and a repetition of at least two sections on the same beach. 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 2). Inhomogeneity also exists in the use of transects which are carried out parallel rather than perpendicular to the coast, at a different distance between each other, and covering determined or variable beach width. Moreover, several studies do not report at all 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 macro-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 attribution of litter categories also plays an important role, as do different interpretations of monitoring guidance. Generally, MBL composition is estimated by grouping the items into different predetermined categories to favour comparability and compatibility of available observations. However, our analysis shows that this classification is usually based on different codes in the existing literature (see Table 2). 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). The available observations can still be considered as a valuable proxy for the amount of litter present in a coastal environment. However, comparing information collected in different areas/seasons/years, by different groups, is generally difficult and represents a limit to the identification of priorities for action or effectiveness of mitigation measures. Moreover, MBL data are usually not accompanied by proper uncertainties, so that they deserve a careful metadata interpretation to evaluate their accuracy and reliability.

Nevertheless, several analysed studies also attempted of determine top litter items over a specific region. Unfortunately, the top items calculation modes were often different among surveys, 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. Thus, obtaining comparable data and sampling strategies remains a priority to provide the basis for reliable litter abundance rankings and previous studies integration. The final report of the EU ARCADIS project, for example, lists the top fifteen MBL items for the Mediterranean Sea from 33 OSPAR screenings indicating plastic cutlery/trays/straws as the dominant fraction (17%), followed by cigarette butts (14%), plastic caps/lids (14%) and plastic drink bottles (12%) (Van Acoleyen et al., 2013). 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).

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. The analysed Scopus dataset shows that several methodological approaches have been used to determine where litter is coming from, but few information is 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, several analysed studies do made use of attribution of sources based on statistical techniques, such as the Matrix Scoring Technique that includes the likelihood criteria. 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.). This information is rarely reported in the analysed Scopus indexed literature.

Another important issue is represented by litter removal during/after beach surveys, and the consequent waste treatment. Actually, removal of litter should be carried out during monitoring activities. 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). 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). 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. When litter is removed, only a few documents provide details about the expected impact of beach cleaning as a factor for loss of species abundance and changes to the beach natural conditions (Defeo et al., 2009; Del Vecchio et al., 2017; Schneider et al., 2018). Information about the specific efforts to recruit, and train, field staff, are also missing in almost all of the analysed studies. Nevertheless, this is essential to ensure data quality and prevent environment damages, especially when citizen and volunteers are involved in the beach monitoring activities.

Finally, 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).

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 strategies 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 (e.g., EMODnet) to group and disseminate MBL observations, so to homogenize the processing of datasets based on different protocols and reference systems, and facilitate the identification of gaps and hindrances. Surveys and clean-up activities carried out along the southern Mediterranean coasts, for example, are rarely reported in scientific publications, 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. 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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Marine beach litter monitoring strategies along Mediterranean coasts. A methodological review

Cinzia Cesarano [a], Giuseppe Aulicino [b,*], Carlo Cerrano [a,d,e,f,g], Massimo Ponti [c,d,g], Stefania Puce [a]

[a] Dipartimento di Scienze della Vita e dell'Ambiente, Università Politecnica delle Marche, Ancona, Italy

[b] Dipartimento di Scienze e Tecnologie, Università degli studi di Napoli Parthenope, Napoli, Italy

[c] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Ravenna, Italy

[d] Reef Check Italia onlus, Ancona, Italy

[e] Fano Marine Center, Fano, Italy

[f] Stazione Zoologica Anton Dohrn, Napoli, Italy

[g] Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), Roma, Italy

* Corresponding author. *E-mail address:* giuseppe.aulicino@uniparthenope.it (G. Aulicino).

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 strategies along the Mediterranean coasts. Scopus indexed studies are analysed to identify discrepancies and similarities among the applied 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 applied 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 monitoring strategies. 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.

Taking advantage of the information about MBL queries provided by the same authors in Cesarano et al. (2021), the search string was set to << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >>, in conjunction with << Mediterranean >> and the main regional terms referring to its main sub-basins, in the “Article title”, “Abstract” or “Keywords”. This query resulted in 255 documents published between 1978 and 2021 (see details in Supplemental material, Table S1). This dataset was exported as .csv file including all the information provided by Scopus, i.e., “Citation Information”, “Bibliographic Information”, “Abstract”, “Keywords” and “References”. To refine this dataset, the documents were further screened by reading the titles and abstracts followed by the exclusion of those that were irrelevant to the objective of this study (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 the present analysis. The meeting criteria for inclusion in the following content analysis (see Section 2.2) was that the study must be 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.

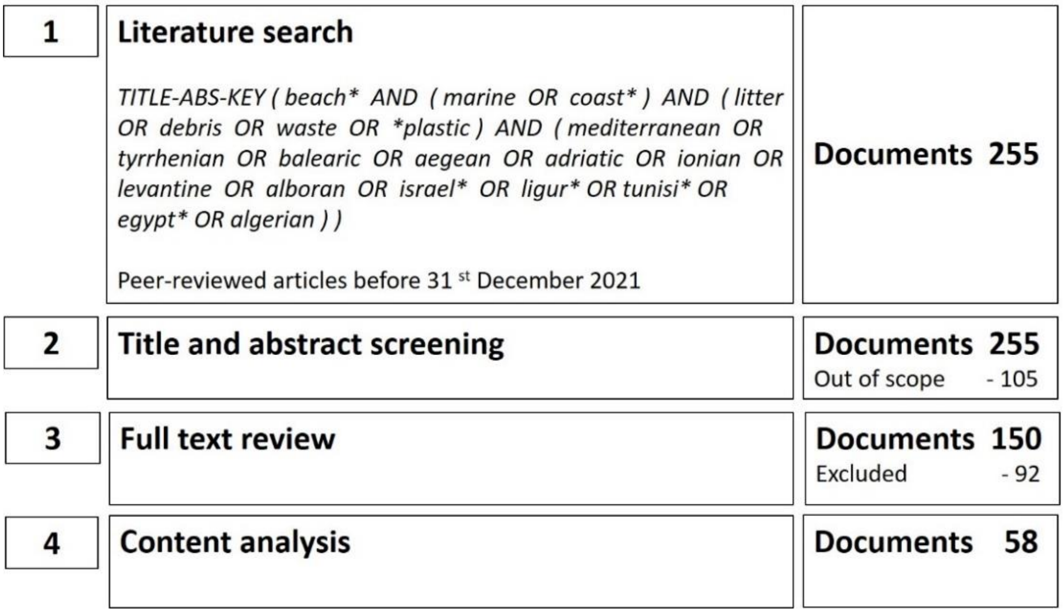

Fig. 1. Flow diagram illustrating the selection process and systematic review of the published literature.

2.2 Content analysis

After the full-text review, 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 strategies adopted for monitoring macro-MBL along the Mediterranean coast as reported in Scopus indexed scientific articles, the occurrence of the sampling activities and the identification of the most (and least) investigated areas.

3. **Results**

3.1. Bibliometric research and data collection

The bibliometric analysis started with title and abstract screening of the selected articles (i.e., step 2 in Figure 1). Among them, 105 documents were discarded because out of the scope of this review since they were related to different environmental compartments (i.e., water surface, seafloor, sediment, biota), study areas (e.g., Atlantic Ocean), or disciplines (see details in Table S2). 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 survey (see Tables 1 to 3).

3.2. Temporal analysis

The bibliometric analysis draws data from 58 documents published between 1991 and 2021 (Table 1). The leading journal is *Marine Pollution Bulletin* that hosted about 42% of the Scopus indexed publications on the Mediterranean macro-MBL data monitoring activities. 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.

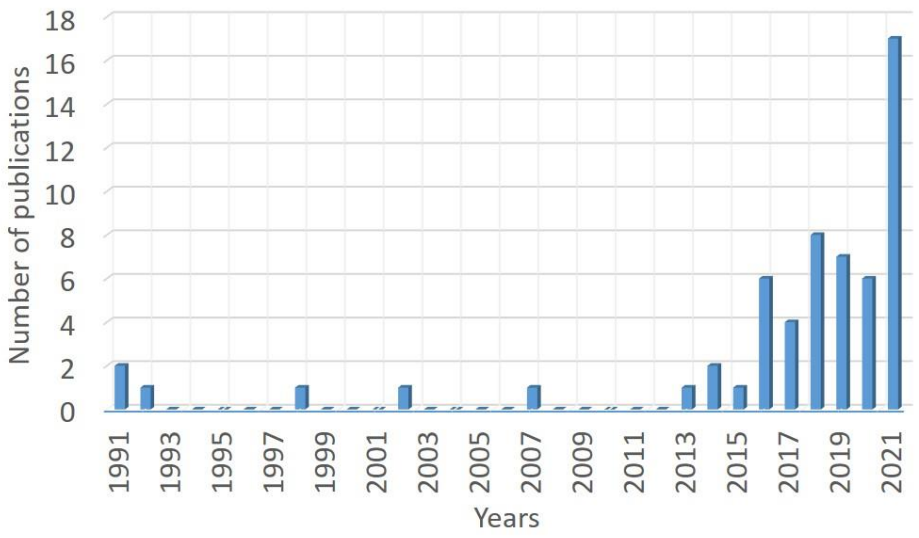

Fig. 2. Number of publications indexed in Scopus per year (1991–2021) dealing with macro-MBL monitoring.

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 1). 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.

Table 1. Extracted temporal and geographical data from enquired Scopus indexed scientific surveys. Countries are reported through the ISO 3166-1 alpha2 code. Sites located in protected areas are indicated in cyano. Colours identify publications reporting information about beach typology (blue), coastal types (green) or both (red). Sites located in protected areas are indicated in blue (additional details in Table S3).

ID	Reference	Time period	Frequence and timing	Number of sites	Location	Country	Journal
1	Shiber and Barrales-Rienda, 1991	1978 - 1978	Twice per week (Jul)	5	Beirut	LB	Environmental Pollution
2	Shiber and Barrales-Rienda, 1991	1988 - 1988	Three times (Mar, Apr)	3	Beirut	LB	Environmental Pollution
3	Golik and Gertner, 1992	1988 - 1989	Monthly (May - May)	6	Israeli coast	IL	Marine Environmental Research
4	Gabrielides et al., 1991	1988 - 1989	Monthly (May - May)	13	Spain, Italy, Turkey, Cyprus, Israel	ES, IT, TR, CY, IL	Marine Pollution Bulletin
5	Bowman et al., 1998	1990 - 1991	Monthly (Jul - Oct)	6	Israeli coast	IL	Journal of Coastal Research
6	Tudor et al., 2002	1998 - 2000	Single/multiple surveys per beach site	7	Turkey, Malta, Spain, Tunisia	TR, ES, MT, TN	Journal of Coastal Research
7	Martinez-Ribes et al., 2007	2005 - 2005	Monthly (Apr, Jun - Sep)	32	Balearic Islands	ES	Scientia Marina
8	Kordella et al., 2013	2006 - 2007	Once	80	Greece	GR	Aquatic Ecosystem Health and Management
9	Poeta et al., 2014; Poeta et al., 2016a	2012 - 2012	Once (Apr, May)	5	Lazio coast	IT	Marine Pollution Bulletin; Estuarine, Coastal and Shelf Science
10	Laglbauer et al., 2014	2012 - 2012	Once (Jul)	6	Slovenia	SI	Marine Pollution Bulletin
11	Pasternak et al., 2017	2012 - 2015	14 to 19 surveys per beach site	8	Israeli coast	IL	Marine Pollution Bulletin
12	Gonulal et al., 2016	2013 - 2015	Once	14	Gokceada Island	TR	Aquatic Ecosystem Health and Management
13	Camedda et al., 2021	2013 - 2016	Twice a year (autumn, spring)	7	Sardinia	IT	Water Air and Soil Pollution
14	Karkanorachaki et al., 2018	2014 - 2014	Summer (Apr - Jun), winter (Nov - Mar)	4	Northern Crete	GR	Marine Pollution Bulletin
15	Aydin et al., 2016	2014 - 2014	Once (Apr)	13	Cilician Basin	TR	Turkish Journal of Fisheries and Aquatic Sciences
16	de Francesco et al., 2018	2014 - 2015	Spring	3	Abruzzo e Molise	IT	Rendiconti Lincei. Scienze Fisiche e Naturali
17	Prevenios et al., 2018	2014 - 2015	Every ~15 days (Jul - Oct)	4	Corfu Island	GR	Marine Pollution Bulletin
18	Poeta et al., 2016b	2014 - 2015	Spring, summer, autumn, winter	3	Montalto Marina	IT	Marine Pollution Bulletin
19	Giovacchini et al., 2018	2014 - 2015	Spring, summer, autumn, winter	11	Pelagos sanctuary (Ligurian Sea)	IT	Marine Pollution Bulletin

20	Vlachogianni et al., 2018	2014 - 2016	Autumn, winter, spring, summer	31	Adriatic Sea	AL, BA, HR, GR, IT, MO, SL	Marine Pollution Bulletin
21	Alshawafi et al., 2017	2015 - 2015	Spring, summer, autumn, winter	1	Martil	MA	Marine Pollution Bulletin
22	Maziane et al., 2018	2015 - 2015	Once (Nov - Dec)	14	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
23	Munari et al., 2016	2015 - 2015	Once (May - Jun)	5	North-western Adriatic coast	IT	Waste Management
24	Munari et al., 2017	2015 - 2015	Once (May)	5	North-western Adriatic coast	IT	Waste Management
25	Nachite et al., 2019	2015 - 2017	Twice a year (autumn, spring)	14	Alboran Sea	MA	Ocean and Coastal Management
26	Fortibuoni et al., 2021	2015 - 2017	Twice a year (spring, autumn)	64	Italy	IT	Environmental Pollution
27	Portman and Brennan, 2017	2016 - 2016	Every ~15 days (Apr - Jul)	3	Jisr-Az-Zarqa	IL	Waste Management
28	Loizidou et al., 2018	2016 - 2017	Once (May - Aug)	9	Island of Cyprus	CY	Environmental Monitoring and Assessment
29	Papachristopoulou et al., 2020	2017 - 2018	Summer, autumn, winter, spring	62	Western Saronikos Gulf	GR	Marine Pollution Bulletin
30	Ozden et al., 2021	2017 - 2019	Monthly (Jan - Jan)	8	Northern Cyprus	CY	Marine Pollution Bulletin
31	Grelaud and Ziveri, 2020	2017 - 2019	Monthly (Feb - Nov 2017, Aug - Sep 2019)	35	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)	1	Velika plaža	ME	Marine Pollution Bulletin
33	Taibi et al., 2021	2017 -2017	10 - 21 replicates per beach site (Feb - Jul)	9	Western Algerian coast	DZ	Marine Pollution Bulletin
34	Gundogdu and Cevik, 2019	2018 - 2018	Once (May)	13	Iskenderun Bay	TR	Environmental Pollution
35	de Francesco et al., 2019	2018 - 2018	Once (Apr – May)	7	Abruzzo e Molise	IT	Sustainability
36	Gjyli et al., 2020	2018 - 2018	Once (Apr)	5	Albanian coastline	AL	Ocean and Coastal Management
37	Asensio-Montesinos et al., 2019a	2018 - 2018	Once (Mar)	56	Alicante coast	ES	Marine Pollution Bulletin
38	Asensio-Montesinos et al., 2019b	2018 - 2018	Twice (Mar, Aug)	56	Alicante coast	ES	Ocean and Coastal Management
39	Mokos et al., 2019	2018 - 2018	Once (Mar - May)	3	Croatian Adriatic Sea	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
40	Vlachogianni et al., 2020	2018 - 2018	Twice (autumn, winter)	23	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)	3	Ligurian Sea, Tuscany	IT	Marine Pollution Bulletin
42	Battisti et al., 2019	2018 - 2018	Once (Mar)	1	Torre Flavia wetland	IT	Environmental Science and Pollution Research

43	Mandic et al., 2021	2018 - 2019	Three times (autumn, winter, spring)	2	Montenegrin coast	MO	The Montenegrin Adriatic Coast: Marine Chemistry Pollution
44	Mokos et al., 2020	2018 - 2019	Summer, autumn, winter, spring	1	Vodenjak cove	HR	Rendiconti Lincei. Scienze Fisiche e Naturali
45	Bozzeda et al., 2021	2019 - 2019	Once (Apr)	1	Aquatina	IT	Marine Pollution Bulletin
46	Asensio-Montesinos et al., 2021a	2019 - 2019	Monthly (Feb - Apr)	12	Ceuta	ES	Water MDPI
47	Romiti et al., 2021	2019 - 2019	Monthly (Apr - Jun)	2	Ionian coast of the Calabria	IT	Journal of Insect Conservation
48	Fanini and Guittard, 2021	2019 - 2019	Weekly (Apr - Sep), twice (Nov - Dec)	2	Island of Crete	GR	Marine Pollution Bulletin
49	Mghili et al., 2020	2019 - 2019	Winter, spring, summer, autumn	5	Mediterranean coast of Morocco	MA	Marine Pollution Bulletin
50	Cesarini et al., 2021	2019 - 2019	Once (Nov)	1	Torre Flavia wetland	IT	Marine Pollution Bulletin
51	Benaissa et al., 2021	2019 - 2019	Once (Mar - Apr)	10	Aïn el Turk Bay	DZ	Geo-Eco-Marina
52	Ertas, 2021b	2019 - 2020	Summer, autumn, winter, spring	1	Adana Akyatan Lagoon Coast	TR	Marine Pollution Bulletin
53	Ertas, 2021a	2019 - 2020	Winter, spring, summer, autumn	1	Homa Lagoon coast	TR	Estuarine, Coastal and Shelf Science
54	Asensio-Montesinos et al., 2021b	2020 - 2021	Every ~15 days (Dec - Mar)	5	Alicante province	ES	Marine Pollution Bulletin
55	Cresta and Battisti, 2021	2021 - 2021	Twice (Apr, May)	1	Torre Flavia wetland	IT	Marine Pollution Bulletin
56	Merlino et al., 2021	2021 - 2021	Once (May)	1	Migliarino, Massacciuccoli and San Rossore park	IT	Water
57	Katsanevakis, 2015	NA	NA	2	Lesvos Island	GR	Mediterranean Marine Science
58	Battisti et al., 2016	NA	NA	1	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 1). 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 analysed 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 1 and Table S3). 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 shoreline characteristics, 78% of analysed papers report information about the coastal type (see Table 1 and Table S3). 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.

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 2 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 (i.e., the fixed section (length) of beach from which measurements of litter number of items, weight or volume are made periodically - Galgani et al., 2013), is usually 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 (Table 2). 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%). 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, 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%).

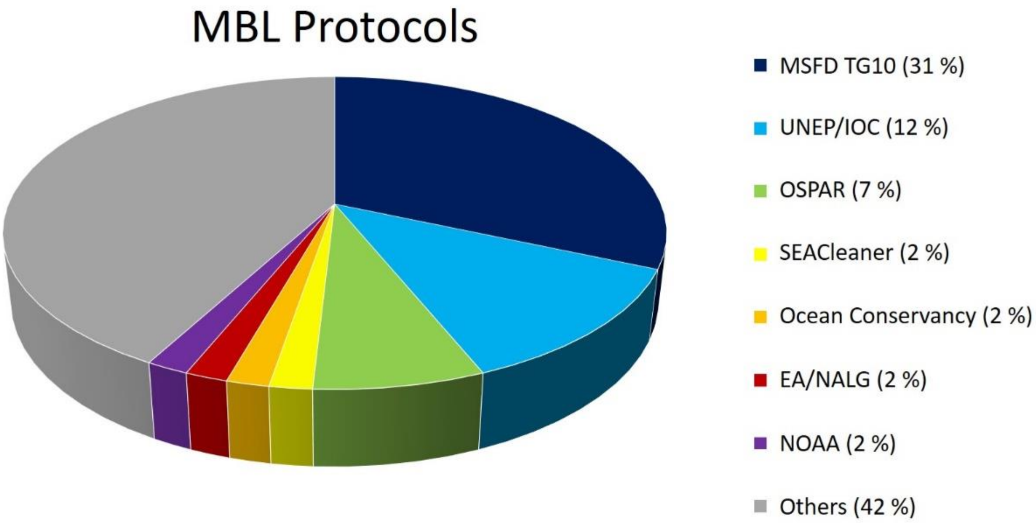

Fig. 4. Percentage distribution of sampling protocols used in MBL data collections indexed in Scopus.

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 2 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 3). 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 surveys, or they adopt methodologies that include visual census without waste removal (Merlino et al., 2021). Moreover, only six studies declare a direct participation of volunteers. However, as stated above, non-scientific initiatives usually have no fixed end-date and are characterized by a massive use of websites and outreach reports, thus appearing in scientific publications only at later stages, frequently after several years, when scientific conclusions can be finally retrieved (Schneider et al., 2018).

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 3). 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 3 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. 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. Nevertheless, 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).

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 proposed 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).

Table 2. Surveys information for scientific collections identified by ID numbers, as in Table 1.

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 3. MBL collection details for surveys identified by ID numbers, as in Table 1.

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 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 must follow commonly agreed methodologies in order to provide results which are comparable over larger regions and different periods.

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.

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). 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 analysed Scopus indexed publications shows that MBL monitoring activities are typically conducted over a limited and short period of time (e.g., covering two years or less, or even including only 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 collections characterized by seasonal repetitions are significantly affected by seasonal variation that might partly mask long-term variability (Schulz et al., 2013). Still, the surveys should be repeated on exactly the same site (Galgani et al., 2013) that should not be subject to any other litter collection activity 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. All these aspects make 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 different collections may have been realized taking advantage of different protocols and guidelines.

The selection of a specific costal sites for the monitoring activities is another factor that can significantly influence the comparability of the achieved results. Geomorphological and sedimentary characteristics, river presence, meteo-oceanographic regimes, litter exposure (e.g., urban sites, rural coasts, marine protected area), demographic and geographical conditions, main beach usage (i.e., recreational, fishing, surfing, boat access) should be always considered and reported. Unfortunately, only few publications clearly define these characteristics.

Even more important is the choice of the MBL sampling unit. Both MSFD and OSPAR guidelines suggest a minimum length of 100 m, which can be reduced to 50 m for heavily littered beaches, and a repetition of at least two sections on the same beach. 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 2). Inhomogeneity also exists in the use of transects which are carried out parallel rather than perpendicular to the coast, at a different distance between each other, and covering determined or variable beach width. Moreover, several studies do not report at all 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 macro-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 attribution of litter categories also plays an important role, as do different interpretations of monitoring guidance. Generally, MBL composition is estimated by grouping the items into different predetermined categories to favour comparability and compatibility of available observations. However, our analysis shows that this classification is usually based on different codes in the existing literature (see Table 2). 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). The available observations can still be considered as a valuable proxy for the amount of litter present in a coastal environment. However, comparing information collected in different areas/seasons/years, by different groups, is generally difficult and represents a limit to the identification of priorities for action or effectiveness of mitigation measures. Moreover, MBL data are usually not accompanied by proper uncertainties, so that they deserve a careful metadata interpretation to evaluate their accuracy and reliability.

Nevertheless, several analysed studies also attempted of determine top litter items over a specific region. Unfortunately, the top items calculation modes were often different among surveys, 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. Thus, obtaining comparable data and sampling strategies remains a priority to provide the basis for reliable litter abundance rankings and previous studies integration. The final report of the EU ARCADIS project, for example, lists the top fifteen MBL items for the Mediterranean Sea from 33 OSPAR screenings indicating plastic cutlery/trays/straws as the dominant fraction (17%), followed by cigarette butts (14%), plastic caps/lids (14%) and plastic drink bottles (12%) (Van Acoleyen et al., 2013). 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).

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. The analysed Scopus dataset shows that several methodological approaches have been used to determine where litter is coming from, but few information is 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, several analysed studies do made use of attribution of sources based on statistical techniques, such as the Matrix Scoring Technique that includes the likelihood criteria. 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.). This information is rarely reported in the analysed Scopus indexed literature.

Another important issue is represented by litter removal during/after beach surveys, and the consequent waste treatment. Actually, removal of litter should be carried out during monitoring activities. 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). 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). 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. When litter is removed, only a few documents provide details about the expected impact of beach cleaning as a factor for loss of species abundance and changes to the beach natural conditions (Defeo et al., 2009; Del Vecchio et al., 2017; Schneider et al., 2018). Information about the specific efforts to recruit, and train, field staff, are also missing in almost all of the analysed studies. Nevertheless, this is essential to ensure data quality and prevent environment damages, especially when citizen and volunteers are involved in the beach monitoring activities.

Finally, 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).

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 strategies 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 (e.g., EMODnet) to group and disseminate MBL observations, so to homogenize the processing of datasets based on different protocols and reference systems, and facilitate the identification of gaps and hindrances. Surveys and clean-up activities carried out along the southern Mediterranean coasts, for example, are rarely reported in scientific publications, 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. 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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Table S1. Summary of the publications results obtained through the different search strings applied. The number of available publications and their time frame are listed. Although it does not represent a selective criterion in the presented analyses, the number of open access publications is also reported. 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*).

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

Table S2. 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 %

Table S3. Surveyed sites information from scientific collections identified by ID numbers, as in Table 1. In parenthesis, the exact number of sites falling into a given category, if explicitly stated in the analysed documents.

ID	Beach typology (sites)	coastal type (sites)	Protected area
1		sandy, rocky	
2		sandy, rocky	
3		sandy, cobbles, rocky	
4			
5		sandy (5), gravel (1)	
6			
7			
8			
9		sandy	
10	touristic / non-touristic		
11	urban, semi-urban, semi-rural	sandy	
12		sandy, rocky	
13	exposed (3), sheltered (4)	sandy	
14		sandy	
15		sandy (12), small gravel (1)	
16		sandy	yes
17	urban (1), remote (2), semi-rural (1)	sandy (3), pebbles and cobbles (1)	
18	natural	sandy	
19	natural, urbanized, urban	sandy	yes
20	urban, semi-urban, semi-rural, remote		
21	wetland		
22	urban, village, rural, remote	cliffed, sandy	
23		sandy	
24		sandy	
25	urban (6), village (2), resort (2), rural (4)	cliffed, sandy	
26		sandy, gravel	
27	urban	sandy	
28			
29	remote		
30	natural, semi-urban	sandy, rocky	
31	very touristic, used by locals, remote		
32	urban	sandy	
33		sandy	
34	agricoltural (5), industrial (3), urban (3), rural (2)	sandy (11), gravel (2)	
35		sandy, rocky, pebbles	yes
36	semi-urban (2), urban (2), semi-rural (1)		
37	remote and rural (19), village (17), urban (20)	sandy, gravel, pebbles, rocky, low cliff, artificial	
38	remote (9), rural (10), village (17), urban (20)	sandy (31), gravel (14), boulders (14), rocky (8), banquettes (6), artificial (1)	
39	semi-urban, semi-rural, remote/natural	sandy, gravel, pebbles	
40	urban, semi-urban, semi-rural, remote/natural		
41	remote/natural	sandy	

42	wetland	sandy	yes
43	urban	stones, sandy	
44	semi-rural	rocky	
45		sandy	yes
46	urban (7), rural (2), remote (3)	sandy (2), gravel (2), sandy and gravel (7), pebbles (1)	
47	river estuary	sandy	
48			
49	urban (3), village (2)	sandy	
50	Wetland	sandy	yes
51	Urban	sandy (8), boulders and cliffs (2)	
52	Lagoon	sandy	yes
53	Lagoon	sandy	
54	rural (2), remote (3)	cobbles	
55	Wetland	sandy	yes
56		sandy	yes
57		pebbles	
58	Wetland	sandy	yes

Declaration of interest statement

Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: