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Scientific knowledge on marine beach litter: A bibliometric analysis

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Abstract

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

1. Introduction

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

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

The Marine Strategy Framework Directive (MSFD) provides the EU legal framework for the protection of the European Seas and requires EU Member States to ensure that, by 2020, "properties and quantities of marine litter do not cause harm to the coastal and marine environment" (European Parliament & Council of the European Union, 2008). Marine litter is also included as one of the Descriptors for the Good Environmental Status (GES) of the European Marine Waters and the European Commission provides details for the assessment of litter in the environment (European Commission, 2017a).

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

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

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

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

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

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

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

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

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

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

2. Materials and Methods

2.1 Bibliographic research and data collection

The publications included in the bibliometric analysis were collected through Scopus, Elsevier's abstract and citation database. This approach is strongly dependent on both the searching string and the analytical criteria, as reported in Table 1 and discussed in Section 3. A preliminary analysis was developed using three search strings: << marine AND litter >>, << beach AND litter >>, << beach AND litter AND marine >>. Several interesting studies dealing with beach litter that used synonyms in the title, abstract and keywords were missing in the resulting datasets. We therefore opted for a more inclusive query: << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >>. All Scopus searches queried the "Article title",

“Abstract”, “Keywords” database for all the publication types published in the English language available up to December 31st, 2020. The dataset was exported as .csv files including “Citation Information”, “Bibliographic Information”, “Abstract”, “Keywords” and “References” on February 28th, 2021.
To further refine the data, a close-up inspection was carried out manually to exclude off topic publications, i.e., studies that did not focus on MBL. The analyses described below were then performed starting from the year of the first publication indexed in Scopus (1971).

2.2. Bibliometric network analysis

Bibliometric network analysis has proved to be a useful tool for assessing trends and patterns of scientific literature (e.g., Buonocore et al., 2018; Appolloni et al., 2020; Sorensen and Jovanovic, 2020), helping identify trends and gaps. Coupling bibliometric data and social network analysis (SNA), the relationships among researchers, organizations, countries, and keywords dealing with a given topic can be explored (Reutters et al., 2008), which also allows further identification of research gaps. The VOSviewer software (version 1.6.16) is based on SNA and allows us to implement and analyse relationship networks based on data from scientific publication databases. In this study we focus on the relationships among countries, journals, authors, and keywords through the selection of co-authorship and co-occurrence analyses to exploit the scientific literature on MBL monitoring and collection. The main terms in VOSviewer software and a description of VOSviewer analyses used in this study are reported in Van Eck and Waltman (2020).
The software generates network graphs that highlight main authors, countries, and keywords related to a given topic. In the cluster plots, the size of items (e.g., authors, countries, and keywords) is a function of “Total Link Strength” (TLS) (i.e., the cumulative strength of the links of an item with others) and number of publications and number of citations. Connections among clusters are represented by curved lines whose thickness is related to the “link strength”. In the case of co-authorship, the link strength is the number of publications that two researchers, organizations or countries have “co-authored”, while in the case of co-occurrences, it represents the number of times that two keywords are paired. Finally, the map resolution determines the number of clusters, thus the higher the detail, the higher the number of displayed clusters. This value can be set to visualize an appropriate number of clusters in the maps (Van Eck and Waltman, 2020). In this study, it was set to 1 for all the analyses.
We restricted the co-authorship analysis to articles with a maximum of 25 authors per publication, as suggested in the default settings of VOSviewer and previous studies (e.g., Pauna et al., 2019; Appolloni et al., 2020). Among these we only selected authors and countries with at least three publications. As for keywords, we only processed terms which occurred in at least 10 of the selected publications.

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

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

3. Results and discussion

3.1 Bibliometric research and data collection

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

The << “beach litter” >> query points out that the scientific interest on this topic is relatively recent. Figure 1 shows only a few publications available before 2000 and suggests that this terminology was not used before 1989 when Scopus registers three studies focusing on the Gulf of Mexico beaches that belong to the Proceedings of the Symposium on Coastal and Ocean Management held in Charleston, USA between 11 – 14th of July 1989.
Moving the search criteria to << “marine litter” >>, the temporal coverage of existing studies goes back to 1975 (Figure 1). Over 700 Scopus publications exist, presenting an exponential increase over the last 45 years. Nevertheless, the analysis of these publications’ abstracts shows that the majority of the older “marine litter” publications deals with open ocean, focusing on plastic, debris transport and water column pollution. On the other hand, the subset of studies including the beach and shoreline pollution as an important component of marine waste was not completely covered by the << “beach litter” >> string results.
Of course, we had to consider that several studies, especially in the past, might not have clearly used “beach litter” and/or “marine litter”. Thus, we searched the strings << beach* AND litter >> and << marine AND litter >>, which include both keywords in the article title, the abstract and/or the keywords, but not necessarily as adjoining words. Moreover, although spelling and plurals are included in standard searches, we included the use of the asterisk wildcard (i.e., *) to ensure the inclusion of derived words (e.g., beached from beach*, coastal from coast*, microplastics and/or macroplastics from *plastic).
The << beach AND litter >> and << marine AND litter >> queries allowed us to obtain a dataset of 686 and 1650 publications on several disciplines, respectively (Table 1). Even though the “beach litter” terminology only appeared as recently as 1989 (Figure 1), our searches suggest that several publications focusing on the presence of marine shoreline waste were being published from the early ‘70s. Much more importantly, is that they clearly point out the worldwide increased interest within the scientific community on beach and marine litter in the last decade (Figure 2). This could be a consequence of the 2008 MSFD and other similar initiatives.

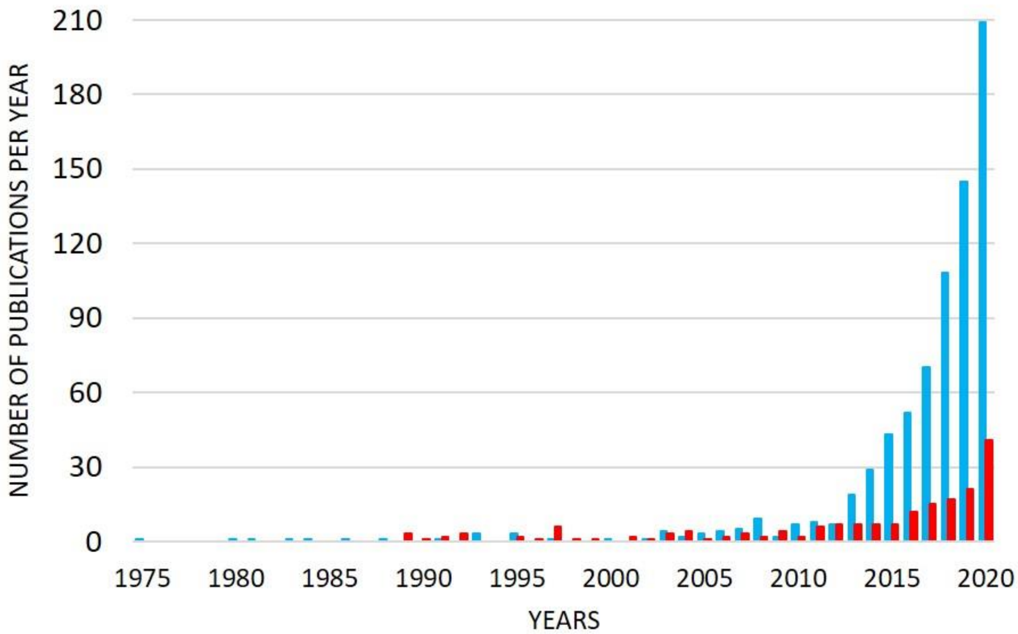

Figure 1. Number of publications indexed in Scopus including the string “marine litter” (blue) or “beach litter” (red).

Nevertheless, this search excluded several Scopus indexed publications which used a different terminology for discussing marine plastic debris and other waste impacts on marine coastal ecosystems, as well as the scientific and governmental efforts for their monitoring, conservation, and management. Conversely, several studies that did not focus on seashore (i.e., focused on open ocean or inland lakes and rivers) were included. Thus, the << beach* AND (marine OR coast*) AND (litter OR debris OR waste OR *plastic) >> query was used to obtain a more complete collection of existing MBL literature. This search resulted in 2077 publications published between 1858 and 2020 (Table 1).

Finally, the resulting data were inspected manually to remove off-topic products and provide a complete and coherent dataset including, hopefully, the entire Scopus indexed bibliography dealing with MBL. Most of the excluded products referred to marine geology, sedimentology, and engineering (71%); a smaller part to veterinary, pharmaceutics and toxicology (19%) or other disciplines (10%).

A total of 1765 publications since 1971 were retained in the final dataset which was then subjected to the following bibliometric analysis (Figure 2). A preliminary qualitative analysis of the queried publications suggests that 55% of the papers dealt with MBL monitoring, as well as with its collection and removal in different regions of the planet. A smaller subset (about 10%) focused on coastline management, tourism and other economic aspects linked to MBL, including the costs of beach cleaning (e.g., Araújo et al., 2018; Zielinski et al., 2020). The urgent need to remove beach and marine litter from the natural environment is widely assessed. In recent papers, the need for international guidelines and protocols of best practices for MBL monitoring, removal and management activities is highlighted. This information should be shared by different communities/governments to facilitate the comparison of data collected in different areas and time intervals (e.g., Roman et al., 2020). An interesting initiative to overcome these hindrances is represented by the first pan-European Marine Litter Database (MLDB) developed by EMODnet, following the advice of the MSFD Technical Group on Marine Litter (Jack et al., 2019). The MLDB contains data for beach and seafloor litter from a variety of very different sources, including existing international heterogeneous datasets published in project specific databases (e.g., OSPAR), which are processed and gathered in a new common format based on existing monitoring protocols and data reporting formats, to synchronise the available information at the European level (Addamo et al., 2018).

Concerningly, we observe that little or no information is available about how this waste should be analysed, treated, or used post collection (Iñiguez et al., 2016; Williams-Wynn and Naidoo, 2020; Ronkay et al., 2021), and about the potential damages to the ecosystems due to the accidental removal of organic biomass during waste collection.

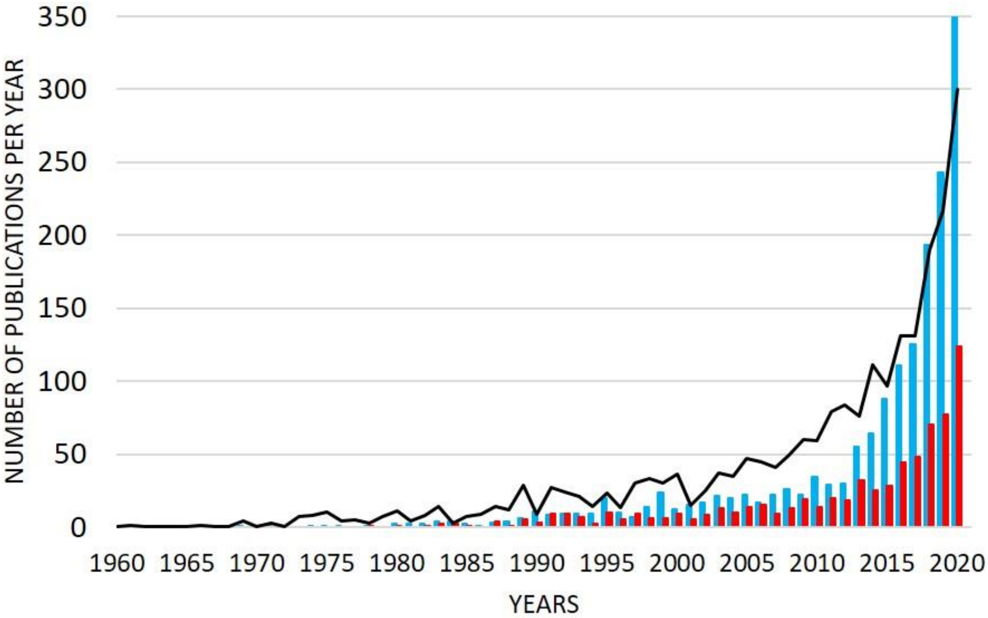

Figure 2. Number of publications indexed in Scopus (1960-2020) dealing with << marine AND litter >> (blue), << beach* AND litter >> (red), in comparison with the final refined dataset used in the bibliometric network analysis (black line).

3.2 Dataset bibliometric analysis

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

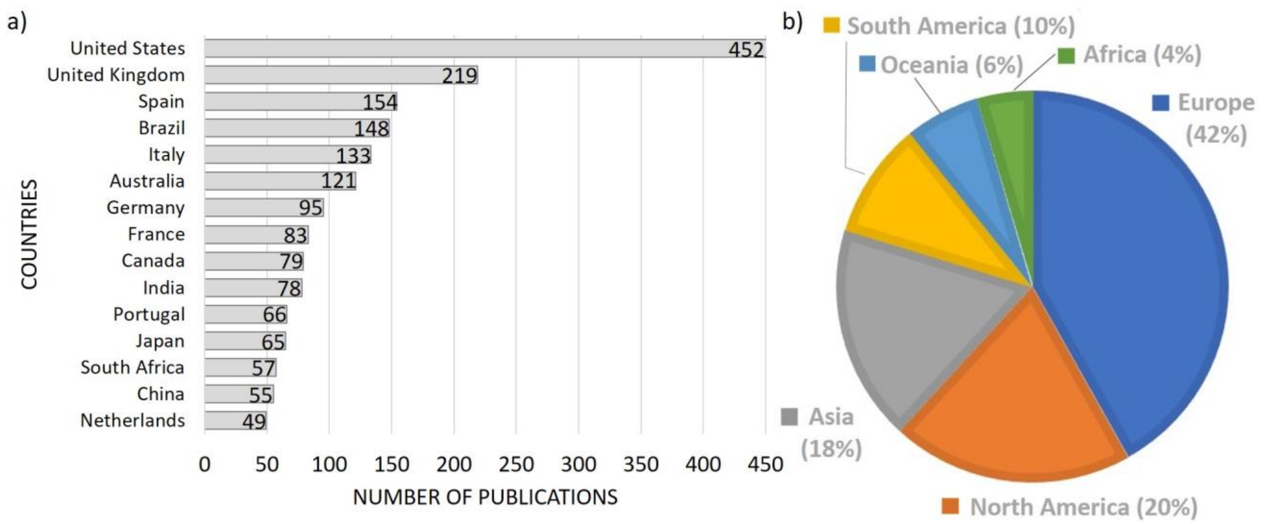

Figure 3. Geographical distribution of MBL publications indexed in Scopus a) per country (top fifteen countries) and b) per continent.

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

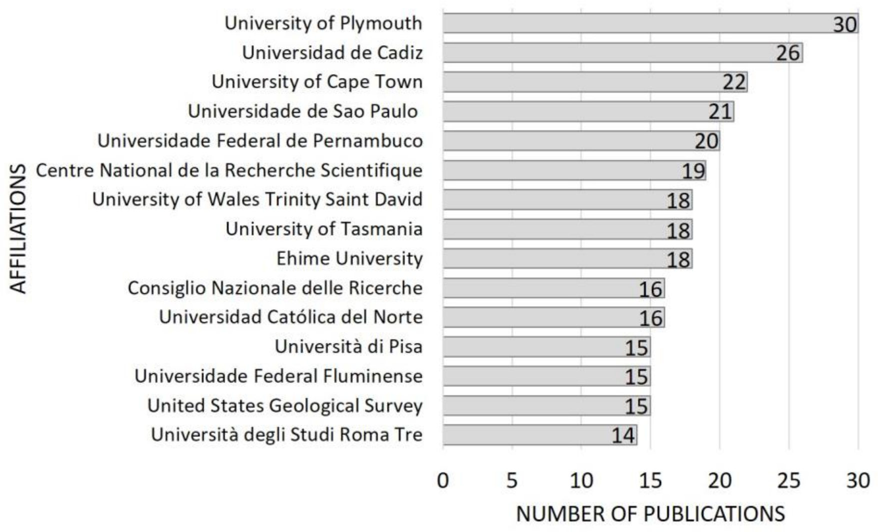

Figure 4. Top fifteen affiliations associated with MBL publications indexed in Scopus.

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

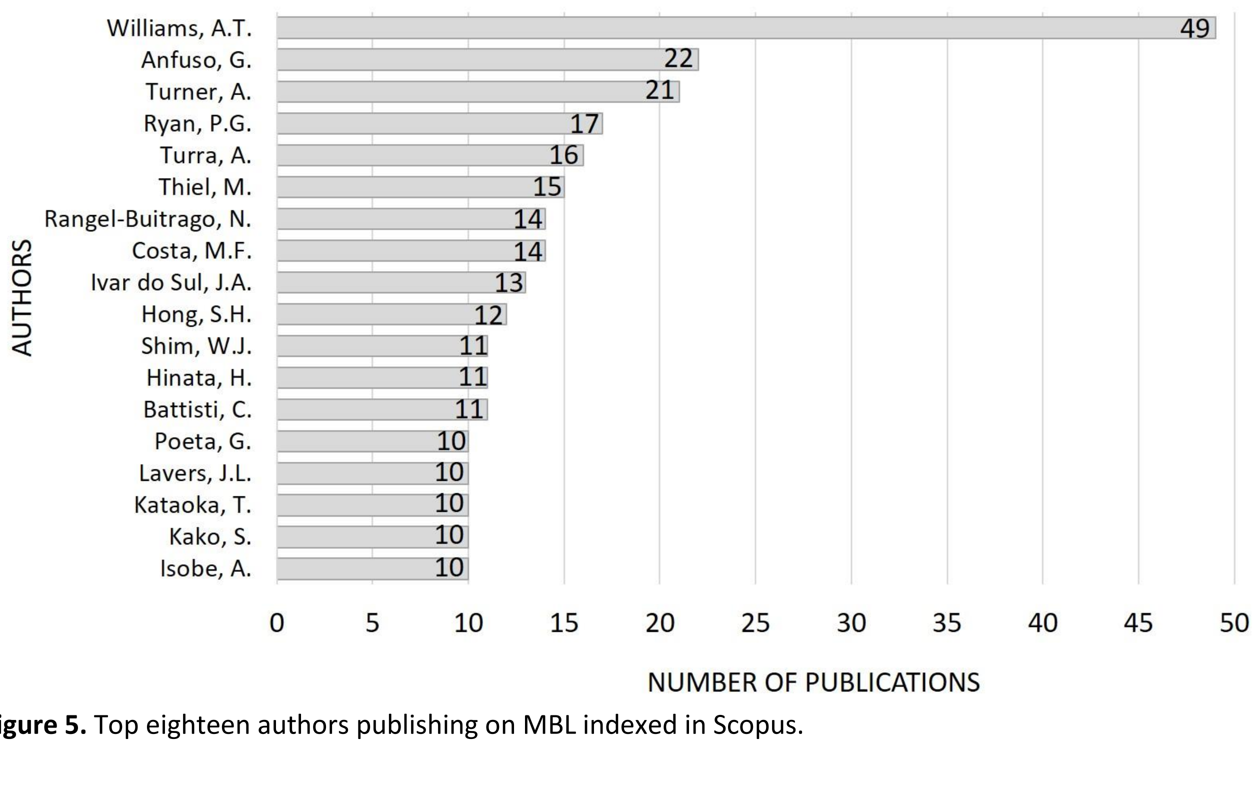

Figure 5. Top eighteen authors publishing on MBL indexed in Scopus.

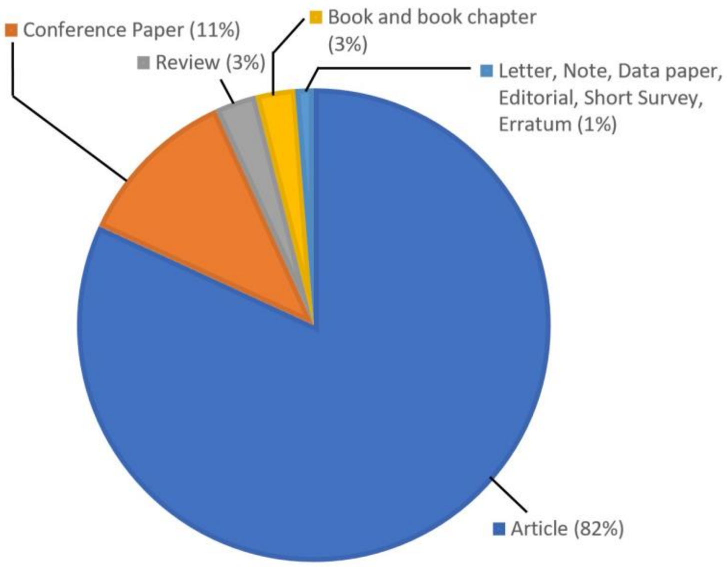

Figure 6. Occurrence of MBL publications indexed in Scopus by a) type (in percentage).

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

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

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

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

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

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

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

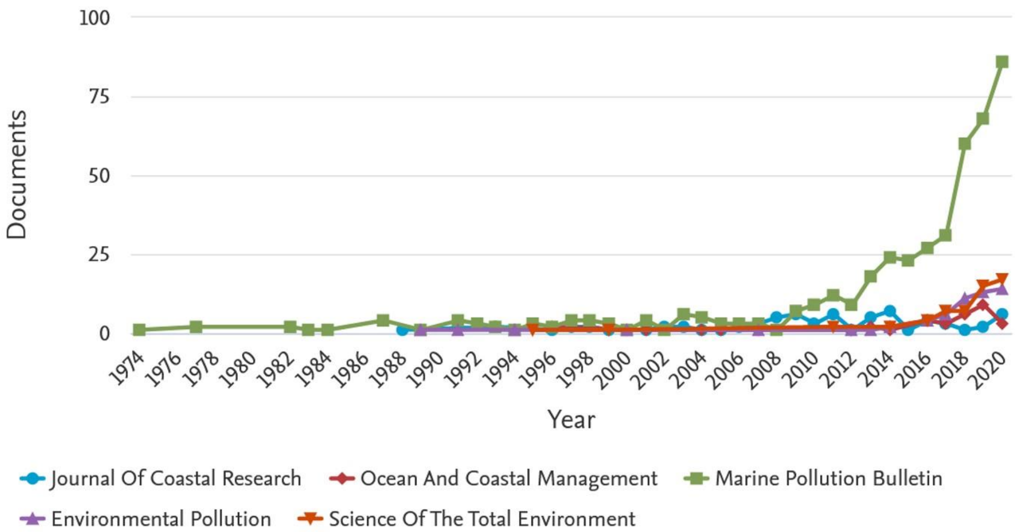

Figure 7. MBL publications indexed in Scopus per year by source since 1971: top five journals.

3.2. Bibliometric network analysis

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

3.2.1 Authors

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

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

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

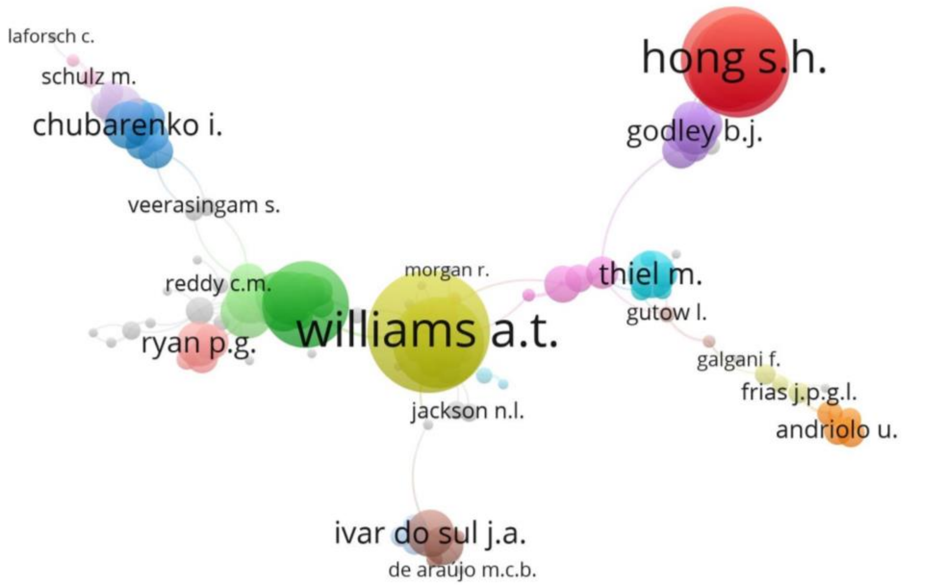

Figure 8. Co-authorship network map of authors based on total link strength. Colours refer to different clusters. The bigger the circle size the greater total link strength the author has. The closer the circles are the more often the authors are found in the same publications.

3.2.2 Countries

The co-authorship countries network only includes 76 publications, which meet the threshold of having at least three publications on MBL, grouped in 6 clusters. The role of EU countries is extremely relevant, with the UK having the highest TLS on MBL research and seven EU countries in the top ten (Table 5). The network map (Figure 9) gives a representation of how countries and clusters are connected. The proximity of their nodes demonstrates a strong collaborative relationship between several countries that are grouped in the same cluster. The main role of the UK and US is emphasized by their position in the centre of the figure and by the high number of existing links with the other countries. The UK is well connected with all the other clusters and leads a small one (purple network) which also includes eastern Mediterranean countries (e.g., Israel, Greece, Turkey). The second cluster in terms of TLS is the one led by the US (red network) which is strongly interconnected with the UK and includes Canada, South Africa, and several Asian countries (e.g., South Korea, China, India, Japan). Another interesting cluster (blue network) is the one that groups Spain and Portugal with Central and South American (e.g., Mexico, Colombia, Uruguay) as well as North African (e.g., Morocco) countries. A proximity is also shown by the geographically focused cluster (green network) that includes central and north European countries (e.g., Germany, Belgium, the Netherlands, Poland, Scandinavia, and the Russian federation). Conversely, the yellow network clusters several countries (e.g., Italy, Australia, New Zealand, Brazil, and Chile) which cannot be grouped based on typical geographic or language criteria, but which share common topic interests in the framework of the MBL scientific research which were not prominent in other clusters (e.g., beach management, tourism, and recreation perspectives). Finally, despite the high TLS score, France appears less interconnected with the rest of the world, being directly related only with Indonesia and Saudi Arabia in the presented network map (cyano network). On the other hand, its location in the middle of the map suggests that it tends to collaborate with several other countries whilst also developing independent research activities and possessing solid exclusive collaborations within its own small cluster.

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

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

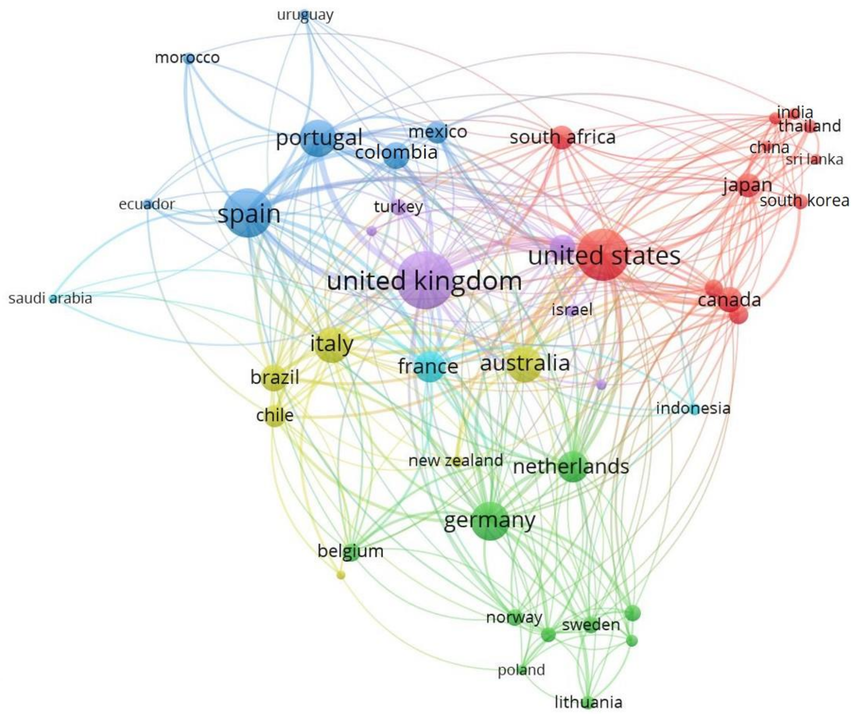

Figure 9. Co-authorship network map of countries based on total link strength. Colours refer to different clusters. Circle size indicates a countries publication frequency. Circle proximity indicates increased occurrence of two countries being found in the same publication.

3.2.3 Keywords

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

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

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

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

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

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

Generally, even though a strong relationship to the blue cluster can be detected, this analysis points out that all the keyword clusters are clearly sector-based and identify recognizable scientific areas, suggesting that the multidisciplinary nature of several studies is often limited to particular and specific aspects of the MBL issue. This hypothesis is confirmed by the small number of interdisciplinary studies available in the analysed database and by the prevalence of sectorial scientific products.

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

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

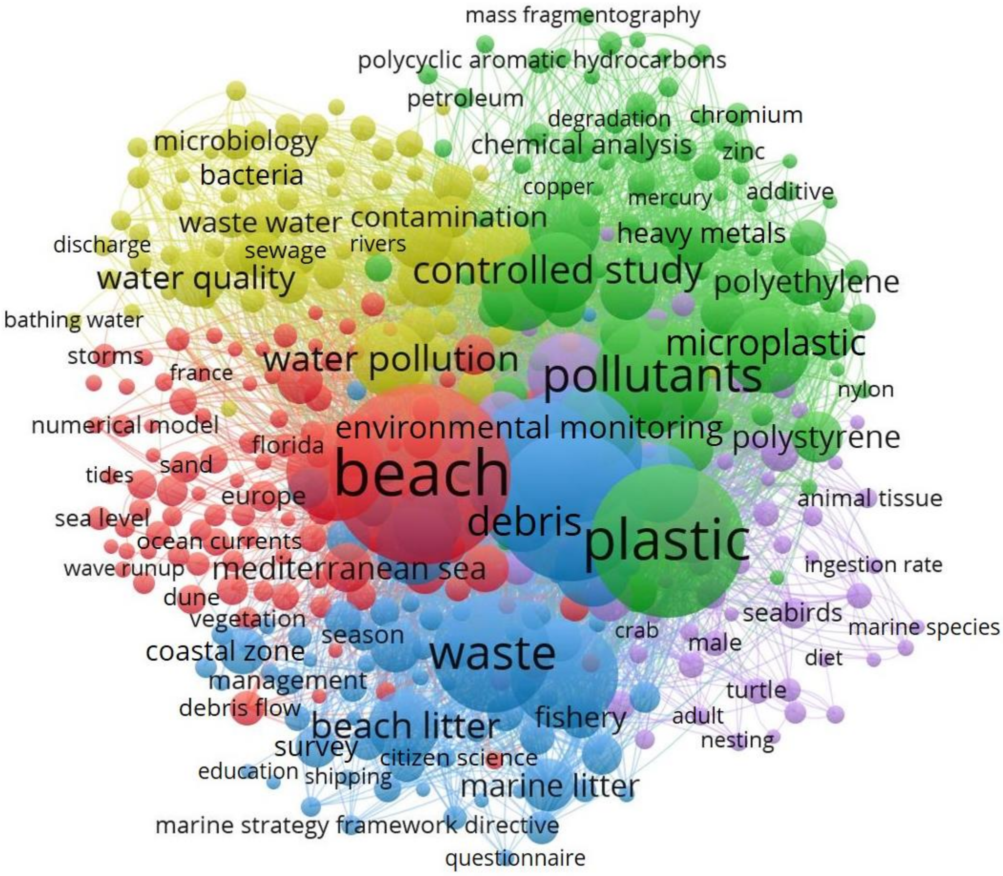

Figure 10. Co-occurrence network map of keywords based on total link strength. Colours refer to different clusters according to the specific aspects of the MBL included (i.e., blue for "environmental monitoring", red for "geophysics", green for "chemistry", yellow for "microbiology", purple for "biology").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

4. Concluding remarks

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

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

A whole-system quantitative assessment for the monitoring and collection of beach litter, as well as for the creation of shared protocols and open access data, is also necessary to encourage future analyses and comparisons among different countries and different areas within each single country (e.g., to be used during different lab experiments, sampling and clean-up activities, impact modelling and environmental quality evaluation). The existing literature (e.g., Hardesty et al., 2017; Jack et al., 2019) points out that important efforts are finally on the way for providing common guidelines, good practices and indexes that could help data comparison and integration between different regions and scientific groups.
On the other hand, a preliminary analysis of the queried publications shows that only a few studies have been devoted to other important aspects, e.g., the impact of coastal currents on MBL transport and deposition. In this context, dedicated studies are needed to create multiplatform observatories able to provide physical and biogeochemical information at different spatio-temporal scales useful for in situ MBL data analyses, numerical model assimilations and connectivity investigations (Aulicino et al., 2016; 2018; 2021; Cotroneo et al., 2021). Still, little or no information is available regarding how beach waste is treated or used post collection (e.g., Williams-Wynn and Naidoo, 2020; Ronkay et al., 2021). Although a few studies (e.g., Zielinsky et al., 2019) focus on the aspect of beach cleaning from both the conservation and intensive tourism use perspectives, a lack of understanding remains as to how this waste presence/removal can affect the biodiversity and the functioning of marine ecosystems, and indirectly the provisioning of ecosystem services, as observed by Pauna et al. (2019) who focused on marine microplastics.
Finally, it is important to note that the results of this study are strongly dependent on the applied searching string and analytical criteria. Studies such as this would benefit from additional detailed research, e.g., through a comprehensive and formal qualitative content analysis. Nevertheless, this study provides a useful piece of information about the existing global scientific literature on MBL. As more and more countries have begun to adopt initiatives to reduce MBL presence, this study is also expected to be useful to regulators that need information about the past and the present scientific research on this topic. It also represents a general basis for future studies that may be carried out to focus on peculiar MBL sub-topics using specific keywords and criteria.

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