Review

The issue of microplastics in marine ecosystems: A bibliometric network analysis

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ARTICLE INFO

Keywords:
Microplastics
Marine ecosystems
VOSviewer
Bibliometrics

ABSTRACT

Human activities lead to several impacts on marine ecosystems, among which a massive input of plastic entering the marine environment. This scenario has the potential to threaten ecosystem health and integrity, also reducing the ability of marine ecosystems to provide good and services on which human well-being relies. In this study, the global scientific literature on marine microplastics was explored by combining social network analysis and bibliometrics. Network maps displayed the relationships among keywords, authors, countries, and journals dealing with the issue of microplastics in marine ecosystems. The citation analysis of journals showed that "Marine Pollution Bulletin" resulted the first among the scientific journals publishing articles on this subject. The results also highlighted that most research on the subject is focused on toxicology and environmental chemistry, while ecological studies focusing on the impact of microplastics at ecosystem level are still limited.

1. Introduction

The coastal areas of the Mediterranean Sea are home to approximately 320 million inhabitants who interact with the marine ecosystem by exploiting natural capital stocks while benefiting from the support of different types of ecosystem services (ES): provisioning (e.g., fish harvest), cultural (e.g., tourism and recreation), and regulating services (e.g., carbon sequestration and climate mitigation) (Häyhä and Franzese, 2014; Hattam et al., 2015; National Research Council, 2008; UNEP, 2006). Unfortunately, the multiple pressures of human activities on marine ecosystems lead to several impacts (Halpern et al., 2015), among which an estimated 8 million metric tons of plastic entering the marine environment annually (Jambeck et al., 2015). This scenario has the potential to not only threaten the marine ecosystem, but also affect its capacity to provide socio-economic benefits on which human well-being relies (GESAMP, 2015).

Several initiatives at European level have been promoted addressing plastic pollution reduction as a high priority target. Marine litter is one of the target pollutants of the EU Marine Strategy Framework Directive (MSFD). In 2018, the European Strategy for Plastics in a Circular Economy was adopted aimed at reducing microplastics in marine ecosystems through a better design of plastic products and higher plastic waste recycling rates (Crippa et al., 2019).

The first studies on marine microplastics were reported in the scientific literature in the early 1970s (Carpenter and Smith, 1972; Carpenter et al., 1972). Since then, although there has been an increasing interest towards the issue of microplastics in marine environment, there remains a lack of understanding of how they can affect the biodiversity and the functioning of marine ecosystems and, indirectly, the provisioning of ES (D'Alessandro et al., 2018; Vihervaara et al., 2019). In this regard, a timely debate addresses the presence and concentration of microplastics in fishes, a critical topic considering that globally more than 40 million people are dependent on fish provisioning (National Research Council, 2008; Rainieri and Barranco, 2019). The ecosystem service of fish provisioning is influenced by both the productivity at lower levels of the trophic chain (Troost et al., 2018) and the energy transfer among trophic levels, and it depends on the overall complexity and structure of marine food webs (Buonocore et al., 2019; Franzese et al., 2017; Picone et al., 2017; Vassallo et al., 2017).

Several recent studies on microplastics focused on their toxicological effects at molecular, cellular, and tissue level of single individuals or specific species (Fastelli et al., 2016; Guzzetti et al., 2018; Renzi et al., 2018; Wright et al., 2013). Still, more research efforts are needed to explore the potential negative effects of microplastics at ecosystem level.

The strong relationship between healthy and resilient marine ecosystems and human well-being is recognized by ecosystem-based management approaches such as the Ecosystem Approach to Fisheries

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https://doi.org/10.1016/j.marpolbul.2019.110612

Table 1
Main terms in VOSviewer software (Van Eck and Waltman, 2018).

TERM	DESCRIPTION
ITEMS	Objects of interest (e.g., publications, researchers, keywords, authors).
LINK	Connection or relation between two items (e.g., co-occurrence of keywords).
LINK STRENGTH	Attribute of each link, expressed by a positive numerical value. In the case of co-authorship links, the higher the value, the higher the number of publications the two researchers have co-authored.
NETWORK	Set of items connected by their links.
CLUSTER	Sets of items included in a map. One item can only belong to one cluster.
WEIGHT ATTRIBUTE: NUMBER OF LINKS	The number of links of an item with other items.
WEIGHT ATTRIBUTE: TOTAL LINK STRENGTH	The cumulative strength of the links of an item with other items.

Table 2
Description of VOSviewer analyses used in this study (Van Eck and Waltman, 2014, 2018).

TYPE OF ANALYSIS	DESCRIPTION
CO-AUTHORSHIP	In co-authorship networks, researchers, research institution, or countries are linked to each other based on the number of publications they have authored jointly.
CO-OCCURRENCE	The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list.
CITATION	In citation networks, two items are linked if at least one cites the other.

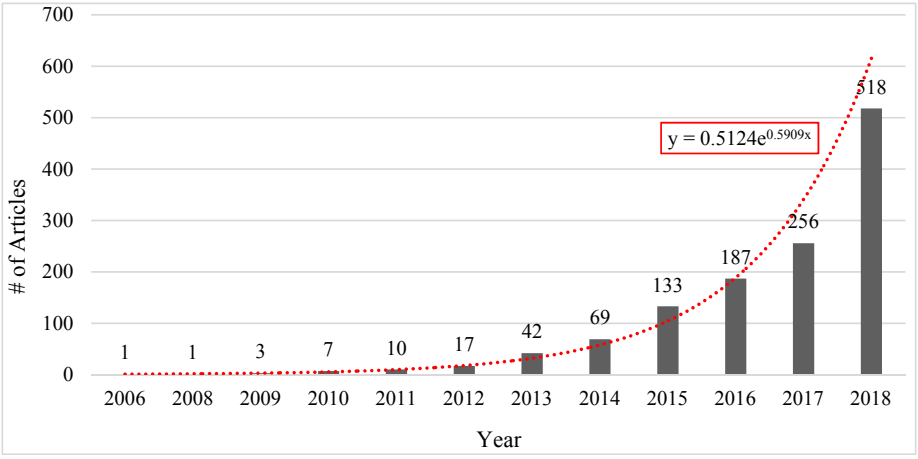

Fig. 1. Temporal trend of scientific articles on marine microplastics.

(EAF) (Hill et al., 2006). Ward et al. (2002) defined EAF as a management strategy which functions by *"recognizing more explicitly the interdependence between human well-being and ecosystem health and the need to maintain ecosystems productivity for present and future generations,* e.g. *conserving critical habitats, reducing pollution and degradation, minimizing waste, protecting endangered species"*.

Considering the importance of the issue of microplastics in marine ecosystems and the international policy promoting scientific research on the topic, it is expected that the scientific literature on marine microplastics will continue increasing over the next years.

The use of bibliometric network analysis has proved to be a useful tool to quantitatively assess trends and patterns of academic literature (Otte and Rousseau, 2002). Recent studies used bibliometric network analysis to explore the scientific literature on important ecological topics such as natural capital and ecosystem services (Buonocore et al., 2018; Pauna et al., 2018).

The present study aims to explore the global scientific literature on the issue of microplastics in marine ecosystems tracking its evolution and trends by using bibliometric network analysis.

2. Methodology

2.1. Bibliometric network analysis

Bibliometric network analysis is an effective tool combining bibliometrics and social network analysis (SNA) to investigate specific field of science (Reuters, 2008; Zou et al., 2018). SNA and maps based on network data allow for the application of systems thinking in bibliometric science. In particular, such analysis allows for the construction of a network based on the relationships among countries, journals, organizations, authors, and keywords related to the investigated topic (Chen et al., 2016).

VOSviewer (version 1.6.11) software was used to perform the bibliometric analysis in this study. This software allows for the creation, visualization, and exploration of maps based on bibliometric network data. The output results are displayed in clusters to allow for clear visualization of the existing connections among the bibliometric data. Table 1 summarizes the main technical terms used by the software.

Co-authorship, co-occurrence, and citation analyses (Table 2) were conducted to create network maps showing: (1) the co-occurrence of keywords, (2) the co-authorship among researchers and countries, and (3) cited scientific journals. Each network map that resulted from the analyses contains nodes with size determined by "total link strength"

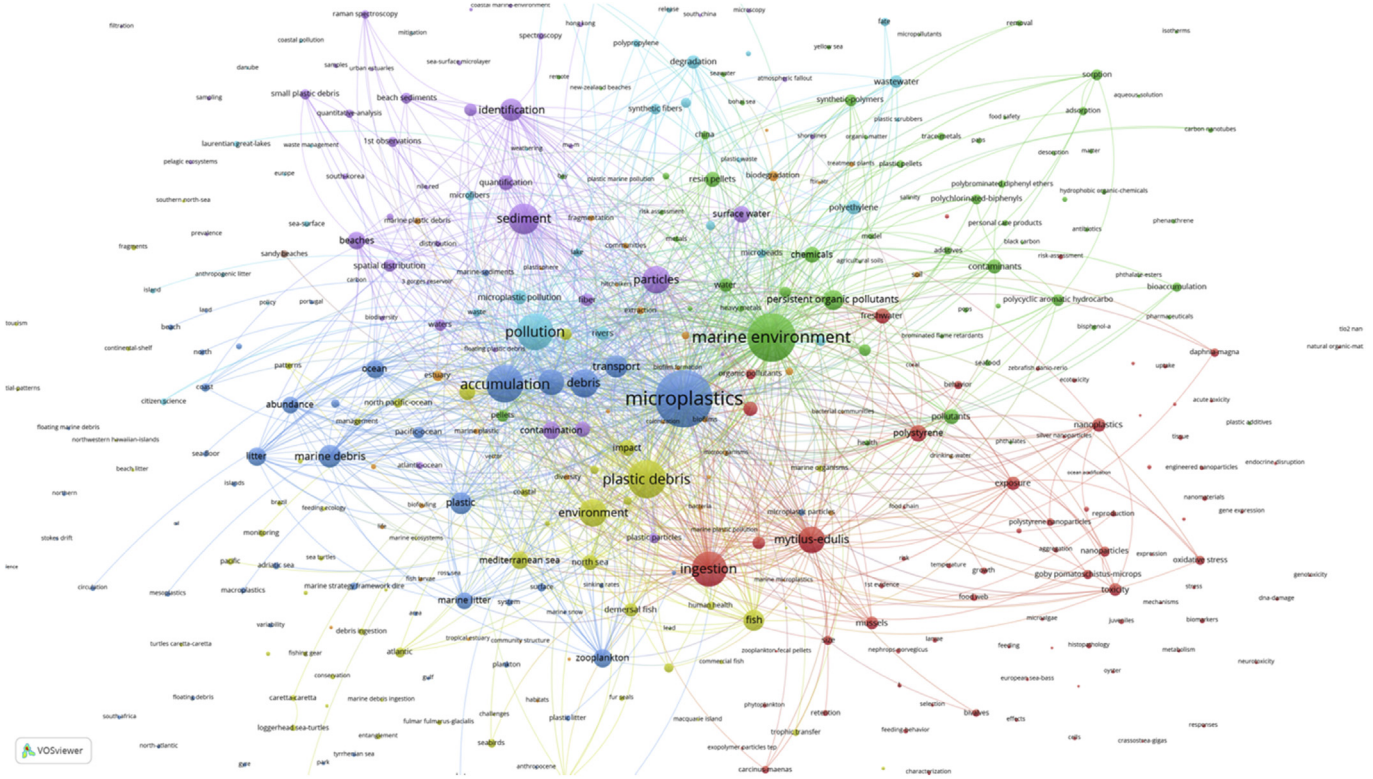

Fig. 2. Network map of keywords co-occurrence with respect to total link strength.

Table 3
Top 5 keywords following "microplastics" and "marine environment". ranked according to the total link strength.

Keyword	Total Link Strength	Links	Occurrences
Plastic debris	4138	390	452
Accumulation	3861	372	411
Pollution	3812	372	417
Ingestion	3424	357	373
Sediment	2760	328	296

(Table 1), and lines connecting the nodes with thickness based on "link strength" (Table 1).

The amount of clusters visualized in the network maps is determined by the resolution parameter. The higher its value, the higher the level of details. This value can be set to visualize an appropriate number of clusters in the maps (Van Eck and Waltman, 2018). In this study, the resolution was set to 1 for all the analyses.

2.2. Bibliographic data acquisition

The documents in this study were retrieved from the Web of Science search engine on June 24th, 2019 using the search input "microplastic* AND marine". The time frame was set to include all available publication years in the Web of Science Core Collection (WSCC) database which is automatically set from 1990 to 2019. All data was saved as "Tab-delimited (Mac)" files which contained "Full Record" and "Full Record and Cited References" content. The "Full Record" and "Full Record and Cited References" content were respectively used for co-authorship and co-occurrence analyses (e.g., network maps of authors, countries, and keywords) and citations analysis (e.g., network map of scientific journals).

2.3. Temporal trend analysis

In addition to the bibliometric network analysis, the number of articles regarding marine microplastics published per year was assessed. Being still in progress, the year 2019 was not considered in this analysis.

3. Results and discussion

3.1. Temporal trend analysis

The WSCC database search resulted in 1244 scientific articles published in the timeframe from 1990 to 2018 and 1518 scientific articles from 1990 to June 24th, 2019. As shown in Fig. 1, the research interest in marine microplastics began to grow substantially starting in 2013 when the number of publications jumped from 17 in 2012 to 42 in 2013, and continued to increase exponentially through 2018.

The WSCC search resulted in 22 articles discussing the relationships between marine microplastics and phytoplankton starting in 2013, 10 of which were published in 2019. This recent research focus on individual organisms at the base of the food web is a first step to investigate the impact of microplastics on marine ecosystems. However, such investigations should avoid using the assumption of a linear and non-flexible food chain, a restriction present in most models of contaminants in marine food webs (Diepens and Koelmans, 2018).

3.2. Bibliometric network analysis

3.2.1. Co-occurrence keywords network

The analysis of the co-occurrence of keywords generated 4830 results. Setting a minimum number of 5 occurrences required to be included in the co-occurrence keywords network, 482 keywords were selected (Fig. 2). As expected, the term "microplastics" was the keyword with the largest total link strength, while "marine environment" showed the second largest total link strength.

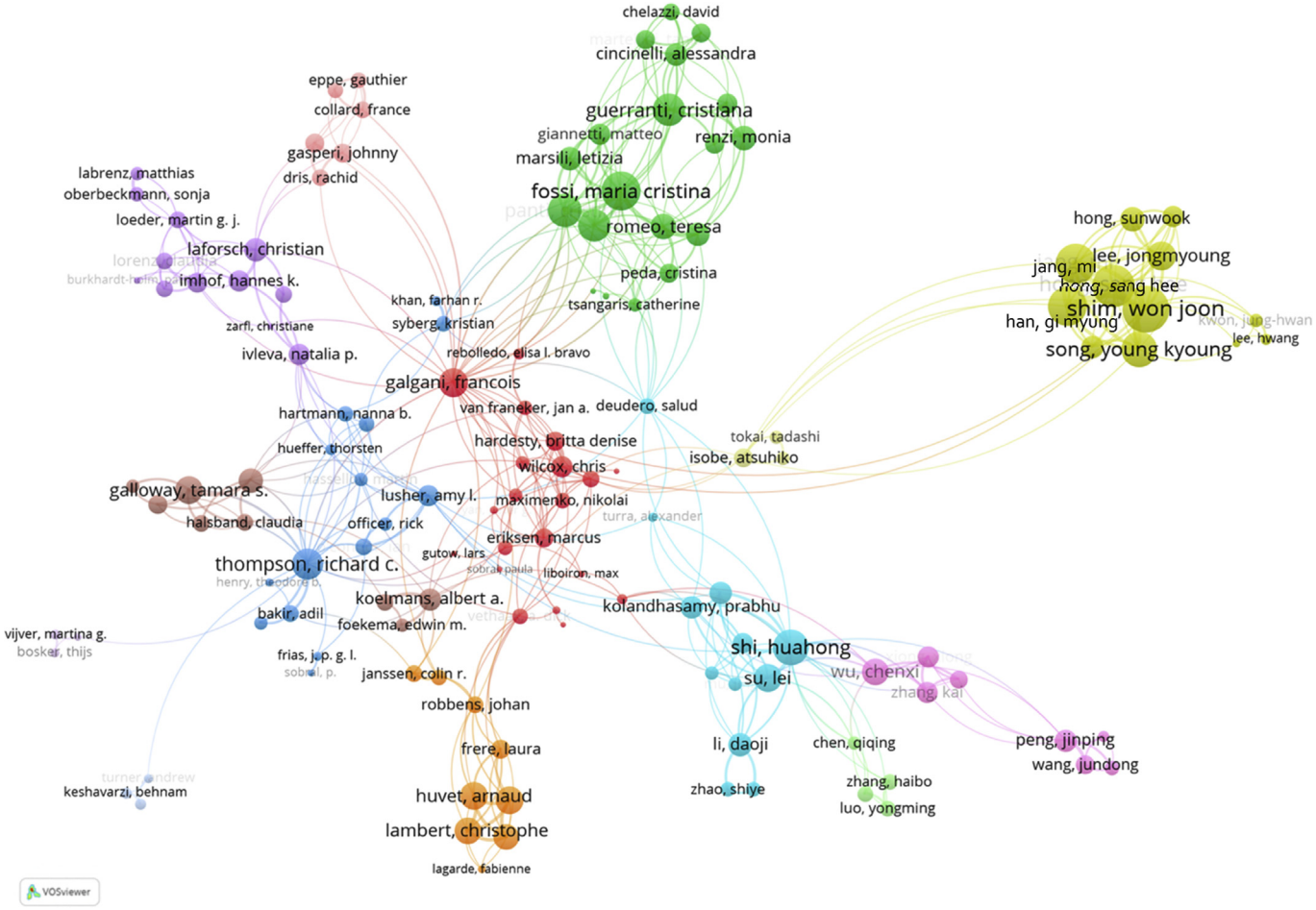

Fig. 3. Co-authorship network map of authors based on total link strength.

Table 4
Top 5 authors ranked by total link strength.

Author	Specialization	Total Link Strength	Links	Articles	Citations
Shim, Won Joon	Ecotoxicology, Environmental Chemistry	91	14	27	1054
Hong, Sang Hee	Environmental Chemistry	77	10	19	617
Jang, Mi	Environmental Chemistry	69	9	15	587
Han, Gi Myung	Environmental Chemistry	66	9	14	564
Fossi, Maria Cristina	Ecology	65	17	19	762

Table 5
Top 5 countries ranked by total link strength.

Country	Total Link Strength	Links	Articles	Citations
England	223	36	185	13,417
USA	204	36	209	10,410
Germany	141	32	165	5567
France	133	31	111	5251
Australia	129	36	89	4236

The top 5 keywords following “microplastics” and “marine environment” were “plastic debris”, “accumulation”, “pollution”, “ingestion”, and “sediment”. Fig. 2 shows the importance and relationship of the top 5 keywords listed in Table 3. The size of their nodes reflects their total link strength indicating that these keywords occur frequently in the literature regarding marine microplastics and that they frequently occur along with “microplastics”.

Instead, the proximity of the nodes indicates how related these research topics are to each other. The network map shows that “ingestion” and “accumulation” have a close relationship to “microplastics”. This result reflects the way in which the issue of microplastics is investigated, hinting that there is a special research focus on the interactions with food webs. However, this finding could also suggest that food web studies assume a linear interaction among trophic levels due to simplified laboratory experiments regarding microplastics uptake by individual species (Diepens and Koelmans, 2018).

The term “ecosystem services” cannot be seen in Fig. 2 because it had an occurrence value of 2 and was therefore not included in the resulting network map. This outcome highlights the lack of studies focusing on the relationships between microplastics and their potential effect on the delivery of marine ES.

3.2.2. *Co-authorship authors network*

The co-authorship authors analysis was restricted to articles with a maximum of 25 authors per document which resulted in 4993 researchers. This quantity was then reduced to 174 by only including authors with at least 5 publications. The final network map shows the largest set of connected items which includes 135 authors (Fig. 3).

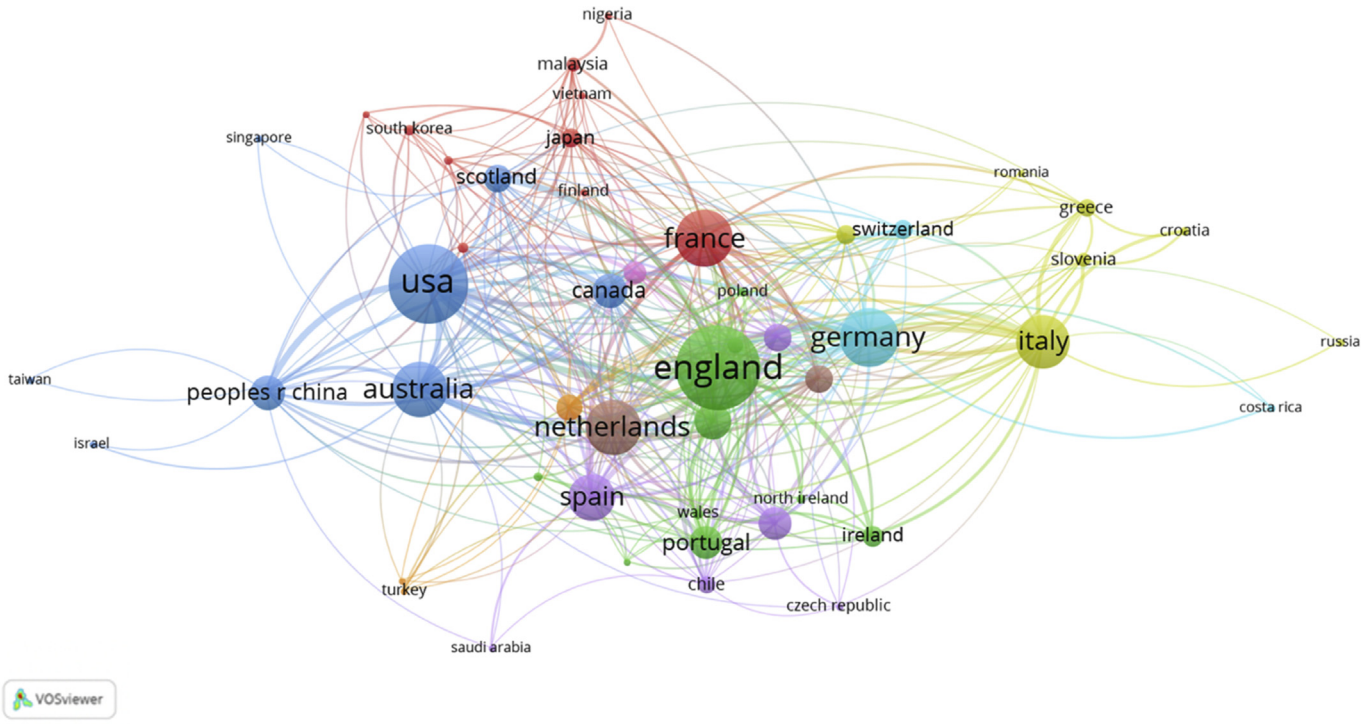

Fig. 4. Co-authorship countries network map based on total link strength.

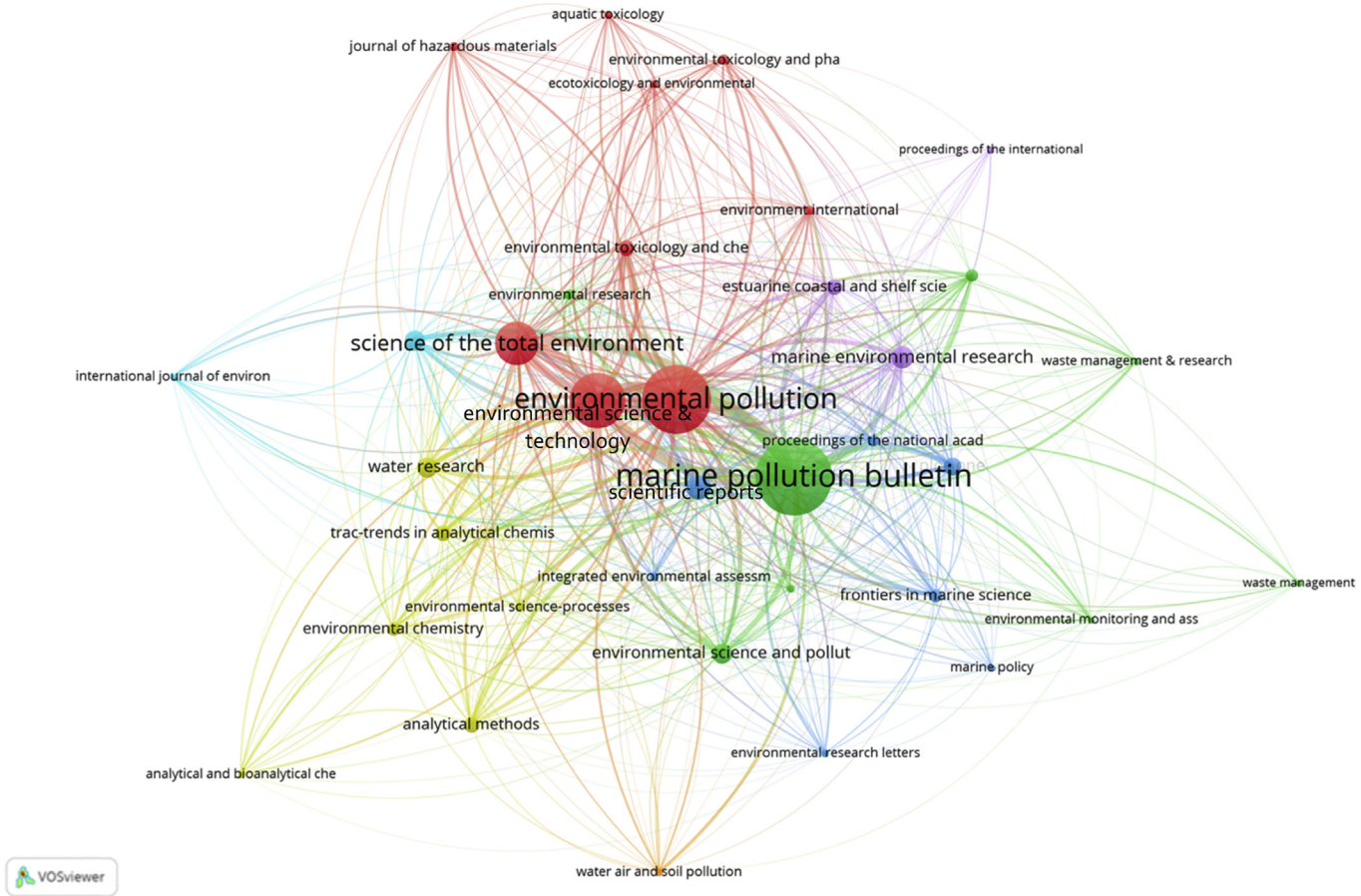

Fig. 5. Network map of citations analysis of journals based on total link strength.

Table 6
Top 5 journals based on total link strength.

Journal	Total Link Strength	Links	Articles	Citations
Marine Pollution Bulletin	9110	35	357	12,236
Environmental Pollution	7597	35	218	7248
Environmental Science & Technology	5438	35	87	7546
Science of the Total Environment	3575	35	116	1965
Scientific Reports	1477	34	40	1532

The resulting network map shows a high commitment of environmental chemists on the issue of marine microplastics. As shown in Table 4, three of the five authors with the greatest total link strength are indeed specialized in environmental chemistry, while only the fifth author is specialized in ecology. These results highlight that most research on microplastics is mainly focused on pollution, toxicology, and environmental chemistry. In the future, it is desirable that the issue of microplastics will be investigated by means of an interdisciplinary approach.

Another interesting observation is the consistent level of collaboration among clusters compared to other studies such as Pauna et al. (2018) where the top 5 authors showed strong collaboration within their cluster, but not among other clusters.

3.2.3. Co-authorship countries network

Documents with no more than 25 countries per article were considered for the co-authorship countries network (Table 5). Of the 98 countries that met this requirement, 50 met the threshold of having at least 5 publications on marine microplastics and were connected in the network map shown in Fig. 4.

The network map shows that the USA and Australia have a strong collaborative relationship on the topic of microplastics. This is shown by the close proximity of their nodes and by the share of the same cluster. Germany, England, and France also show a close proximity although included in different clusters. Since these countries do not share the same cluster, it could be that they also tend to collaborate with each other meanwhile possessing mutually exclusive collaborations with other countries.

3.2.4. Citation analysis of journals

The citation analysis resulted in a network map containing 36 sources out of 226 that met the threshold of having at least 5 publications on the topic (Fig. 5). The top 5 journals listed in Table 6 are ranked based on total link strength. Among them, the journal “Marine Pollution Bulletin” resulted the first-ranked with 357 articles published on the topic. The citation analysis results are a reflection of the fields of study which provide the most information about microplastics in the marine environment. These results also indicate that an ecological perspective have not yet been prioritized in microplastics research because the top 4 journals mainly focus on pollution, toxicology, and environmental chemistry.

4. Concluding remarks

In this study, we explored the global scientific literature on the issue of microplastics in marine ecosystems. The total number of scientific articles published on the subject (1,518) revealed that the issue of marine microplastics is a relatively new field of research. The results also highlighted that most research on the subject is focused on toxicology and environmental chemistry, while ecological studies focusing on the impact of microplastics at ecosystem level are still limited. In addition, the analysis of the co-occurrence of keywords showed a very weak connection between the issues of marine microplastics and ES. This weak connection prevents from understanding the potential loss of ES (e.g., reduction of fish harvest) due to microplastics pollution.

An increasing trend of publications focusing on microplastics is expected in the next future. Considering the broad implications of microplastics on human and ecosystem health, it is desirable that future studies would explore the issue of microplastics adopting an interdisciplinary perspective. Such a perspective to the study of marine microplastics requires the integration of different technical and scientific competences. In particular, a holistic approach should involve different steps, among which sampling activities, lab experiments, and modeling tools capable of integrating multiple scientific data to analyze and simulate the complex relationships between microplastics and marine trophic chains.

In conclusion, the combined use of social network analysis and bibliometrics proved to be a useful approach for performing comprehensive literature reviews by applying systems thinking in bibliometric science.

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