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Marine Pollution:

Global issue, clustered research?

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**Marine Pollution Bulletin**

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**Abstract (Include intro, methods, results, discussion)**

Why you did it 1-2: Marine pollution is a global issue that negatively impacts environmental, economic, and social systems. Discovering research clusters and trends in topics areas will help us determine where there may still be gaps. Determining geographic concentrations, patterns of collaboration in research, and the evolution of topic areas will help us see how our understanding of marine pollution and its impacts have changed over time and where there may yet be gaps. Identification of gaps can direct future research and allocate resources to those most impacted by marine pollution and often with the least resources to address it.

What you did 1-2: Extracted all articles within scopus that have keyword “marine pollution” and analysed them with bibliometrix package.

What you found 2-4:

What it means 1-2:

# Keywords: Marine pollution, bibliometrics, network analysis, marine environment, scopus

# Introduction

Marine pollution is a global issue that has widespread negative impacts on ecological, social, and economic systems (Beaumont, et al. 2019). It is estimated that up to 12 million metric tonnes of plastic alone enters the ocean each year, costing roughly $13 billion in economic costs and impacting more than 800 marine and coastal species (United Nations 2020)***.*** The definition of marine pollution has evolved from a focus on the effects of industrial activity to a broader notion of the interdependence between human activity and nature (Tomczak 1984). The first widely accepted definition resulted from the United Nations *Convention of the Law and the Sea* in 1982. Marine pollution was defined as the ‘introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities’ (United Nations 1982).

The environmental, economic, and health implications of marine pollution are global in scale however the research is not standardised and the full impacts are not understood (Galgani 2015). The negative impact of marine pollution is widely accepted by scientists, policy makers, and the general public although knowledge gaps make it difficult to address the issues (Bonanno and Orlando-Bonaca 2018).

Determining geographic concentrations, patterns of collaboration in research, and the evolution of topic areas will help us see how our understanding of marine pollution and its impacts have changed over time and where there may still be gaps. Bibliometrics, a method of analysing a large amount of published records, could help by illuminating geographic, author, and keyword connections in the body of literature.

This paper aims to reveal clusters in geographies and topic areas with the goal of recording who is driving this research and how our understanding of marine pollution and its impacts have changed over time. I will use bibliometrics evaluate research trends in published marine pollution research and answer two key questions. The first is to discover the key players in marine pollution research and their pattens of collaboration through both geographic affiliation and bibliographic coupling of shared citations. The second is to determine how the topical focus has changed over time. Firstly, I predict that research is clustered and dominated by key players, because although pollution does not respect national boundaries, research institutions are bound by them. Secondly, I predict that although published research has grown overall, the topic proportions have changed over time from a focus on industrial pollutants to debris and specifically plastics.

# Materials and Methods

* 1. **Research Methodology**

Bibliometric analysis uses information on authors, citations, and keywords in order to describe the structure and evolution of publications throughout time (Nakagawa et al 2019). I assessed four types of patterns in scientific literature relating to marine pollution using a bibliometrics approach. The first is an analysis of the patterns in publication including annual publications, productive authors, and highly cited papers. The second is a geographic analysis of high producing countries. The third is a network map of intra and international collaborations based on author addresses. The fourth is a visualisation of author keywords in order to determine evolution of topic areas. Determining geographic concentrations, patterns of collaboration in research, and the evolution of topic areas will reveal how our understanding of marine pollution and its impacts have changed over time and where there may yet be gaps.

* 1. **Data Collection**

In order to analyse marine pollution literature I extracted article metadata from Scopus online academic literature database ([www.scopus.com](http://www.scopus.com/)). In the first instance, I queried Scopus using the following search string:

EXACTKEYWORD ( "marine pollut\*" )  AND  ( LIMIT-TO ( SUBJAREA ,  "ENVI" ) )  AND  ( LIMIT-TO ( DOCTYPE ,  "ar" )  OR  LIMIT-TO ( DOCTYPE ,  "cp" )  OR  LIMIT-TO ( DOCTYPE ,  "re" ) )  AND  ( LIMIT-TO ( LANGUAGE ,  "English" ) )

This instructs Scopus to search for records tagged with the keyword ‘Marine Pollution’ and limited to the subject area of ‘Environmental Science’. I used additional filters to include only publications in English and to limit document types to articles, conference papers, and reviews. I excluded articles published in 2020 in order to assess only full calendar years.

After searching and filtering records I identified a total of 9,757 articles on marine pollution published between 1970 and 2019. I downloaded the records with full article rmetadata and used *bibliometrix* package 3.0.2 (Aria and Cuccurullo 2017) in R 3.6.2 (R Core Team 2020) to transform the Scopus BibTeX file into a dataframe. I used *bibliometrix* package outputs from the functions *biblioAnalysis, authorProdOverTime,* and *citations* to determine the total number of articles published each year, the country where the research is based, and top authors assessed by number of articles published and total number of citations.

* 1. **In-depth Analysis**

I used *circlize* package 0.4.10 (Gu 2014) to visualise bibliographic coupling relationships between authors and *tmap* package 3.0 (Tennekes 2018) in order to map the spatial distribution of marine pollution publications based on the author’s address. To further assess the geography of marine pollution research I used network mapping with *igraph* package 1.2.5 (Csardi and Nepusz 2006) to visualize intra and international collaboration networks. I plotted this network using the Fruchterman-Reingold layout to reflect the structure of the networks while distributing connected vertices near each other without being drawn so close that they are obscured (Fruchterman & Reingold 1991). I then used the *igraph* preset layout in order to spread the structure of the network and visualise the individual vertices and connections. In order to assess the changes in topic areas over time I extracted 16,770 author keywords and calculated the frequency of each word. I used thematic mapping to identify patterns in keywords for the total dataset. Thematic mapping uses co-word analysis to measure centrality (the degree of interaction) and density (the internal cohesion) of keyword clusters (Cobo, et al. 2011), dividing them into four zones. Keywords in zone one (motor-themes) are long-lived and well-defined. Zone two suggests topics that may move to zone 1 in the future, and provide links between clusters. Zone three are keywords that have become marginalised in the literature. Zone four are niche keywords that are loosely connected to the common themes in the literature (Cabo et al 2011). I then split the dataset into early research (1970-2009) and recent research (2010-2019) and created a wordcloud for each using *wordcloud2* package 0.2.1 (Lang and Chien, 2018) to visualise changes through time. Supplementary material for this paper including R code and figures may be found at GitHub (<https://github.com/brieaspasia/mp-diagnostics>).

# Results

* 1. **Publications**

The main subject disciplines represented in the dataset are Environmental Science (9,757 articles), Earth and Planetary Sciences (4,294 articles), Agricultural and Biological Sciences (4,261 articles), Chemistry (975 articles), and Pharmacology, Toxicology and Pharmaceuticals (615 articles). The top journals are Marine Pollution Bulletin (3,179 articles), Science of the Total Environment (563 articles), Environmental Science and Technology (445 articles), Environmental Pollution (433 articles), and Chemosphere (385 articles).



Figure Annual scientific production of marine pollution research, data from Scopus search (see Methods for details)

Figure 1 shows the first published article to record the keyword ‘marine pollution’ was in 1970 but it wasn’t until 1985 that the number of publications per year passed ten. The number of publications per year remained marginal until 1995 marked the year that the number rose above 100. The annual percentage growth rate from 1970-2019 is 15% and much of that has been in the last ten years.

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Figure Influential papers on marine pollution research, publications per year, data from Scopus search (see Methods)

I have defined ‘influential papers’ as those with more than 100 citations each, shown in Figure 2 on their year of publication. All are about plastics; three about microplastics, two about plastic waste in general, and one about the impact of plastics on marine life. Four out of the six are reviews, and five out of the six were published within the last ten years.

* 1. **Authors**

There are 43,788 author appearances collated in the literature representing 26,790 unique authors. In Fig 3 we see that the graph of top producing authors largely follows the trends in annual production with authors increasing number of publications rather than being staggered throughout time. Many of the top producing authors began publishing around the year 2000 and have either been publishing steadily or increasing their publication rate since.

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Figure Top producing authors based on number of articles (N. Articles) and total citations (TC) per year

A table of the top 20 cited authors has little overlap with the top producing authors, demonstrating that the most influential authors are not publishing most frequently. Only four authors appear in both top cited and top producing; S. Tanabe, J. Wang, Z. Wang, and WX Wang. They are affiliated with institutions in Japan, China, and Hong Kong; and are largely researching micropastics and heavy metals.

I visualized relationships between the top 20 authors using a chord diagram (Gu 2014) to represent the bibliographic coupling network with authors as nodes and shared references as edges. This type of plot can aid in identifying research structure even in very recent articles that have not had time to be cited prolifically (Belter and Seidel 2013). Figure 4 indicates that the citation structure is quite equally spread with the top authors all referencing similar material.

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Figure Bibliographic coupling of the top 20 authors. Authors are nodes and shared references are edges.

* 1. **Geography**

The *tmap* (Tennekes 2018) analysis in Figure 5 shows the national affiliation of marine pollution researchers based on the percentage of articles from each country. More than 50% of the research is based in the top seven countries, the USA, China, the UK, Italy, Spain, Canada, and Australia. The research contributions came from researchers affiliated to institutions in 102 countries total. The research institutions are based predominantly in the northern hemisphere, with only Brazil and Australia representing the tropics and the southern hemisphere.

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Figure Global distribution of publication numbers by authors’ affiliations

**3.4 Intra and International Collaborations**

An analysis of networks between the top 75 institutions and 747 edges of collaboration between them reveals patterns of shared research within and between nations. Figure 6 shows that Chinese institutions (green cluster) collaborate primarily intra-nationally. Other Asian nations (pink cluster) collaborate internationally and dominated by institutions in Japan, Hong Kong, Korea, and India. Portugal (red cluster) collaborates intra-nationally with strong ties between three institutions. The UK (orange cluster) is loosely tied with continental Europe but collaborating primarily intra-nationally while other European nations (blue cluster) collaborate primarily internationally. Canadian universities (brown cluster) are clustered intra-nationally but also have ties with Arctic specific institutions internationally. The USA (purple cluster) collaborates intra-nationally and internationally with Brazil. Australian universities are spread between clusters based in the UK, USA, and Canada rather than collaborating intra-nationally. In Figure 7 the Fruchterman-Reingold layout allows us to the see the closeness of the clusters. Chinese institutions are quite tightly clustered. Clusters in continental Europe, the UK, Canada/Arctic, and Portugal have distinct groupings, but are not clustered as tightly. The institutions in the USA and throughout Asia are much more loosely clustered.

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Figure Collaborations links between institutions involved in marine pollution research

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Figure Intra and international collaboration clusters of marine pollution researcher institutions

**3.5 Research Topics**

The thematic map of author keywords in Figure 8 demonstrates the high density and centrality of the purple cluster represented by microplastics, marine debris, and Mediterranean Sea. The green cluster represented by bioaccumulation, metals, and biomarkers is placed midway in density and high in centrality. The red cluster represented by heavy metals, sediments, and oil spills is very dense, but not central to the literature as a whole. The blue cluster represented by mercury, cadmium, and copper as well as the orange cluster represented by fish, biomonitoring and the Baltic Sea display low density and centrality.

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Figure Thematic map of author keywords based on centrality (the degree of interaction) and density (the internal cohesion).

3.5.1 Early Research Topics (1970-2009)

Analysis of the frequency of early keywords (1970-2009) in Figure 9 reveals that the topic trends are related to heavy metals, sediments, and bioaccumulation; each of this within the top five frequent words. Other notable keywords in the top fifty most frequent include those related to metals (metals, trace metals, metal, mercury, lead, cadmium, copper), and other pollutants such as nutrients, pesticides, DDT, organochlorines, sewage, oil spills, and tributyltin (TBT, an anti-fouling agent). There is evidence of impact assessment with words such as bioaccumulation, monitoring, water quality, biomarkers, toxicity, risk assessment. Other keywords in the top fifty for early research include PAH (from emissions) and PCBs (from plastics, electronics, and paints). Within the top 50 early keywords, the only locations listed are the Baltic Sea, the Mediterranean Sea, Antarctica and the Arctic.

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Figure Wordcloud visualisation of early (1970-2009) research topics based on frequency of keywords

3.5.2 Recent Research Topics (2010-2019)

The subset of recent publications (2010-2019) also mentions heavy metals and sediments in the top five, however they are displaced from their top spot by marine debris, microplastics, and oil spills. Figure 10 keywords reveal many overlaps with the early research, although there was less mention of specific heavy metals. In addition, there were many new plastics related keywords including marine litter, microplastics, plastic pollution, plastics, and plastic debris. Rounding out the top fifty were bioremediation, climate change, and pharmaceuticals. Locations mentioned include Mediterranean Sea, Gulf of Mexico, the Arctic, and the Baltic Sea.

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Figure Wordcloud visualisation of recent (2010-2019) research topics based on frequency of keywords

# Discussion and limitations

This study aimed to use bibliometrics to answer two questions about marine pollution research. First, to reveal key players in the field and the networks between them, and second to determine how the topical focus has changed over time. Analysis of publication history and author production reveal that the research is growing, yet there remain questions about the influences of the authors in regards the evolution of the research and the issue as a whole. Geographic analysis reveals that the research is widespread but clustered, although we can still learn more about the structure of the research clusters.

Research topics analysed by author keywords are evolving and quantifying the changes would aid our understanding of the nature of this evolution.

* 1. **Authors and Publications**

The quantity of knowledge produced does not necessarily correspond to its influence. In figures two and three we can see that the authors producing the most research are not the same as the authors that are the most heavily cited. One issue is that *bibliometrix* may be merging authors with common names, misrepresenting the count of productive authors. In casual observation I’ve noted that the highest producing authors are largely writing about heavy metals and organic pollutants, which, as we’ve seen in figures 9, correlates to these topic areas prominence in the literature for a longer period of time. The most highly cited papers, however, are about plastics and debris. This may speak to new trends and recent growth in the research that is heavily focused on plastics. In order to more fully answer these questions we would need to analyse the focus areas of these authors using *rscopus* package to determine if and where there are overlaps between high producing and highly cited authors in relation to their areas of expertise.

For the sake of this analysis I measured influential papers by the number of citations, but one could argue that not all citations are equal (Wan and Fang 2014), and furthermore that there are other ways to measure influence. Further analysis using Altimetric scores could provide a means to assess whether research has led to policy changes, another means of measuring influence.

The bibliographic coupling analysis, see figure 4, reveals that main players overlap in their citations networks. This visualisation isn’t particularly helpful in determining the structure of the research and a different visualisation such as a dendrogram would potentially be able to reveal a history of the citation network. With a dendrogram we’d be able to identify influential papers and the successive research that these papers inspired.

* 1. **Geography and Collaborations**

Pollution does not respect national boundaries, yet research institutions do. Mapping is effective for visualising the location of the research institutions that employ researchers working on marine pollution. However, this does not necessarily match the location of their field work. For example, the map in Fig 5 shows no publications based in institutions throughout much of the tropics. In order to determine if the research site corresponds to the author’s national affiliation, we would need to use text mining to extract site locations of the studies more specifically. This additional analysis would find many research sites abroad from the institutional affiliation and reveal a more widespread coverage of marine pollution research. This is important, as many nations without influential academic institutions have the least policy surrounding pollution and are the most impacted by its negative effects (Yap 1992).

The geographic analysis produced in *bibliometrix* is not adjusted for research effort, meaning that nations with fewer research institutions have lower total publication output. Spatial maps also cause visual bias towards geographically large nations that are easier to notice. For example, Hong Kong is the 12th most producing nation, as shown in this work,but there is no representation of small island nations in the global spatial file.

The network analysis in figure 7 shows clusters of collaborations, with some countries mostly collaborating within (e.g. China, Portugal), and others relying on extensive international collaborations (e.g. Europe, Asia). Intra-national research clusters in the USA, China, and the UK, revealed in figure 7, may be due to the large number of institutions in these countries; as demonstrated in figure 5 where we see that they are the dominant players in marine pollution research. International collaboration is occurring in continental Europe, Asia, and across the Arctic regions in Northern Europe and Canada.

The collaboration analysis would be more meaningful if we had more information about the nature of these collaborations. We may hypothesise that collaboration occurs around shared coastlines. The appearance of keywords such as Baltic Sea and Mediterranean Sea in figures 10 and 11 may illuminate the nature of some collaboration in continental Europe. Other collaborations may be due to a focus on solving issues of concern in certain regions, for example the Chinese focus on heavy metals may be due to their growing population and increasing focus on metal contamination (Pan and Wang 2012).

Certain research institutions may be connected for specific purposes, for example figure 8 reveals that Canadian Universities have strong ties to Arctic specific institutions in northern Europe. The lack of prominent locational keywords in Asia or the Americas may be due to the nature of the research being more focused on the general nature of pollution rather than health of a specific ecosystem. These are only guesses until we quantify the linkages between keywords and collaboration clusters.

* 1. **Research Topics**

Author keyword frequency visualised in figures 9 and 10 reveals that topics dominating early research such as heavy metals and bioaccumulation are still present in recent research, although they’ve been surpassed by mention of plastics and marine debris. These findings demonstrate that our knowledge of marine pollution is evolving, and that we continue to expand the scope of the research. In figure 8, we see the structure of the keyword clusters. Zone 1, referred to as motor-themes, are long-lived and well-defined (Cobo et al 2011). Prominent keywords in this cluster include marine debris, microplastics, and Mediterranean Sea; topics that we know are central to current trends in the literature and the location of dominant nations involved in collaborative research. Zone 2 includes emerging themes and links between clusters, Zone 4 are niche topics, and Zone 3 have become marginalised in the literature (Cobo et al 2011). The duplicate appearance of terms related to metals or specific metal contaminants in these zones may speak to our evolving understanding of this type of contamination. In the green cluster, we see that the study of metals and bioaccumulation is a prominent theme cluster challenging plastics and debris in a central space in the literature, and we see that it is a connecting theme between the other clusters. The red cluster reveals that the study of metals in sediment has become marginalised, which is supported by figures 9 and 10. The low ranking of the blue cluster in figure 8 suggests that the study of individual heavy metal contaminants is niche and not well connected to the study of metals and ecotoxicology in general. The orange cluster represented by fish, biomonitoring and the Baltic Sea do not display density or centrality, which suggests that studies of biomonitoring in fish may have evolved to wider ecotoxicology issues in the green cluster.

In order to fully understand the evolution of the literature we would need to quantify the keywords. There are many duplicate records that skew the results, for example we could consolidate metal, heavy metal and trace metal as well as the plurals of those words. Depending on the questions we were asking we could include the individual names of each type of metal in that group. However, assigning groups to keywords could be subjective. For example; biomarkers, bioaccumulation, and biomonitoring all refer to ecotoxicology studies (Hamza-Chaffai 2014) but one would need an in-depth understanding of the nuances in the field to assess in which instances these studies could reliably be grouped together.

Quantifying the changes in keyword frequency would help us understand whether each topic area is growing or shrinking in terms of research production and citation influence. In figure 10 we see the impact of pharmaceuticals in the marine environment as one example of a recent addition to the literature. Pharmaceuticals are an emerging threat in aquatic systems that are not well monitored or included in environmental legislation due to our emerging understanding of their environmental impact (Zenker, et al. 2014). The emergence of new topics in the literature such as pharmaceuticals demonstrate our evolving understanding of the many connections between the ocean and life on earth.

It is clear from figures 8 and 10 that plastics have emerged as a current focus of the literature, yet even within the plastics research it is often limited to toxicology and environmental chemistry rather than impact to the ecosystem as a whole. (Pauna, et al. 2019). We may find that the growth in plastics research is overshadowing the prominence of earlier research topics, and further analysis would help to quantify the emerging and disappearing trends in topic areas.

# Implications and future direction

In this paper I have used a bibliometrics approach to reveal patterns in the global research of marine pollution including the key players, their collaboration networks, and the evolving topic areas within the field. The negative impacts of marine pollution are widely acknowledged by scientists, policy makers, and the general public (Bonanno and Orlando-Bonaca 2018) and effect public health as well as ecological, economic, and social systems (Galgani 2015). It is important to understand how this research has shifted and whether there are regions, habitats, and topics that remain marginal. The evolution and expansion of topic areas reflects the nature of pollution as a global issue that intersects with many layers of life of earth.

A positive influence of research occurs when scientists are able to communicate their findings with policy makers and the general public. Although scientists often advise on complex policy issues such as environmental pollution, there are challenges in bridging the science-policy gap (Spruit, et al. 2014). In this study I’ve made progress towards identifying the clusters in the geography and topic areas of marine pollution. Further study could illuminate gaps in the literature that could inform future research and direct resources, particularly towards marginalised regions that may be most impacted by marine pollution while having the least resources to manage it. Measuring links between research and corresponding policy could illuminate the influence of academic findings on certain topic areas. If current trends continue the literature on marine pollution will continue to grow as we explore more of the ocean and discover all of the ways that our lives interact with it.

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