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Does marine environmental research meet the challenges of marine pollution induced by the COVID-19 pandemic? Comparison analysis before and during the pandemic based on bibliometrics

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ABSTRACT

The outbreak of the COVID-19 pandemic has brought enormous challenges to the global marine environment. Various responses to the COVID-19 pandemic have led to increased marine pollution. Has the COVID-19 pandemic affected marine pollution research? This work comprehensively reviewed marine pollution publications in the Web of Science database before and during the COVID-19 pandemic. Results show that the COVID-19 outbreak has influenced the marine pollution research by: (i) increasing the number of publications; (ii) reshaping different countries' roles in marine pollution research; (iii) altering the hotspots of marine pollution research. The ranking of countries with high productivity in the marine pollution research field changed, and developed economies are the dominant players both before and after the outbreak of the COVID-19 pandemic in this field. Other high-productivity countries, with the exception of China, have higher international cooperation rates in marine pollution research than those before the pandemic. Microplastic pollution has been the biggest challenge of marine pollution and has been explored in greater depth during the COVID-19 pandemic. Furthermore, the mining results of marine pollution publications show the mitigation of plastic pollution in the marine environment remains the main content requires future research. Finally, this paper puts forward corresponding suggestions for the reference of researchers and practitioners to improve the global ability to respond to the challenges posed by the pandemic to the marine environment.

1. Introduction

The ocean is not only an important part of the ecological environment, but also one of the crucial natural resources for human survival. Marine pollution has long been a global concern, particularly pollution of the marine environment caused by plastic waste (Dobradaran et al., 2018). Plastics absorb toxic substances as they travel through the environment (Luo et al., 2022; Suman et al., 2021), prompting the synthetic polymers in the ocean identified as hazardous waste (Lim, 2021; Zaman and Newman, 2021). Only 9 % of global plastic production is identified as recycled (Parker, 2018), 12 % is incinerated, and the remaining 79 % ends up in the environment (Geyer et al., 2017). The remaining pollution causes at least 14 million tons of plastic entering the ocean each year (IUCN, 2021). According to a UNEP report, plastic is the

largest, most harmful, and most persistent component of marine litter, accounting for at least 85 % of total marine litter. And plastic pollution in oceans and other bodies of water continues to rise dramatically, with estimates indicating that it will more than double by 2030 (Nations, 2021; UNEP, 2021). As a result, the marine ecosystem is under increasing threat, and the issue of marine environmental pollution must be addressed.

However, hazardous plastic wastes for medical use during the COVID-19 shock are currently aggravating marine environmental pollution. There has been an unprecedented increase in the production, consumption, and disposal of single-use plastics (SUPs) and personal protective equipment (PPE) (Arduoso et al., 2021; De-la-Torre et al., 2022b). A large number of plastic debris enters the global ocean and have been destroying marine ecosystems (Chowdhury et al., 2021),

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posing a new threat to the marine environment. Recent research provides evidence that the overuse of PPE during the COVID-19 pandemic is exacerbating plastic pollution in the marine environment (De-la-Torre and Aragaw, 2021). Numerous media and publications have reported an increase in the use of PPE such as masks, gloves, face shields, and SUP items on beaches, coastlines, and rivers (Akhbarizadeh et al., 2021; CNN, 2020; De-la-Torre et al., 2021; Euronews, 2020; Hajiouni et al., 2022; Okuku et al., 2021). Research reveals that 193 countries/regions around the world generated more than 8 million tons of plastic waste since the outbreak of the COVID-19 shock, additionally causing more than 25,000 tons of plastic waste have entered the global ocean. The majority of the plastic comes from hospital waste generated during the pandemic (Peng et al., 2021).

Despite the fact that many countries have proposed management measures for marine pollution (Ariana et al., 2021; Clayton et al., 2021; Pettipas et al., 2016; Xanthos and Walker, 2017), the outbreak of COVID-19 has hampered marine pollution research. There is an urgent need to understand its impacts on marine environment associated with the COVID-19. To address this, numerous studies on the COVID-19 and marine pollution have been conducted in response to the current crisis. For example, some studies investigated the marine environment challenges caused by increased waste during the COVID-19 (Benson et al., 2021; Chowdhury et al., 2021; De-la-Torre and Aragaw, 2021), some discussed how to solve the marine plastic pollution crisis caused by COVID-19 (Ammendolia and Walker, 2022; Azevedo-Santos et al., 2021); some research evaluated chemical and physical changes in masks and gloves recovered from the marine environment (De-la-Torre et al., 2022a; Pizarro-Ortega et al., 2022).

Furthermore, many scholars have reviewed the relevant literature on marine pollution in the existing research. Wu et al., for example, reviewed marine microplastic research to identify research hotspots and research gaps (Wu et al., 2021). Cesarano et al. systematically reviewed the scientific literature on marine beach debris and explored its temporal development and geographic distribution (Cesarano et al., 2021). Kasavan et al. used bibliometrics to investigate the research trends and research hotspots of plastic pollution in aquatic ecosystems (Kasavan et al., 2021). However, to the best of our knowledge, few studies have systematically reviewed COVID-19 and marine pollution research to investigate the impact of the COVID-19 pandemic on marine pollution research. To fill this gap, this study synthesized the existing body of knowledge in this field based on published articles and research findings, with the goal of investigating whether the COVID-19 pandemic has changed marine pollution research by comparing the research status before and during the COVID-19 pandemic. This paper specifically seeks to answer the following three questions: (1) Has the COVID-19 pandemic affected the output trend of publications on marine pollution? (2) Has the performance of marine pollution research in various regions changed since the COVID-19 pandemic? (3) What are the differences in marine pollution research hotspots before and during the COVID-19 pandemic?

2. Material and methods

2.1. Research design

The relevant literature on marine pollution was systematically reviewed in the Web of Science (WOS) Core Collection database, focusing on the publication output pattern, the global research landscape and the research hotspots. In addition, five datasets were created and compared to better explore the changes in marine pollution research prior to and during the COVID-19 pandemic, marine pollution research publications during (a) January 1, 2010–December 31, 2021; (b) January 1, 2010–December 31, 2019; (c) January 1, 2015–December 31, 2019; (d) January 1, 2020–December 31, 2021; and (e) January 1, 2018–December 31, 2019.

To ensure the article's timeliness and relevance, we chose January 1,

2020 as the starting point for COVID-19. As a result, the marine pollution research status during the COVID-19 period was analyzed using the publications dataset from January 1, 2020 to December 31, 2021.

In the global research landscape comparative analysis, datasets cover the period between January 1, 2010 and December 31, 2019 and January 1, 2015 to December 31, 2019 were used as long-term and medium-term publication identification indicators prior to COVID-19, respectively. Furthermore, to align with the rapid changes in research content, we compared and analyzed the research hotspots from 2018 to 2019 with those from the COVID-19 pandemic concerning the research theme of marine pollution. Fig. 1 depicts the study's specific research framework.

2.2. Methodology

2.2.1. Bibliometrics and visual analysis

Bibliometric analysis is a method of evaluating research output and developing a thorough understanding of current scientific output. Bibliometric analysis has become an indispensable tool for measuring scientific progress for its advantage of integrating qualitative and quantitative analysis (van Raan, 2005). As a result, we used bibliometric analysis in this study to objectively capture and summarize the marine pollution research.

Visual analysis demonstrates results by mapping the knowledge domain. Visual analysis reveals the dynamic of relevant literature and translating the complex knowledge into a visual knowledge map. There are numerous visualization software tools to assist with bibliometric analysis. CiteSpace is one of the most widely applied visualization programs that combines data mining algorithms, bibliometrics and information visualization (Kou et al., 2021). Given the fact that keywords are typically the core and essence of an article, serving as a high-level summary and refinement of the article's topic. The keywords clustering view visually classifies the research fields from various perspectives, providing easier access to researchers among complex data information. As a result, we used the CiteSpace software's keyword cluster diagram to track the research hotspots and relevant changes throughout the research process.

2.2.2. Calculation of international cooperation rate

The international cooperation rate is a useful indicator of demonstrating changes in cross-national research cooperation. Prior studies have adopted this indicator to assess the level of cooperation in various countries (Choi et al., 2021; Lee and Haupt, 2021). This paper used the international cooperation rate during three periods, i.e., 2020–2021, 2015–2019, and 2010–2019, to investigate whether countries increased or decreased their international cooperation in the marine pollution before and during COVID-19 pandemic.

The international cooperation rate of a country is calculated as the percentage of international cooperation publications to total publications. The calculation formula is as follows:

$$R_{tc} = \frac{I_{tc}}{T_{tc}} \quad (1)$$

where t represents time periods, and c refers to a specific country. I_{tc} denotes the number of international cooperation publications by country c in time period t . T_{tc} is the total number of publications published by country c during time period t . R_{tc} is the international cooperation rate of country c in the time period t .

To calculate a country's international cooperation rate of a country, the country's number of international cooperation publications is needed. Specifically, the number of international collaborations is the total number of collaborations a country has with all other countries/regions in the data sets. It is calculated by subtracting a country's total number of publications with domestic only affiliations from its total number of publications. The formula is as follows:

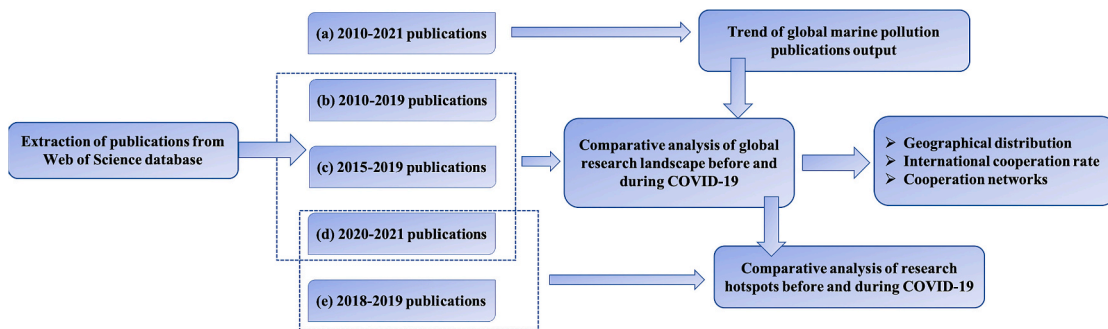


Fig. 1. Workflow of the system analysis.

$$I_{tc} = T_{tc} - B_{tc} \tag{2}$$

B_{tc} is the total number of publications with domestic only affiliations in the country c in the time period t . It is calculated by excluding all other countries in WOS results windows.

2.3. Data collection

The data in this article is derived from Clarivate Analytics' WOS Core Collection of databases. The WOS database is a high-quality digital database that covers a wide range of publications from various fields. The WOS database is a comprehensive citation database has the advantages of good transparency and orderliness (Archambault et al., 2006; Mongeon and Paul-Hus, 2016). Furthermore, the WOS Core Collection has always maintained strict journal selection standards and evaluation processes, and its journal evaluation standards are recognized by the international academic community. The WOS database is recognized as one of the world's most authoritative scientific and technical literature indexing tools. Currently, a large number of publications have used WOS as a data source for bibliometric analysis, yielding reliable results (Gao et al., 2020; Wang and Han, 2021; Zhang and Liang, 2020). As a result, data from the WOS Core Collection database were used to conduct the corresponding research. The search field used in this study is TS, which contains title, abstract, author keywords and keywords plus. The searched keywords include "marine pollution" and "ocean pollution". The time spans are: 2010–2021, 2010–2019,

2015–2019, 2018–2019, and 2020–2021. Select articles with document types "Article" and "Review". Data retrieval time is June 23, 2022. All data are exported with full records for analysis of results.

3. Results and analysis

3.1. Trend of global marine pollution publications output

Fig. 2 depicts the annual number and annual growth of publications in marine pollution research. The number of publications on marine pollution has increased from 2010 to 2021. Fig. 2 also shows an interesting trend that the rapid increase in the number of publications started in 2019. The number of publications in 2020 reached 2486, with an average increase of 573 publications annually and a 30.0 % growth rate. Since then, the number of publications were increasing, and has reached 3014 by 2021. This changing trend may have been influenced by the outbreak of COVID-19 in late 2019. After the outbreak of COVID-19, the global attention to the epidemic has increased, and the marine environment has been affected to a certain extent. The corresponding marine pollution has attracted increased attention of many scholars, and the number of publications on marine pollution research has increased rapidly. The growth rate for the 2020–2021 period declined shortly, where the key reason accounts for this is many countries/regions around the world have implemented measures such as blockade to prevent the spread of the epidemic. These measures inevitably have a negative impact on scientific research output, resulting in a slowdown in the

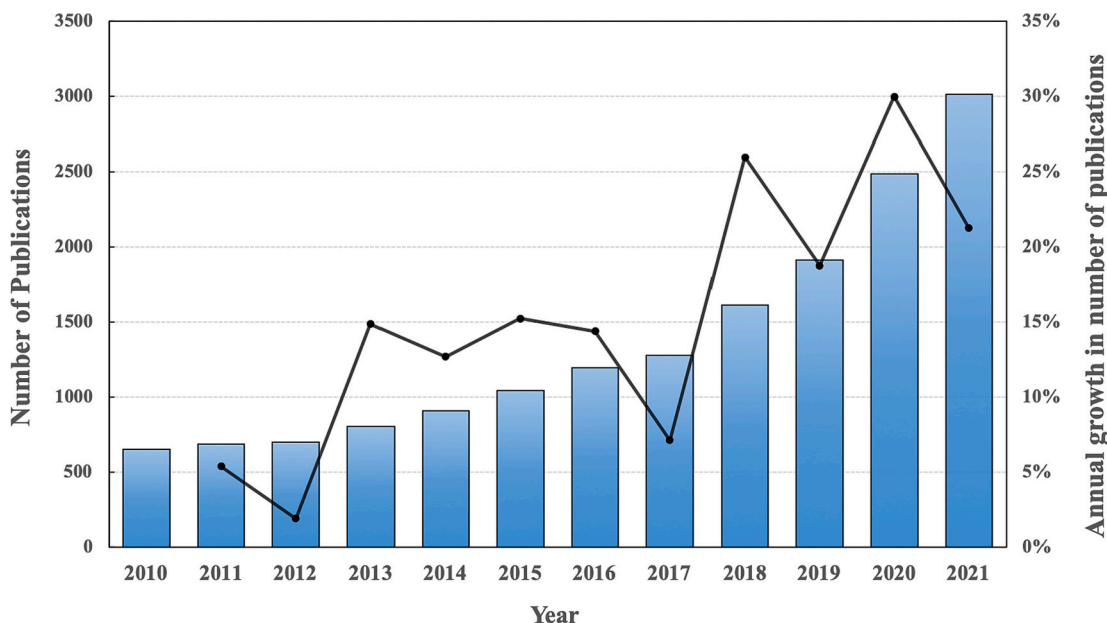


Fig. 2. Annual number and annual growth of publications in marine pollution research (2010–2021).

number of publications. On the other hand, because there is a time lag between receiving publications and including them, the number of publications in 2021 will be affected as well. Overall, the number of publications on marine pollution has increased during the COVID-19 era.

3.2. Comparative analysis of global research landscape before and during COVID-19

3.2.1. Comparative analysis of geographical distribution before and during COVID-19

Fig. 3 and Table 1 show the geographical distribution of the marine pollution research and the annual numbers of publications of the high-productivity countries. These data cover outputs marine pollution from over 150 high-productivity countries during 2010–2019, 2015–2019, and 2020–2021. Shades of map color (blue) in Fig. 3 differentiate the number of publications, specifically, darker colors indicate more publications.

The figure shows that, both before and during the pandemic, the majority of countries are located in Asia, Europe, and the Americas, with Oceania also playing an important role. Moreover, the United States contributed the most publications during 2010–2019, with an average of 188.0 publications per year. Meanwhile, China had slightly fewer publications than the United States (183.2 publications). China has the most publications in the remaining two time periods, with 633.0 publications per year between 2020 and 2021, which is 1.715 times that of the United States. China is the most relevant country in marine pollution research, followed by the United States.

The top 10 most productive countries in the field of marine pollution research secure their places after the epidemic, while the total outputs have increased significantly during the COVID-19 era. Specifically, China (633.0 publications), the United States (369.0 publications), Italy (228.0 publications), the United Kingdom (200.5 publications), Spain (170.5 publications), India (165.5 publications), Australia (158.0 publications), Germany (154.5 publications), France (136.0 publications), and Brazil (131.5 publications) are the top 10 countries with the highest annual number of publications during 2020–2021. However, the inner ranking of the number of publications in the ten countries altered during

the COVID-19 pandemic. The number of publications in China, Italy, and India increased in the proportion of the world, and the annual outputs of the three countries has more than tripled compared to before the epidemic. Relevant publications in the remaining countries have all declined. China and India are the only two developing countries among the high-productivity countries. Developed countries have taken the lead in marine pollution research, and there is a productivity gap between developing and developed countries.

3.2.2. Comparative analysis of international cooperation rate before and during COVID-19

Then we explore how the top 10 contributors of impact of COVID-19 on marine pollution research (China, the United States, Italy, the United Kingdom, Spain, Australia, France, Germany, India and Brazil). The international cooperation rates of the top 10 countries with high productivity in the marine pollution research before and during the pandemic are analyzed.

Fig. 4 depicts the trends of the international cooperation rates for 10 countries during 2020–2021, 2015–2019 and 2010–2019. Except for China, the international cooperation rates of marine pollution studies during the COVID-19 in other countries are higher than before the pandemic. China's international cooperation rate (28.9 %) is lower than it was five (31.5 %) and ten (31.4 %) years prior to COVID-19. This could be attributed to China's timely regulation in response to the outbreak of COVID-19. As China's scientific research is largely unaffected, a large number of papers on marine pollution are published. The total publications in China have increased, while the rate of international cooperation has decreased. To sum up, COVID-19 has not hindered the cooperation among high countries, and even promoted relevant scientific cooperation.

Second, the United Kingdom has always had the highest rate of international cooperation both before and after the outbreak of the COVID-19 pandemic, and it is as high as 82.0 % during 2020–2021, followed by France (82.9 %). The rate of increase in international cooperation in Australia, India and France is higher than that of other countries. It is worth noting that China and India demonstrate a lower international cooperation rate than other countries. Although India's international cooperation rate has increased since the COVID-19

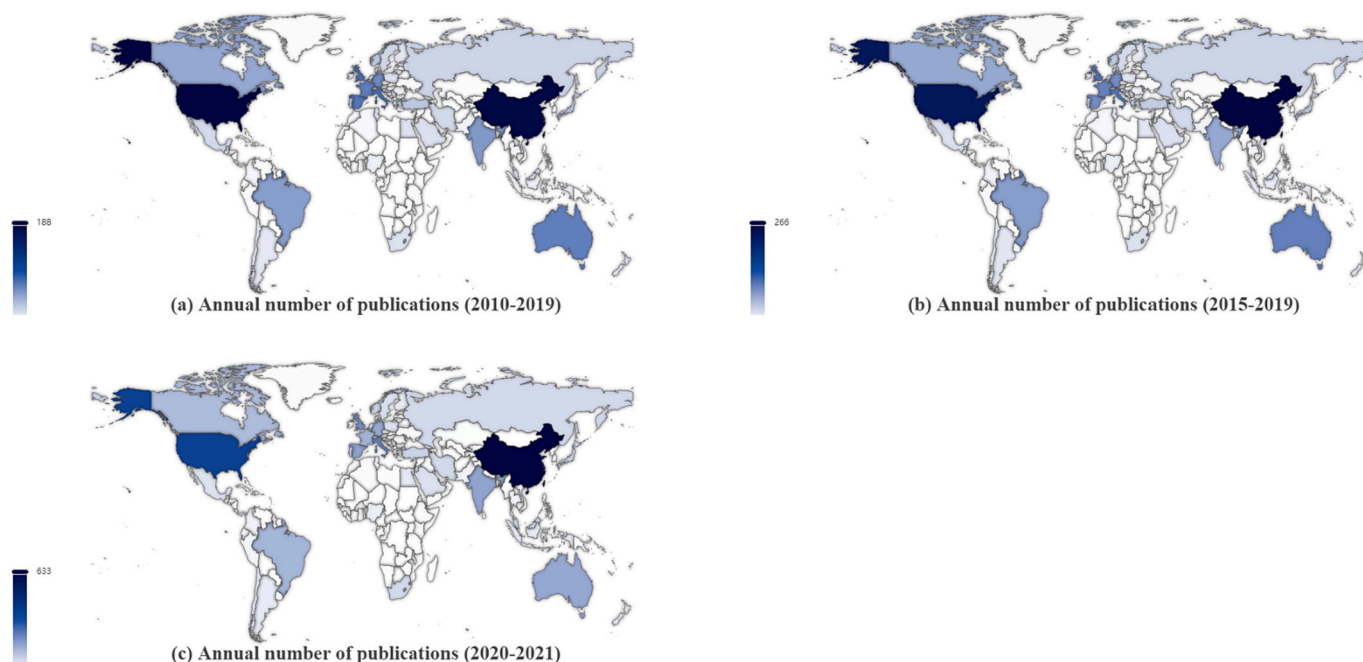


Fig. 3. Geographical distribution of marine pollution publications, (a) Annual number of publications (2010–2019); (b) Annual number of publications (2010–2015); (c) Annual number of publications (2020–2021).

Table 1

Top 10 productive countries of the articles on marine pollution during 2020–2021, 2015–2019 and 2010–2019.

2020–2021		2015–2019		2010–2019	
Countries	Publications/year	Countries	Publications/year	Countries	Publications/year
China	633.0	China	266.0	United States	188.0
United States	369.0	United States	232.8	China	183.2
Italy	228.0	United Kingdom	105.0	Italy	77.7
United Kingdom	200.5	Italy	103.8	United Kingdom	76.7
Spain	170.5	Australia	96.2	Spain	74.7
India	165.5	France	94.2	France	70.0
Australia	158.0	Germany	86.2	Australia	68.0
Germany	154.5	Spain	86.2	Germany	63.6
France	136.0	Brazil	75.2	India	55.3
Brazil	131.5	India	66.2	Brazil	52.2

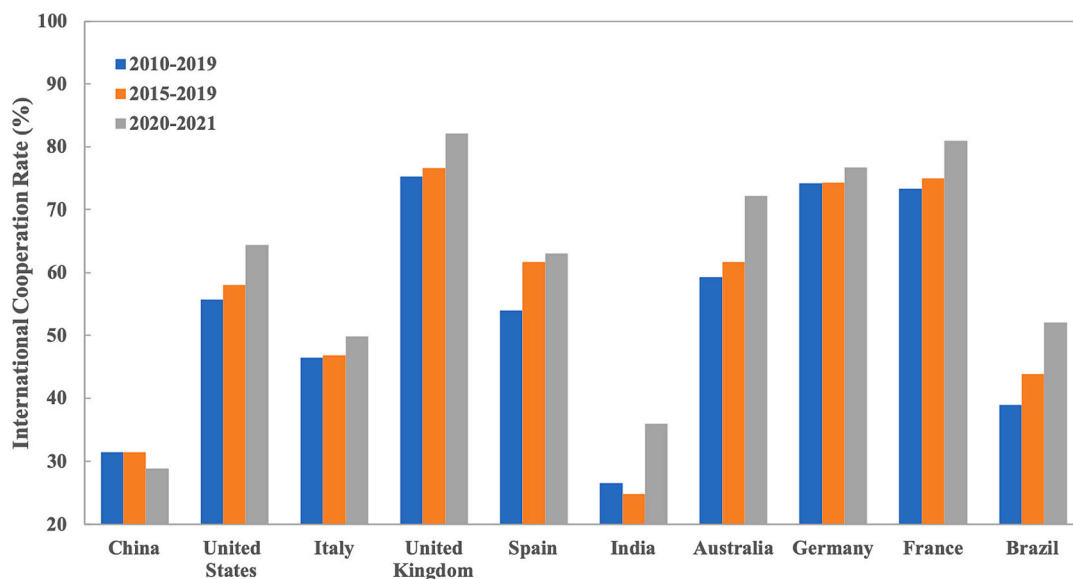


Fig. 4. The international cooperation rates during 2010–2019, 2015–2019 and 2020–2021.

pandemic, it remains low. In general, developed countries have a higher international cooperation rate than developing countries.

3.2.3. Comparative analysis of cooperation networks before and during COVID-19

Fig. 5 shows the cooperation map of marine pollution research for the 10 high-productivity countries before and during COVID-19 during 2010–2019, 2015–2019, and 2020–2021. Different colors represent results in various nations on the map, and the width of the arc-circle contact area represents the annual number of publications for each country. The line connecting the two points on the circle represents the relationship between the two countries, and the width of the connecting line indicates the degree of cooperation. The thicker the line, the higher the degree of cooperation between the two countries. Thinner lines, on the other hand, represent a lower level of cooperation between countries.

More countries have started to tighten international cooperation from 2020 to 2021, and the number of annual cooperation between countries has increased. Prior to the epidemic, China and the United States had the closest cooperation. The annually collaborative publications during 2010–19 and 2015–19 are 23.4 and 34.4, respectively. Following that are the links: between United Kingdom and the United States (15.1 and 20.6, respectively) and between Australia and the United States (13.2 publications, 18.6 publications). During the epidemic, the average annual collaborative publication between China and the United States reached 55.5. The United Kingdom and the United States are in second place (35.5 publications), followed by Germany and

the United States (30.0 publications). Furthermore, China and the United States collaborate far more on marine pollution research than other countries in all periods. They have always been each other's closest collaborators and the primary contributors to research in this field.

Some countries' main collaborators have shifted. Prior to the pandemic, the United States was the largest partner country of the United Kingdom, India, Australia, Germany, France, and Brazil. During the pandemic, India's largest partner country shifted from the United States to China, Australia to the United Kingdom, and Brazil to Portugal. Furthermore, while India has increased its cooperation with China, the cooperation in marine pollution is still primarily concentrated among developed countries. To summarize, during the COVID-19 pandemic, some changes occurred in the regional cooperation model, and various countries actively pursued international cooperation.

3.3. Comparative analysis of research hotspots before and during COVID-19

In this section, a comparative analysis of the keyword clustering results of high-productivity countries in 2018–2019 and 2020–2021 is performed to determine whether COVID-19 has changed the main content of marine pollution research. Each '#' in Fig. 6 represents 1 cluster.

The cluster tags for 2018–2019 are #0 microplastic pollution, #1 ocean acidification, #2 regional transport, #3 plastic ingestion, #4 coral reef, #5 heavy metal, #6 oil spill, #7 nutrient enrichment, and #8 persistent organic pollutant. Cluster tags for 2020–2021 are #0

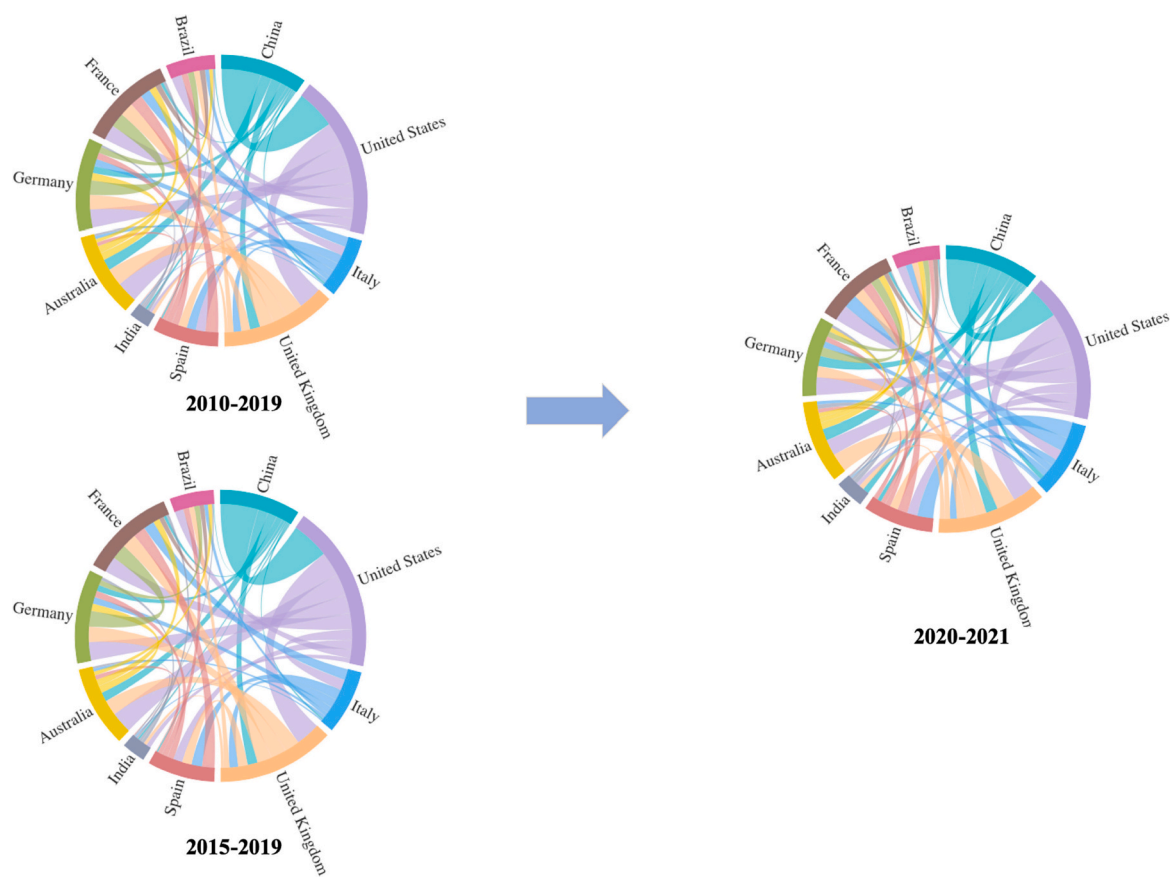


Fig. 5. The cooperation graph of 10 highly productive countries during 2010–2019, 2015–2019 and 2020–2021.

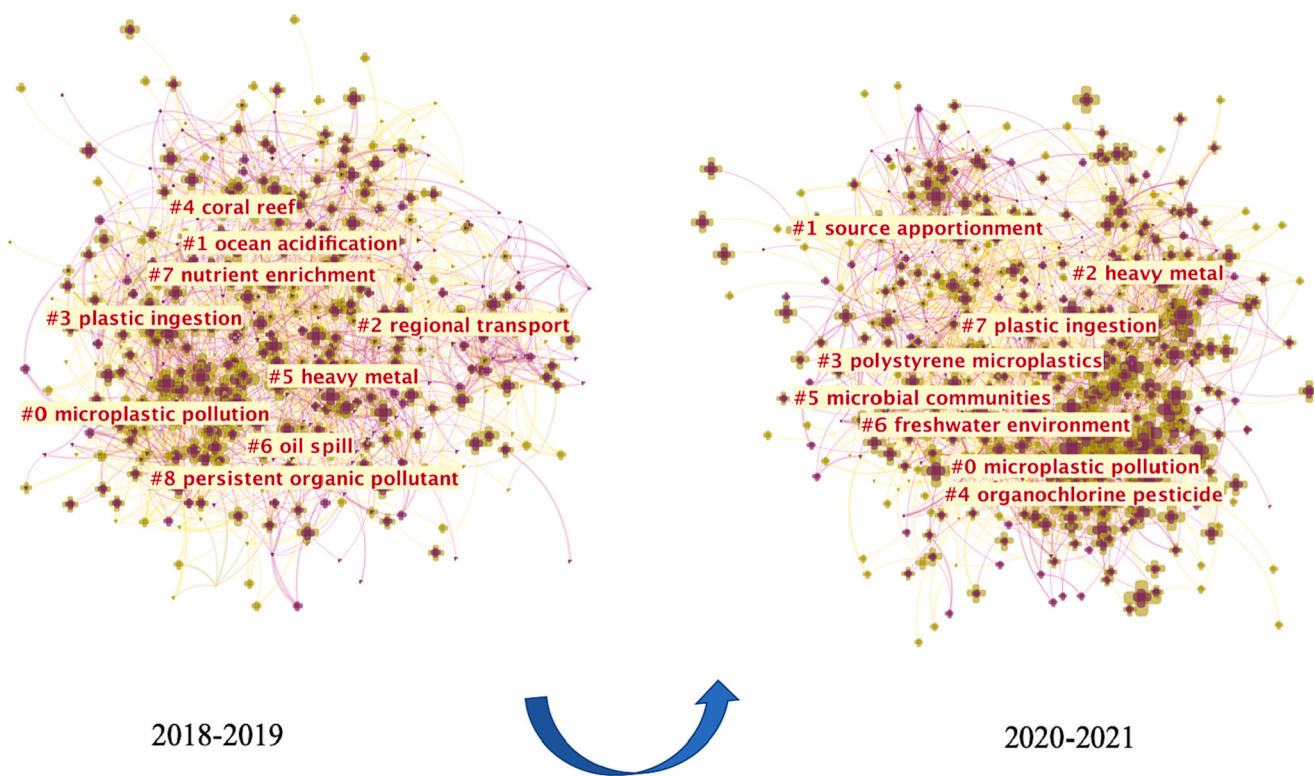


Fig. 6. Keyword clustering network graph during 2018–2019 (left) and 2020–2021 (right).

microplastic pollution, #1 source apportionment, #2 heavy metal, #3 polystyrene microplastics, #4 organochlorine pesticide, #5 microbial communities, #6 freshwater environment, and #7 plastic ingestion. These cluster labels represent the main research hotspots in the marine pollution field before and during the COVID-19 pandemic. The largest cluster is about microplastic pollution in the marine pollution research when the clustering outputs of the two time periods are compared. Microplastic pollution has always been the most serious problem in marine pollution, and the problem of microplastic pollution in the marine environment has worsened during the pandemic, attracting widespread attention from scholars. Second, heavy metal and plastic ingestion are the key research topic before and during the epidemic, but the clustering order has shifted. Taken together, it can be concluded that COVID-19 has posed an impact on the main content of marine research. Although some research themes overlapped before and during the pandemic, the level of emphasis on these research themes has shifted. In order to have a deeper understanding of the research content of marine pollution, next, we further analyze the keyword clustering results during 2020–2021.

(a) marine pollution & microplastic pollution

Microplastic pollution remains the focus of marine pollution researchers both before and during the epidemic. Clusters #0 microplastic pollution, #3 polystyrene microplastics, and #7 plastic ingestion are related to plastic pollution in the marine environment. Plastic pollution is a serious issue in coastal and marine ecosystems around the world (Barboza and Gimenez, 2015). Microplastics, in particular, have received considerable attention as an emerging environmental pollutant. According to research, the majority of marine plastic wastes are microplastics (Alimba and Faggio, 2019; Martin et al., 2018). Microplastics play the role of the carriers for heavy metals, organics, and other harmful substances, which combine to form complex pollutants that endanger marine biota (Avio et al., 2015).

Following the outbreak of COVID 19, microplastic pollution has become increasingly serious. The widespread use of PPE during the COVID-19 pandemic has resulted in increased levels of microplastic pollution as they are routinely discarded into oceans, rivers, streets, and other areas of the environment. According to estimates by Chowdhury, et al., approximately 150,000 to 390,000 tons of plastic debris may end up in the global ocean within a year (Chowdhury et al., 2021). The overuse of plastic products to prevent the spread of infection adds to the plastic load in the environment (Shams et al., 2021; Vaid et al., 2021; Wang et al., 2022a). Furthermore, the widespread use and improper disposal of PPE may change the primary source of marine litter pollution. PPE could become a significant source of microplastics in the ocean and contribute to a surge of plastic pollution in the near future (Ma et al., 2021; Morgana et al., 2021; Saliu et al., 2021; Shen et al., 2021; Wang et al., 2021c).

As a result, scholars all over the world have conducted extensive research on microplastic pollution in the marine environment in order to address the significant challenges posed by microplastic pollution in the marine environment. Wang et al., 2021c, for example, reviewed the characteristics of microplastics in freshwater environments and discussed their sources and potential impacts (Wang et al., 2021d). Tang et al. investigated the composition and adsorption capacity of microplastics in aquatic environments and made some recommendations to promote the long-term use of microplastics (Tang et al., 2021). Kumar et al. reviewed current research on the occurrence and distribution of microplastic pollution in river ecosystems (Kumar et al., 2021). On the other hand, as people become more aware of the threat posed by microplastics, they pay more attention to it, leading to an increase in microplastics research.

(b) marine pollution & source apportionment

In the field of marine pollution, source apportionment is considered a mainstream research front. Exploration of the source allocation of various pollutants in the ocean is critical for understanding the status of various pollutants in the marine environment and developing control policies. Stringent prevention and control measures were implemented during the COVID-19 period, resulting in changes in pollutant emissions. As a result, many relevant studies investigated the source apportionment of related pollutants (Cecchi, 2021). Wang et al. used field surveys and microplastic morphological characteristics to infer the main sources of microplastics in each sea area (Wang et al., 2021b). Cui, et al. explored the distribution characteristics and potential sources of emerging contaminants such as pharmaceuticals and personal care products (Cui et al., 2019). Some studies extensively discussed is the source apportionment of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in sediments from many sea areas (Han et al., 2019; Shi et al., 2022).

(c) marine pollution & heavy metal

Heavy metals are the third hotspot in marine pollution research that academics are focusing on. Marine heavy metal pollution is a significant threat to the marine environment, which is attributed to certain heavy metals entering the ocean via various channels. Because of their toxicity, persistence, non-degradability, and bioaccumulation, heavy metals pose serious threats to human health, organisms, and natural ecosystems (DeForest et al., 2007). Heavy metals enter marine environments through a variety of natural and anthropogenic sources. Heavy metals that enter seawater can interact with suspended particles via adsorption, complexation, and precipitation before being transferred to sediments and enriched (Liu et al., 2019). Therefore, heavy metal pollution in sediments is an important environmental quality indicator, indicating pollution status and guiding ecological risk assessment (Wang et al., 2018). Scholars have also evaluated and assessed heavy metal pollution in various sea areas based on this (Jeong et al., 2021; Leung et al., 2021; Liu et al., 2021).

(d) marine pollution & organochlorine pesticide (OCP)

Research on marine pollution and OCPs has also attracted increased attention of scholars. OCPs, a type of legacy persistent organic pollutant, have received a lot of attention due to their widespread distribution, resistance to degradation, and toxic effects (Han and Currell, 2017). The contamination range of OCPs has reached the deepest part of the global ocean and has shown severe toxic effects in various biota in and around coastal areas (Mennillo et al., 2020; Merhaby et al., 2020). Tsygankov et al. studied the bioaccumulation of OCPs in organisms in the marine environment (Tsygankov et al., 2019). Basu et al. investigated bioaccumulation patterns by measuring OCPs in surface water, zooplankton, and some representative fish and shrimp (Basu et al., 2021). Some studies revealed the concentration, spatial distribution, potential sources, and ecological risks of OCPs in the ocean (Khozanah et al., 2022; Wang et al., 2022c). Because of their hydrophobicity, OCPs are more easily absorbed by microplastics than other hydrophilic pollutants, which is a significant aspect of OCPs marine pollution.

(e) marine pollution & microbial communities

Microbial communities are frequently explored in marine sediments, where microorganism biodegradation is critical to the restoration of the marine environment. Numerous studies have been conducted to investigate microbial communities. Many studies have concluded that microbial communities in marine sediment play an important role in the degradation of petroleum pollutants (Catania et al., 2018; Wang et al., 2022b), some researchers have assessed the ability of microbial communities to degrade hydrocarbons (Gouveia et al., 2018). Plastic waste biodegradation is an important solution to many environmental issues. Microbial communities exposed to plastic can produce active catalytic

enzymes and form dense biofilms on plastic surfaces. These enzymes can degrade synthetic polymers, allowing for the biodegradation of plastics (Ganesh Kumar et al., 2020). The diversity, composition, and biodegradation potential of microbial communities, as well as the impact of various factors on microbial communities, have all been thoroughly investigated (Coutinho et al., 2019; Lee et al., 2020; Seeley et al., 2020; Wang et al., 2021a). In addition, studies have found that measures such as the global population lockdown imposed during COVID-19 have had an indirect impact on terrestrial and marine fauna. During this period, some microbial communities decreased due to factors such as reduced atmospheric nitrogen loads, lower wastewater fluxes and reduced fishing activity (Sala et al., 2022).

(f) marine pollution & freshwater environment

Growing studies on marine pollution involve the freshwater environment. Microplastic pollution of freshwater is well known to be a serious problem and they are ubiquitous in freshwater systems and can be discharged into coastal environments via rivers, posing a threat to the global marine ecosystem (Xu et al., 2021b). As a result, research on this subject has concentrated on plastic pollution in freshwater environments. Azevedo-Santos et al., for example, provided an overview of plastic pollution in freshwater ecosystems worldwide (Azevedo-Santos et al., 2021). Strady et al. assessed baselines of microplastic concentrations in selected marine and freshwater environments (Strady et al., 2021). Xu et al. reviewed microplastic pollution in urban freshwater watersheds in China and identified key knowledge and policy gaps that need to be filled to improve understanding of the environmental risks of microplastics (Xu et al., 2021a). Ding, et al. reviewed the source, fate and toxicity of microplastics in freshwater ecosystems (Ding et al., 2021). The COVID-19 pandemic and its economic and social impacts have brought several benefits and risks to biodiversity. Research by Cooke, et al. elucidated the interplay between social disruption caused by the COVID-19 pandemic and pre-existing threats to freshwater ecosystems (Cooke et al., 2021).

4. Conclusions and implications

This study systematically reviewed marine pollution publications in the WOS database, and conducted an in-depth analysis of publication output, global research landscape and research hotspots before and during the COVID-19 pandemic. The primary goal of this study is to explore whether the COVID-19 pandemic affects marine pollution research. The main conclusions of this paper are as follows:

- (i) The COVID-19 pandemic has caused significant impacts on the trend of marine pollution research publication output. Total number of publications on marine pollution research is constantly growing. Moreover, the number of publications has risen sharply during the COVID-19 era.
- (ii) The outbreak of COVID-19 pandemic has altered the global research landscape in the field of marine pollution. The number of publications of marine pollution research in various countries increased significantly during the epidemic, and the ranking of high-productivity countries changed. Other high-productivity countries, with the exception of China, have higher international cooperation rates than those before the pandemic.

The regional cooperation model of marine pollution research was discovered to alter. COVID-19 has not hampered international cooperation, by contrast, there has been increased international cooperation during the epidemic. Furthermore, there is still a research capability gap between developing and developed countries in marine pollution research both before and after the COVID-19's outbreak. The countries with the greatest influence in marine pollution research are primarily developed nations. In general, the rate of international cooperation in

developed countries is higher than in developing countries. Cooperation across developed countries plays a significant role in the total outputs.

- (iii) The COVID-19 pandemic has affected marine pollution research hotspots in many aspects. The research focus and degree of attention are found to alter after mining the keyword clustering results. Microplastic pollution is the primary focus of marine pollution research prior to and during the pandemic. As the problem of microplastic pollution in the marine environment worsens, academics conducted that increased and deepened research on various aspects of microplastic pollution during the pandemic.

We make recommendations on the problems existing in the research status of COVID-19 and marine pollution. Continued efforts are needed to make the deeper understanding of the marine pollution research associated with the COVID-19 more accessible. Second, cross-national cooperation should be strengthened as the current research indicates that developed countries are the dominant force in global research. Developing countries may benefit more from international cooperation in the marine environment research. To maximize the scientific outputs in the marine pollution-related research, developing countries should build more international cooperation and strengthen cooperation with developed countries in the future. The close bond will establish a stable global scientific research cooperation force. Third, microplastic pollution remains the biggest challenge in today's marine environment, and the negative impact of COVID-19 on marine plastic pollution has not been eliminated. Therefore, the microplastic pollution research needs continuous focus in the long term.

This paper provides a macro-system analysis of the global COVID-19 pandemic and marine pollution research, which aids in determining the relationship between COVID-19 and marine pollution in future research. However, there are some limitations to this study that needs further exploration in the future. First, a portion of the research in the article focuses on countries high-productivity countries, with no detailed analysis of international cooperation with other countries/regions. Second, search queries may be insufficient to completely capture all publications related to the marine pollution. Selecting articles from a single database may result in the omission of some publications, which may have an impact on the final results of our analysis. Further research might extend the research scope and investigate the developing research status concerning marine pollution in more regions with the updated database.

CRediT authorship contribution statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Supervision, Writing – review & editing. **Min Zhang:** Methodology, Software, Data curation, Investigation, Writing – original draft, Writing – review & editing. **Rongrong Li:** Conceptualization, Methodology, Data curation, Investigation, Writing – original draft, Writing – review & editing. **Xue-ting Jiang:** Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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