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Bibliometric analysis and current research in the field of microplastics (MPs) in mangrove

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Abstract
The marine MPs' hazard to ecological safety and environmental health has been confirmed. However, mangrove forests are a special land-sea interface, and their MP pollution characteristics and ecological risks have been studied more broadly. It is necessary to sort out the current status of mangrove MP research among the existing homogeneous and limited literatures, to summarize the representative views and point out the direction for future research trends. In this paper, the bibliometrics method was adopted for text mining and knowledge mapping analysis. The development process, knowledge structure, hotspots, and potential trends were discussed to provide researchers with a macro perspective. A total of 71 articles were selected from 93 articles focused on MPs in mangroves, downloaded from Science Citation Index and China Knowledge Network. The number of studies on MPs in mangroves has increased over time in which China had the most research literature (41%), followed by Brazil (7%), Indonesia (6%), and Colombia (6%). From 2019 onwards, the intensity and density of research in Chinese literature increased rapidly. The MPs' abundance in mangrove sediments was majorly attributed to their degree of self-aggregation and deposition rate. The mechanism underlying the correlation between mangrove sediment structure and volatilized characteristics of MPs remains to be further studied. Further studies should focus on the carbon sink process, ecological risk, environmental behavior, barrier mechanism, and combined pollution.

Keywords Mangrove · Current status · Microplastics · Bibliometric analysis · Future trends

1 Introduction

Plastic is widely used in agriculture, industry, and daily life, and can be transported over long distances by wind, rivers, currents, and other external factors. It can break down physically or chemically into smaller particles (< 5 mm diameter) forming microplastics (MPs)

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(Cole et al., 2011; Cózar et al., 2014). The MPs have become an emerging pollutant due to their chemical stability and long-term persistence in the environment (Arthur et al., 2009; Aytan et al., 2016; Hidalgo-Ruz et al., 2012; Thompson et al., 2004). The MPs are non-degradable, chemically toxic, and biohazardous thus widely detected in various environmental media worldwide and are accumulating year by year (Galloway & Lewis, 2016; Ng & Obbard, 2006; Peeken et al., 2018).

Mangroves are salt-tolerant plant communities that grow in tropical and subtropical intertidal zones. Globally, mangroves are distributed in 124 different countries, of which nearly 38% of the area is concentrated in Asia (Sarker et al., 2019). However, only mainly 10 countries (8% of the total number of mangrove countries) have investigated MPs pollution in mangroves (Yona & Sari, 2019). The abundance of MPs in mangrove sediments from Dongzhai Harbor, Hainan province, was identified to range from 1.39 to 13.65 mg/kg in mass concentration and 30.71–839.51 n/kg in quantitative abundance (Zaki et al., 2021). The abundance of MPs in fish of mangrove habitats in Beibu Gulf, Guangxi province, was the highest, up to 5.32–6.21 items/individual. The dominant polymers were opaque white fibrous-shaped polyethylene and polyethylene terephthalate of 100–500 µm size (Zaki et al., 2021). The abundance in mangrove sediments from Zhanjiang, Guangdong province, ranged from 108.00 to 486.00 n/kg with an average of 333 n/kg and particle size range of 200–500 µm. Fisheries production and river transport are the main sources of MPs in mangroves from Zhanjiang (Hamid et al., 2020). The research trend on MPs pollution in mangroves is in the infant stage. However, systematic studies on MP pollution in mangroves are still relatively limited.

High levels of MPs were inspected in sediment and surface water, in which the uptake of MPs by habitat organisms in mangroves is currently being studied more broadly (Hamid et al., 2020; Zaki et al., 2021). On the other hand, mangroves have also been considered an effective medium for MP retention (Law & Thompson, 2014; Mohamed Nor & Obbard, 2014). The high density of respiratory and strut roots in mangrove species is considered a major factor in the retention of MPs in mangroves wetland. The strut and stilt roots of the mangrove species *Rhizobium* descend from the trunk and branches to form a complex barrier that has proven to be very effective in mitigating strong waves due to extreme events while representing their efficient interception of plastic litter (Dahdouh-Guebas & Koedam, 2006).

The systemic research on mangrove MPs is relatively limited and scattered. Thus, the objective of this study was to describe the percentage of publications and collaborations between existing countries using the bibliometrics approach. The frequency of keyword occurrences in the searched literature was used to analyze temporal characteristics of the number of publications, hot spots, and research trends. The correlation between MPs and the physicochemical properties of mangrove sediments was emphasized. Characterization of MPs contamination by inhabiting organisms and deterrence mechanisms in mangroves were highlighted to provide a summary of the existing literature and a reference for future research directions.

2 Materials and methods

Academic papers are the main manifestation of scientific research results, such as their publication date and the quantity, while research hotspots are one of the important indicators of the capacity of scientific output and the activity of scientific research.

Bibliometric analysis is a method to visualize the duration cycle, citation, and collaboration relationships based on literature databases. Based on the results of the aforementioned literature analysis, representative academic papers, important academic ideas, and research hotspots can be summarized in a more targeted manner.

2.1 Data collection and sources

The data were obtained from the full-text journal database of the China Knowledge Network (CNKI) and the English-language database of the Science Citation Index (WOS). A subject search was conducted using the keywords "microplastic + mangrove" for the period 2006-01-01 to 2021-12-31. Each article contained the title, author, abstract, and keywords that were selected, exported, and then organized into tables. The terms (such as MPs, plastic debris, plastics pellets, mangrove, wetland, sediment, and water) were also used to broaden the search scope.

The scientific studies were downloaded from the Web of Science Core Collection (WoSCC) and CNKI. Search session Queries: TS = (microplastic) AND TS = (mangrove) OR TS = (microplastics) OR TS = (plastics debris) OR TS = (plastics pellets) OR TS = (mangrove) OR TS = (wetland) OR TS = (sediment) OR TS = (water); Publication date: "2006-01-01" to "2021-12-31"; Document types: "review and experimental articles." The search results were exported with a "Plain Text file," and the record content was chosen "Full Record and Cited References" and stored in download_*.txt format. The WoSCC is the most commonly used database for scientometric analysis and contains most of the information on relevant articles. However, the variable quality of data collected in the study may affect the credibility of the knowledge graph as the studies not available in WoSCC were omitted and it may lead to bias (Garcés-Ordóñez et al., 2020). However, the visual-based literature analysis laid the foundation for researchers to understand the hotspots and potential trends of MPs in mangroves.

2.2 Bibliometric analysis methods

The VOSviewer software was used for bibliometric analysis in this study to identify productive and co-cited journals. Target studies were retrieved from WoSCC and CNKI, and analyzed with VOSviewer based on the full counting method, which means each co-citation link or co-occurrence could have the same weight. In productive journal analysis, the minimum number of documents per journal was set at index 5, and in co-cited journals analysis, the minimum number of citations per source was set at index 20. Annual outputs were managed using Microsoft Office Excel to show research trends in this area. The journal impact factor (IF) and Journal Citation Reports (JCR) were also obtained from the WOS.

While HistCite was used for mapping scientific knowledge through the construction and visualization of relationships in 'network data' to demonstrate the structure, evolution, collaboration, and other relationships in the knowledge domain. It can not only count the number of publications and frequency of citations of literature, but also map the development history and relationships between the literature in a certain field, and quickly pinpoint the scientific papers with significant influence.

3 Results and discussion

The search and collation of key insights were completed in February 2022, and 71 articles were screened for analysis, out of a total of 93 articles published in Chinese and English literature. The top 18 representative academic papers were selected based on bibliometric research and summarized by sieving and systematically analyzing the specific research content of relevant academic papers. The systematic analysis was based on factors such as citation rate, author popularity, and journal influence. The hotspots and important ideas of mangrove MP research were finally reorganized and summarized.

3.1 Distribution of literature in different countries and collaborative relationships

China has the most research literature in the field of mangrove MPs with 41% as of 31 articles by December 2021 (Fig. 1). In the second tier are Brazil with 7%, Indonesia with 6%, and Colombia with 6%. The third tier is Malaysia, Vietnam, and India with mangrove distribution. The smallest proportion of publications is from European countries (such as Spain, Netherlands, and France) as these countries are located at latitudes where mangroves are not distributed. Italy, Japan, Germany, Denmark, and Vietnam all have scientific cooperation with China. Japan and Italy have the most cooperation with China, followed by Germany and Denmark. In terms of the diversity of collaborations, Saudi Arabia has

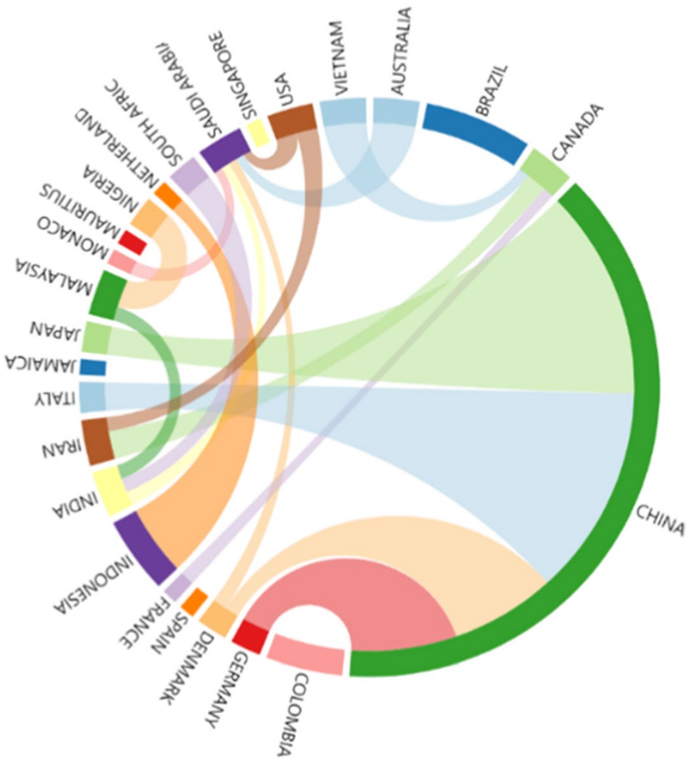

Fig. 1 Distribution of publications and cooperation on MPs in the mangrove

the most collaborations with Australia, the USA, Denmark, India, and Morocco, respectively, while Vietnam has collaborations with Canada, Indonesia with the Netherlands, and Malaysia with India. China is in the top echelon of mangrove MPs-related research, in terms of both the number of literature and collaborative networks. Overall, the research on mangrove MP worldwide has indicated a multifaceted collaboration between countries, and mangrove MP research is no longer limited to the countries where mangroves are distributed.

3.2 Temporal variation in the number of papers and research processes

Foreign literature was the first to start research on MPs in mangroves, and before 2014, the number of Chinese literatures was almost zero (Fig. 2). There were relatively few studies on mangrove MPs in both Chinese and English literature till 2018. After 2019, studies on mangrove MPs grew rapidly. In 2020, Chinese literature reached 15 articles, surpassing English literature, whereas in 2021, there are 17 studies published in Chinese and 15 in English.

The temporal change of the research process showed that English literature had a clear research direction since 2010, while Chinese literature only started in 2017 (Fig. 2). From 2010 to 2014, the English literature focused on the broader environmental issues, such as marine debris and beach litter, and did not focus on the field of MPs in mangroves, while the research in China during this period was still blank. In 2017, research in the Chinese literature began to focus on offshore areas and compound pollution. From 2015 to 2018, research in the English literature focused on fish larvae, feeding, biodegradation, habitat, the Mediterranean Sea, and polystyrene, with the longest duration of research on the absorption effect. From 2018 to 2019, studies in the Chinese literature focused on sediment, Shenzhen and Hong Kong mangroves, sorption, partition coefficients, and antibiotics. Starting in 2019, studies in the Chinese literature shifted to focus on environmental media such as mangrove sediment, surface water bodies, and correlated with coastal MPs fugacity characteristics. Meanwhile, the English literature focuses on mangrove ecosystems, plastic debris in 2019 and shifts to focus on the coastal zone, beach, bay debris and their correlation in 2020.

In terms of journal distribution, the largest number of publications was "Science of the Total Environment," followed by the "Marine Pollution Bulletin," "Environmental

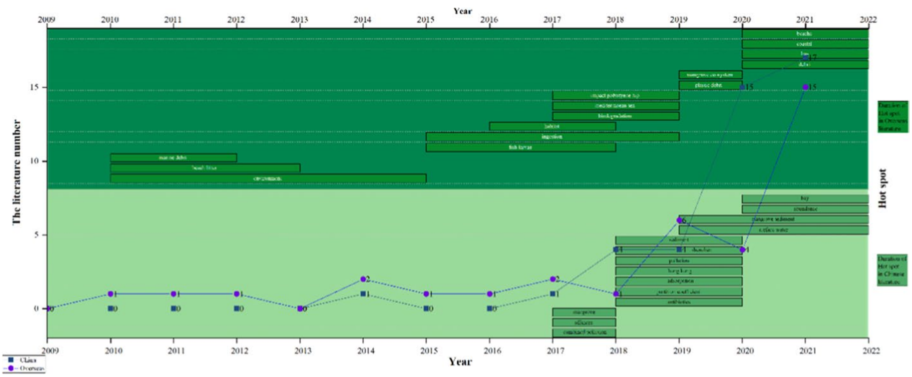

Fig. 2 Temporal variation in the number of papers and research processes

Pollution," and "Environmental Research" with the number of 17, 12, 11, and 3, respectively. Science of Total Environment receives a wide range of disciplines and publishes a large number of papers each year. This may be the reason for its number-one ranking. In terms of publishing house distribution characteristics, Elsevier is far ahead with 50 articles, which is twice the number of articles published by all other publishing houses (Fig. 3), while MDPI is in second place, and open-source journals are probably the main reason for more articles. Tied for third place are Springer Nature, Wiley, and Frontiers Media SA. In summary, various publishers and their affiliated journals are paying more and more attention to the emerging research field of mangrove MPs. Overall, studies in English literature are earlier than those in Chinese literature, with a time difference of about 7 years and a longer duration in the English literature. The Chinese literature only started to report on mangrove MPs in 2017, and the research directions are more concentrated and homogeneous. However, from 2019 onwards, the intensity and density of research in the Chinese literature increased rapidly. Currently, mangrove MPs-related studies in Chinese and foreign languages are entering a period of rapid development.

Fig. 3 Distribution characteristics of journals (**a**) and publishers (**b**) through co-citation analyses (WOS)

3.3 Frequency of keywords in the literature and the trends

The darker warm colors represent higher keyword frequencies while darker cool colors represent lower keyword frequencies from 2009 to 2021 (Fig. 4). The overall word frequency search ratings for targeted studies directly using mangroves and MPs as keywords were low, and specific research directions were scattered until 2019. For instance, some scholars studied the characteristics of heavy metal pollution in mangroves; others studied broader issues, such as marine litter, the marine environment, and plastic pollution.

Although a very small number of keywords mention MPs or small plastic debris, the frequency of the keywords is low and is only more evident in 2014 and 2017. The frequency of MPs keywords rapidly becomes greater, and more targeted keywords (such as mangrove ecosystems, MPs pollution, sediment, and plastic pollution) begin to increase in popularity in 2019. With MPs as a keyword in 2021, the frequency has reached more than 25 times, and the frequency of mangroves is also above 10 times. Overall, the research related to mangrove MPs is becoming more and more targeted. Research trends focused on MPs pollution in mangrove ecosystems, sediment environments, organisms, estuarine mangroves, offshore transport, and deterrent processes.

3.4 Bibliometric characteristics of representative literature

In terms of temporal characteristics, in 2010, the paper "Evaluation of solid residues removed from a mangrove swamp in the Sao Vicente Estuary, SP, Brazil" published in MARINE POLLUTION BULLETIN by Cordeiro CAMM was the first representative academic paper (Table 1). This article focused on waste in mangrove swamps. However, it was still a solid waste concept at that time. The largest output of high-impact literature was in 2019. In terms of journal characteristics, academic papers on mangrove MPs were mainly published in JCR Q1, such as ENVIRONMENTAL POLLUTION, SCIENCE OF THE TOTAL ENVIRONMENT, ENVIRONMENTAL SCIENCE & TECHNOLOGY, and other such TOP level journals of environmental SCI, with a maximum impact factor (over 11). In addition, several articles have been published in

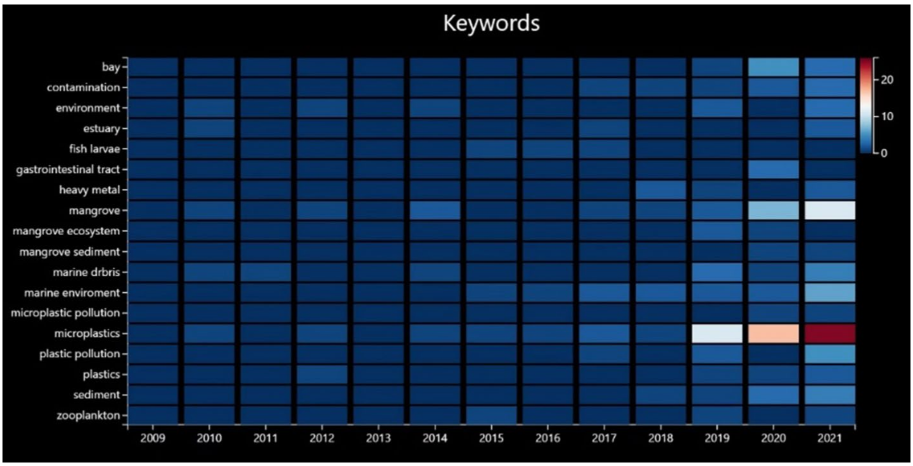

Fig. 4 Keyword frequency and the research trend

Table 1 List of the top 18 most influential academic papers

No	Paper title	Year	Periodicals	First author	Number of local citations	Number of global citations
1	Microplastics in Singapore's coastal mangrove ecosystems	2014	MARINE POLLUTION BULLETIN	Nor NHM	33	372
2	Mangrove forests as traps for marine litter	2019	ENVIRONMENTAL POLLUTION	Martin C	27	86
3	Characterization, source, and retention of microplastic in sandy beaches and mangrove wetlands of Qinzhou Bay, China	2018	MARINE POLLUTION BULLETIN	Li J	21	76
4	Abundance and characteristics of microplastics in the mangrove sediment of the semi-enclosed Maowei Sea of the South China Sea: New implications for location, rhizosphere, and sediment compositions	2019	ENVIRONMENTAL POLLUTION	Li RL	17	66
5	Evaluation of solid residues removed from mangrove swamps in the Sao Vicente Estuary, SP, Brazil	2010	MARINE POLLUTION BULLETIN	Cordeiro CAMM	12	47
6	Small microplastic particles (S-MPPs) in sediments of the mangrove ecosystem on the northern coast of the Persian Gulf	2019	MARINE POLLUTION BULLETIN	Naji A,	10	39
7	Marine debris: A proximate threat to marine sustainability in Bootless Bay, Papua New Guinea	2012	MARINE POLLUTION BULLETIN	Smith SDA	8	65
8	Plastics buried in the inter-tidal plain of a tropical estuarine ecosystem	2011	JOURNAL OF COASTAL RESEARCH	Costa MF	7	53
9	Inhabiting the technosphere: The encroachment of anthropogenic marine litter in Neotropical mangrove forests and its use as habitat by macrobenthic biota	2019	MARINE POLLUTION BULLETIN	Riascos JM	6	14
10	Growth kinetics and biodeterioration of polypropylene microplastics by *Bacillus* sp. And *Rhodococcus* sp. isolated from mangrove sediment	2018	MARINE POLLUTION BULLETIN	Auta HS	4	113
11	Changes in the composition of ichthyoplankton assemblage and plastic debris in mangrove creeks relative to moon phases	2016	JOURNAL OF FISH BIOLOGY	Lima ARA	4	37

Table 1 (continued)

No	Paper title	Year	Periodicals	First author	Number of local citations	Number of global citations
12	Feeding behavior is the main driver for microparticle intake in mangrove crabs	2020	LIMNOLOGY AND OCEANOGRAPHY LETTERS	Not C	4	13
13	Screening of Bacillus strains isolated from mangrove ecosystems in Peninsular Malaysia for microplastic degradation	2017	ENVIRONMENTAL POLLUTION	Auta HS	3	91
14	Characterization of microplastics in the surface waters of Kingston Harbour	2019	SCIENCE OF THE TOTAL ENVIRONMENT	Rose D	3	39
15	Seasonal distribution and interactions between plankton and microplastics in a tropical estuary	2015	ESTUARINE COASTAL AND SHELF SCIENCE	Lima ARA	2	80
16	New Insights into the Microplastic Enrichment in the Blue Carbon Ecosystem: Evidence from Seagrass Meadows and Mangrove Forests in Coastal South China Sea	2021	ENVIRONMENTAL SCIENCE & TECHNOLOGY	Huang YZ	1	8
17	Plastic debris retention and exportation by a mangrove forest patch	2014	MARINE POLLUTION BULLETIN	Do Sul JAI	0	84
18	Spatial distribution and seasonality of ichthyoplankton and anthropogenic debris in a river delta in the Caribbean Sea	2017	JOURNAL OF FISH BIOLOGY	Correa-Herrera T	0	19

LIMNOLOGY AND OCEANOGRAPHY LETTERS, ESTUARINE COASTAL AND SHELF SCIENCE. The representative literature with a high number of submissions and acceptances is MARINE POLLUTION BULLETIN.

In terms of authorship characteristics, there are still mainly foreign-named authors, with only three Chinese authors. The local citation score (LCS) indicates the frequency of citations in the local database and the number of peer-referenced articles. The higher the LCS value of a paper, the more attention it has received from researchers in the field, and the more important literature in the field can be quickly located. In terms of local citations (LCS), Nor NHM's "MPs in Singapore's coastal mangrove ecosystems" published in 2014 has the highest number of citations at index 33. This is followed by Martin C.

Global citation score (GCS) indicates the number of times the article has been cited by all literature in the global database, and a high GCS value indicates that the literature is of high interest to researchers. In terms of global citation counts (GCS), Nor NHM's 'MPs in Singapore's coastal mangrove ecosystems' published in 2014 had the highest number of citations at 372. The lowest was Correa-Herrera's article "Spatial distribution and seasonality of ichthyoplankton and anthropogenic debris in a river delta in the Caribbean Sea," with only 19 citations. In general, there is a significant positive correlation between the number of local citations and the number of global citations. However, Smith SDA's "Marine debris: A proximate threat to marine sustainability in Bootless Bay, Papua New Guinea," published in 2012, has 8 local citations, but 65 global citations. The impact of the article, which was published in 2018 by Auta HS in the MARINE POLLUTION BULLETIN, is ranked 10th, with only 4 local citations, but 113 global citations. Overall, influential academic papers have been published mainly in recent years.

3.5 Correlation between the physicochemical properties of mangrove sediments and MPs

3.5.1 Correlation between MPs abundance and mangrove sediment pH

The pH is the negative of the common logarithm of hydrogen ion concentration (activity) as a conventional chemical parameter, i.e., $-\log [H^+]$. The acidity and alkalinity of mangrove sediments affect the solubility of various compounds, the ratio of exchangeable ions, and the microbial activity in the sediment. Studies have shown that lower pH is associated with sediment organic matter content (Jayachandran et al., 2018). The pH of mangrove sediments is influenced by the type of organic and inorganic matter in the environment, as well as the sediment ion content and exchange ratio (Sudjana et al., 2017). The pH values of mangrove sediment samples have been reported as 8.89, 7.8, 6.29–8.45, 7.64, and <7 in different studies in the literature (Gao et al., 2019; Mafi-Gholami et al., 2015; Saravanakumar et al., 2008). In mangrove sediments in the northern Persian Gulf with a pH of 6.86, the abundance of MPs was higher than where the average pH was about 10, and the results showed that pH was negatively correlated with the abundance of MPs particles (Maghsodian et al., 2021). However, no significant correlation was found between pH and MPs particle abundance when the mean pH of the sampling sites was 7.54 at high tide and 7.49 at low tide (Naji et al., 2017). Then, more extensive studies are still needed to analyze the relationship between mangrove sediment pH and its MPs content.

3.5.2 Correlation between MPs abundance and mangrove sediment texture

Sediment texture is an important influence on the distribution of MPs in sediments. Due to its porosity and permeability, the coarse structural organization of the sediment may contain more MPs particles (Maghsodian et al., 2022). Size-wise, fine-grained sediments can hold large amounts of MPs. Texturally, clay sediments can hold more MPs (Zhou et al., 2020). However, the available reports on the systematic study of the correlation between MPs abundance and mangrove sediment texture are relatively limited.

The MPs particles integrate with other organic debris into the aggregated material before accumulating in the sediment (Rillig, 2018). In several studies on MPs pollution, there is a significant relationship between sediment particle characteristics and MPs. Numerous studies have indicated very high MPs concentrations on various beaches and tidal sediments offshore, and near-shore (Xu et al., 2018). The presence of MPs in sediments is likely to be related to the fragmentation of plastic debris in mangroves (Mohamed Nor & Obbard, 2014). It has been reported that large MPs particles are more common in areas of coarser sandy sediments (Cordova et al., 2021). In most of the literature, a significant correlation between the abundance of MPs particles and sediment texture was also observed (Govender et al., 2020). However, some other studies reported the opposite, with MPs abundance being independent of sediment texture and particle size (Maghsodian et al., 2021). Almost all reports attribute the abundance and distribution of MPs in mangrove sediments to their source, degree of self-aggregation, or deposition rate (Cheung et al., 2018; Waller et al., 2017).

3.6 Risk of MPs in mangrove habitats

The organisms consume at least one quantity of MPs during the different growth and developmental stages of their lives (Mallik et al., 2021). Some of these particles are removed from the organism through excretion so that in the long term, MPs do not harm living organisms. However, MPs can be transferred to different organs within an organism and some can remain in the body for long periods, adversely affecting its growth and development (Auta et al., 2017). The MPs in the environment can be transported into organisms through direct ingestion or indirectly through contaminated trophic levels (Markic et al., 2018). Carnivorous organisms can introduce MPs particles into their bodies indirectly by preying on other species. In contrast, omnivorous organisms have more MPs in different parts of their bodies because they feed widely (Garcés-Ordóñez et al., 2020). The presence of plastics of different sizes in aquatic ecosystems can have irreversible effects on aquatic organisms and ultimately on human health (Maghsodian et al., 2021). Many studies have reported the presence of plastic components in the tissues of different organs of fish, and their contamination characteristics suggest a wide range of sources of MPs, which in turn are transferred through interwoven and complex food webs.

MPs may be part of the ephemeral habitat of mangrove organisms (Riascos et al., 2019), and high plastic litter cover may clog burrowing holes and reduce the available foraging area for surface sediment feeders, increasing foraging time for intertidal benthic organisms. It has been shown that the size of MPs in mangrove wetland habitats is largely dependent on trophic feeding habits and biological behavior (Deng et al., 2020). Mangrove-inhabiting organisms play an important role in maintaining overall ecosystem health, and until MPs received attention, a few studies focused on the effects of anthropogenic stressors on them

(Not et al., 2020). Crabs, for example, have been shown to consume less food and thus reduce their energy balance due to MPs ingestion (Watts et al., 2015). Furthermore, the potential transfer of MPs from the stomach to the hepatopancreas in mangrove crabs in the tropics has been suggested in experimental studies (Brennecke et al., 2015). At least one type of MPs was identified in all organs of the body (stomach and gills) of crabs, indicating the level of pollution in their habitat, i.e., mangrove areas (Not et al., 2020). The presence of mangrove MPs as a potential threat to habitat crabs, both through their digestive and respiratory systems, was also confirmed in another study, where MPs were detected in all collected specimens. Current research also confirmed the vast differences in MPs abundance and type between sites and biological species, where the differences between species appear to be due to their specific feeding habits, with species that are less selective in their feeding ingesting more particles.

In other reports, five species of mollusks were collected from mangrove wetlands, and the results showed that various microfibers, films, and particles were detected in the body. Studies have also found that MPs may be transferred to higher trophic levels through the food chain. A total of 15 MPs were identified and isolated from different parts of the body (tissues and abdominal cavity) of 14 species of elasmobranchs (Maghsodian et al., 2021). Another investigation concluded that the abundance of MPs was positively correlated with the length and weight of the fish. Benthic organisms have more MPs than planktonic organisms. Studies have shown that more organisms in mangrove sediments with high MPs contamination are contaminated with MPs (Maghsodian et al., 2021). Overall, the high-frequency detection or high concentration of MPs in mangrove organisms is because of their widespread endowment in the marine environment. Tracing its origin may be from the mismanagement of plastic waste from sewage discharge, coastal tourism, and especially fish farming (Garcés-Ordóñez et al., 2020).

3.7 The retarding mechanism of mangroves to MPs and the source–sink issues have become future research hotspots

There is an imminent risk of marine ecosystems arising from severe MP pollution caused by anthropogenic activities in coastal areas. Mangroves accumulate carbonaceous organic matter and are known as ‘sedimentation enhancers’ (Valiela & Cole, 2002). Due to their high fertility, the fragmentation and deposition mechanisms of MPs in mangrove wetlands differ significantly from other marine environments (Jacotot et al., 2018). The unique structure of the land-sea interface in mangrove wetlands is responsible for increased MPs pollution (Govender et al., 2020). As shown in Fig. 5, mangroves are generally located where they are protected from waves and minimal currents mean that more MPs can accumulate in the sediment (Kamali & Hashim, 2011). Sediments in mangroves come from different sources, either sediment from external sources or re-suspended indigenous sources. In other words, sediment formation in mangroves is enriched in different ways, for example, from terrestrial or marine sources, or by re-suspension.

The MPs distribution in mangroves is influenced by different forest species and tides (Zhang et al., 2021). Unlike marine sediments, mangrove sediments are rich in plant organic matter and clay particles, which makes it difficult to separate MPs particles (Duan et al., 2021). Some studies have shown that over 93% of MPs debris is found in beaches and sediments off mangroves (Fok et al., 2017). The MPs particles in the sediment increase the permeability of the sediment and reduce the diffusion of sediment temperature. The MPs can accumulate in sediments over time. Approximately 3.3% of the sediment weight

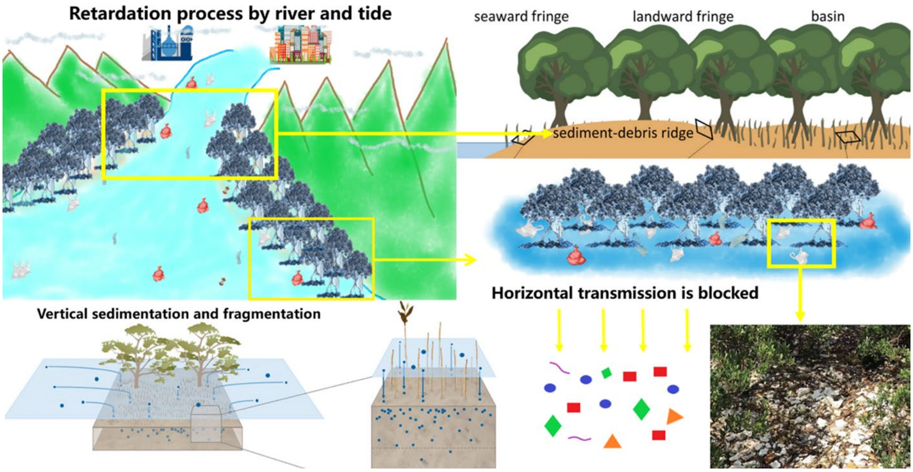

Fig. 5 Model of the retarding mechanism of mangrove to MPs (Martin et al., 2020; van Bijsterveldt et al., 2021)

is MPs. Studies have found that a high abundance of MPs in mangrove and salt marsh habitats are potentially important pools of MPs (Weinstein et al., 2016). Other studies also have shown that mangrove vegetation can sustain MPs. The MPs are not only confined to the mangrove soil surface and can potentially sink to greater depths (Govender et al., 2020; Weinstein et al., 2016).

While mangroves are highly vulnerable to debris due to their coastal habitat. The hydrodynamics of mangrove wetlands are the main determinant of MPs content (Boelens et al., 2018). As reported by Ibrayev, the water flow velocity at the entrance is much lower than at the estuary and this phenomenon (i.e., low flow velocity) may accelerate the vertical deposition of low-density plastics or MPs from the water to the sediment (Ibrayev, 2001). Regarding the study of mangrove forests' deterrent mechanism for MPs (Fig. 5), it has been reported that most mangrove plants have respiratory and strut roots, and their coiled basal surfaces are effective in retaining incoming sand from land and maintaining water and soil. At the same time, the well-developed root systems of mangroves also retain plastic waste from land and sea, which may break up into MPs, making mangroves potentially more polluted than other environments. Mangroves are considered a reservoir for a variety of pollutants (Zuo et al., 2020). The dense vegetation of wetlands can effectively retain MPs floating on the water surface (Boelens et al., 2018). Moreover, the spatially complex nature of mangrove ecosystems provides many opportunities for debris entanglement, which enhances their role as a sink for plastic pollution. The MPs trapped in coastal forests are readily broken down into MPs, and recent studies have reported a significant accumulation of MPs in mangrove root systems (Garcés-Ordóñez et al., 2020). Apart from the above studies, estimates of macro- and MPs abundance within mangroves are still scarce.

In summary, almost all previous reports attributed the source-sink of MPs in mangrove sediments to their source, the extent of self-aggregation, and deposition rates (Cheung et al., 2018; Waller et al., 2017). The MPs content of mangrove sediments is attributed to a variety of factors including human activities, water flow rates, and in particular, the unique root characteristics of mangrove plants and the high organic matter characteristics of mangrove sediments (Seeruttun et al., 2023).

4 Conclusions and recommendations

The hydrodynamics of mangrove wetlands are a major determinant of MPs content, with water flow rates at the inlet being much lower than in the estuary. The distribution of MPs in mangroves is influenced by different forest species and tides. Mangrove vegetation detains macroscopic plastic litter, fragments, and accumulates in the sediment over time. Most mangrove plants have respiratory and strut roots, and their well-developed root systems can also trap plastic waste from land and sea, which may fragment into MPs, making mangroves potentially more contaminated than other environments.

The bibliometric analysis showed a significant research trend in this field. China is the main country concerned about MPs pollution in the mangrove. However, cooperation and communication between countries and institutions need to be strengthened. Additionally, the bibliometrics bias should also need to be considered to improve further analysis in the research field. There is a need to pay attention to implicating the research results into practical work. The significant correlation between mangrove sediment pH and MPs particle abundance is also unclear in terms of research hotspots and key insights. Further focus on carbon sink processes and ecological risks, environmental behavior, deterrent mechanisms, and compound pollution is recommended for the future.

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Declarations

Conflict of interest The authors declare no competing interests.

Consent to participate All participants have given written informed consent for participation before the study began.

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