Visualized Quantitative Research of Marine Pollution in the South China Sea

Wei Ye^{ab*}

^aGuangdong Ocean University, Zhanjiang, China

^bChiang Mai University, Chiang Mai, Thailand

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Abstract

The rapid social-economic development of the countries bordering the South China Sea has resulted in increased marine pollution of the region, yet little study has been carried out on marine pollution in the region. This article is one of the first few attempts among existing literature to understand marine pollution in the South China Sea as a large marine ecosystem and its implications for sustainability. We have conducted systematic literature reviews for marine pollution in the South China Sea and three other regional seas/large marine ecosystems, namely, the Gulf of California, the Mediterranean Sea, and the North Sea with the assistance of CiteSpace. By comparison of studies in the three regional seas, the research of marine pollution in the South China Sea only touches on the impact of microplastics, and existing literature in the area is less efficient in the study of impacts of modern pollution on marine organisms and the uncertain bioaccumulation effect on humanity. Therefore, it is recommended that researchers in the region cooperate to conduct a holistic study of ocean pollution, and study of biological impacts of pollution on marine organisms should be strengthened.

Keywords: marine pollution; South China Sea; regional sea; CiteSpace; visualized quantitative research

1. Introduction

The South China Sea is the world's most diverse shallow-water marine area. Bordered by nine countries, it is home to over 270 million people that have had some of the fastest development and most vibrant economies on the globe (Morton and Blackmore, 2001). The past half a century has witnessed a rapid socio-economic development of countries bordering the South China Sea. Over-exploitation of coastal environment and marine resources, such as land reclamation, waste water discharge, aquaculture and

overfishing in the South China Sea, has resulted in severe marine pollution of the region (Han et al., 2012). On one hand, marine pollution leads to environmental degradation and depreciation of the value of marine resources; on the other hand, it poses an imminent threat to human health as well as the sustainability of economic development by increasing the costs for environmental conservation and social stability.

Little existing literature has studied the South China Sea as a whole largescale marine ecosystem. Given the geographic and meteorologic complexity of the South China Sea, and the fact that many island groups of this marginal sea are disputed with sovereignty claimed by a number of littoral states, the whole South China Sea is poorly understood regarding its marine biota, ecology and the human impacts upon it. Anthropogenic activities, such as over-exploitation of marine resources and marine pollution, are anticipated to be huge although, in reality, relatively little is known about them. What is known is most often contained in reports, workshop and conference documents that are not available to the wider scientific community. Conflicts arising in recent decades have interrupted research on marine pollution in the South China Sea. Therefore, it is essential to study marine pollution in the South China Sea from a holistic perspective as it is required by the transboundary nature of marine pollution and the interconnectedness of things in and between ecosystems.

This study is one of the first few attempts among existing literature to understand marine pollution in the South China Sea as a large marine ecosystem. Given the emerging economies around the coast of the South China Sea and people's increasing awareness of marine conservation, it is pressing to understand the status quo of marine pollution in the South China Sea, and how pollution impacts on marine ecosystem as well as the human society. Only from knowing the damage that has been caused and how bad the damage is and will be, can humans start to make amendments, for the sustainability of marine ecosystem, of economy development, and for human beings' sustainability on earth.

The objective of this study is to provide a systematic literature review for marine pollution in the South China Sea, as a large marine ecosystem; and via learning from the research of marine pollution in other regional seas/large marine ecosystems, it can help researchers to devise more targeted studies to understand the status of marine pollution in the South China Sea and to build a common governance mechanism among the neighboring states for the sustainable use of the ocean.

* Corresponding Author

Tel.: +86 13828224831; E-mail: alwaysbeakid@hotmail.com

Based on the relevant literature in the core database of the Web of Science, this article reviews the current research status of marine pollution in the South China sea, along with three regional seas, namely, the Gulf of California, the Mediterranean Sea, and the North Sea. With the information visualization analysis software CiteSpace, a scientometric of the literature (from the year 1996 to 2020) relating to marine pollution in the above-mentioned regional seas are conducted. Through literature co-citation analysis, keyword co-occurrence analysis, and keyword burst detection, the knowledge structure, research hotspots and frontiers of marine pollution in the regional seas are displayed in a holistic manner in the map of knowledge.

2. Methodology

2.1 Research methods

This study conducts a scientometric analysis of marine pollution in the South China Sea along with that in three comparable regional seas to draw a comparison. CiteSpace is employed in the research to do a comprehensive literature review of the study of marine pollution in the context of regional seas. Based on co-citation analysis theory and network pathfinding algorithm, CiteSpace can explore the research themes, hotspots and evolution history of a certain knowledge domain, and help researchers to form an overall understanding of the knowledge structure and frontier dynamics in the field.

In order to investigate the research theme in the field of marine pollution in the three chosen regional seas of the world, literature co-citation analysis is first conducted on related research groups. Key literature is identified through citation frequency, centrality and burst index provided in the literature co-citation analysis results (Zhang et al., 2019). The LLR (Likelihood ratio test) algorithm is selected to extract cluster names from keywords to add labels since the keywords extracted with this method emphasize the characteristics of research (Chen, 2017). Then cluster analysis is carried out on the literature co-citation network. Combined with the core literature, the cluster view is analyzed to understand the distribution of research topics of marine pollution in the three selected regional seas. Furthermore, the cluster view is transformed into a timeline view to study the evolution of these research topics. As to research hotspots in the field of marine pollution in the three sampled regional seas, keyword co-occurrence analysis of the related research groups was conducted, then a cluster analysis and keyword burst detection of the visualized network was undertaken (Luo et al., 2020). Learning from the cluster view and burst keywords, research hotspots of marine pollution in the three prominent regional seas are located. Additionally, the cluster view is transformed into a timeline view, and the evolution history of the research hotspots is looked into along with the burst keywords. Lastly, through a keyword

co-occurrence analysis of the marine pollution related literature in the South China Sea, the study in the South China Sea is compared with that in the sampled regional seas to understand the current research progress of marine pollution in the South China Sea.

2.2 Sample selection

The sampling strategy to select the comparable regional seas used in this study followed the stated logic: (1) Both the Gulf of California and the South China Sea are regional seas of the Pacific on a similar latitude, so they are border the same ocean with some geographical similarity. They are both bordered by a large dominant economy (the Gulf of California - the United States, the South China Sea - China) and other small developing states. This influences how the states interact within the area, usually the dominant economy takes the lead in handling regional marine problems. (2) The Mediterranean and South China seas are both famous for biodiversity. Most of the ecosystems in the South China Sea can find replicates in the Mediterranean, such as coral reefs and seagrass; therefore, the impacts of marine pollution on both large marine ecosystems are comparable. (3) A common feature that the North Sea and the South China Sea share is that they both have a large fishing industry and a rising aquaculture industry, the economic value of the fishing industry is important for the bordering countries of the two regional seas, and they suffer from the same pollution from aquaculture. States in both these regional seas have to consider the environmental impact from economic development for a sustainable future. (4) The majority of cutting-edge marine science and advanced ocean governance research institutes are situated on the coast of the three regional seas selected in the study, so it is essential for the South China Sea, a less developed area, to learn from them.

2.3 Data acquisition

The data in this study are sourced from the core database of the Web of Science. The retrieval method is as follows: Topic = [(marine pollution) And ("Gulf of California" or "the Mediterranean" or "North Sea")]. The time span is all the years (1996-2020), and the update time is January 14, 2021. A total of 1076 literature items were retrieved.

It should be noted that there is often a trade-off between recall and precision in data retrieval. In the case of this study, the above-mentioned keyword retrieval scheme can achieve a relatively high precision rate on account of low recall ratio. Some papers that have substantial studies of marine pollution in the three regional seas might not be included in our sampled literature due to the search keywords adopted in this research. For the purpose of supplementing the undesirable effects caused, it is necessary to expand the existing retrieval results. Chen et al. (2012) indicate that citing articles of the initial retrieval results can be obtained through "Create Citation Report" in

the database, and provided that such citing articles have referred to the results of the initial search, it is reasonable to assume that these citations are also relevant in the research field. In consideration of this approach, this study has enriched its search results by creating a citation report in the core database of the Web of Science, and 24191 articles without self-citations were retrieved.

3. Results and discussion

3.1 Result overview

To begin with, a preliminary descriptive summary on the distribution of publication time, country/area, and research themes of the 1076 keywords retrieval articles and 24191 citing articles without self-citations is looked into to foster a general understanding of the research situation in the field of marine pollution in the three chosen regional seas.

As shown in Figure 1, there has been a trend of fluctuating growth of the research on marine pollution in the designated regional seas during the 25-year span between 1996 and 2020. 1998, 2009, 2013, 2016–2020 are the four periods that have witnessed a surge of academic outputs on the subject. As for the citing articles, there has also been a steady increase over the two decades, as illustrated in Figure 2. The results indicate that marine pollution has gradually come to the attention of academia, and nowadays it is one of the research hotspots in the three sampled regional seas.

Figure 2 Distribution of publication time of the 24191 citing articles without self-citations

Sources: Web of Science search result analysis

In regards to country/area, Italy is the first in record count (231 articles) for keyword retrieved articles and second in the record count (3034 articles) for citing articles without self-citations (see Table 1). Other leading nations in the study of marine pollution in the regional seas include Spain, Germany, France, England and the United States, each taking up 14.03%, 13.85%, 11.25%, 10.04% and 7.62% of the total publications respectively. For citing articles, the United States has a record of 3700 articles, which accounts for 15.39% of the sum. Spain takes the third place with a ratio of 11.67%, while China follows closely behind with a percentage of 11.05%. The distributions of publication location are aligned with the key coastal states that border the three more-developed regional seas. In general, Europe and the United States are the research frontiers of marine pollution. Though a major developing country on the South China Sea, China pays quite a lot of attention to marine pollution research in the three selected regional seas, and the lessons learned are critical research themes in China.

Table 1 Top countries with publications of marine pollution research in the three selected regional seas

Countries	Record Count of 1076	% of 1076	% of 24191
Italy	231	21.47%	12.54%
Spain	151	14.03%	11.67%
Germany	149	13.85%	8.04%
France	121	11.25%	9.42%
England	108	10.04%	8.00%
USA	82	7.62%	15.39%
China	--	--	11.05%

Sources: organized from the Web of Science search result analysis

When it comes to research areas, for either keyword retrieved articles or citing articles, Environmental Sciences Ecology has an absolute advantage in terms of the number of articles, accounting for 64.13% (638 articles) and 56.18%

Figure 1 Distribution of publication time of the 1076 initial retrieved articles

Sources: Web of Science search result analysis

(12138 articles) (See Treemap 1 and Treemap 2 below). This indicates that marine pollution related research in the three regional seas has received special attention from the field of ecological and environmental science. Other than that, the number of papers published in the research direction of Marine Freshwater Biology, Oceanography, Toxicology and Engineering are also quite prominent, which prove that marine pollution has been the common concern of many research fields, and the studies on marine freshwater organisms, toxicology of marine pollution, and engineering means for their treatment are relatively sufficient.

Figure 3 Distribution of research topics in Web of Science
Categories of the 1076 keywords retrieval articles
Sources: Web of Science search result analysis

Figure 4 Distribution of research topics in Web of Science
Categories of the 24191 citing articles without self-citations
Sources: Web of Science search result analysis

3.1 Quantitative analysis

3.2.1 Literature co-citation analysis

With the use of CiteSpace, we can visualize a literature co-citation network with 959 nodes and 3177 links. When we continue to do a cluster analysis on the literature co-citation network, the visualized result is shown in Figure 5 (a); then the cluster view was converted to the timeline view, with the visualized result is displayed as Figure 5 (b). With the modularity being 0.7 and the mean silhouette being 0.5, the cluster structure in the visualization is considered to be significant and reasonable.

(a)

(b)

Figure 5 Results of the co-citation analysis of literature concerning marine pollution in the three selected regional seas

In the visualization of the co-citation network, nodes are the analysis subject (article). The node size represents the citation frequency of the article, and the connection between nodes represents the co-citation relation. The color and width of the layered rings in the nodes represent the citation frequency of different periods, and the change of color from the cold color band (purple and blue etc.) to the warm color band (orange and yellow etc.) represents the timeline from early to recent. The meaning of the line color is the same as that of the node color. From the visualization in Figure 5, we can see that most of the research concerning

marine pollution in the three regional seas are quite recent since most of the nodes and links in the visualized results are either orange or yellow.

As displayed in Figure 5 (a), literature concerning marine pollution in the three regional seas can be sorted into four main categories, i.e., No. 0 trophic transfer, No. 1 Mediterranean Sea, No. 2 microplastic, and No. 7 riverine litter. As CiteSpace automatically filters cluster groups that have less than 10 members, so the numbering of clusters is not sequential in this case.

3.2.1.1 Key literature

Key literature in a research domain is a fundamental breakthrough in the field which plays an important role in the whole literature group, and is a good representation of the research topic. The criteria that CiteSpace provide for identifying key literature include citation Frequency, Centrality, and Burst. Literature with higher citation frequency and centrality has higher research value and can be regarded as the foundation literature in the field; while burst literature means that its citation frequency increases rapidly in a certain period, and it has the potential to become the central literature in the later stage (Zhang et al., 2019).

As the study of marine pollution in the three regional seas are quite scattered, we can only derive centrality of 0.01. Along with the consideration of citation frequency, there are 12 articles that can be seen as essential literature in the study of marine pollution in the three regional seas. Information concerning the 12 key articles is illustrated in Table 2.

Overall, the research topics of the 12 articles can be categorized into two classes; one concerns (micro)plastic pollution in the oceans, and the other focuses on microplastic contamination in marine organisms. As early as 2014, Eriksen et al. (2014) made estimation of worldwide plastic pollution in the oceans, and hinted that since a tremendous loss of microplastics was observed from the ocean compared to expected rates of fragmentation, there were mechanisms at play that removed plastic particles from the sea surface. Hidalgo-Ruz et al. (2012) reviewed the methods used for identification and quantification of microplastics in the marine environment. Lusher et al. (2013) perceived that plastic particles were ingested by most fishes from the English Channel regardless of their feeding habitat; Foekema et al. (2013) came to the same conclusion for most North Sea fishes irrespective of their size-weight relationship. Cole et al. (2011) conducted a comprehensive review of microplastic contaminants; as an illustration, their properties, pollution routes, the detection methods, spatial and temporal trends of microplastic abundance and their environmental impact. The study of Devriese et al. (2015) furthered the understanding of microplastic intake by brown shrimp in the coastal waters of the Southern North Sea and Channel area. Farrell and Nelson (2013) investigated the trophic transfer of microplastic from mussels to crabs, which was the first to show 'natural' trophic transfer of

microplastic. Later on, Romeo et al. (2015) looked into the presence of plastic debris in large pelagic fish in the Mediterranean, and shed light on the potential transfer of contaminants on human health. Rochman et al. (2015) also reported plastic debris in fishes directly sold for human consumption which raised concerns for human health. The survey carried out by Guven et al. (2017), which was believed to have the largest sample size analyzed at the time being, indicated that the higher microplastic particle count in the seawater and sediment a site has, the higher number of ingested particles that would be found in the fish originating from that site. The findings of a study by Lebreton et al. (2017) contended that a large number of plastic wastes entered the ocean every year from rivers, and 67% of polluting rivers of the globe were located in Asia; their work provided baseline data for ocean plastic mass balance exercises, and assisted in prioritizing future plastic debris monitoring and mitigation strategies. Lastly, Free et al. (2014) evaluated microplastic pollution in freshwater systems.

It can be noted in Table 3 that Eriksen and Cole's articles have burst values of 4.3 and 3.91 respectively, meaning that their work was a research hotspot at the time which aroused the attention of peer researchers. Along with them, other literature that has a burst value ≥ 6 is summarized in Table 3. Barnes (Barnes et al., 2009) in 2009 have raised concern of plastic debris in the open ocean, on shorelines of even the most remote islands and in the deep sea. The study of Browne et al. (2011) suggested a large proportion of microplastic fibres found in the marine environment might be derived from sewage as a consequence of washing of clothes. Law et al. (2010) gave a quantitative description of the scope of plastic marine pollution in the North Atlantic Ocean, and concluded that the majority of surface plankton net tows collected plastic debris, and the concentration of plastic pieces in subtropical latitudes was quite severe due to sea current dynamics.

From Table 3, it may be inferred that the period from 2008 to 2010 was significant for the evolution of the study of marine pollution. And Browne has acted as a vital facilitator for the development of the field since some of his work, Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks with a burst value of 7.91 and Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, *Mytilus edulis* (L.) with a burst value of 6.63, have pushed for transition of the domain in different times.

Table 2 Information table of key literature

No.	Centrality	Count	Author	Publication year	Title
1	0.01	64	Eriksen M	2014	Plastic Pollution in the World's Oceans: More than 5 trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
2	0.01	53	Hidalgo-Ruz V	2012	Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification
3	0.01	52	Lusher AL	2013	Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel
4	0.01	51	Foekema EM	2013	Plastic in North Sea Fish
5	0.01	41	Cole M	2011	Microplastics as contaminants in the marine environment: A review
6	0.01	36	Devriese LI	2015	Microplastic contamination in brown shrimp (Crangon crangon, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area
7	0.01	31	Farrell P	2013	Trophic level transfer of microplastic: Mytilus edulis (L.) to Carcinus maenas (L.)
8	0.01	31	Romeo T	2015	First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea
9	0.01	26	Rochman CM	2015	Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption
10	0.01	22	Güven O	2017	Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish
11	0.01	17	Lebreton LCM	2017	River plastic emissions to the world's oceans
12	0.01	14	Free CM	2014	High-levels of microplastic pollution in a large, remote, mountain lake

Table 3 Literature with a high burst value				
No.	Burst	Author	Publication year	Title
1	14.66	Barnes DKA	2009	Accumulation and fragmentation of plastic debris in global environments
2	7.91	Browne MA	2011	Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks
3	6.72	Law KL	2010	Plastic Accumulation in the North Atlantic Subtropical Gyre
4	6.63	Browne MA	2008	Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.)
5	6.54	Gregory MR	2009	Environmental implications of plastic debris in marine settings—

6	6.42	Boerger CM	2010	entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre	2	microplastic	(1) Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification; (2) Microplastics in the marine environment; (3) Microplastics as contaminants in the marine environment: A review; (4) Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks; (5) Spatial Patterns of Plastic Debris along Estuarine Shorelines
7	4.3	Eriksen M	2014	Plastic Pollution in the World's Oceans: More than 5 trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea			
8	3.91	Cole M	2011	Microplastics as contaminants in the marine environment: A review	7	riverine litter	(1) River plastic emissions to the world's oceans; (2) The Danube so colorful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river; (3) Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification; (4) The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation; (5) Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritization of research needs

3.2.1.2 Cluster analysis

Cluster analysis of the literature co-citation network enables grouping of literature with similar research content. CiteSpace will automatically sum up the name for each cluster, which grasps the common topic of the class of literature. The view of results of cluster analysis is a good representation of the evolution of the research topics. In order to better understand the theme of each cluster, based on citation frequency and centrality, classical literature of each cluster is summarized in Table 4.

Table 4 Information table of highly cited classical literature in each cluster

No.	Label	Title of classical literatures
o	trophic transfer	(1) Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel; (2) Plastic in North Sea Fish; (3) The physical impacts of microplastics on marine organisms: A review; (4) Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea; (5) Microplastic contamination in brown shrimp (<i>Crangon crangon</i> , Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area
1	Mediterranean Sea	(1) Plastic waste inputs from land into the ocean; (2) Plastic Pollution in the World's Oceans: More than 5 trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea; (3) Plastic debris in the open ocean; (4) Plastic Accumulation in the Mediterranean Sea; (5) Accumulation and fragmentation of plastic debris in global environments

The classical literature in Cluster o (trophic transfer) focuses on the harmful effects of microplastic pollution in marine organisms. Wright et al. (2013) discussed the physical impacts of microplastics on marine organisms in terms of sources, susceptibility, and trophic transfer, and presented the findings that there was not only microplastic transfer through pelagic food chains, but that microplastics can also modify marine organism population structure. The study of Rummel et al. (2016) found higher occurrence of plastic ingestion in pelagic fish than demersal fish; and it was very likely that fish have adapted to microplastic ingestion in their body.

In the case of Cluster 1 (Mediterranean Sea), it confirms the selection of this regional sea as a study sample for a great deal of research was centred in the Mediterranean. Within this group of literature, the article of Jambeck et al. (2015) entitled Plastic Waste Inputs from Land into the Ocean was the most frequently cited within the 1076 selected research articles, with 76 counts. The focus of Jambeck's work was on land-based pollution of the ocean. He maintained that population size as well as the quality of waste management system of a country determined its plastic debris discharge into the sea. Hence, they urged for waste management infrastructure improvement to alleviate the problem.

Cluster 2 consists of literature with the theme of microplastic. Discussion of classical literature in this regard refers to the sources, trajectory, sinks, identification and quantification etc. of microplastics resulted from mass

production half a century ago. Andrady (2011) again reviewed the mechanisms of generation and potential impacts of microplastics on the marine environment, and found that as the relevant distribution coefficients for common persistent organic pollutants (POPs) favoured plastic media, when marine organisms ingested microparticles, they were likely to be exposed to high levels of POPs; consequently, they called for more study to understand the influence of microplastics exerting on the ocean food web and the unforeseen damage posed by plastic pollution on the marine ecosystem.

Lastly, Cluster 7 attributes marine pollution to riverine litter. Plastic debris in freshwater systems which would flow into the three regional seas was analysed in the light of occurrence, circulation, spatial patterns and identification. Interestingly, Eerkes-Medrano et al. (2015) compared microplastic presence and interactions in freshwater systems to marine systems and pointed out the similarities shared by the two systems. They put forward the urgency to understand how microplastics transfer from marine to terrestrial ecosystems and eventually affect the health of humans.

The distribution of research topics reflected by the 4 cluster groups of literature is basically consistent with that of the 12 key articles identified in Table 2. To be more exact, the research topics primarily fall into two aspects: (1) the sources, spatial distribution, influencing factors, and prevention and remediation of plastic pollutants in the marine environment; (2) the occurrence, identification and quantification of microplastics in marine organisms and the biomagnification effect they might have on human beings.

In accordance with the analysed results of key literature identified in the literature co-citation analysis and cluster analysis, we may reach the conclusion that research themes of marine pollution in the three chosen regional seas are centred around (1) the sources, spatial distribution, influencing factors, and prevention and remediation of plastic pollutants in the marine environment; (2) the occurrence, identification and quantification of microplastics in marine organisms and the biomagnification effect they might have on human beings.

To further investigate the evolution of the research topics, the timeline view of the literature co-citation network is analysed (Figure 5 (b)). In the timeline view of the co-citation network, the literature nodes with the same first citation time are placed in the same timeline, and the connection between nodes in the timeline represents the progress of research, thus showing the evolution of the research topics from the time dimension (Chen, 2012).

For the first three clusters, it can be seen intuitively that the nodes in each timeline are dense and evenly distributed from 2006 to 2019, indicating that research interest in trophic transfer and microplastic in the three selected regional seas was relatively high during this period, and a large number of influential research results emerged, such as the literature identified in the above section. In this stage, the links between nodes in the timeline are also highly intensive, which means a strong inheritance

relationship among literature in the period. The important literature achievements in the early stage have a certain degree of theoretical innovation, which provide a foundation for the later research.

As for Cluster 7 riverine litter, critical literature of this topic is scattered around the timeline of 2012-2019. Comparatively speaking, the number of nodes and links in this timeline is relatively small; that is, there are few influential research results, and they are not closely related to the previous publication. All in all, analysis of the timeline view of the literature co-citation network indicates that research interest in the field of marine pollution in the three selected regional seas have substantially increased since 2006, and the research topics presented a trend of diversification.

3.2.1 Keywords co-occurrence analysis

Keywords are the highly condensed contents of literature. Through keyword co-occurrence analysis, we can identify the scientific questions that are jointly discussed by much literature, that is, the research hotspots.

3.2.2.1 Cluster analysis

Running CiteSpace, we obtain a keyword co-occurrence network with 942 nodes and 2926 links. The cluster view of keyword co-occurrence analysis is visualized in Figure 6 (a), while the timeline view is displayed as Figure 6 (b).

(a)

(b)

Figure 6 Results of keyword co-occurrence analysis of literature concerning marine pollution in the three selected regional seas

Cluster analysis was performed on the keyword co-occurrence network to observe the distribution of research hotspots (Figure 6 (a)). There are altogether 16 significant clusters of marine pollution in the three selected regional seas. They include Cluster 0 microplastics, Cluster 3 North Sea, Cluster 4 species diversity, Cluster 5 heavy metals, Cluster 6 shipping, Cluster 7 chlorinated compound, Cluster 8 surface ozone, Cluster 9 macroplastic, Cluster 10 mullus barbatus, Cluster 11 parasite community, Cluster 12 marine eutrophication, Cluster 13 macrobenthos, Cluster 14 nitrogen compounds, Cluster 16 conservation, Cluster 17 metabolization, Cluster 19 mollusca.

Along with the conclusion from the literature co-citation analysis, we can see that for the first research theme of “the sources, spatial distribution, influencing factors, and prevention and remediation of plastic pollutants in the marine environment”, keyword Cluster 0 microplastics, Cluster 5 heavy metals, Cluster 6 shipping, Cluster 7 chlorinated compound, Cluster 8 surface ozone, Cluster 9 macroplastic, Cluster 12 marine eutrophication, Cluster 14 nitrogen compounds may be deemed as research hotspots. Microplastics are the most popular research subject, and are often related to the study of heavy metal, chlorinated compound, surface ozone, macroplastic and nitrogen compounds contamination. In the field of marine pollution prevention and remediation, marine eutrophication is constantly a topic of discussion.

As to “the occurrence, identification and quantification of microplastics in marine organisms and the biomagnification effect they might have on human beings”, keyword Cluster 0 microplastics, Cluster 4 species diversity, Cluster 10 mullus barbatus, Cluster 11 parasite community, Cluster 13 macrobenthos, Cluster 16 conservation, Cluster 17 metabolization, Cluster 19 mollusca are viewed as the research hotspots, to be more exact, marine biological association, biomarkers for evaluation and the conservation of marine species.

The timeline view of the keyword co-occurrence network is looked into (Figure 6 (b).) to form a visual understanding of the evolution of the research hotspots. For over two decades, the study of microplastics has been the main line of marine pollution research. It provides the basis for other research progress, and the knowledge inheritance in the period is strong. Other than that, the research topics on marine pollution in the three regional seas have been quite diverse and scattered.

3.2.2.2 Keywords burst detection

Aside from cluster analysis, keyword burst detection is also a good representation of research hotspots, and it can provide quantitative description of the research hotspots and their evolution (see Chen et al., 2012). Figure 7 shows the top 25 keywords with the strongest citation bursts in a chronological order. Aligned with the two key research themes identified above, the 25 high burst keywords can be sorted into two categories: (1) pollutants: pollution, PCB (polychlorinated biphenyl), cadmium, trace metal, PAH,

mercury, heavy metal, persistent organic pollutant; (2) marine organisms: mussel, biomarker, fish, mytilus eduli, benthic community. As this result is basically consistent with the analysis above, it further confirms the conclusions about the research themes and research hotspots.

Top 25 Keywords with the Strongest Citation Bursts

Figure 7 Results of keywords burst detection of literature concerning marine pollution in the three selected regional seas

Note: the color red represents the duration of the active period of the keyword, while the color blue represents the inactive period of the keyword

Emergence and duration of burst keywords can reflect the evolutionary process of research hotspots. The top 25 high-intensity burst keywords selected in this study appeared in a concentrated time respectively, in the time span of 1996-2012, which shows that this period is an active period of marine pollution research in the chosen regional seas. There were no high burst keywords appearance after 2012, meaning that no new research hotspots and frontiers emerged in the field of marine pollution in the regional seas selected thereafter. This phenomenon is largely attributed to the fact that researchers have endeavored to deepen their understandings on the impacts of microplastics as it has become mainstream research for marine pollution (see Figure 6 (b)).

At an early stage, “North Sea” obtained a high burst strength of 10.72, which indicates that the study of marine pollution has been carried out in the North Sea for a long time. Since 2005, as seen from a high burst value of 8.57, “trace metal” has been closely studied for marine pollution, and this induced a shift of research direction in the field. Overall, PCB has sustained a lasting period of interest in the time frame and been thoroughly studied by scholars in the three selected regional seas. Again, the variance in strongest cited keywords along the timeline explains the research focus of marine pollution over the years in the three selected regional seas as being quite diversified.

3.3 Comparison of the study of marine pollution in the three selected regional seas and in the South China Sea

Learning from the research of marine pollution in other regional seas can help to develop more specific research in the South China Sea to understand the status of marine pollution and to devise a common governance mechanism among the neighboring states for the sustainable use of the ocean. By comparing the research of marine pollution in the three regional seas, the study of marine pollution in the South China Sea can be improved and the pressure of marine pollution can be alleviated in the area.

3.3.1 Literature review of marine pollution studies in the South China Sea

Song (2008) examined the potential threat of marine pollution caused by offshore oil and gas development in the disputed areas of the South China Sea, and discussed the legal obligations and political commitment of the littoral states in regard to marine environment protection in the area. Xu & Li (2013) further emphasized the importance of strengthening cross-strait cooperation for environmental preservation in the South China Sea. In terms of ship-source pollution in waters surrounding the disputed parts of the South China Sea, Beckman & Bernard (2013) proposed designation of Particularly Sensitive Sea Areas (PSSAs) to prevent, reduce and control marine pollution from shipping activities. Recently, Deng et al. (2021) have reviewed the current knowledge of microplastics pollution in mangrove ecosystems in the South China Sea. In addition, the forty-year pollution history of microplastics in the northern South China Sea was studied to get insights of how microplastics have contaminated this marginal sea (Chen et al., 2020).

In short, the current literature on marine pollution in the South China Sea either focuses on a specific kind of marine pollution in the area, or the research work merely covers parts of the South China Sea. Particularly, there have been quite active academic reflections on the environmental pollution in the coastal waters off south China, i.e., the northern South China Sea. Han et al. (2012) provided a comprehensive overview of the environmental problems as well as existing policies in the south China coastal sea, and pointed out the challenges going forward, as well as recommendations for the sake of sustainable use of the ocean. Peng et al. (2020) analyzed the relationship between fisheries economic growth and marine pollution in China's coastal regions, and found that this relationship in the southern coast of China was an inverted U-shape.

3.3.2 Quantitative analysis of literature of marine pollution in the South China Sea

This study further conducts a scientometric analysis of literature concerning marine pollution in the South China Sea with CiteSpace to grasp the map of knowledge of the subject. Again, the data used for the study of marine pollution in the South China Sea are sourced from the core

database of the Web of Science. The retrieval method is as follows: Topic = [(marine pollution) And ("South China Sea")] . The time span is all the years (1996-2020), and the update time is February 16, 2021. A total of 183 articles were retrieved.

A keyword co-occurrence analysis was undertaken for the 183 retrieved literature regarding marine pollution in the South China Sea, with the visualization of the cluster analysis illustrated in Figure 8 (a). It can be seen that most of the relevant literature has selected China (Cluster 2) and Japan (Cluster 7) as the research areas, and they focus on microplastic pollution (Cluster 1). Biomonitoring (Cluster 6) as well as canonical correspondence analysis (Cluster 4) are the typical research methods. Researchers' attention is directed towards "butyltin residue" (Cluster 5), "sediment quality criteria" (Cluster 8), "enrichment factor" (Cluster 10) and "depositional history" (Cluster 11).

Compared with the study of marine pollution in the South China Sea, academic discussion of the subject in the three selected regional seas is more active and the research topics are more diverse. At present, the research of marine pollution in the South China Sea simply touches on the impact of microplastics. Although "fish" (Cluster 3) is included in the critical keywords, literature in the South China Sea is less efficient in the study of the impacts on modern pollution on marine organisms, let alone the uncertain bioaccumulation effect of ocean pollution on humanity.

From the timeline analysis (Figure 8 (b)), we can further infer the below problems in the existing study of marine pollution in the South China Sea, (1) From the time dimension, the earliest literature of marine pollution in the three selected regional seas dates back to 1989, while literature of the kind in the South China Sea didn't begin until 1998, which is relatively late. (2) From the research area dimension, most of the existing literature of marine pollution in the South China Sea focuses on the northern South China Sea (southeast China); there are few studies on the west and south coasts of the South China Sea, which are bordered by a variety of smaller developing nations where, due to the social-economic development pressure, anthropogenic impacts, such as over-exploitation of resources and pollution, are anticipated to be huge although, in reality, relatively little is known about them. Additionally, as conflicts have in recent decades arisen over the island groups of the South China Sea because of perceived national rights, there is a lack of coordinated research on the overall planning for regional and marine pollution prevention and control. (3) From the perspective of the distribution of research topics, the research on marine pollution in the South China Sea is relatively hot on microplastic pollutants and chemical pollutants; in comparison, the research on the impacts of pollution on marine organisms is relatively minimal and primitive, and there are relatively few central problems that have received the common concern of all the neighboring states, despite the transboundary nature of marine pollution.

Figure 8 Results of keyword co-occurrence analysis of literature concerning marine pollution in the South China Sea

The coastal fringes of the South China Sea have some of the fastest developing economies in the world, most of which are dependent on low-order manufacturing. Moreover, as it provides shelter for more than 270 million people, the contradiction between socio-economic development and environmental protection has been highlighted, yet little research has been undertaken with regards to marine pollution in the South China Sea (Morton and Blackmore, 2001). As marine pollution is transboundary and sensitive to land-based pollution, it has been proved that pollutants will affect adjacent waters and marine organisms therein through migration and transformation. Given the populated demographic profile on the coast of the South China Sea, ocean pollution will not only threaten marine biodiversity in the region, but also bring non-negligible influence on the health of the coastal residents. Consequently, when dealing with marine pollution in the South China Sea, it is essential to consider the matter in a holistic manner, to devise governance policy from the perspective of the entire marine ecosystem, and to take marine pollution prevention and control as a breakthrough to promote and protect marine biodiversity. It has been concluded in the previous analysis that the study of marine pollution in the other three regional seas attaches 30

considerable efforts to the impacts of ocean pollution on marine organisms, and has enriched the academic debate in the regard. It is necessary to supplement and improve and the study of the association between marine pollution and marine organisms in the South China Sea.

4. Conclusion

Through literature co-citation analysis, keyword co-occurrence analysis, and keyword burst detection of CiteSpace, the study finds that research theme of marine pollution in the regional seas of the Gulf of California, the Mediterranean Sea, and the North Sea mainly focuses on two aspects: (1) the sources, spatial distribution, influencing factors, and prevention and remediation of plastic pollutants in the marine environment; (2) the occurrence, identification and quantification of microplastics in marine organisms and the biomagnification effect they might have on human beings.

The study of marine pollution in the South China Sea took-off relatively late, and most of the existing literature is centered in the northern South China Sea (southeast China), and there are few studies on the west and south coasts of the South China Sea. Compared to the three selected regional seas, the research of marine pollution in the South China Sea simply touches on the impact of microplastics. Although “fish” is included in the critical keywords, literature in the South China Sea is less efficient in the study of the impacts of modern pollution on marine organisms, let alone the uncertain bioaccumulation effect of ocean pollution on humanity.

By analyzing the research themes and hotspots of marine pollution related literature in the world’s three major regional seas and drawing on the experience of cutting-edge marine pollution studies, the following suggestions are put forward for further research on marine pollution in the South China Sea: (1) Study of marine pollution on the west and south coasts of the South China Sea should be conducted, enhanced and integrated along with the study of the situation on the north coast.

Academics of the bordering states of the South China Sea should cooperate in terms of information sharing and knowledge structure perfecting, to carry out joint studies for ocean pollution in the South China Sea so as to improve the present unbalanced distribution of research areas. (2) Marine pollution in the South China should be studied as a whole marine ecosystem. Study on the impacts of pollution on marine organisms should be strengthened, further research on the land-based source pollution should be conducted to reexamine the association of anthropogenic activities and the marine ecosystem. Marine pollution risk early warning systems and comprehensive treatment plans should be set up to prevent and control ocean pollution in the South China Sea for the sake of all the residents in the area.

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