A global bibliometric analysis of research on microplastics from 2004 to 2020

Ming Li
Jilin Jianzhu University
Binshuo Liu
Jilin Jianzhu University
Lei Wu
Jilin Jianzhu University
Shuang Zhong
Jilin Jianzhu University
Chunqing Wang
JILIN JIANZHU
Ying Wang
Jilin Jianzhu University
Mengnan Shen
Jilin Jianzhu University
Na Li
Jilin Jianzhu University
Shuang Liang
Jilin Jianzhu University
Honghai Xue (xuehonghai@jlju.edu.cn)
Jilin Jianzhu University
Pengfei Zhao
Jilin Jianzhu University

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Abstract

Microplastics (MPs) pollution has garnered significant interest as a serious environmental problem. To date, a large amount of research has been published on this topic. We analyzed the related studies to assess the global developments of MPs regarding the evolution, research trends, and hotspots by bibliometric. A total of 2,872 bibliographic records were retrieved from the Web of Science Core Collection, and CiteSpace 5.4 was used for bibliometrics. The results visually displayed the contributing countries, institutions, authors, keywords, and potential research directions in the MPs fields. The scientific developments in this field began in 2004 and have accelerated considerably since 2012. China and the USA are the leading countries in MPs research. The research on MPs is multidisciplinary and involves Ecology, Chemistry, Molecular Biology, Environmental Science, and Oceanography. Among these, Oceanography was the most connected with MPs and was the most well-developed. Overall, we mapped the development of MPs research and attempted a comprehensive discussion and understanding of scientific advances, as well as the progress made.

1 Introduction

Plastic polymers have a high molecular weight and are usually made from the byproducts of refined fossil fuels, such as petroleum. They are corrosion-resistant and highly insulating owing to their stable physical and chemical properties. The industrial production process of plastics is simple and inexpensive; therefore, plastics have a variety of applications in many fields. It has been estimated that global plastic production will reach 33 billion tons by 2050 (Rochman et al., 2013). The plastic industry has been increasing in development, providing great convenience and efficiency for daily life. However, the use of huge amounts of plastics has produced vast quantities of plastic waste, and due to the random disposal and improper treatment, microplastics (MPs) pollution has become an emerging environmental issue. Plastic is known to deteriorate and disintegrate by physical and chemical degradation processes (Andrady, 2017).

MPs, which are plastic particles with diameters less than 5 mm (Thompson et al., 2004), have been frequently detected in a variety of environments, including the oceans (Andrady, 2011), surface water (Mintenig et al., 2020) sediment (Corcoran et al., 2020; Mani et al., 2019), air (Wang et al., 2020; Wright et al., 2020) soil (Xu et al., 2019) and even in drinking water (Koelmans et al., 2019). Additionally, MPs were also considered as a carrier that can adsorb other contaminants, including traditional organic pollutants and heavy metals (Engler, 2012; Seidensticker et al., 2018; Sharma et al., 2020; Tang et al., 2020; Wang et al., 2020). Therefore, MPs pollution will cause complicated environmental impacts and increased ecological risks, and more attention should be paid to this issue.

Interest in MPs among researchers has been increasing dramatically in recent years, with many papers now published on the topic. Most research fields are highly dynamic, responding quickly to changes in society and the environment. Therefore, a regular review of current work can provide reference and direction for further research. With increasing concern about MPs, some researchers have been analyzing

the developments in this field. Reviews of research activities in a field are dependent on individual literature collection and subsequent summarization, and extraction, and is based on subjective processing (Blettler et al., 2018; Guo et al., 2020; Wright et al., 2013).

Bibliometric analysis is a scientific research technique that has been attracting recent interest. It uses statistical and quantitative analysis of research publications to show quantified data in assessing research trends from literature growth of specific subjects (Mallawaarachchi et al., 2020; Mao et al., 2018; Marvuglia et al., 2020). Furthermore, it is highly focused on metrological characteristics of research literature in a given field (Ellegaard and Wallin, 2015) and can assess the research patterns specifically to countries, institutions, journals, authors, and keywords related to specific publications (Chen et al., 2016; Zhang et al., 2020; Zhou et al., 2018). It is also a scientific research technique that is receiving growing attention.

CiteSpace information visualization and analysis software is a new way of conducting bibliometric analysis, which has revolutionized conventional reviewing methods and is among the most popular tools for knowledge mapping (Chen, 2006). It is designed particularly to support the visualized analytic process and provides easy access to the bibliometric structure in a specific research field. This can help researchers discover hotspot topics that are likely to be the focus of research in the future. Therefore, this paper analyzed articles related to MPs research using CiteSpace, which was downloaded from the database of Web of Science (WOS).

The study aims to (1) analyze the distribution of year, authors, countries, institutions, and journals on MPs research; (2) identify the cooperation between countries and institutions in MPs research; and (3) explore the emerging topics and prospects. The results can reflect the spatial and temporal distribution of researchers, institutions, and journals in this field, and visualize the internal structure of the knowledge bases and research focuses. This can help provide a clear picture of how knowledge and theories change with time and can help scholars seize the developmental opportunities in the field and steer their future work in those directions.

2 Methodology

2.1 Data source and search strategy

The core collection of WOS was used as the source database, with the retrieval formula: TS = ("Micro plastic*") or (TS = "micro-plastic*") or (TS = microplastic*); the language was chosen as "English" and the literature type was "article". In 2004, Thompson et al. (2004) from the University of Plymouth suggested the concept of "micro plastics" for the first time. Therefore, the research period was selected as 2004–2020. Data on literature related to research on MPs were downloaded from WOS on March 29, 2020. The source journals are set to Social Sciences Citation Index, Science Citation Index, Emerging Sources Citation Index, and Arts and Humanities Citation Index, and a total of 3,094 records were retrieved. After screening and removing duplicate and unrelated data, 2,872 records remained. These were downloaded

in the plain text format of "full record and references" and named with the extension download_x.txt. Finally, the data was analyzed by CiteSpace.

2.2 Research tools

CiteSpace knowledge visualization software is a new tool widely used in scientific metrology (Hsin-Ning Su, 2010). It is a multivariate, time-sharing, and dynamic knowledge mapping tool. It uses visual references to analyze basic knowledge contained in scientific literature and can promote analysis and reasoning through data mining of literature and visual interaction. This can help researchers better understand trends and movements in their field of study, as well as connect to other researchers studying similar topics (Jie Zhu, 2017).

3 Results And Discussion

3.1 Temporal distribution of publications about MPs research

Figure 1 shows the number of publications on MPs for each year, based on 2,872 papers published from 2004 to 2020. Research in the field of MPs began in 2004, and the overall level of publishing has been rising over time. To analyze the current status as well as the development trends in this field, this paper divides the period of research into two periods: the development period (2004–2011) and the rapid growth period (2012–2019). At different periods, the degree of attention concentrated in the field of MPs is different, and the number of papers published in a field in a year can indicate the level of development of research in that field.

When "microplastics" was first defined by Thompson in 2004 (Thompson et al., 2004), international scholars paid little attention. Only 18 papers were published in 2004. During the development period (2004–2011), the number of annually published research papers was relatively stable with an average of 26.5. During the rapid growth period (2012–2019), the number of annually published research papers increased sharply. United Nations Environment Programme (UNEP) Year Book 2014 stated that plastic pollution had threatened the survival of marine organisms and the development of tourism, fisheries, and commerce, and drew attention to MPs. Since then, the number of publications on MPs increased significantly, the number reached a maximum (829) in 2019, and a maximum growth rate of 68.51% occurred during 2017–2018. In addition, 323 papers were published in 2020 as of March 29, suggesting that the number of papers on MPs will continue to rise.

3.2 Spatial distribution of publications about MPs research

The development of MPs research differs from country to country. Analysis of the geographical distribution of research activities, as well as the cooperation, allows researchers to obtain a thorough understanding of research dynamics in a particular field. Figure 2 is the result of running the software

with "country" as the node, time slice = 3, top n = 50 for 2004–2020, and the top 10 productive institutions in the field of MPs (Supplementary Table S1).

Figure 2 demonstrates that many countries are interested in MPs research. Among them, P. R. China is the most productive country with the largest corresponding nodes compared to other countries and regions. The lines between countries in Fig. 2 indicate the cooperative relationships between countries and regions. There are many cooperative relationships between countries, especially between P. R. China and the USA. At the same time, the thin connections between nodes indicate that the intensity of cooperation between countries and regions is low and needs to be strengthened in the future.

According to Supplementary Table S1, the total number of Chinese publications is 581, accounting for 20.23% of the total literature, followed by the USA with 437 publications, accounting for 15.22%. Besides P. R. China and the USA, Germany, England, Italy, France, Spain, the Netherlands, Australia, and Canada also have a high number of publications. Finally, the geographical distribution of countries and regions shows that the top 10 high-yield countries with respect to research publications on MPs are mainly distributed in Europe (1243, 43.28%), Asia (581, 20.23%), North America (561, 19.53%) and Oceania (131, 4.56%).

3.3 Cooperation between scientific research authors and institutions

The data was imported into the software with "author" and "institution" as the analysis fields. The period was set to 2004–2020 with a three-year time slice (time slice = 3) and top n = 50 as the threshold value. Cooperation between the authors and institutions in MPs research from 2004 to 2020 is shown in Fig. 3 and Fig. 4, respectively.

The circle in the graph represents the node, with each node corresponding to an author or institution, and the line indicates that there is a cooperative relationship between the authors or institutions. The more frequently an author appears, the larger the node in the map; the thicker the line is, the stronger the cooperation degree is, with no lines or thin lines indicating no or weak cooperation. The top 10 authors and institutions that published the most papers in the field of MPs research from 2004 to 2020 are summarized (Supplementary Table S2).

Figure 3 demonstrates that the node corresponding to Shi HH is the largest, indicating him as the scholar who has published the most papers at present in this domain. Shi HH from East China Normal University has published 36 related papers(Supplementary Table S1). In general, a research group consists of researchers almost from the same institution, and academic links between different groups or between authors from different institutions are relatively weak (Fig. 3), such cooperation should be strengthened in the future.

As Fig. 4 suggests, worldwide institutions are increasingly engaged in MPs research from the perspective of the cooperative relationships between high-yield institutions in the field. According to Supplementary

Table S2, three institutions from China are within the top 10 productive institutions. Generally, the number of publications from a country is heavily relevant to the proportion of researchers, research institutions, and the availability of research funding involved.

3.4 Double-map overlay analysis

The double-map overlay analysis mainly uses the coupling relationship of papers to analyze the internal relationship between the disciplines of papers (Chen, 2004). The double-map overlay of journals is the result of the superimposition and simplification of disciplines by using the Z-score, which is used to represent the distribution of papers, citation trajectories, and focus shift of research (Chen, 2014). In the double-map overlay results of journals, Part A is the distribution of reference disciplines of the source data of this study, and Part B is the distribution of citation disciplines in the data. The colored lines indicate the relationship between a certain field represented by the citing journal and a field represented by the cited journal, and the thickness of lines indicates the degree of closeness in the relationship between corresponding disciplines.

The double-map overlay analysis for MPs research is shown in Fig. 5. The research on MPs in Part A has mostly cited research literature on Ecology, Chemistry, Physics, Oceanography, Zoology, Ecology, and System Science, which laid the foundation for the development of MPs research. Part B shows that the research on MPs is more involved in the fields of Ecology, Chemistry, Physics, Environmental Science, Molecular Biology, and Plant Studies.

The thickness of the connection reflects the closeness of the relationship between different disciplines, and the color of the connection shows the path of the relationship between them (Fig. 5). For example, the purple line is present from Part A 5 to Part B 3, 4, and 6; the yellow lines are present from Part A 7 to Part B 2, 4, 8, and 10. From Fig. 5, research on MPs involves a wide range of disciplines, and many pathways connect corresponding categories in different disciplines cited, Ecology, Chemistry, Physics, Molecular Biology, Environmental Science, and Oceanography are the fields with the richest and complex connections, indicating that the research on MPs is multidisciplinary.

3.5 The evolution of the frontiers in MPs research

3.5.1 Co-citation analysis

A co-citation network refers to the knowledge network that is formed by both two articles cited by the third article simultaneously. This concept was proposed by the Soviet intelligence scientist Irina Massakova and the American intelligence scientist Henry Small in 1973. To some extent, co-citation literature represents the trend of knowledge foundation and development in a certain field, reflecting the relationship between the cited papers, which is a dynamic association. As a major quantitative technique for mapping scientific knowledge, co-citation analysis can locate, identify, and determine the research in terms of popular topics, research centers, and research correlations.

In the visualization process shown in Fig. 6, the cited reference was the node, LBY = 8 (backtracking period is 8 years), time slice = 2 years, top n = 50. The pathfinder tool was used, the merged data was pruned, and time zones are displayed. As evident from Fig. 6, it can be concluded that co-citation relationships in the field of MPs for 2004–2020 are very close, while the highly cited literature is more concentrated in 2010–2015. Co-citation analysis of the literature can efficiently narrow down the scope of key knowledge in a particular field when drawing from a large database of cited references. This is known as core classic literature, which has the functions of both analyzing and mining the literature to gauge the developments in the field.

3.5.2 Highly cited papers

The research frontiers of a field are reflected in the academic papers actively cited by researchers. The most cited publications on MPs research were presents in Supplementary Table S3. Among the top 10 highly cited publications, the top five articles were review or overview articles.

The most highly cited article is "Microplastics in the marine environment" which was cited 799 times, and published in the Marine Pollution Bulletin by Andrady in 2011 (Supplementary Table S3). The generation mechanism and potential influence of MPs on the marine environment were reviewed in this particular study (Andrady, 2011). They indicated that the source of MPs was the surface embrittlement and microcrack caused by the weathering and degradation of plastics on the beach, yielding microparticles that were carried into the marine environment by wind or wave action. Microparticles are rich in persistent organic pollutants (POPs), and often ingested by marine organisms. However, the bioavailability of POPs and the efficiency of transfer across trophic levels are unclear and the potential impact of MPs on the marine food web and ecosystem was not yet quantified. The second most cited article with 664 citations was published in the Marine Pollution Bulletin by Cole et al. In this article, comprehensive reviews of MPs including basic concepts, sources, both spatial and temporal transfers, and the impact of MPs on the marine environment were provided (Cole et al., 2011). Ranked third is the article cited 655 times and published in Environmental Science & Technology by Hidalgo-Ruz et al. This review provides a detailed comparison of the methodologies used for the identification and quantification of MPs from the marine environment (Hidalgo-Ruz et al., 2012).

Jambeck et al. (Jambeck et al., 2015) analyzed the relationship between solid waste, population density, and economic status with plastic waste inputs from land into the ocean; the study was published in Science and was cited 641 times. Their findings on population size and the quality of waste management systems revealed the countries which contributed the greatest mass of the uncaptured waste. If poor waste management infrastructure was not improved, the cumulative amount of plastic waste entering the ocean from the land was expected to increase by an order of magnitude by 2025. Wright et al. published a paper in Environmental Pollution, where the main points discussed the effect of MPs size and density on bioavailability, the relative susceptibility of different feeding guilds, and trophic transfer of MPs (Wright et al., 2013). This paper's importance is in guiding marine litter research and management strategies and the number of citations for this paper was 621. Browne et al. provided new insights into the sources of MPs, whereby a large proportion of MP fibers was from sewage-contaminated by fibers

from washing clothes (Browne et al., 2011). This paper was published in Environmental Science & Technology and the number of citations was 587. In the latest systematic study, the washing of synthetic textiles was identified as one of the main sources of MP fibers (Cai et al., 2020).

Eriksen et al. (Eriksen et al., 2014) conducted a comparative study on four plastic size classes (small MPs, 0.33–1.00 mm; large MPs, 1.01–4.75 mm; mesoplastics,4.76–200 mm; macroplastics, greater than 200 mm) in the world's oceans for the first time and published in Plos One which was cited 468 times. The results show that plastics of various sizes are found in all oceans, but are mainly concentrated in the convergence zone of subtropical circulation under the influence of prevailing winds and currents. Oceans of the northern hemisphere contain 55.6% of particles and 56.8% of the plastic mass, while the North Pacific contains 37.9% and 35.8% by particle count and mass, respectively. In the southern hemisphere, the Indian Ocean appears to have a greater particle count and mass than the South Atlantic and South Pacific oceans combined. In addition, a recent study shows that seafloor currents will play a crucial role in the transfer and storage of MPs in the deep ocean in the future (Kane et al., 2020). Cole et al. used bioimaging techniques to document ingestion, egestion, and adherence of MPs in a range of zooplankton which was published in Environmental Science & Technology and the number of citations was 422. The study’s findings imply that marine MP debris can negatively impact zooplankton function and health (Cole, 2013). Lusher et al. (Lusher et al., 2013) studied and documented MPs in 10 species of fish from the English Channel, the results of which were published in the Marine Pollution Bulletin and the number of citations was 390. 504 fish were examined and plastics found in the gastrointestinal tracts of 184 fish (36.5%) that had ingested plastic and the average number of pieces per fish was 1.90 ± 0.10. A total of 351 pieces of plastic were identified by using FT-IR Spectroscopy; polyamide (35.6%) and the semi-synthetic cellulosic material rayon (57.8%) were the most common. Cozar et al. (Cozar et al., 2014) provided a global map and a first-order approximation of the magnitude of the plastic pollution in surface waters of the open ocean, which was published in PNAS and was cited 366 times. It suggested that the gathering of floating plastic debris, mainly MPs, occurs in all subtropical gyres.

The above information shows that the research interest in highly cited literature mainly focused on the pollution level of MPs, the source of MPs, the quantification of the size of MPs, the distribution characteristics in the ocean, and the relationship between MPs and the food web.

3.6 Research Hotspots and Trends

3.6.1 Co-occurrence keywords

Keywords offer a summary of the research topics and the main contents of the literature. Through the research of keywords, we can grasp the hotspots of the whole field. In the CiteSpace software interface, "Keyword" was used as the network node, "Years Per Slice" was set to 2, top n was set to 50, and finally, 214 nodes and 432 lines were generated in total. At the same time, the irrelevant keywords without practical significance were eliminated during processing. Figure 7 shows the research hotspots in the field of MPs since 2004. The node represents the frequency of keyword occurrence. The larger the node represented, the higher the frequency of keyword occurrence. The node color changes from cold color to

warm color from the center to the outside. The connection between nodes represents the frequency of keyword co-occurrence; the thicker the connection, the higher the frequency of co-occurrence. The details of the top 30 high-frequency keywords in MPs research are listed (Supplementary Table S4).

Figure 7 intuitively shows that in MPs research, the frequency of "microplastics", "marine environment" and "pollution" is high with a frequency of 1658, 771, and 645, respectively. In this paper, "microplastics" was the subject of retrieval, so it is normal for "microplastics" and other related words to rank first in frequency. In addition, "plastic debris", "accumulation", "ingestion", "sediment", "particle", "zooplankton", "impact", "surface water", "nanoparticle" and other high-frequency keywords were also in the forefront, which are emerging issues in MPs research. The purple outer circle in Fig. 7 indicates that the centrality value of the node was greater than 0.1. The larger the purple outer circle, the greater the centrality, the more representative it is of becoming significant and having a connecting role in this research field. In addition to the keywords mentioned above (Supplementary Table S4), keywords with centrality above 0.1 include "accumulation (0.21)", "particle (0.17)", "toxicity (0.15)", "marine environment (0.12)" and "ingestion (0.1)". This indicates that the above keywords are also in a central position and have a significant influence in MPs research.

3.6.2 Burst keywords

Research frontier is an emerging trend in research theory and subject content, which can be expressed by burst keywords (Chen, 2004). The burst detection algorithm was proposed by Kleinberg in 2002 and burst keywords refer to words with a suddenly increased relative growth rate at a given time (Chen, 2006). Through the function of burst detection in the CiteSpace software, it is possible to discover content that does not reach the frequency threshold but does have informatics significance in the process of academic development. It can represent the interaction and development trends of the research frontiers more practically and scientifically by detecting the changes in hotspots. Therefore, we can comprehend the development of the research topic through the keywords of an article (Chen et al., 2012; Synnestvedt et al., 2005).

Keywords were selected as nodes according to the papers retrieved by WOS. Then ‘burstness’ was selected and the “minimum duration” was set to 2 years to detect the “burstness” in CiteSpace. Burstness indicates breakthroughs or progress in research and the future development trend. The list of 19 keywords with the strongest bursts based on co-occurrence with keywords for MPs from 2004 to 2020 is shown in Fig. 8, which presents the period and burst strength of the keywords. “Year” refers to the time of the first occurrence in the retrieval record, “Strength” refers to the intensity of mutation, “Begin” refers to the time of starting of mutation, “End” refers to the time of ending of mutation.

From 2004 to 2020, *Mytilus edulis* had the strongest burst strength (27.9133) between 2013 and 2017. However, the burst strength of “microplastic pollution” and “nanoplastics” were 11.2293 and 11.0156, respectively, and it began from 2018 and 2019 and extended to 2020, indicating that MPs pollution and nanoplastics became new research frontiers. MPs are a relatively new marine pollutant, and they belong to a subject that requires urgent attention. It is noteworthy that MPs are a toxicological hazard, as they

can accumulate and transport toxic elements (Acosta-Coley et al., 2019). Research on the mechanism of its action at a molecular level is not sufficient, and research on the pollution characteristics, potential sources, and toxic mechanism of MPs needs to be focused on in the future.

4 Conclusion

As an emerging contaminant, the persistence and biological hazards of MPs in the environment have attracted the attention of researchers and the public in recent years. With the increasing papers on MPs, bibliometrics helps researchers understand academic collaboration, research trends, and emerging issues. On this basis, Citespace was used to analyze the literature of MPs from the core journals of WOS published from 2004 to 2020, and systematically summarized information about the countries, institutions, authors, journals, and co-cited data.

On the basis of reviewing the history and present situation of microplasticity research by bibliometrics, the key research directions in the future are put forward as follows: (1) formulating standardized analysis methods for sampling and separating MPs samples; developing identification and quantitative methods for MPs to establish an effective monitoring and detection system. (2) It is necessary to further strengthen the research on the source, abundance, type, migration, and distribution characteristics of MPs in soil, atmosphere, and water to master the environmental behavior characteristics of MPs and provide the basis for further control of MPs in the environment. (3) To provide a theoretical basis for objective assessment of ecological effects and environmental risks of MPs, in-depth study on toxicology and environmental behavior characteristics of MPs and their combined pollution, as well as studies on the colonization and spread of microorganisms (bacteria, fungi, viruses, resistance genes, etc.) on the surface of MPs. (4) There are too many unknowns about MPs in the environment regarding the research of human intake pathways, such as air and diet, so more initial research is needed to assess the potential human health risks. (5) In order to reduce the release and pollution of MPs to the environment, we should develop MPs removal technology and establish policies and regulations.

Declarations

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Authors' contributions

Ming Li: Conceptualization, Methodology, Software. Binshuo Liu, Lei Wu, Shuang Zhong, Chunqing Wang: literature search and data analysis. Ying Wang, Na Li and Shuang Liang: Data curation. Honghai Xue and Pengfei Zhao: Writing-Reviewing and Editing. All authors read and approved the final manuscript.

Declaration

We declare that we have no known commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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Figures

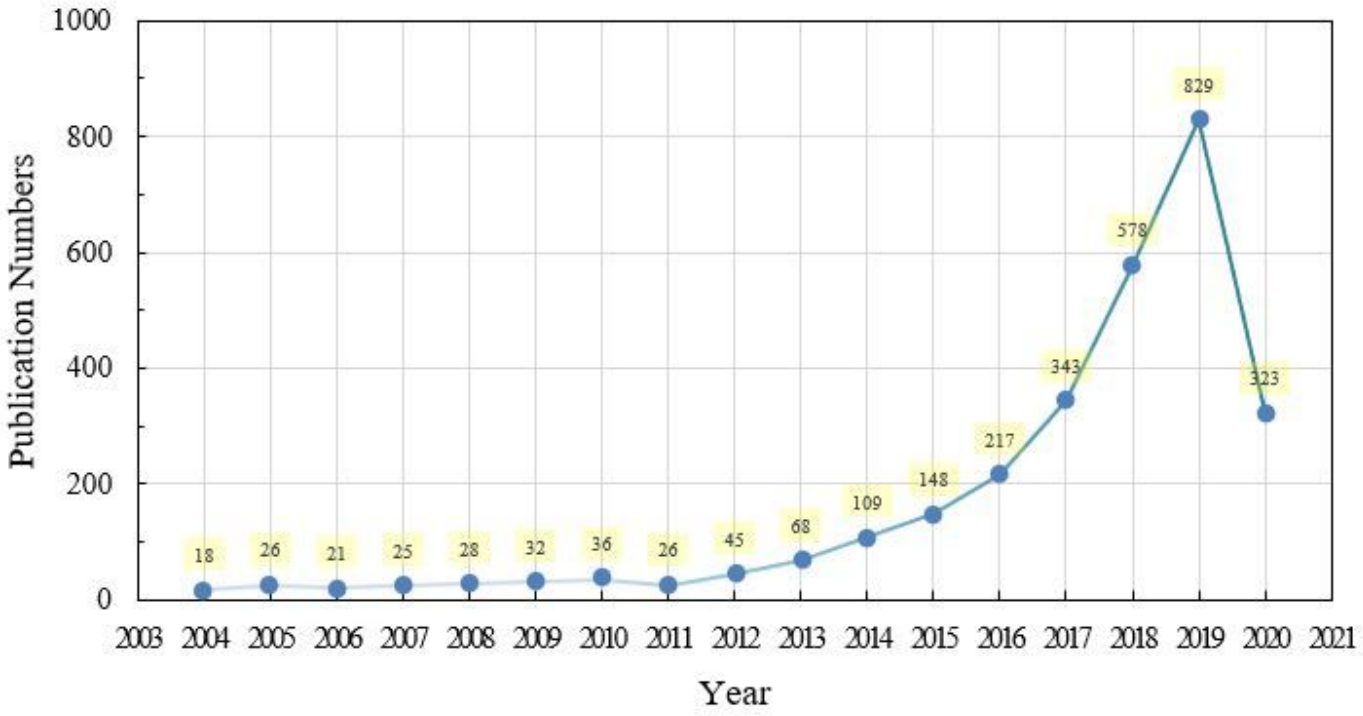

Figure 1

Temporal distribution of published articles on microplastics from 2004 to 2020

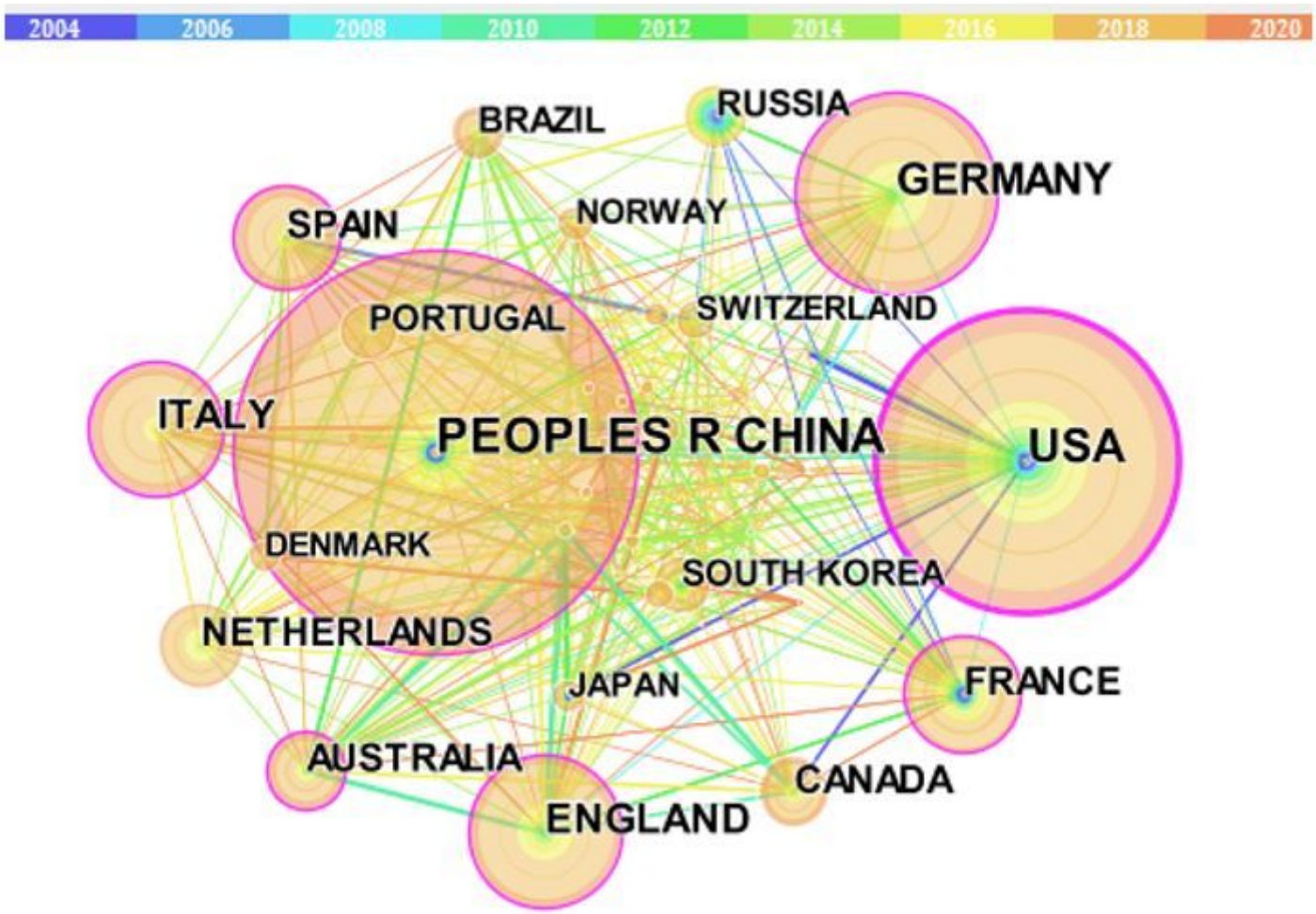

Figure 2

Countries performing microplastic research

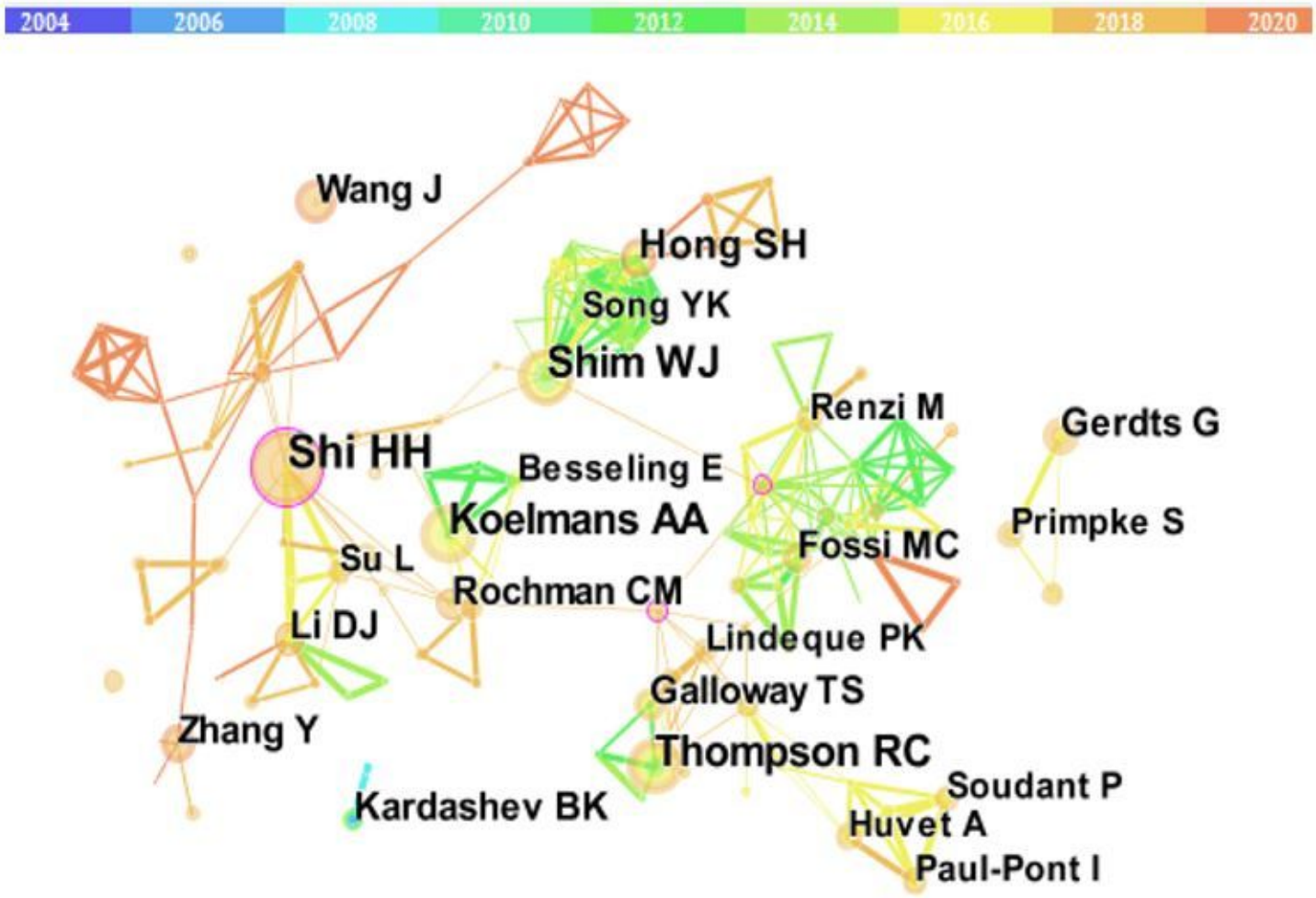

Figure 3

Authors and their cooperation relationship in microplastic research

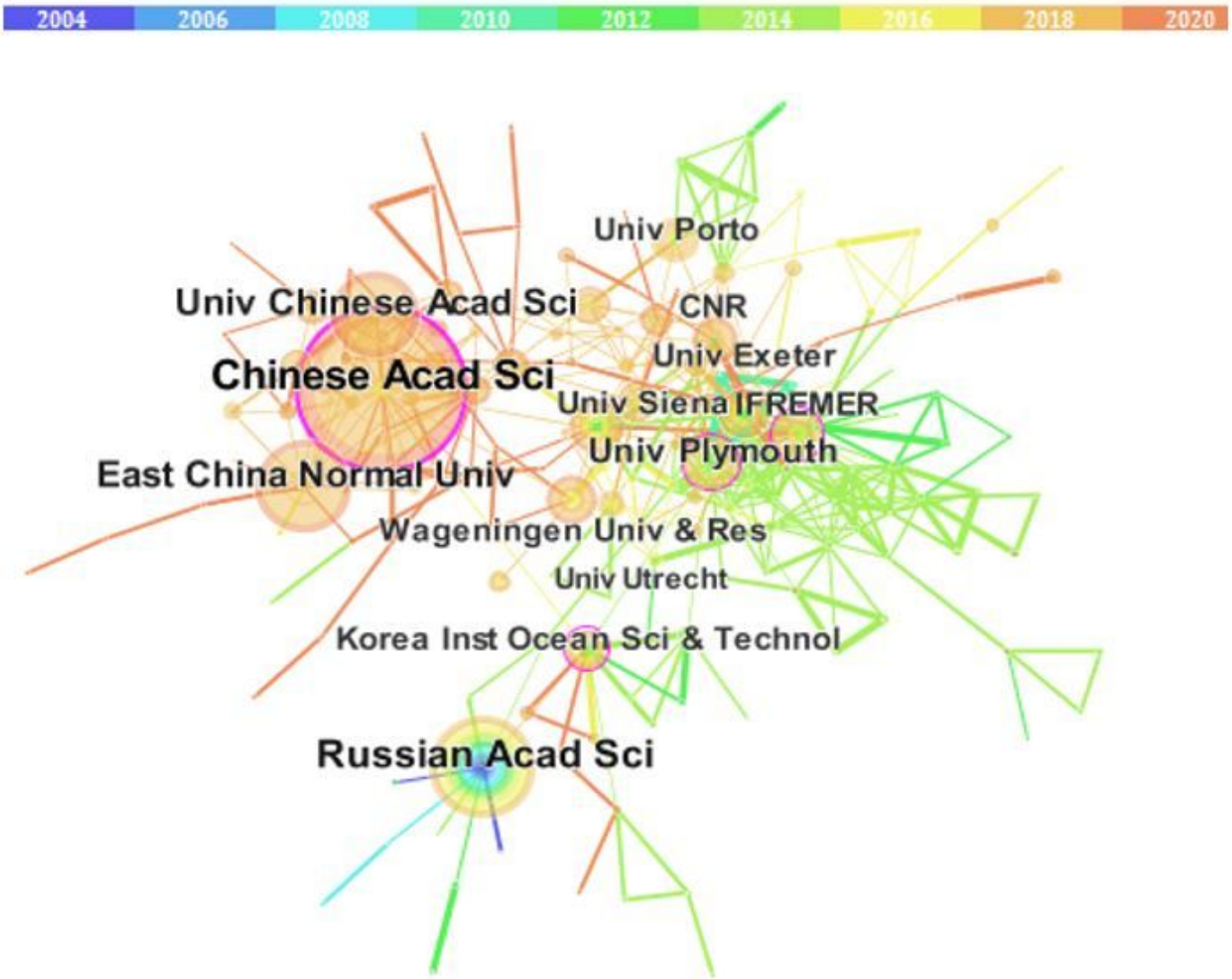

Figure 4

Institutions and their cooperation relationships of microplastic research

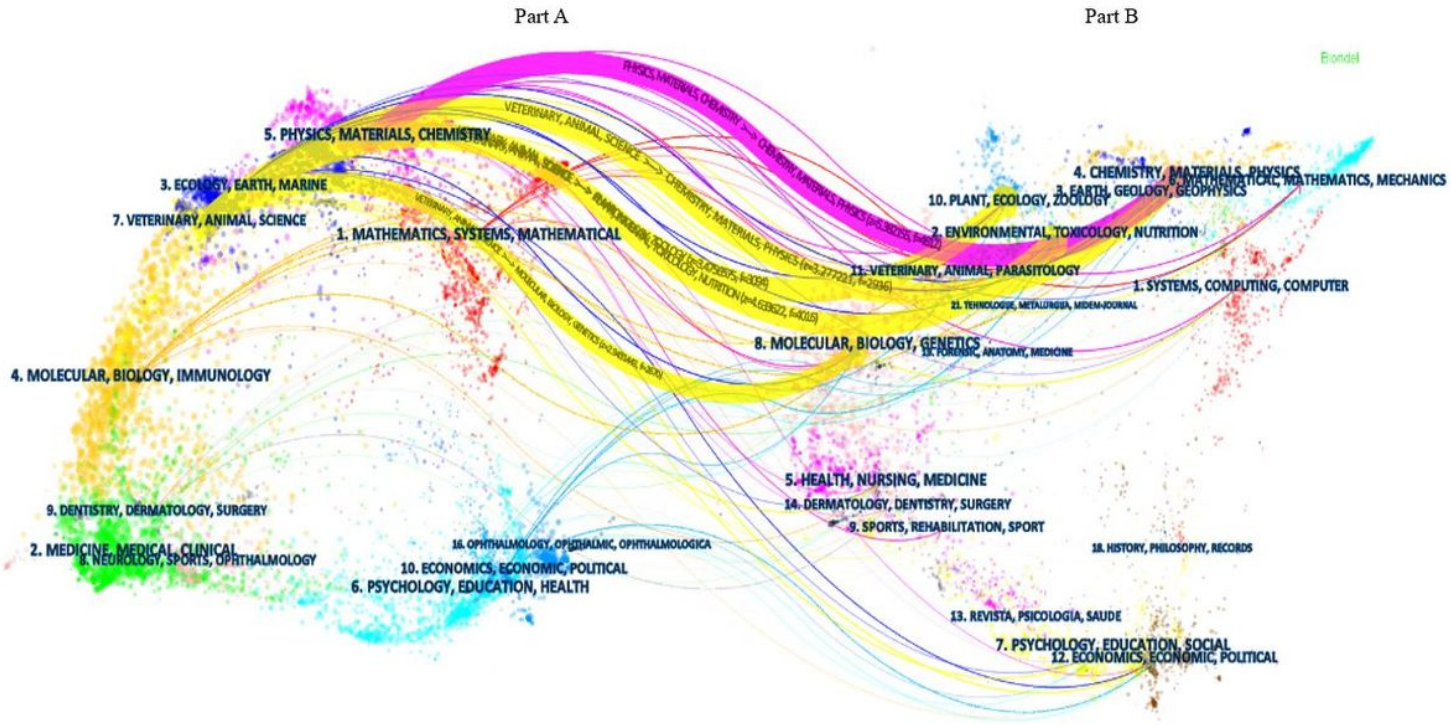

Figure 5

Double-map overlay for microplastics research

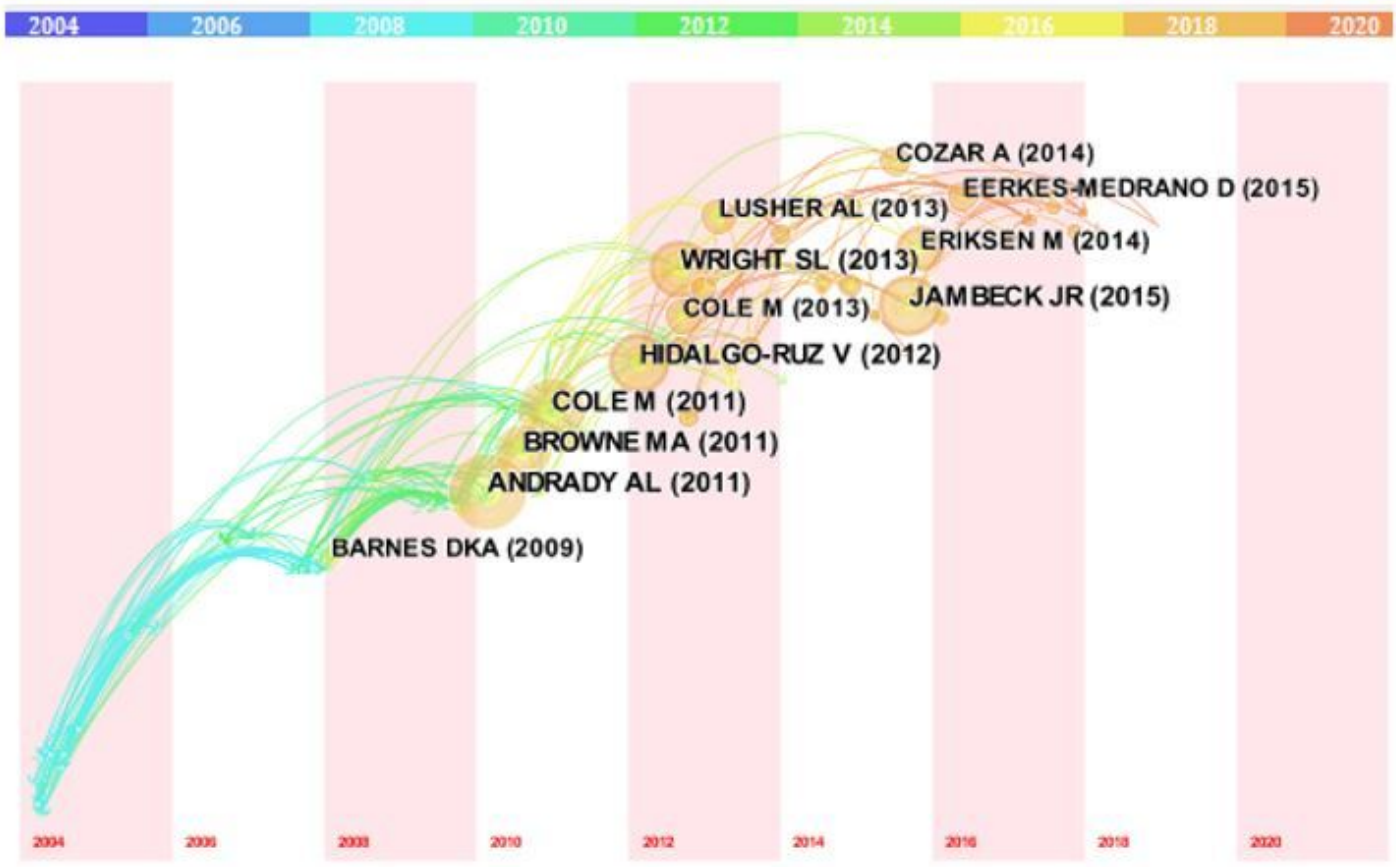

Figure 6

Time-zone view of co-citations in microplastics research

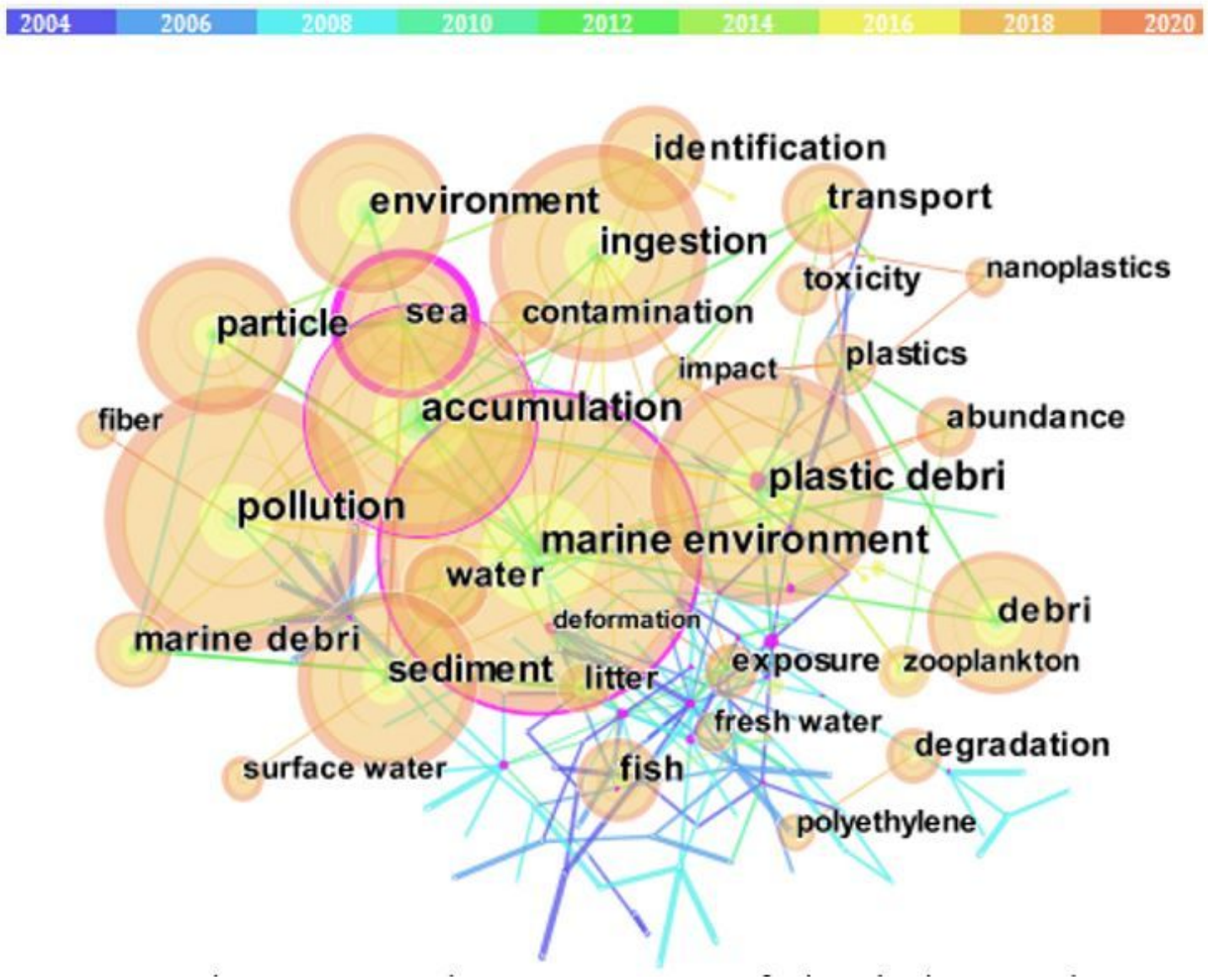

Figure 7

Keyword co-occurrence map of microplastics research

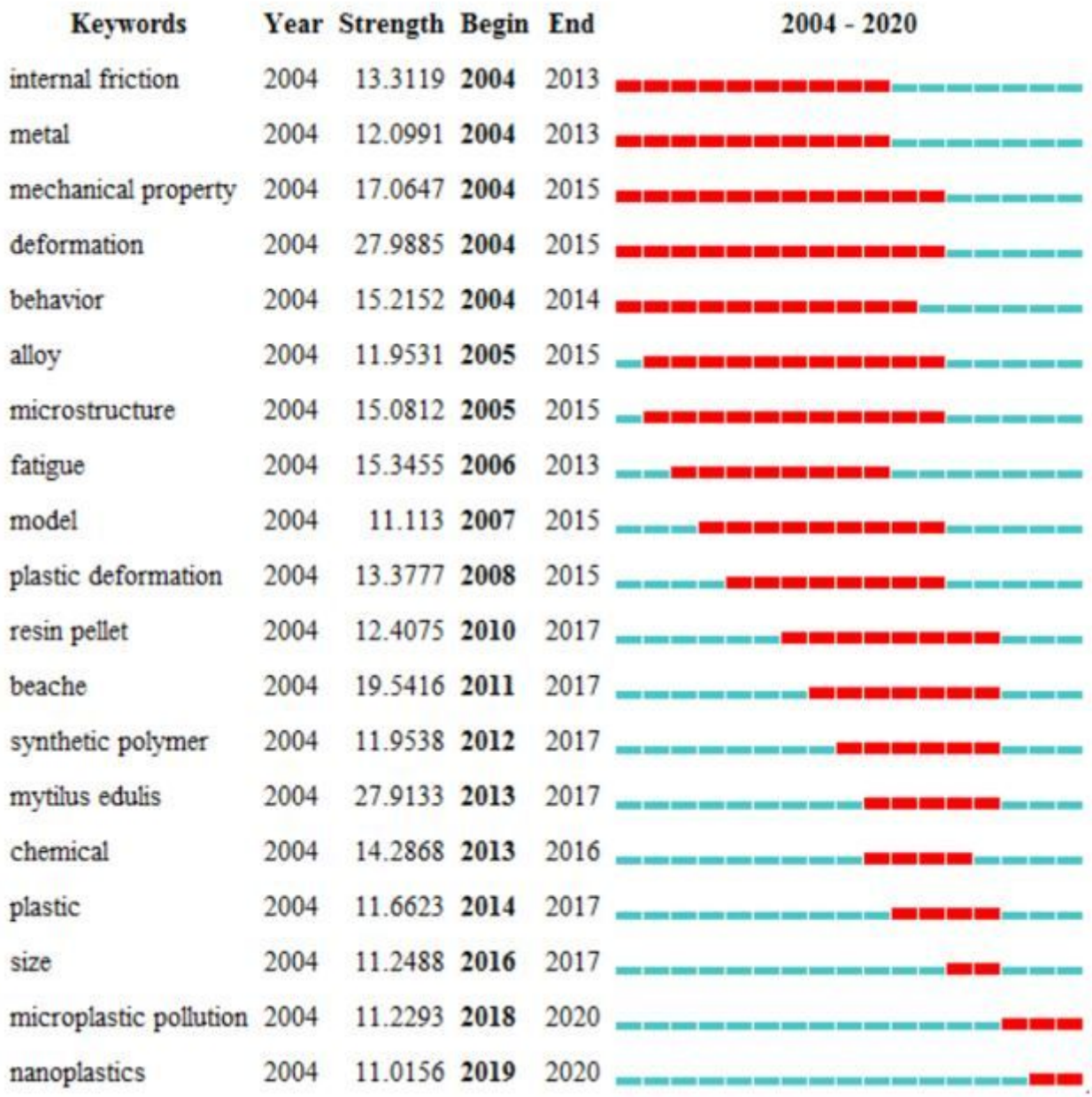

Figure 8

Top 19 keywords with the strongest citation bursts. (Red bars indicate keywords cited frequently; blue bars indicate keywords cited infrequently)

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