Ecological and Biological Studies Insights

Article

A Literature Analysis of Coastal Zone Carbon Cycle Research Based on Knowledge Graphs

Bojun Wang [1,*]

[1] School of Earth Sciences and Engineering, Sun Yat-sen University, Zhuhai, Guangdong, 519082, China
* Correspondence: Bojun Wang, School of Earth Sciences and Engineering, Sun Yat-sen University, Zhuhai, Guangdong, 519082, China

Abstract: This paper conducts a comprehensive literature analysis of coastal zone carbon cycle research utilizing CiteSpace software to visualize the intellectual structure and evolution of the field from 1999 to 2025. The study categorizes various coastal ecosystems into 12 groups, examining 12,460 documents sourced from the Web of Science databases. The analysis reveals publication dynamics, identifies key publication types, and maps the research topics and cooperation network of participating countries, with a particular focus on the United States and China as leading contributors. The paper also highlights influential authors and thematic clusters within the literature, such as dissolved organic matter, blue carbon, and ocean acidification. The analysis provides a systematic overview of the coastal carbon cycle research field, informing future research directions and policy decisions related to coastal carbon management and climate change mitigation strategies. The study concludes that while significant advancements have been made, there are still considerable gaps and challenges that need to be addressed, emphasizing the potential of coastal ecosystems in mitigating climate change and promoting sustainable development.

Keywords: coastal carbon cycle; knowledge graph analysis; CiteSpace; climate change mitigation

Published: 17 December 2024

1. Introduction

The coastal carbon cycle is a critical component of the Earth's biogeochemical systems, playing a pivotal role in the global carbon balance and climate regulation [1].This paper aims to provide a comprehensive analysis of the current state of research on coastal carbon cycles, leveraging the analytical capabilities of CiteSpace software to visualize and understand the knowledge structure and evolution within this field [2].

Coastal ecosystems, which include mangroves, salt marshes, seagrass beds, and other vegetated and unvegetated systems, are known for their high productivity and carbon sequestration potential [3]. These ecosystems, despite covering only a small fraction of the Earth's surface (5.8%) [4], contribute significantly to the global carbon cycle, accounting for 55.2% of carbon transport from the climate-active carbon cycle to the geological carbon cycle. The coastal zone, influenced by terrestrial and open oceanic reservoirs, is subject to various natural and anthropogenic perturbations, including land-use changes, nutrient inputs, and climate change.

The significance of coastal carbon sinks in mitigating climate change cannot be overstated. Coastal blue carbon ecosystems, such as mangroves, salt marshes, and seagrass beds, are highly efficient at capturing and storing carbon through photosynthesis and slow decomposition in anoxic soils. These ecosystems are integral to international frameworks and conventions aimed at climate change mitigation and adaptation, including the Ramsar Convention and the United Nations Framework Convention on Climate Change [5].

Human activities have significantly impacted the coastal carbon cycle. Inputs of nutrients and organic matter from agriculture and urban runoff have altered the natural balance of carbon in these ecosystems, affecting their ability to act as carbon sinks [6]. Additionally, coastal development and land reclamation have led to the loss of critical coastal habitats, reducing their capacity for carbon sequestration [7].

Climate change further complicates the coastal carbon cycle. Rising sea levels and changes in precipitation patterns affect the distribution and function of coastal ecosystems, potentially altering their role in carbon storage and release [8]. Warmer waters can also enhance the respiration rates of marine organisms, increasing the release of carbon dioxide.

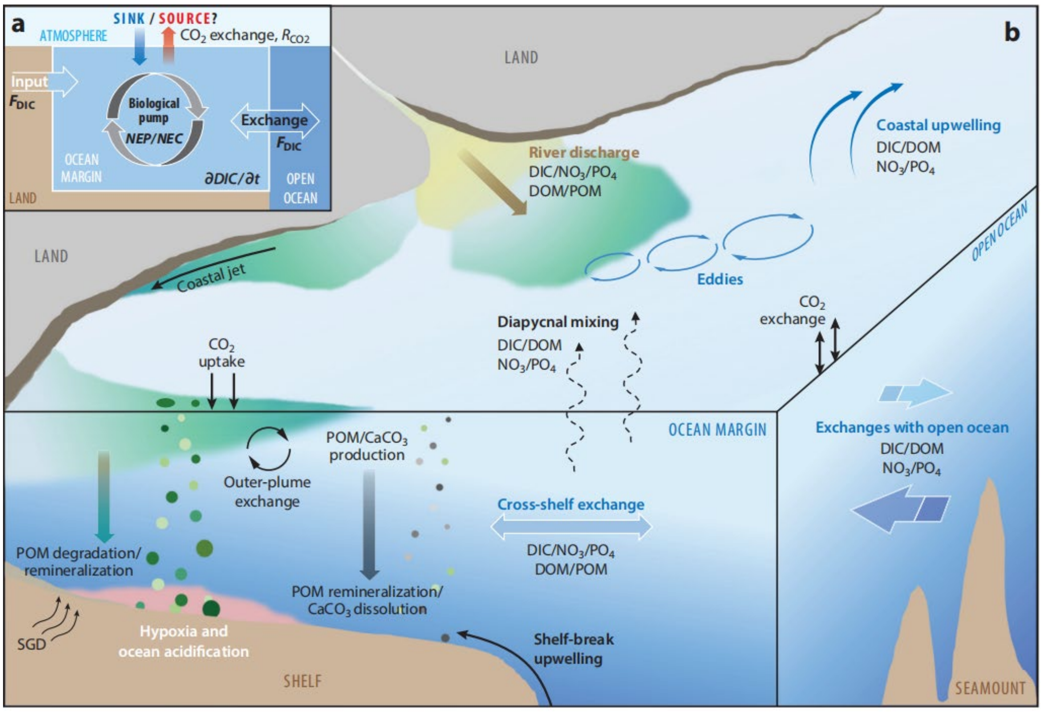

Figure 1. Conceptual schematics of air-sea CO2 exchanges (a) and major physical and biogeochemical processes in the coastal ocean (b), highlighting the transport of matter between land, ocean margin, and open ocean.

The sea-air CO_2 flux (R_{CO2})The sea-air CO_2 flux (R_{CO2}) is balanced by the sum of dissolved inorganic carbon (DIC) inputs and outputs (F_{DIC}) across the boundaries, net ecosystem production (NEP) and net ecosystem calcification (NEC), and the rate of change of DIC over time (dDIC/dt) within the coastal system.

The ocean margin is demarcated by the coastline on the landward side and the open ocean on the seaward side. Rivers discharge DIC, nitrate (NO_3), phosphate (PO_4), dissolved organic matter (DOM), and particulate organic matter (POM) onto the continental shelf through a buoyant plume, and submarine ground discharge (SGD) also supplies significant fluxes of carbon and nutrients to coastal waters. These riverine nutrients enhance phytoplankton growth and POM production in the mid- and far-fields of the plume, which interact with oceanic waters at plume fronts and can extend beyond the shelf break when entrained by sub-meso- and mesoscale eddies. The produced POM sinks and is degraded or remineralized in bottom waters, leading to severe consequences such as hypoxia and ocean acidification (OA). Wind-induced upwelling at the shelf break and in nearshore regions, and upward diapycnal mixing, also supply nutrients as well as DIC and DOM to the surface, facilitating primary production ($POM/CaCO_3$ production). As POM sinks to deep waters, it is remineralized, and calcium carbonate ($CaCO_3$) dissolves. The biogeochemistry of upwelled or upward mixed waters is governed by the exchange of DIC, nutrients, DOM, and/or POM at the ocean margin-open ocean interface. The sea-air CO_2 exchange ultimately depends on the relative supply or consumption of DIC and nutrients due to water mass mixing and intrinsic biological metabolism.Abbreviations: $CaCO_3$, calcium carbonate; DIC, dissolved inorganic carbon; DOM, dissolved organic matter; NEC, net ecosystem calcifcation; NEP, net ecosystem production; NO_3, nitrate; OA, ocean acidifcation; PO_4, phosphate;POM, particulate organic matter; SGD, submarine ground discharge.

This literature analysis will explore the dynamics of the coastal carbon cycle, the impacts of human activities, and the potential for restoration and conservation efforts to enhance the carbon sequestration capacity of coastal ecosystems. By employing CiteSpace, we aim to map the intellectual structure of coastal carbon cycle research, identifying key themes, trends, and gaps in the existing literature. This knowledge graph-based approach will facilitate a more systematic understanding of the field, informing future research directions and policy decisions related to coastal carbon management and climate change mitigation strategies.

2. Data and Methodology

The data were sourced from the Scientific Citation Index Expanded and Emerging Sources Citation Index databases of the Web of Science, covering the period from 1999 to 2025. To ensure clarity, various types of ecosystems were categorized into 12 groups. These ecosystem groups include estuaries and river deltas, continental shelves, coastal sediments and mudflats, lagoons, coral reefs, seaweeds, beaches, mangroves, coastal wetlands and salt marshes, coastal upwellings, seagrass meadows, and a miscellaneous category encompassing coastal canyons, submerged riverbanks, polar ecosystems, shallow nearshore habitats, coastal hydrothermal vents, caves, and hypersaline coasts [9].

The search function was defined as" TS = (((coast* SAME fjord*) OR (coastal SAME upwelling*) OR (shallow SAME nearshore SAME habitat*) OR (hypersaline SAME coast*) OR ((coastal ecosystem*) OR (coastal water*) OR (((large marine ecosystem*) OR LME*) AND coast*)) OR (coral reef*) OR (mangrove*) OR ((coastal sediment*) OR (coastal SAME sediment*)) OR (estuary OR estuaries) OR (shelf OR shelves) OR (lagoon*) OR ((coastal SAME wetland*) OR (coastal AND ((salt?marsh*) OR (mud?flat*)))) OR (river* delta*) OR (coast* SAME canyon*) OR (submerged SAME bank*) OR (beach*) OR ((coast* SAME ((sea ice) OR (polar ecosystem*)))) OR (estuar* SAME plume*) OR ((seagrass* bed*) OR (algal bed*) OR (seagrass* meadow*) OR kelp* OR (macroalgal communit*) OR (microalgal communit*) OR (algal communit*) OR (kelp* forest*) OR (kelp* communit*)) OR (cave*) OR (hydrotherm* SAME coast* SAME vent*) OR (subtidal SAME hydrotherm* SAME area*) OR ((shallow water*) SAME hydrotherm* SAME system*))AND((((coast* not coastral) same flux*) and (carbon dioxide or CO2 or pCO2))OR (((DIC OR (dissolved inorganic carbon*)) OR (DOC OR (dissolved organic carbon*)) OR (dissolved carbon dioxide*))))")' and a total of 12460 documents were collected. The in-depth understanding was assessed based on the following characteristics, including publications, subject categories, countries, authors, and keywords. Frequency calculations, citations, and co-occurrence analysis were performed utilizing CiteSpace (6.4.R1) [10]. Statistical graphs depicting the number of published articles and disciplinary category frequencies were generated using Origin 2021[11].

3. Publication Dynamics

3.1. Publications Analysis

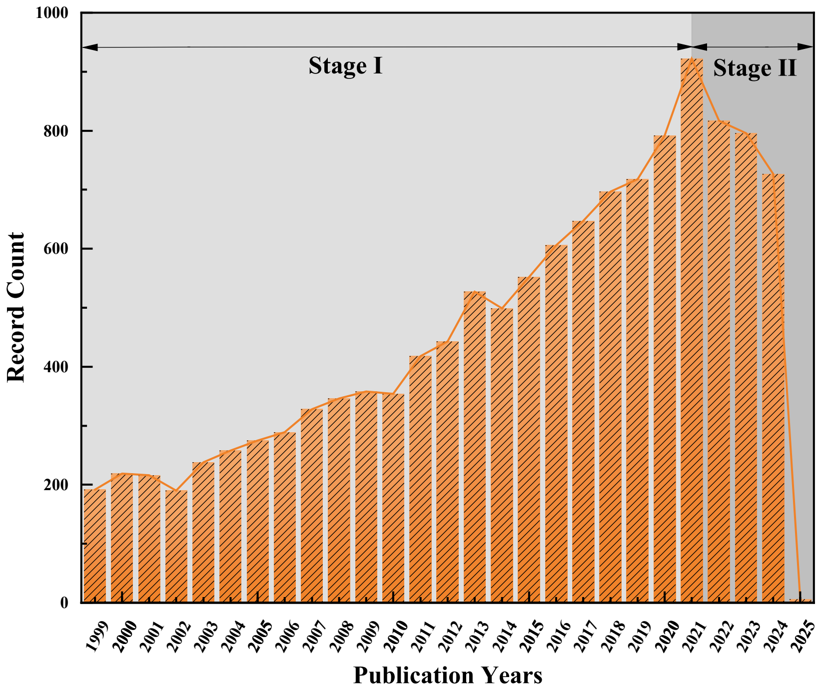

Figure 2. Annual Publication Trends in Coastal Carbon Cycle Research (1999–2025).

Figure 1 illustrates the annual number of publications on coastal carbon cycle research from 1999 to 2025. The development of this field during this period can be divided into two distinct stages. The first stage, spanning from 1999 to 2021, represents a phase of rapid growth. During this time, the number of publications increased significantly, from 192 in 1999 to 922 in 2021, reflecting a sharp rise in scholarly attention and interest. The second stage, from 2021 to the present, marks a period of stable development. Although the annual number of publications has declined slightly from 2021 to 2024, the average remains at 815, substantially higher than the average over the preceding 20 years. This indicates that the field continues to garner considerable scholarly attention and is likely to remain a focus of research in the future [12].

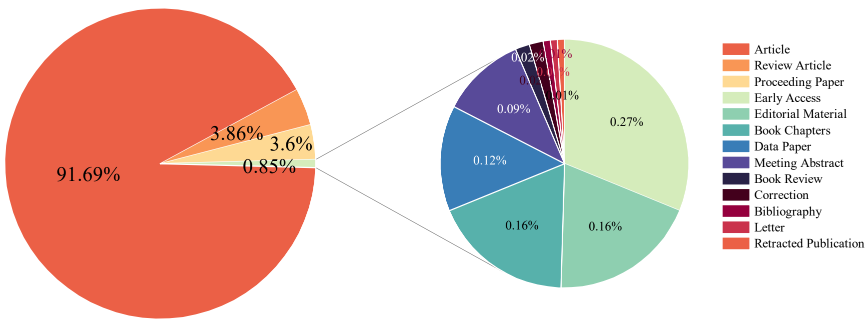

Figure 3. Distribution of 13 Article Types in the Web of Science Database (1999–2025).

A total of 13 publication types were identified in the surveyed literature, as shown in Figure 2. Articles constitute the most common type, with 11,764 publications, accounting for 91.69% of the total. Reviews are the second most prevalent type, comprising 495 publications (3.86%), followed by proceeding papers, with 462 publications (3.60%). The remaining 10 types, including book chapters, meeting abstracts, and editorial materials, collectively account for only 0.85% of the total [13].

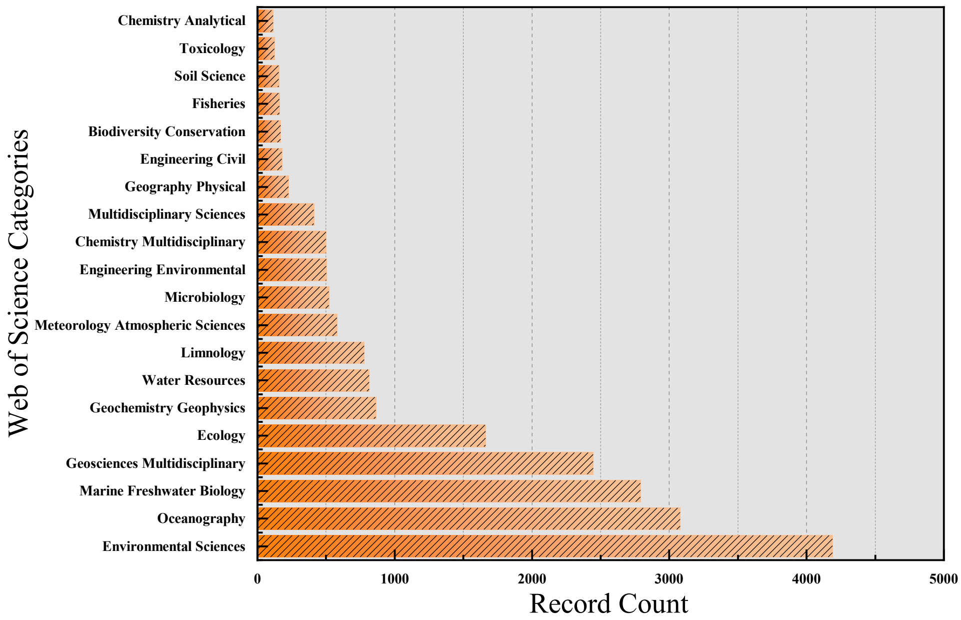

Figure 4. trend of the top 20 published categories in Web of Science.

In coastal carbon cycle research, the top 20 research topics are presented in Figure 3. Among these, environmental science ranks highest, with 4,191 articles (33.72%). This is followed by oceanography, marine and freshwater biology, geosciences multidisciplinary, and ecology [14].

3.2. Publication Performance and Cooperation Network

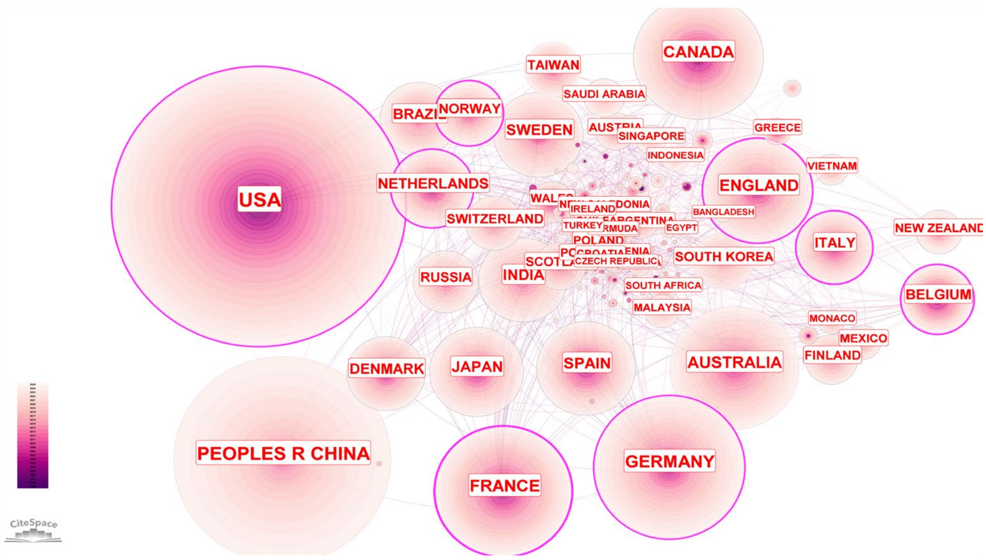

Figure 5. the cooperation network of the countries. (The circle size represents the total publications from a country; the color depicts publication time variation; the thickness of the lines represents the frequency of cooperation).

Between 1999 and 2025, papers on the coastal carbon cycle were published across 149 countries. The United States and China lead in publications, contributing 35.88% and 20.39% of the total, respectively, followed by Germany, France, the United Kingdom, Canada, Australia, and others. Historically, the United States, France, and Germany began extensive research on this topic earlier, while countries such as China, Canada, Australia, Japan, and Spain initiated significant studies later. The figure also highlights frequent international collaboration in coastal carbon cycle research. To achieve a more comprehensive understanding of this field, future efforts should focus on strengthening international cooperation.

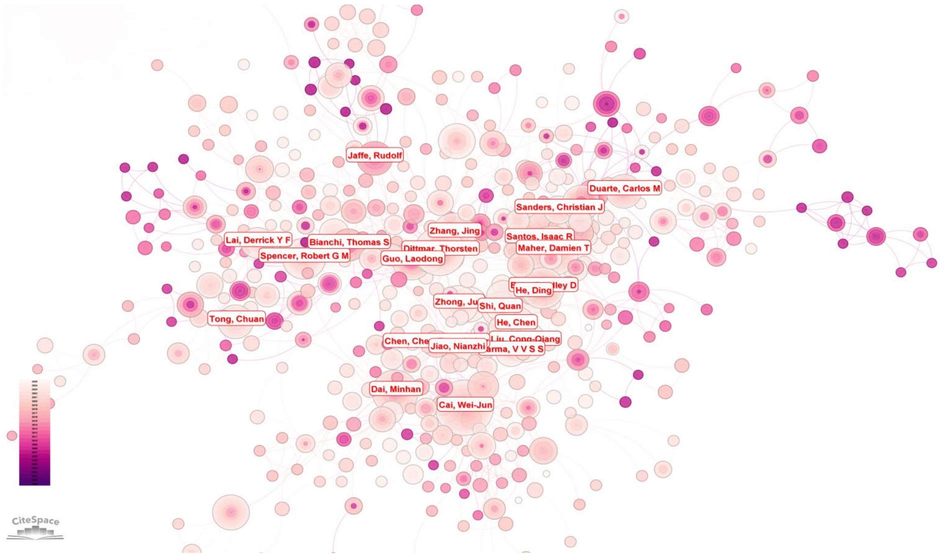

Figure 6. the co-authorship analysis map.

In the field of coastal carbon cycle research, a scientometric analysis has identified key authors whose work significantly shapes the discourse. Prominent among them is Isaac R. Santos, with a substantial citation count of 108, indicating his foundational contributions to understanding carbon dynamics in coastal environments. Wei-Jun Cai, with 106 citations, emerges as another influential figure, particularly in the context of the Chesapeake Bay, suggesting his research has had a broad impact on regional carbon cycle studies.

The analysis also highlights a global perspective, with authors like Robert G. M. Spencer and Cong-Qiang Liu being cited 40 times each, reflecting the international scope of coastal carbon cycle research. Notably, Ding He has experienced a significant burst in citations, with a score of 15.41, indicating a recent and notable influence in the field, likely due to groundbreaking work on carbon evasion rates.

These authors, with their high citation counts and bursts, serve as pivotal nodes in the scholarly network, connecting diverse research areas and indicating the vibrancy of coastal carbon cycle research. Their work not only reflects the current state of knowledge but also points towards future research trajectories, suggesting that the field is dynamic and responsive to new insights and methodologies. This analysis underscores the importance of recognizing and following the lead of these scholars to stay at the forefront of coastal carbon cycle research.

3.3. International research collaboration Analysis

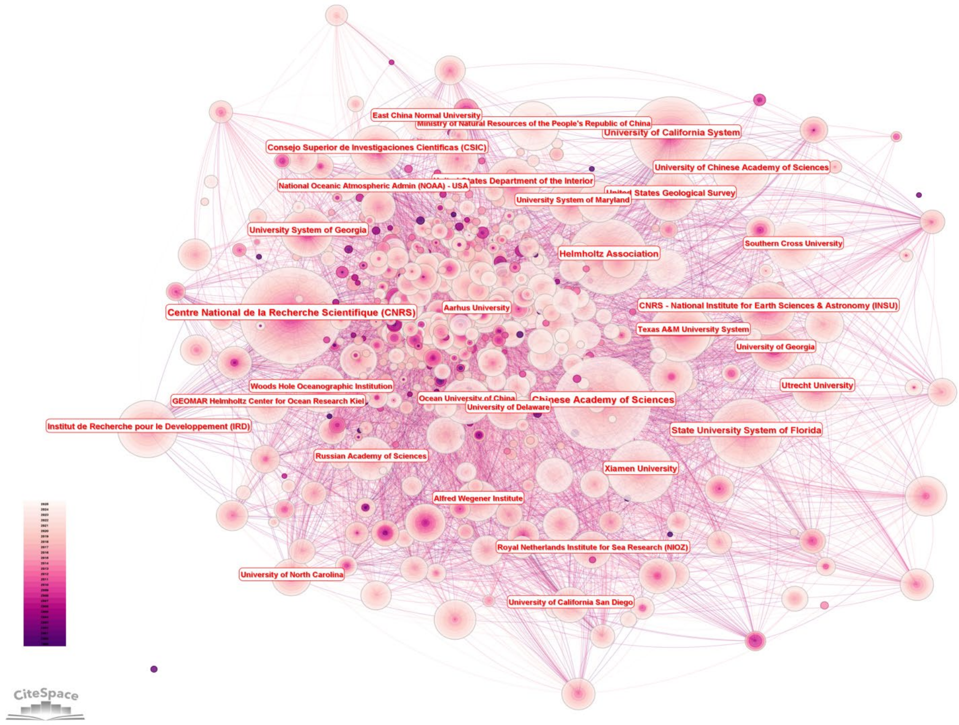

Figure 7. International research collaboration network.

In the academic landscape, the metrics of citation counts, bursts, degree, centrality, and sigma provide a comprehensive view of the influence and impact of various institutions on their respective fields. The image highlights the prominence of the Centre National de la Recherche Scientifique (CNRS), which leads in citation counts and bursts, indicating a significant and consistent contribution to the scientific discourse. This is closely followed by the Chinese Academy of Sciences and the University of California System, further underscoring the global reach and relevance of their research. The degree metric, which measures the number of connections an institution has within the academic network, places Columbia University at the forefront, suggesting its extensive collaborative efforts. Centrality, reflecting an institution's importance within the network, sees CNRS at the top once again, with Columbia University and Sorbonne Universite not far behind, indicating their pivotal roles in shaping academic conversations. Lastly, the sigma metric, which indicates the standard deviation from the mean of an institution's network position, shows that CNRS, Columbia University, and several others maintain a stable and significant presence across clusters. Collectively, these metrics underscore the importance of these institutions in driving academic progress and setting the agenda for future research.

3.4. Keywords Analysis

The network of paper analyzed consists of 12 distinct clusters, each representing a thematic grouping of publications and citations. Cluster #0, the most significant with 108 documents, is characterized by a silhouette value of 0.714, indicating a cohesive group of articles. This cluster is dominated by the theme of dissolved organic matter, which has garnered a substantial citation count of 482, highlighting its central role in the discourse.

Notably, the articles by Soares, ARA (2019) and Dittmar, T (2003) are among the major citing articles, suggesting their influential positions within the cluster.

Table 1. Summary of the largest 12 clusters.

ClusterID	Clusters	Size	Silhouette	Average Year
0	dissolved organic matter	108	0.714	2008
1	blue carbon	93	0.614	2015
2	dissolved inorganic carbon	89	0.647	2011
3	ocean acidification	87	0.766	2012
4	dissolved organic carbon	73	0.637	2009
5	organic carbon	63	0.684	2011
6	Organic matter	60	0.712	2008
7	gulf of cadiz	34	0.862	2012
8	remote sensing	32	0.877	2011
9	artificial neural network	8	0.955	2020
10	humic lakes	5	0.989	2010
11	biogeochemical cycles	5	0.973	2007

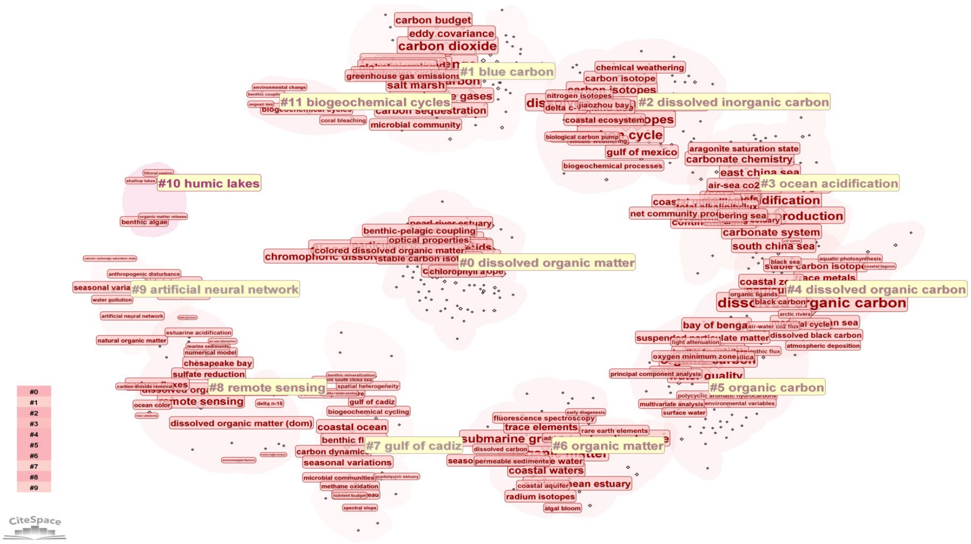

Figure 8. Top 12 cluster of keywords co-occurrence map.

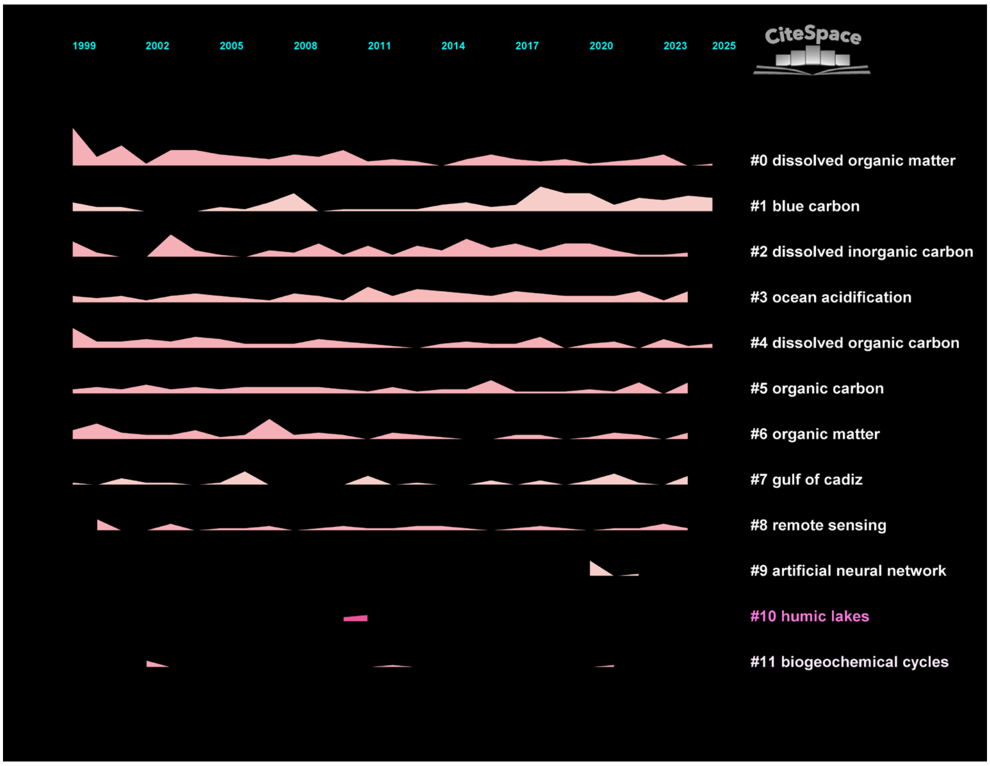

Figure 9. the timeline view of keywords of top 12 cluster.

Further analysis of the clusters reveals a thematic progression over time. For instance, Cluster #1, with 93 documents and a silhouette value of 0.614, focuses on climate change-related topics, with 'carbon dioxide' and 'climate change' being the most cited terms. The prominence of these terms, along with the citation burst of 'blue carbon', suggests an increasing research interest in the intersection of coastal carbon cycling and climate change mitigation strategies.

Cluster #2, with 89 documents, emphasizes stable isotopes and the carbon cycle, indicating a methodological focus on tracing carbon fluxes within coastal ecosystems. The average publication year of these clusters provides insights into the temporal development of research interests, with Cluster #2 documents published around 2011, suggesting a maturation of isotope tracing methodologies during that period.

The analysis also underscores the multidisciplinary nature of coastal carbon cycle research. For example, Cluster #3, with 87 documents, includes terms like 'ocean acidification' and 'primary production', pointing to the integration of chemical and biological perspectives in understanding coastal carbon dynamics. The citation counts and bursts within these clusters indicate not only the volume of research but also the intensity of scholarly attention, with 'blue carbon' in Cluster #1 and 'bacterial production' in Cluster #0 exhibiting significant bursts, reflecting their emergence as focal points in recent years.

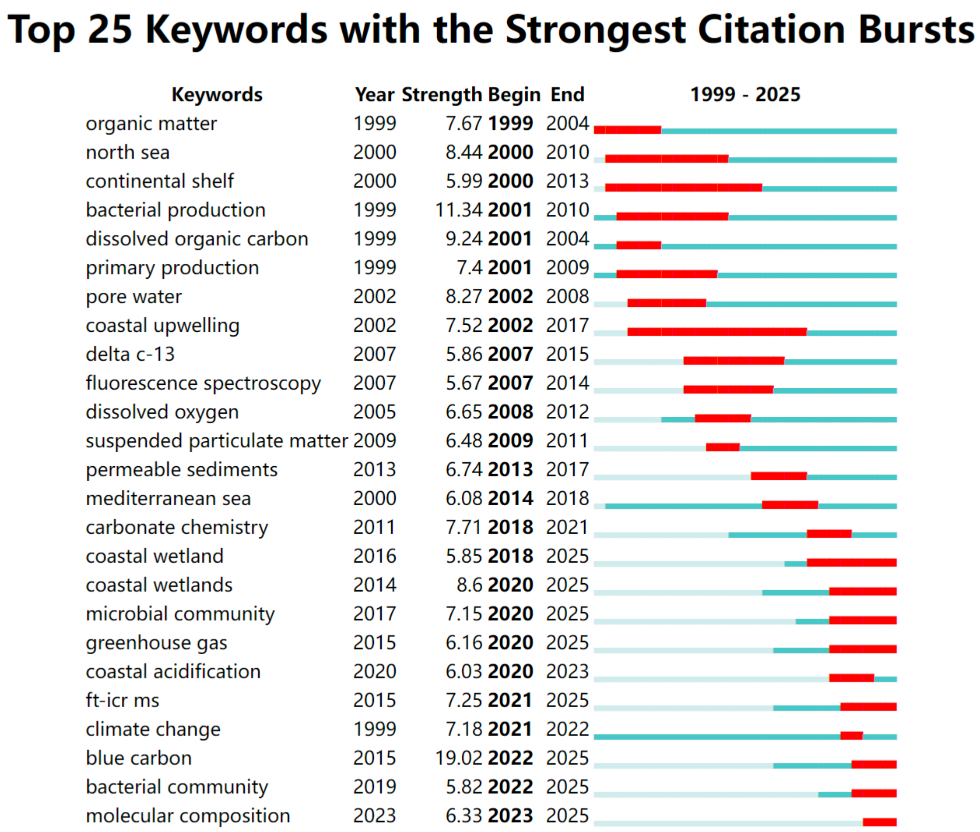

Figure 10. WoS key words emergence map.

The image illustrates the top 25 keywords that have experienced the strongest citation bursts between 1999 and 2025, indicating periods of heightened research interest and activity. Each keyword is associated with a specific year when the burst began, its strength, and the duration of the burst. For instance, the keyword "bacterial production" shows the highest strength of 11.34, beginning in 2001 and lasting until 2010, suggesting a significant research focus on the role of bacteria in carbon cycling during that period. Similarly, "blue carbon" emerges as a recent area of intense interest, with a strength of 19.02, starting in 2022 and projected to continue through 2025. This reflects a growing awareness and study of the carbon sequestration potential of coastal vegetation.

The timeline of the bursts also reveals shifting research priorities. Early on, from 1999 to 2004, "organic matter" and "dissolved organic carbon" were prominent, highlighting the foundational studies on the basic components of the carbon cycle. As the field matured, there was a shift towards more specific and applied topics, such as "coastal wetlands" and "microbial community," which began their bursts in 2014 and 2017, respectively, and are still ongoing.

The image serves as a visual representation of the dynamic nature of scientific inquiry, with research foci expanding and intensifying over time. It underscores the importance of identifying and understanding these trends to inform future research directions and policy decisions related to coastal zone carbon cycle management.

In summary, the CiteSpace analysis depicts a dynamic and evolving research landscape in coastal carbon cycling, with key terms and clusters reflecting the field's core themes and burgeoning areas of interest. The visual and data-driven approach of CiteSpace has allowed for the identification of knowledge gaps, trends, and potential areas for future research, providing a valuable tool for both researchers and policymakers in navigating the complex terrain of coastal carbon cycle science [15].

The coastal carbon cycle is a complex and dynamic system that plays a crucial role in global carbon balance and climate regulation[16,17]. Despite significant advancements in our understanding of these systems, there are still considerable gaps and challenges that need to be addressed. Future research should focus on enhancing our understanding of coastal carbon dynamics, developing standardized monitoring protocols, and integrating socioeconomic factors into coastal carbon management. By addressing these challenges, we can better harness the potential of coastal ecosystems in mitigating climate change and promoting sustainable development [18-20].

4. Conclusion

This literature analysis provides a comprehensive overview of the current state of research on coastal carbon cycles, highlighting the key themes, trends, and gaps in the existing literature. The use of CiteSpace software to generate a knowledge graph has facilitated a more systematic understanding of the field, informing future research directions and policy decisions related to coastal carbon management and climate change mitigation strategies.

This paper presents a comprehensive literature analysis of coastal zone carbon cycle research through the lens of knowledge graph analysis using CiteSpace software. The study spans a period from 1999 to 2025, encompassing a total of 12,460 documents sourced from the Web of Science databases. The analysis categorizes various coastal ecosystems and biogeochemical processes into 12 groups, providing a structured approach to understanding the intellectual structure and evolution of the field.

The paper delineates the publication dynamics, identifying key publication types, the distribution of research topics, and the performance and cooperation network of countries involved in coastal carbon cycle research. It highlights the United States and China as leading contributors, emphasizing the importance of international collaboration in advancing the field.

Furthermore, the analysis reveals the most influential authors and their contributions, such as Isaac R. Santos and Wei-Jun Cai, whose work has significantly impacted the discourse on coastal carbon dynamics. The study also identifies thematic clusters that represent the central topics within the literature, including dissolved organic matter, blue carbon, and ocean acidification, among others.

In conclusion, this literature analysis offers a systematic overview of the coastal carbon cycle research field, highlighting key themes, trends, and research gaps. By employing a knowledge graph-based approach, the study informs future research directions and policy decisions, emphasizing the potential of coastal ecosystems in climate change mitigation and sustainable development.

References

1. B. M. T. Brett, S. E. Bunn, S. Chandra, et al., "How important are terrestrial organic carbon inputs for secondary production in freshwater ecosystems?" *Freshwater Biol.*, vol. 62, no. 5, 2017, DOI: 10.1111/fwb.12909.
2. J. A. Raven, C. J. Gobler, and P. J. Hansen, "Dynamic CO2 and pH levels in coastal, estuarine, and inland waters: Theoretical and observed effects on harmful algal blooms," *Elsevier*, 2020, DOI: 10.1016/j.hal.2019.03.012.
3. C. Lnborg, C. Carreira, T. Jickells, et al., "Impacts of global change on ocean dissolved organic carbon (DOC) cycling," *Front. Mar. Sci.*, vol. 7, 2020, DOI: 10.3389/fmars.2020.00466.
4. N. D. Ward, J. P. Megonigal, B. Bond-Lamberty, et al., "Representing the function and sensitivity of coastal interfaces in Earth system models," *Nat. Commun.*, vol. 11, no. 1, pp. 2458, 2020, DOI: 10.1038/s41467-020-16236-2.
5. P. Regnier, L. Resplandy, R. G. Najjar, et al., "The land-to-ocean loops of the global carbon cycle," *Nature*, Dec. 16, 2024, DOI: 10.1038/s41586-021-04339-9.
6. N. D. Ward, T. S. Bianchi, P. M. Medeiros, et al., "Where carbon goes when water flows: Carbon cycling across the aquatic continuum," *Front. Mar. Sci.*, vol. 4, no. 7, 2017, DOI: 10.3389/fmars.2017.00007.
7. A. Pessarrodona, R. M. Franco-Santos, L. S. Wright, et al., "Carbon sequestration and climate change mitigation using macroalgae: A state of knowledge review," *Biol. Rev. Camb. Philos. Soc.*, 2023, DOI: 10.1111/brv.12990.

8. Dai M, Su J, Zhao Y, et al., "Carbon fluxes in the coastal ocean: synthesis, boundary processes, and future trends," *Annual Review of Earth and Planetary Sciences*, vol. 50, no. 1, pp. 593-626, 2022.
9. C. Chen and M. Song, "Visualizing a field of research: A methodology of systematic scientometric reviews," *PLoS One*, vol. 14, no. 10, e0223994, 2019, DOI: 10.1371/journal.pone.0223994.
10. ZHANG Q, ZHOU Y, GUO Lanxuan, et al., "Intelligent application of knowledge graphs in mineral prospecting: A case study of porphyry copper deposits in the Qin-Hang metallogenic belt," *Earth Science Frontiers*, vol. 31, no. 4, pp. 7-15, 2024.
11. D. Alongi, "Carbon cycling in the world's mangrove ecosystems revisited: Significance of non-steady state diagenesis and sub-surface linkages between the forest floor and the coastal ocean," *Front. Mar. Sci.*, 2020, DOI: 10.3390/f11090977.
12. A. Yamuza-Magdaleno, R. Jiménez-Ramos, I. Casal-Porras, et al., "Long-term sediment organic carbon remineralization in different seagrass and macroalgae habitats: Implication for blue carbon storage," *Front. Mar. Sci.*, 2024, DOI: 10.3389/fmars.2024.1370768.
13. H. Wang, X. Tang, J. Chen, et al., "Comparative studies on the response of Zostera marina leaves and roots to ammonium stress and effects on nitrogen metabolism," *Aquat. Toxicol.*, vol. 105965, 2021, DOI: 10.1016/j.aquatox.2021.105965.
14. F. Roth, E. Broman, X. Sun, et al., "Methane emissions offset atmospheric carbon dioxide uptake in coastal macroalgae, mixed vegetation and sediment ecosystems," *Nat. Commun.*, Dec. 16, 2024, DOI: 10.1038/s41467-022-35673-9.
15. T. Rixen, "Past changes in and present status of the coastal carbon cycle," *Cambridge Prisms: Coastal Futures*, vol. 1, 2023, DOI: 10.1017/cft.2023.20.
16. V. L. M. B. Ver, F. T. Mackenzie, and A. Lerman, "Carbon cycle in the coastal zone: Effects of global perturbations and change in the past three centuries," *Chem. Geol.*, vol. 159, no. 1, pp. 283–304, 1999, DOI: 10.1016/S0009-2541(99)00042-X.
17. ZHU B, CAO W, YU P, et al., "Research hotspots and cutting-edge analysis of geological big data and artificial intelligence based on CiteSpace," *Earth Science Frontiers*, vol. 31, no. 4, pp. 073-086, 2024.
18. Zhang Q, Zhou Y, He J, et al., "A Review on Global Cooperation Network in the Interdisciplinary Research of Geo-chemistry Combined with Artificial Intelligence," *Minerals*, vol. 13, no. 10, 2023, DOI: 10.3390/min13101332.
19. Han F, Deng Y, Liu Q, et al., "Construction and application of the knowledge graph method in management of soil pollution in contaminated sites: A case study in South China," *J. Environ. Manage.*, vol. 319, 2022, p. 115685.
20. C. Chen, "System and method for automatically generating systematic reviews of a scientific field," U.S. Patent US8566360 B2, Dec. 16, 2024.