The role of estuarine wetland in carbon storage for climate change mitigation : A bibliometric analysis

Hery Fajeriadi[1*], *Fahmi* Fahmi[2], *Dharmono* Dharmono[1], *Muhammad* Zaini[1], *Aminuddin Prahatama* Putra[1], *Suyidno* Suyidno[3], *Yudha* Irhasyuarna[2], *Suryajaya* Suryajaya[4], and *Much. Fuad* Saifuddin[5]

[1]Department of Biology Education, Universitas Lambung Mangkurat, Banjarmasin, Kalimantan Selatan, Indonesia
[2]Department of Science Education, Universitas Lambung Mangkurat, Banjarmasin, Kalimantan Selatan, Indonesia
[3]Department of Physics Education, Universitas Lambung Mangkurat, Banjarmasin, Kalimantan Selatan, Indonesia
[4]Department of Physics, Universitas Lambung Mangkurat, Banjarbaru, Kalimantan Selatan, Indonesia
[5]Faculty of Teacher Training and Education, Universitas Ahmad Dahlan, Yogyakarta, Daerah Istimewa Yogyakarta, Indonesia

Abstract. The 2023 progress report on the Sustainable Development Goals (SDGs) is weak, even regressing, including key targets related to climate change, and at risk of failure. Estuarine ecosystems dominated by mangrove vegetation are critical for climate change mitigation. However, these ecosystems continue to be degraded at multiple levels. Indonesia, with the largest mangrove forest area in the world, requires conservation and restoration efforts to effectively mitigate climate change impacts. This study aims to analyze the role of estuarine ecosystems in storing carbon for climate change mitigation. This research uses bibliometric analysis method to produce an in-depth and comprehensive analysis. The data source is the Scopus database, visualized using the VOSviewer application. After limitation, 219 out of 1485 documents that fit the inclusion criteria were obtained. The results showed a significant increase in interest in the topic of the role of estuarine ecosystems for climate change mitigation in the last two years. This research underscores the importance of mangroves restoration in estuarine ecosystems, as their condition has significant impacts on climate change and coastal communities. Nature-based solutions such as the use of green energy, implementation of new technologies such as remote monitoring, and ecosystem balance-based policy-making are recommended. The integration of multi-disciplinary and multi-technology approaches is crucial to build resilient, natural estuarine ecosystems and restore ecosystem services. These findings can also provide a scientific basis for the management of estuarine ecosystems to support SDG 13 Climate Action.

* Corresponding author: heryfaje@gmail.com

1 Introduction

The Sustainable Development Goals (SDGs) 2023 report warns that halfway through the 2030 Agenda, more than half the world has fallen behind. Progress on more than 50% of the SDG targets remains weak, and 30% have regressed, including critical targets on poverty, hunger and climate. Without urgent action, the 2030 Agenda risks failure [1]. The eight years since the Paris Agreement came into force have been the hottest on record and carbon emissions and temperatures continue to rise [2]. It is no longer possible to separate climate change from sustainable development because 80% of the SDGs targets are directly related to climate change, symbolized by SDG 13 Climate Action [3,4]. Based on this analysis, the SDGs still need support and contributions from various parts of the world.

Coastal communities suffer from the impacts of climate change, such as coastal flooding and erosion, sea and river overflows, heat waves, cold weather, droughts and landslides. These climate change impacts pose additional challenges and major impacts to coastal areas [5]. Studies on climate change and environmental threats are expanding towards ecosystem services in the last decade, especially with regard to mangrove forests [6]. Mangroves are the dominant vegetation in estuarine ecosystems. The influence of climate change on estuarine ecosystem structure and function has been a dominant topic in estuarine shoreline studies since 2004. Estuarine wetland habitats around the world are currently degraded to varying degrees [7]. Estuarine ecosystems have great potential to be a natural solution to climate change, and are widely distributed in tropical countries.

Indonesia as one of the tropical countries located on the earth's equator experiences dry and rainy seasons throughout the year. The abundance and biodiversity of the tropics have been well documented [8]. The Global Mangrove Alliance (GMA) 2022 presented that Southeast Asia is home to the most extensive mangrove forests, with Indonesia accounting for one-fifth of the world's total mangrove area [9]. However, the country with the largest mangrove cover in the world is experiencing the highest mangrove loss mainly due to conversion of mangroves into ponds [10]. Based on previous research, mangroves cover 2.6% of Indonesia's total forest area. However, mangrove degradation and deforestation account for 10% of total greenhouse gas emissions arising from the forestry sector [11]. The rehabilitation and conservation of mangroves in Indonesia are crucial as they will have positive impact on 74 millions coastal residents and have the potential to contribute to a reduction of up to 16% in national land-sector emissions [12]. The large source of greenhouse gas emissions from this small forest area, the well-documented biodiversity of mangroves, and their significant benefits to society and the environment underpin the importance of incorporating mangroves in estuarine ecosystem as nature-based solution for climate change mitigation.

This research aims to conduct an in-depth analysis of the role of estuarine ecosystems, with most studies on this topic focusing on the potential of mangroves as the dominant vegetation for climate change mitigation. The analysis is carried out using bibliometric methods to examine publication patterns and research trends on this subject. The Scopus database, as a large source of reputable research publications, serves as the primary data source. Bibliometric analysis is used to thoroughly examine the relationship between one topic and another, supporting multidisciplinary analysis and producing more comprehensive findings [13,14].

The need for global support to optimize the achievement of the SDGs, the potential of estuarine ecosystems represented by mangrove vegetation in carbon storage, and the necessity for in-depth analysis to produce more comprehensive findings form the basis for

this research. The study aims to analyze, using bibliometric methods, the role of estuarine wetlands in carbon storage for climate change mitigation.

2 Material and Methods

This research is a literature study with a bibliometric analysis approach. Bibliometric analysis is used to describe the relationship between several topics and show research trends on certain topics based on the database. The database that is the source of data in this study is the Scopus database with the largest source of reputable international publication data. This data collection begins with searching for articles that match the topic "The role of estuarine ecosystems in carbon storage for climate change mitigation" on the page https://www.sciencedirect.com/. Initial search results obtained 1485 scientific papers that have been published on the page. Limitation is done according to Table 1. After limitation, the eligible search data is 219 documents.

Table 1. Limitation of articles based on inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Article access	Open access	No open access
Range of years	2014-2024*	Over the past 11 years
Document types	Review articles and research articles	Other than review articles and research articles

Notes: * = in 2024, the data are documents published until September 30, 2024

The collected database was exported. The database was visualized using the VOSviewer application. The results of the visualization were analyzed descriptively to answer questions about keyword trends and research shifts from year to year. The analysis continued by examining the 10 articles with the most citations. The article analysis was aimed at describing the perceptions of each researcher related to the topic "the role of estuarine ecosystems in carbon storage for climate change mitigation".

The stages and conditions of visualization using the VOSviewer Application are selecting Create a map based on text data at the Choose type of data stage, selecting Read data from reference manager files at the Choose data source stage, selecting files with RIS format that have been saved through the Scopus database export, selecting Title and abstract fields at the Choose fields stage, selecting Binary counting at the Choose counting method stage, the minimum number of occurrences of a term at the Choose threshold stage is 10, and the Number of terms to be selected at the Choose number of terms stage is 85 as 60% most relevant terms. The research stage is presented in Figure 1.

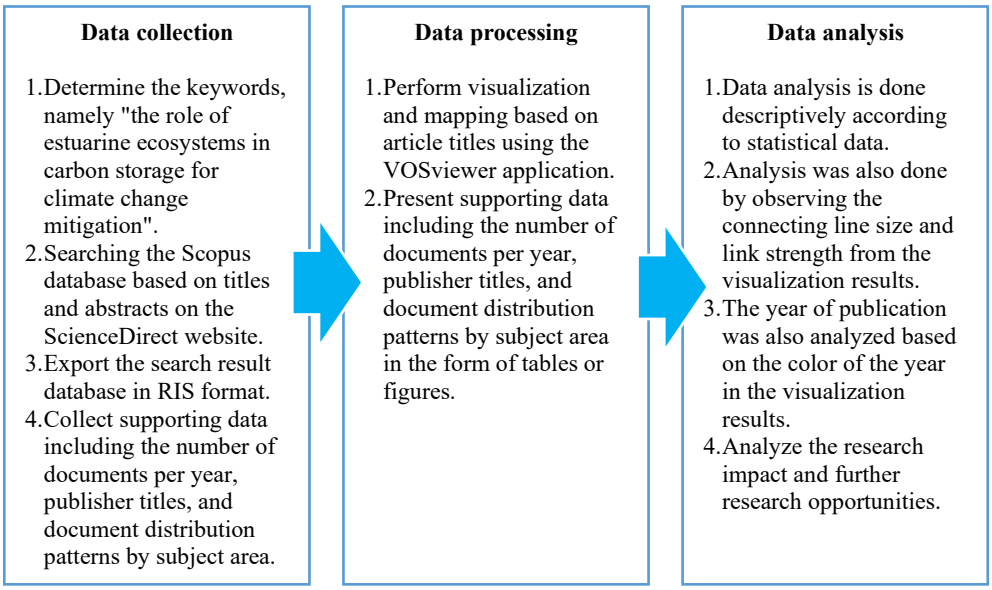

Fig. 1. Phases of bibliometric research

3 Results and Discussion

The results show an increase in attention to the topic “the role of estuarine ecosystems in carbon storage for climate change mitigation” from year to year. The total documents are divided into two types of documents, 68 review articles and 151 research articles. The stretched linear line indicates a spike in research in the last two years that is higher than the average annual increase (Figure 2).

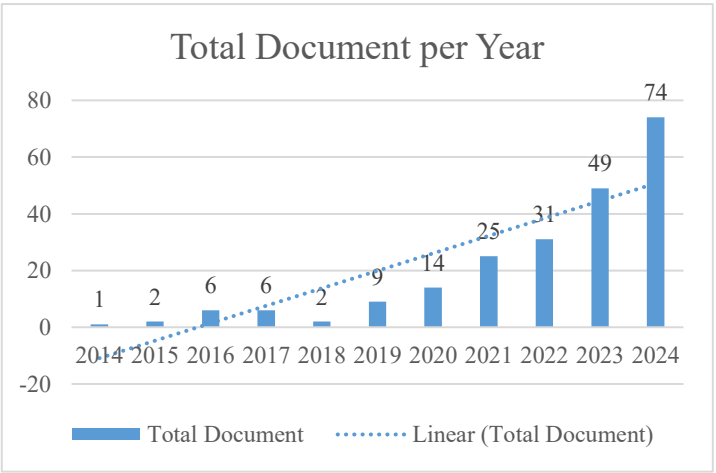

Fig. 2. Number of publications that tend to increase from year to year

The total documents were published to 25 publishers according to the information in Table 2. Then based on the subject area, the total documents are divided into 10 fields presented in Figure 3.

Table 2. List of 25 publisher titles and total documents published

Publication Title	Document	Publication Title	Document
Science of The Total Environment	33	Chemosphere	3
Estuarine, Coastal and Shelf Science	20	Environmental Science & Policy	3
Ecological Indicators	14	Ecotoxicology and Environmental Safety	3
Ocean & Coastal Management	9	Ecosystem Services	3
Marine Pollution Bulletin	8	One Earth	3
Earth-Science Reviews	7	Environmental Reviews	3
Heliyon	7	Aquatic Toxicology	2
Marine Policy	6	CATENA	2
Geoderma	4	Marine Environmental Research	2
Progress in Oceanography	4	Environmental Pollution	2
International Journal of Applied Earth Observation and Geoinformation	4	Geochimica et Cosmochimica Acta	2
Journal of Hydrology: Regional Studies	4	Journal of Environmental Management	2
Remote Sensing of Environment	3		

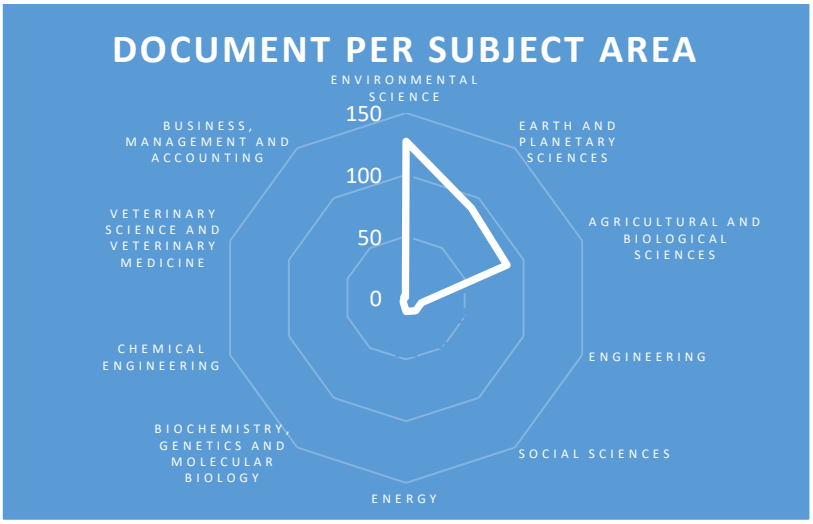

Fig. 3. Document distribution pattern by subject area

Based on Table 2, the topic of the role of estuarine ecosystems in carbon storage for climate change mitigation is mostly published in journals whose focus and scope are the environment and coastal ecosystems. This is evidenced by Science of The Total Environment publishing 33 documents being the most, followed by Estuarine, Coastal and Shelf Science with 20 documents, and Ecological Indicators with 14 documents completing in third position. Other publication titles are also dominated by environment and coastal, both in general scope and focused on one particular study such as ecology, toxicology, marine, and ecosystem services. This result is supported by the subject area graph in Figure 3 which shows that environmental science is the largest with 127 documents, followed by earth and planetary sciences with 90 documents, then agricultural and biological sciences in third position with 86 documents. Previous research also shows environmental science as the most popular category in this discussion with the percentage of articles related to mangroves, salt

marshes, and seagrasses at 63.87%, 40.36%, and 40.65% respectively [15]. Another study also proved that Science of The Total Environment published the most papers out of 524 journals that were screened [16]. Other studies also related to environmental science have also described a recent growth in research interest focused on mangrove conservation, restoration, and around 2019, and underscored the importance of focusing future research on mangrove ecosystem services [6].

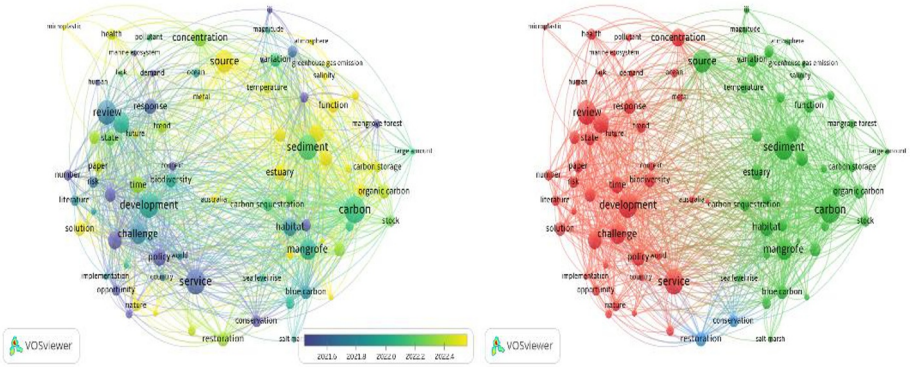

Fig. 4. Visualization results of the collapsed Scopus database

The results of the database visualization are presented in Figure 4 which contains information about the keyword relationship of research topics and the shifting focus of research trends from year to year. This visualization shows three main clusters related to ecological studies and environmental management. The green cluster focuses on ecosystem carbon and sediment functions, with topics such as carbon sequestration, mangrove habitats, estuaries and carbon storage. The red cluster examines environmental management challenges and policies, covering literature reviews, environmental risks, and policy development related to ecosystem services. Meanwhile, the blue cluster highlights ecosystem restoration topics, including conservation efforts and restoration opportunities, particularly in wetland ecosystems such as mangroves and swamps. Overall, these three clusters indicate a focus on the interactions between carbon, ecosystems, environmental policy challenges, and restoration strategies to climate change mitigation. The research topics most relevant to climate change mitigation are shown in Figure 5.

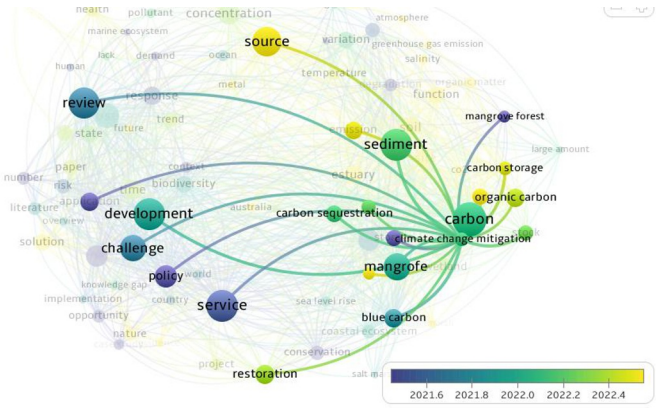

Fig. 5. Research keywords related to climate change mitigation

Based on Figure 5, climate change mitigation is related to several topics including "source", "review", "application", "development", "challenge", "policy", "service", "restoration", "carbon sequestration", "emission", "capacity", "sediment", "mangrofe", "blue carbon", "carbon", "organic carbon", "carbon storage", "mangrove forest", "ability", "stock", and "biomass". Recent trends in research on climate change mitigation are about climate change sources, emissions, carbon storage capability, organic carbon, and biomass. Fossil fuels and deforestation as sources of carbon emissions are the main focus in climate change mitigation [17]. This step needs to be supported by technological development in the field of mitigation, such as the use of clean energy, carbon storage technology, and ecosystem restoration approaches [18,19]. Managing these emission sources, increasing renewable energy and ecosystem restoration are important steps to reduce the impacts of climate change.

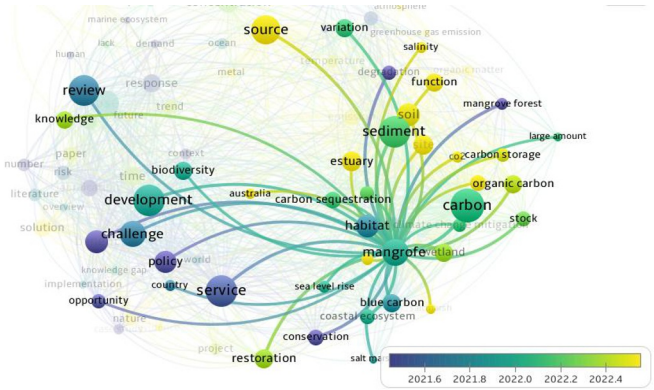

Fig. 6. Research keywords related to mangrove as dominant vegetation on estuarine

Restoration of ecosystems such as mangrove forests and wetlands play an important role in carbon sequestration, especially blue carbon, and reducing emissions [20,21]. Mangroves are specifically mentioned in climate change mitigation studies. A more focused discussion on estuarine is represented by mangroves as the dominant vegetation that occupies this ecosystem. Based on Figure 6, the most recent topics discussed related to mangroves are "source", "Australia", "estuary", "salinity", "function", "soil", "CO_2", "site", "carbon storage", "saltmarsh", "ability", and "biomass". Based on previous research, soil, CO2, function, and ability are related to the organic carbon storage ability of ecosystem [22,23]. Restoration of degraded land as mangrove and saltmarsh are key in storing organic carbon and increasing carbon storage capacity. Mangroves, saltmarshes and seagrasses are considered effective nature-based approaches to climate change mitigation through blue carbon sequestration [15,24].

The increasing productivity of publications addressing this topic demonstrates the great interest in land restoration [6], application of new technologies [25], and policy making that supports ecosystem balance [9] to support climate change mitigation. Restoration of ecosystems such as mangroves is a strategic step that not only strengthens natural carbon sequestration but also contributes to global climate stability [26]. In addition to ecosystem restoration, ecosystem monitoring using remote monitoring technology has also proven effective for observing mangrove reduction and development, as well as changes in water quality [8,27,28]. These facts and strategies also need to be addressed in science learning so that future natural resources realize the urgency of environmental issues [29–31].

Based on the analysis of publication productivity per year, the publisher who publishes the most documents, distribution patterns based on subject areas, and visualization results on the topic "the role of estuarine ecosystems in carbon storage for climate change mitigation",

there is increasing research and attention on estuarine ecosystems, especially mangroves, as a natural solution to climate change, in line with the goal of SDG 13 Climate Action which focuses on urgent action to address climate change and its impacts. These ecosystems are considered capable of storing carbon naturally, which makes them an important solution in reducing emissions. These solutions involve land restoration, implementation of new technologies, and pro-ecosystem balance policy making to support climate change mitigation.

4 Conclusion

The conclusion of this discussion is that the role of estuarine ecosystems, especially mangrove forests and wetlands, in carbon storage is very important in mitigating climate change. Based on the data analyzed, this topic is most widely published in journals with a focus on coastal environments and ecosystems. The three main clusters identified through data visualization reflect the research focus on ecosystem function and carbon storage, environmental management policy challenges, and ecosystem restoration efforts. Mangroves and other vegetation such as salt marsh and seagrass are key in nature-based approaches to blue carbon sequestration, which play an important role in reducing emissions and supporting climate change mitigation. In addition, the research also underscores the importance of managing emission sources such as fossil fuels and deforestation, as well as improving mitigation technologies through clean energy and ecosystem restoration. Nature-based solutions, protection of ecosystems, implementation of new technologies, and pro-ecosystem balance policy making are needed to combat the impacts of climate change to support the achievement of SDG 13.

References

1 The-Sustainable-Development-Goals-Report-2023, (n.d.).
2 Seeking Synergy Solutions A New Financial System to Enable Both Climate and SDG Action, (2024)
3 F. Fuso Nerini, B. Sovacool, N. Hughes, L. Cozzi, E. Cosgrave, M. Howells, M. Tavoni, J. Tomei, H. Zerriffi, and B. Milligan, Connecting climate action with other Sustainable Development Goals, Nat Sustain **2**, 674 (2019)
4 Seeking Synergy Solutions Integrating Climate and SDG Knowledge and Data for Action, (2024)
5 E. Laino and G. Iglesias, Scientometric review of climate-change extreme impacts on coastal cities, Ocean Coast Manag **242**, 106709 (2023)
6 S. Tasneem and Md. N. Ahsan, A bibliometric analysis on mangrove ecosystem services: Past trends and emerging interests, Ocean Coast Manag **256**, 107276 (2024)
7 L. Long, J. Bai, T. Xie, C. Xiao, G. Zhang, and G. Chen, Living estuarine shorelines as nature-based green engineering for coastal stabilization: A scientometric analysis, Ecol Eng **208**, 107361 (2024)
8 S. Mohd Razali, M. A. Radzi, A. Marin, and Z. Samdin, *A Bibliometric Analysis of Tropical Mangrove Forest Land Use Change from 2010 to 2020*, Environment, Development and Sustainability.
9 J. Husna, I. Wijayanti, L. Budiastusi Wiratmo, S. Indrahti, A. Naryoso, N. Edzan Che Nasir, M. Patria Ratna, B. Mulyaning Andini, and D. Raihan Putra Ratarno, *Mapping the Scientific Literature on Mangrove Conservation in Indonesia: A Bibliometric*

Analysis to Environmental Research, in *E3S Web of Conferences*, Vol. 448 (EDP Sciences, 2023)
10 V. B. Arifanti, *Mangrove Management and Climate Change: A Review in Indonesia*, in *IOP Conference Series: Earth and Environmental Science*, Vol. 487 (Institute of Physics Publishing, 2020)
11 V. B. Arifanti, J. B. Kauffman, J. B. Subarno, M. Ilman, A. Tosiani, and N. Novita, Contributions of mangrove conservation and restoration to climate change mitigation in Indonesia, Glob Chang Biol **28**, 4523 (2022)
12 S. D. Sasmito, M. Basyuni, A. Kridalaksana, M. F. Saragi-Sasmito, C. E. Lovelock, and D. Murdiyarso, Challenges and opportunities for achieving Sustainable Development Goals through restoration of Indonesia's mangroves, Nat Ecol Evol **7**, 62 (2023)
13 P. Ülker, M. Ülker, and K. Karamustafa, Bibliometric analysis of bibliometric studies in the field of tourism and hospitality, Journal of Hospitality and Tourism Insights **6**, 797 (2023)
14 N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, How to conduct a bibliometric analysis: An overview and guidelines, J Bus Res **133**, 285 (2021).
15 L. Jiang, T. Yang, and J. Yu, Global trends and prospects of blue carbon sinks: a bibliometric analysis, Environmental Science and Pollution Research **29**, 65924 (2022).
16 C. Zhong, T. Li, R. Bi, E. Sanganyado, J. Huang, S. Jiang, Z. Zhang, and H. Du, A systematic overview, trends and global perspectives on blue carbon: A bibliometric study (2003–2021), Ecol Indic **148**, 110063 (2023).
17 W. R. Moomaw, B. E. Law, and S. J. Goetz, Focus on the role of forests and soils in meeting climate change mitigation goals: Summary, Environmental Research Letters **15**, (2020).
18 D. Huisingh, Z. Zhang, J. C. Moore, Q. Qiao, and Q. Li, Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling, J Clean Prod **103**, 1 (2015).
19 R. Wennersten, Q. Sun, and H. Li, The future potential for Carbon Capture and Storage in climate change mitigation – an overview from perspectives of technology, economy and risk, J Clean Prod **103**, 724 (2015).
20 A. Chowdhury, A. Naz, and S. Bhattacharyya, *Plantation Methods and Restoration Techniques for Enhanced Blue Carbon Sequestration by Mangroves*, in *Sustainable Agriculture Reviews 37: Carbon Sequestration Vol. 1 Introduction and Biochemical Methods*, edited by Inamuddin, A. M. Asiri, and E. Lichtfouse (Springer International Publishing, Cham, 2019), pp. 127–144.
21 J.-J. Zhu and B. Yan, Blue carbon sink function and carbon neutrality potential of mangroves, Science of The Total Environment **822**, 153438 (2022).
22 X. Gao, H. Li, X. Zhao, W. Ma, and P. Wu, Identifying a suitable revegetation technique for soil restoration on water-limited and degraded land: Considering both deep soil moisture deficit and soil organic carbon sequestration, Geoderma **319**, 61 (2018).
23 P.-L. Hu, S.-J. Liu, Y.-Y. Ye, W. Zhang, K.-L. Wang, and Y.-R. Su, Effects of environmental factors on soil organic carbon under natural or managed vegetation restoration, Land Degrad Dev **29**, 387 (2018).
24 S. Wang, D. Yan, C. Wang, L. Wu, and Y. Huang, A bibliometric analysis of blue carbon (1993–2023): evolution of research hot topics and trends, Front Mar Sci **11**, (2024).
25 L. B. L. da Silva, M. H. Alencar, and A. T. de Almeida, Multidimensional flood risk management under climate changes: Bibliometric analysis, trends and strategic

guidelines for decision-making in urban dynamics, International Journal of Disaster Risk Reduction **50**, 101865 (2020).

26 S. Yin, J. Wang, and H. Zeng, A bibliometric study on carbon cycling in vegetated blue carbon ecosystems, Environmental Science and Pollution Research **30**, 74691 (2023).

27 M. Jia, Z. Wang, Y. Zhang, D. Mao, and C. Wang, Monitoring loss and recovery of mangrove forests during 42 years: The achievements of mangrove conservation in China, International Journal of Applied Earth Observation and Geoinformation **73**, 535 (2018).

28 L. T. H. Pham, T. Q. Vo, T. D. Dang, and U. T. N. Nguyen, Monitoring mangrove association changes in the Can Gio biosphere reserve and implications for management, Remote Sens Appl **13**, 298 (2019).

29 F. Fahmi, H. Fajeriadi, and Y. Irhasyuarna, Feasibility of the Prototype of Teaching Materials on the Topic of Classification of Living Things Based on the Advantage of Local Wetland, BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan **3**, 113 (2021).

30 Fahmi, H. Fajeriadi, Y. Irhasyuarna, Suryajaya, and Abdullah, *The Practicality of Natural Science Learning Devices on the Concept of Environmental Pollution with Problem-Solving Learning Models*, in *Journal of Physics: Conference Series*, Vol. 2104 (IOP Publishing Ltd, 2021).

31 H. Fajeriadi and R. Arisandi, Indonesian Journal of Science Education and Applied Science (IJSEAS) how does students' environmental literacy support the sustainable development goals? a literature review, n.d.