

# Sediment carbon of Indonesian mangrove: a bibliometric analysis and systematic literature review

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**Abstract.** Indonesia hosts the largest mangrove ecosystem globally and has high potential for carbon storage, particularly in sediments. However, studies on mangrove sediment carbon in Indonesia remain limited, fragmented, and unevenly distributed. This study aims to systematically identify, analyze, and visualize research trends on mangrove sediment organic carbon in Indonesia using a bibliometric analysis and systematic literature review. Bibliometric data were obtained from the Scopus database and analyzed using OpenRefine and VOSviewer to assess publication trends, and research networks. A systematic literature review was conducted using publications from ScienceDirect and Google Scholar. From 176 identified documents, 35 studies specifically focusing on Indonesian mangrove sediments were selected for detailed analysis. Indonesia ranks fourth globally in mangrove sediment carbon publications, although research locations are strongly concentrated on Java Island. Various analytical methods were applied, including LOI, Walkley–Black, and elemental analysis, with sediment sampling depths ranging from 15–300 cm. The reviewed studies indicate that sediment carbon contributes the largest proportion (46–80%) of total ecosystem carbon stocks, with spatial variability influenced by mangrove condition, sediment bulk density, texture, and organic matter inputs. Improving methodological consistency, strengthening interdisciplinary collaboration, and expanding research coverage to under-represented regions are essential to advance Indonesia’s blue carbon research.

**Keywords:** Soil, carbon, research, Indonesian mangroves

## 1 Introduction

Mangrove ecosystems play a crucial role in the carbon cycle in coastal areas and in reducing the impact of climate change [1–4]. Through photosynthesis, mangroves absorb atmospheric

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CO<sub>2</sub> and store it as biomass (aboveground carbon) [5] and sediments (belowground carbon) [6]. Previous studies have shown that sediments can store up to 70-80% of the total mangrove carbon stock [3, 7, 8], making them a major long-term carbon sink within coastal ecosystems.

Commonly, the sources of carbon sediment in the mangrove ecosystem come from the decomposition of mangrove litter itself (*autochthonous*), and from external inputs such as river sediments, seas, and inland forests (*allochthonous*) [3, 9]. Several factors, such as ecosystem condition, spatial differences, tides, texture, sediment grain, sediment density (sediment bulk density/SBD), and organic matter, affect sediment carbon stock.

Although Indonesia is home to the largest mangrove area in the world, covering approximately 3.36 million hectares [10], studies focusing on sediment carbon stock and its spatial variability remain limited. The existing global literature on mangrove sediment carbon is dominated by studies from Australia, the United States, and China. However, publications specifically addressing Indonesian mangrove sediments are scarce and geographically variable. The available research is mostly concentrated on Java Island, despite other regions, such as Kalimantan and Papua, which have the largest mangrove coverage in Indonesia.

This imbalance reflects a knowledge gap regarding the magnitude, distribution, and methodological variation in mangrove sediment carbon studies in Indonesia. Understanding the current state of research and identifying under-explored regions and methods are essential for strengthening Indonesia's role in blue carbon initiatives and evidence-based climate policy.

Therefore, this study aimed to systematically identify, analyze, and visualize the research trends related to mangrove sediment carbon in Indonesia through a combination of bibliometric analysis and systematic literature review. Specifically, it seeks to map the publication dynamics and research networks over the last decade, examine the methodological approaches used in sediment carbon assessment, and evaluate the spatial patterns of the sediment carbon stock across the Indonesian mangrove region. Through this integrated approach, this study provides an evidence-based synthesis of the progress and challenges in mangrove sediment carbon research in Indonesia, which could serve as a foundation for future studies and policy directions in blue carbon management.

## 2 Methodological approach

This study applied mixed analytical methods, combining bibliometric analysis with a systematic literature review, to provide a comprehensive overview of mangrove sediment carbon research in Indonesia.

### 2.1 Data collections

The data were obtained from reference analyses, especially from international journals, conference papers, books, and article reviews. All references are related to the study of sediment carbon in mangroves. The data for the bibliometric analysis were obtained from Scopus (<https://www.scopus.com/search>) with the keywords: “soil AND carbon AND mangrove AND “blue carbon” OR “mangroves carbon” AND “soil carbon” OR “sediment carbon” OR “carbon AND burial” OR “carbon sediment”. The data for the last 10 years (2015–2024) were also obtained from Google Scholar (<http://scholar.google.com>) and ScienceDirect (<http://sciencedirect.com>). A total of 35 articles published in international journals and conference papers were obtained.

## 2.2 Bibliometric analysis

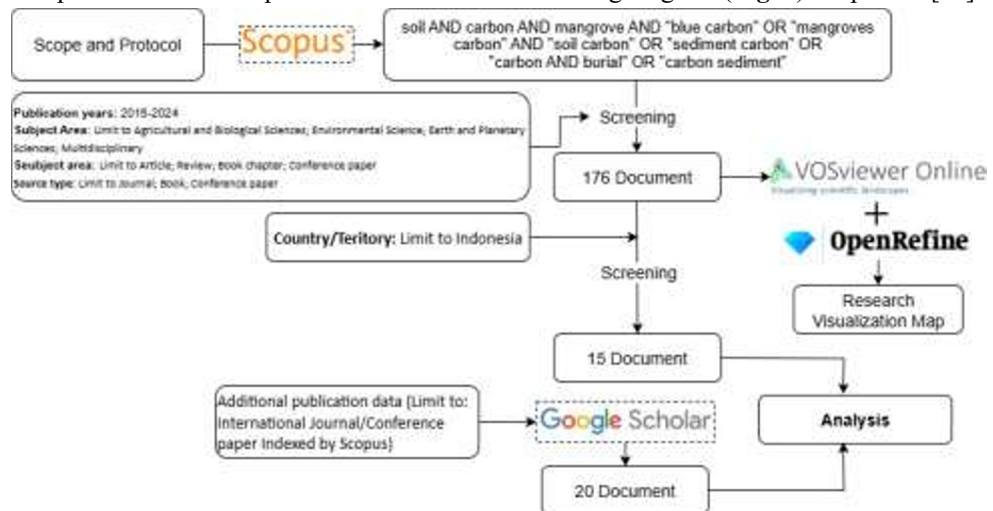
The bibliometric data from Scopus were exported to CSV format and processed using Open Refine software to remove duplicate data. The data were then analyzed using VOS viewer software to visualize the publication networks by country, organization, and keyword co-occurrence. This step identified global research trends and relative contributions of Indonesia.

## 2.3 Systematic literature review

From the bibliometric dataset, studies that explicitly focused on Indonesian mangrove ecosystems were further screened using criteria based on the research location in Indonesia, direct measurement of sediment carbon, and availability of methodological details. Additional data were obtained from Google Scholar (<http://scholar.google.com>) and ScienceDirect (<http://sciencedirect.com>) for the last 10 years (2015-2024). The final dataset consisted of 35 publications.

## 2.4 Data extraction and synthesis

Each selected document was analyzed. Key information was extracted, including research location, sediment depth, methodological approach of carbon analysis, and main findings of the sediment carbon stock. The data were qualitatively synthesized to identify the spatial distributions, methodological variations, and sediment carbon variability across sites and interpreted. The review process is shown in the following diagram (**Fig. 1**) adopted in [11]:



**Fig. 1.** Diagram processes of bibliometric analysis and literature review. This figure illustrates the sequential steps used to identify, screen, and analyze publications related to mangrove sediment carbon in Indonesia.

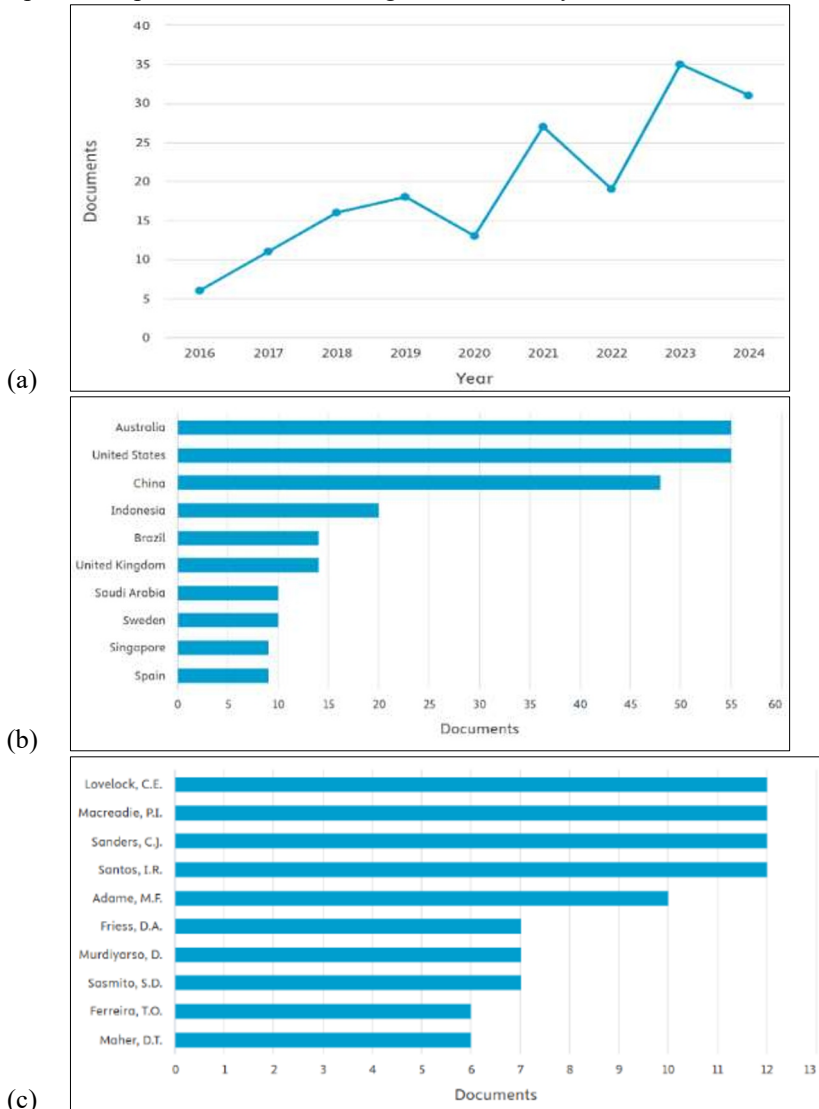
## 3 Result and discussion

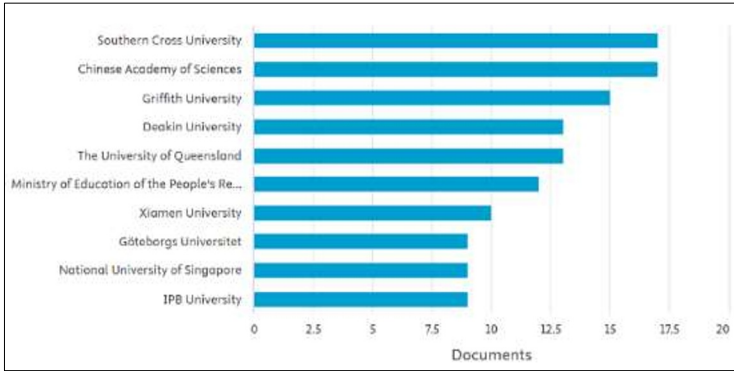
### 3.1 Mangrove sediment carbon research

The results from the VOS viewer regarding the distribution of publications were nine clusters (**Fig 2**). Based on country analysis, there were 12 clusters: the first (seven countries), second



A total of 176 documents were identified from the Scopus database over the last 10 years (2015-2024). The documents were dominated by Australia (55 documents), the US (55 documents), and China (46 documents). Indonesia was ranked fourth place with a total of 20 documents. Based on publication years (**Fig. 3**), the highest number of publications was in 2023 with a total of 35 documents, 2024 with a total of 31 documents, and 2021 with a total of 27 documents. In addition, there were less than 5. Based on these data, it can be concluded that sediment carbon research shows an increasing trend every year, and shows a decreasing trend in 2020, 2022, and 2024. In addition, Lovelock, C. E. (12 documents), Macreadie, P. I. (12 documents), Sanders, C. J. (12 documents), Santos, I. R. (12 documents), and Adame, M. F. (10 documents). The authors affiliated with Indonesia's organization, especially Murdiyarto D were in seventh place with a total of seven documents. Meanwhile, based on the total number of documents by affiliation, IPB University is an Indonesian organization that occupies tenth place with more than eight documents by affiliation.



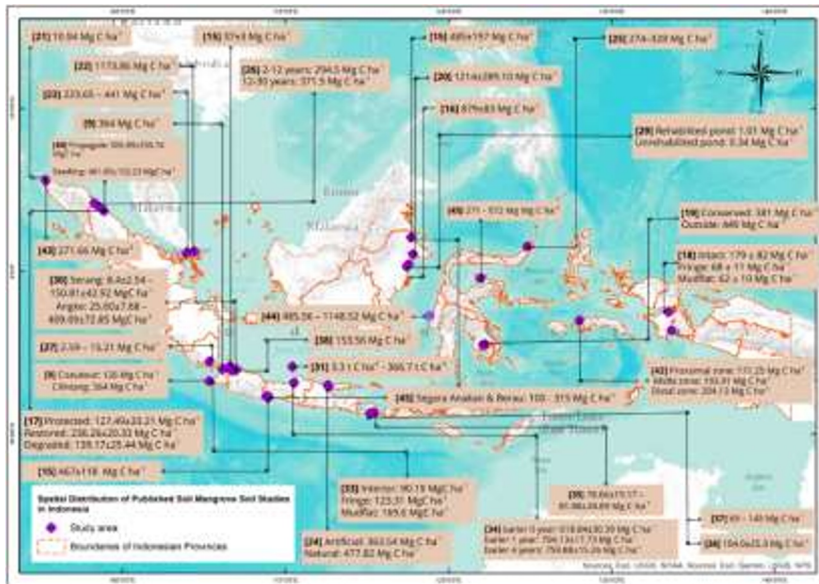


(d)

**Fig. 3.** Publication data from the last 10 years (2015-2024), source: <https://www.scopus.com/search>. a: documents by year; b; documents by country or territory; c: documents by author; and d: documents by affiliation.

### 3.2 Spatial distribution of mangrove sediment carbon research in Indonesia

Based on the spatial distribution of the research location in each document (**Fig. 4**), Central Java Province was the research location with the highest number of publications (six publications). The research sites were Segara Anakan, Cilacap, Karimunjawa, and Demak. East Kalimantan and Bali had four publications distributed in Berau, Delta Mahakam, Kutai Timur, Kutai Kartanegara (East Kalimantan), Teluk Benoa, and Nusa Lembangan (Bali). Meanwhile, North Sumatra, Banten, and West Papua were ranked third with three documents. These research locations were distributed in Belawan, Langkat, Deli Serdang, Lubuk Kertang (North Sumatra), Serang, Ujung Kulon, Pandeglang (Banten), and Bintuni and Kaimana (West Papua). Meanwhile, the research locations with the lowest number of publications were in four provinces: North Sulawesi, Maluku, West Java, and Lampung.

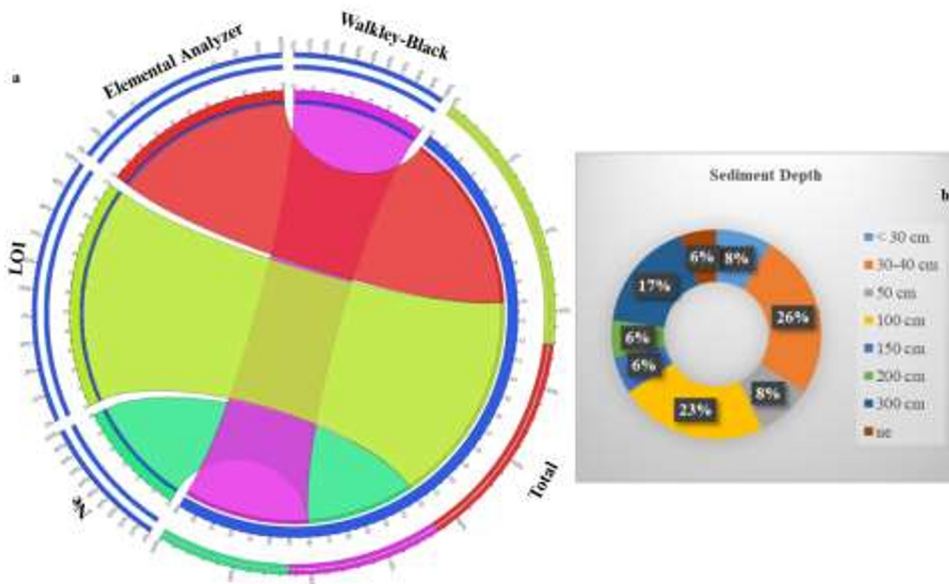


**Fig. 4.** Spatial distribution of mangrove sediment carbon research in Indonesia. This figure shows the geographic distribution of published studies on mangrove sediment carbon across Indonesian provinces based on the systematic literature review. The map highlights a strong concentration of research sites on Java Island.

The area of Indonesian mangroves is approximately 3.36 million hectares (FAO, 2023). Papua Island has the largest mangrove area (1.497.724 hectares). The lowest mangrove areas are in Bali and Nusa Tenggara (34.835 ha), Java Island (35.911 ha), and Sulawesi (34.835 ha) (National Mangrove Map, 2021). However, Java Island has the lowest mangrove area. Research and publications from the mangrove ecosystem of Java Island were dominant (14 documents). Papua, Kalimantan, and Sumatra islands have three, four, and eight documents, respectively. The presence of Universities and Research organizations in some areas has had a direct impact on the total number of publication documents [12], especially on Java Island, with various universities and research organizations, as well as research facilities, which also contribute to the publication document. This is supported by Tereshchenko and Shcherbakov [13], who stated that the presence of universities makes a significant contribution to regional research activities.

### 3.3 Methodological approach of sediment carbon analysis of Indonesian mangrove

Further analysis was conducted to identify several published studies related to mangrove sediment carbon stocks in Indonesia. Several considerations were the title, abstract, keywords, research location, sediment sampling method, carbon analysis approach, and sediment depth. In addition, the publication year and publication type (research papers, conference papers, review papers, and book chapters) were used as criteria. Based on the results of the analysis (Fig. 5), 33 documents related to the main topic were published.



**Fig 5.** Publication document related to the main topic (a: (a) Distribution of analytical methods used for sediment carbon assessment, including loss-on-ignition (LOI), Walkley-Black, elemental analysis, and studies with unspecified methods. (b) Distribution of sediment sampling depths applied in the reviewed studies, ranging from 15 to 300 cm. Ne= not explained).

Generally, to analyze the carbon content in sediment, two common methods are the dry combustion method and wet combustion method [46, 47]. **Fig. 5a** shows two common methods used for sediment carbon research in Indonesia: the dry combustion method (LOI and *Walkley-Black*) and the wet combustion method. Several published documents affiliated

with Indonesian organizations have used elemental analyzers to determine carbon content. In addition, several published studies used simpler instruments for the LOI approach. Some considerations for method selection were access to the laboratory facility, carbonate content of the sediment sample, time, and availability of additional chemicals.

The depth of the sediment samples (**Fig. 5b**) varied (15 – 300 cm). The authors commonly use 30-40 cm sediment depth (9 documents/ 26%), 100 cm sediment depth (8 document/ 23%), and 300 cm sediment depth (6 document/ 17%) compared to the other sediment depths. The most common method used to determine the sediment depth for carbon analysis is a *highly depth-aggregated sampling technique* with a sediment depth of  $\geq 100$  (18 documents) [46, 47].

### 3.4 Sediment carbon stock of Indonesian mangrove

Several previous studies have found that mangrove sediment is an important part of calculating the total carbon content of mangrove ecosystems. Sediment can store a large amount and percentage of carbon compared to mangrove biomass. In addition, carbon storage varies in some mangrove ecosystems in Indonesia. These conditions are influenced by several factors, such as ecosystem type, zonation, environmental conditions, and sediment type. Several previous studies on sediment carbon stocks are shown in the following table (**Table 1**).

**Table 1.** Summary of sediment carbon stocks reported from mangrove ecosystems in Indonesia. This table compiles sediment organic carbon stock values derived from published studies across different Indonesian mangrove regions, including variations in ecosystem condition, sediment depth, and analytical approaches.

References	Finding
[14]	<ul style="list-style-type: none"> <li>- Organic carbon content in mangrove sediment is significantly different for each sediment layer.</li> <li>- The highest value was in the 40-50cm layers with an average of 4.53%, and it was higher than the surface layer (0-10cm = 2.40%).</li> <li>- This trend shows that the C-organic accumulation was more stable in the middle layer of sediment. Meanwhile, the surface layer was more vulnerable to carbon loss caused by the flushing of tides.</li> </ul>
[15]	<ul style="list-style-type: none"> <li>- The highest organic carbon stock was found in Berau (<math>485 \pm 197 \text{ Mg C ha}^{-1}</math>), followed by the eastern part of Segara Anakan Lagoon (<math>467 \pm 118 \text{ Mg C ha}^{-1}</math>), and the lowest was in Kongs Island (<math>37 \pm 3 \text{ Mg C ha}^{-1}</math>).</li> <li>- In the center of SAL, the lowest organic carbon (<math>161 \pm 34 \text{ Mg C ha}^{-1}</math>) is shown, caused by degradation and sediment input from the river.</li> <li>- In the Berau and eastern part of SAL, dominated by autochthonous carbon (from leaves and roots of mangrove), while in the center part of SAL was dominated by allochthonous carbon (from river's sediment and terrestrial).</li> <li>- The sources of sediment carbon in Kongs Island were from marine particles (coastal POM).</li> </ul>
[16]	<ul style="list-style-type: none"> <li>- The contribution of sediment carbon was around 86% of the total ecosystem carbon in intact mangrove (average <math>879 \pm 83 \text{ Mg C ha}^{-1}</math>).</li> <li>- In the inactive ponds, the sediment carbon stock dropped drastically to <math>486 \pm 55 \text{ Mg C ha}^{-1}</math>.</li> <li>- The average of sediment carbon loss caused by the mangrove conversion to become ponds was <math>393 \text{ Mg C ha}^{-1}</math>, which is equivalent to <math>1442 \text{ Mg CO}_2\text{e/ha}</math>.</li> </ul>

References	Finding
	<ul style="list-style-type: none"> <li>- Most of the carbon emissions came from the sediment, not from the surface biomass. It means that the importance of sediment layers as main carbon sources.</li> </ul>
[17]	<ul style="list-style-type: none"> <li>- Mangrove restoration and conservation increase the sediment capacity to store carbon, compared to the degraded area.</li> <li>- Sediment burial contributes to the sediment carbon accumulation.</li> <li>- The high value of sediment accretion did not always mean that the carbon content was also high, depending on the composition of sediment organic matter.</li> </ul>
[18]	<ul style="list-style-type: none"> <li>- Intact mangrove could store <math>\sim 956 \text{ Mg C ha}^{-1}</math>, and about 80% of it was stored in the sediment layer.</li> <li>- Sediment carbon content (%C) was decreased significantly after LULC (<math>P &lt; 0.005</math>). Meanwhile, the sediment bulk density was significantly increased (<math>p &lt; 0.001</math>).</li> </ul>
[3]	<ul style="list-style-type: none"> <li>- Sediment organic carbon stock (top 50cm) was interior mangrove (<math>179 \pm 82 \text{ Mg Mg C ha}^{-1}</math>), fringe mangrove (<math>68 \pm 11 \text{ Mg C ha}^{-1}</math>), and mudflat (<math>62 \pm 10 \text{ Mg Mg C ha}^{-1}</math>).</li> <li>- Interior mangrove sediment could store up to 3 times more carbon than mudflat and fringe mangrove. This was related to the primary productivity and litter accumulation, which were higher in the interior mangrove.</li> <li>- Mudflat and fringe mangrove were dominated by allochthonous carbon. Meanwhile, in the interior, mangroves have a combination of autochthonous and allochthonous characteristics.</li> </ul>
[7]	<ul style="list-style-type: none"> <li>- Sediment organic carbon in the conservation mangrove was <math>381 \text{ Mg C ha}^{-1}</math>, and outside the conservation area was <math>449 \text{ Mg C ha}^{-1}</math>. But the differences were not statistically significant.</li> <li>- Even though the outside of the conservation area has more carbon stock, this was probably caused by the organic materials input from the land (agriculture, residence, and nickel mining activity), not by the good condition of the mangrove ecosystem.</li> <li>- There was a negative correlation between sediment bulk density and concentration of SOC. It means that the denser the sediment, the organic carbon content tends to decrease.</li> </ul>
[19]	<ul style="list-style-type: none"> <li>- The total average of ecosystem carbon stock was <math>1385,22 \text{ Mg C ha}^{-1}</math> which includes aboveground biomass carbon, belowground biomass carbon, necromass, and sediment carbon. Sediment carbon becomes the highest contributor (<math>1214 \pm 289.10 \text{ Mg C ha}^{-1}</math>).</li> <li>- The difference in sediment carbon stock between stations was influenced by location and external factors, i.e., the distance from the settlement, organic matter inputs, and sediment bulk density.</li> </ul>
[20]	<ul style="list-style-type: none"> <li>- The highest carbon stock was from the trees (<math>55.43 \text{ Mg C ha}^{-1}</math>); meanwhile, the sediment carbon was low, compared to the other components (<math>10.94 \text{ Mg C ha}^{-1}</math>).</li> <li>- The low sediment carbon organic was caused by its location, which is near the sea, and influenced by the tides. Also, the sediment composition was dominated by sand, which has a low capacity to absorb organic carbon.</li> </ul>

References	Finding
[21]	<ul style="list-style-type: none"> <li>- Sediment carbon (1173.86 Mg C ha<sup>-1</sup>) was the biggest carbon store in the mangrove ecosystem. About 57% was stored in the sediment compared to the carbon from aboveground biomass, belowground biomass, and necromass.</li> <li>- Sediment carbon becomes the major contributor of carbon stock because mangrove can trap the organic matter from litter. Meanwhile, the aerobic sediment inhibits the decomposition process so that the carbon could be stored in the long term.</li> <li>- The carbon content in sediment was influenced by sediment texture (grain size, dominance of mud or sand), sediment depth and sediment bulk density, as well as C-organic percentage.</li> </ul>
[22]	<ul style="list-style-type: none"> <li>- There was no significant difference in sediment carbon stock between research locations (<math>p&gt;0.05</math>). Thus, it means that all areas of Dompok Island have the same potential as a mangrove-based carbon sink.</li> <li>- Muddy sand sediment was more effective at storing organic matter than sandy sediment.</li> <li>- The semi-enclosed waters condition has low current and encourages the accumulation of mud and organic matter.</li> </ul>
[9]	<ul style="list-style-type: none"> <li>- Sediment carbon stock was higher in the rehabilitation area of Ciseukeut (364 Mg C ha<sup>-1</sup>) compared to the natural mangrove of Cilintang (126 Mg C ha<sup>-1</sup>).</li> <li>- The location was a protected lagoon environment, with low mineral input, and more dominant organic carbon from mangroves (autochthonous) supports high carbon stocks in Ciseukeut. Besides that, finer sediment texture (muddy-sand) supports the capture and preservation of organic carbon. This was supported by the high C:N ratio (30.7±10.7), indicating the dominance of carbon sources from mangrove.</li> </ul>
[23]	<ul style="list-style-type: none"> <li>- Intact mangrove has more sediment carbon stock (477.82 Mg C ha<sup>-1</sup>) compared to the artificial mangrove (363.54 Mg C ha<sup>-1</sup>).</li> <li>- Sediment bulk density was low in natural mangrove (0,73 g/cm<sup>3</sup>), compared to artificial mangrove (0,96 g/cm<sup>3</sup>). This shows the highest porosity in natural mangrove.</li> </ul>
[24]	<ul style="list-style-type: none"> <li>- If extrapolated to a depth of 1 m, the sediment carbon ranged from 274 to 328 Mg C ha<sup>-1</sup>.</li> <li>- According to isotope <math>\delta^{13}\text{C}</math> analysis, about 81-96% of carbon sources came from its mangrove vegetation (autochthonous).</li> <li>- There was no significant difference in sediment carbon between mangrove zones (seaward, middle, landward), indicating that the carbon distribution of the oceanic mangrove of Wori was homogenous.</li> </ul>
[25]	<ul style="list-style-type: none"> <li>- The sediment carbon stock of the young mangrove stand (2-12 years) was 294.5 Mg C ha<sup>-1</sup>, while that of the older mangrove stand (12-30 years) was 371.5 Mg C ha<sup>-1</sup>.</li> <li>- More than 60% of the ecosystem's carbon pool comes from sedimentary carbon.</li> <li>- Sediment carbon does not always increase with the age of the mangrove, but depends on the sedimentation conditions and history of the location.</li> </ul>

References	Finding
	- The process of sediment carbon accumulation is influenced by sedimentation and ecosystem stability, not just mangrove biomass input from leaves or roots.
[26]	- The highest sediment carbon is about 15.21 Mg C ha <sup>-1</sup> on <i>R. stylosa</i> stand in Pesawaran; meanwhile, the lowest is about 2,59 MgC/ha <sup>-1</sup> on <i>C. Tagal</i> stand in South Lampung. - The environmental factors that have a positive correlation to the carbon content were salinity, <i>silt</i> and <i>clay</i> sediment. Meanwhile, the negative correlations were temperature, total dissolved solids, and sand sediment.
[27]	- Carbon sources of mangrove sediment were autochthonous and allochthonous carbon. - The increase of human activity since the 18th century (agriculture, forestry, industry, and settlement) has caused an increase in erosion, sediment input to lagoon, and dilution of organic carbon in sediment due to the large amount of inorganic material.
[28]	- Sediment carbon stock in the rehabilitated pond area was higher (1.01 Mg C ha <sup>-1</sup> ) than in the unrehabilitated pond area (0.34 Mg C ha <sup>-1</sup> ). These two areas have significant differences (p<0.01). This was caused by the density of mangrove vegetation (replanted by <i>R. mucronata</i> ) in the rehabilitation area, which could increase the sediment carbon.
[29]	- The sediment carbon in Serang was lower (8.4±2.54 – 150.81±42.92 Mg C ha <sup>-1</sup> ) than in Angke (8.4±2.54 – 150.81±42.92 Mg C ha <sup>-1</sup> ). This was caused by the history of sand mining since 2003, which has caused sediment degradation and slow vegetation regeneration. Besides, mangrove regeneration was younger, and the density was lower than in Angke.
[30]	- Sediment carbon stock values vary, ranging from 3.3 Mg C ha <sup>-1</sup> to 366.7 Mg C ha <sup>-1</sup> . - On average, sedimentary carbon contributes 45.5% of the total ecosystem carbon stock. - There was a positive correlation between distance from the coastline and sediment carbon stocks, especially on the longest transects. - In the interior of the mangrove, the sediment was deeper and protected from erosion, so carbon accumulation was greater.
[31]	- The percentage of sediment carbon between Tahura Ngurah Rai (average 2.92 ± 1.03%) and Nusa Lembongan (average 1.97 ± 1.10%) differs significantly (ρ = 0.031). - The mangrove area of Tahura Ngurah Rai was more influenced by human activities, while the Nusa Lembongan mangrove area was more natural. - The high value of C/N ratio in Tahura indicates carbon dominance from terrestrial inputs (vegetation and human waste), while the low ratio in Lembongan indicates input from marine organisms (rich in nitrogen).
[32]	- The sediment carbon of Interior mangrove about 90.19 MgC ha <sup>-1</sup> , Fringe: 123.31 MgC ha <sup>-1</sup> , and Mudflat: 169.6 MgC ha <sup>-1</sup> . - The highest carbon accumulation rates were in the interior zone, reinforcing the importance of maintaining mangrove areas far from the coastline.
[33]	- Sediment carbon from 0 years of permeable barrier about 618.84±30.39 Mg C ha <sup>-1</sup> , 1 year of permeable barrier about 704.13±17.73 Mg C ha <sup>-1</sup> , and 4 years of permeable barrier about 759.88±15.26 Mg C ha <sup>-1</sup> .

References	Finding
	<ul style="list-style-type: none"> <li>- The older a permeable barrier is, the higher the carbon storage in the sediment. Barriers accelerate carbon accumulation in sediments because they trap carbon-rich sediments from the ocean or rivers.</li> <li>- Permeable barriers are an effective nature-based solution to increase soil carbon stocks, stabilise coastlines and support mangrove regeneration.</li> </ul>
[34]	<ul style="list-style-type: none"> <li>- Sediment carbon stocks in Nusa Lembongan with sample depths up to 30 cm ranged from <math>78.66 \pm 19.17</math> – <math>81.88 \pm 28.89</math> Mg C ha<sup>-1</sup>.</li> <li>- Station 5, which has a high sediment carbon stock, tends to have a low %Clay particle, high %C and low SBD.</li> </ul>
[35]	<ul style="list-style-type: none"> <li>- Sedimentary carbon contributes 24–36% of total ecosystem carbon.</li> <li>- The average value of sediment carbon was <math>104.0 \pm 25.3</math> Mg C ha<sup>-1</sup>.</li> <li>- The <i>Sonneratia</i> zone has the highest sediment carbon value (<math>127.2 \pm 15.7</math> Mg C ha<sup>-1</sup>).</li> <li>- Low SBD supports the accumulation of organic carbon because it provides more sediment pores, allowing organic matter to fill these pores.</li> </ul>
[36]	<ul style="list-style-type: none"> <li>- The sediment carbon of natural mangrove areas was greater (<math>126 - 145</math> Mg C ha<sup>-1</sup>) compared to rehabilitation (<math>69 - 126</math> Mg C ha<sup>-1</sup>).</li> <li>- Sedimentary carbon contributes about 80% of the total carbon of the mangrove ecosystem.</li> </ul>
[37]	<ul style="list-style-type: none"> <li>- There was a correlation between SBD and sediment organic carbon, where high organic carbon is found in sediments with low SBD.</li> <li>- Sedimentary carbon was higher in deeper layers, likely due to the influence of decomposition processes. Meanwhile, in surface sediment layers, carbon is lower due to the influence of the sand substrate from the ocean.</li> </ul>
[38]	<ul style="list-style-type: none"> <li>- About 86.82% and 87.97% of the total ecosystem carbon stock was contributed by fringe and interior mangrove sediments.</li> <li>- The ability of mangroves to trap sediment makes this ecosystem capable of accumulating large amounts of carbon in the sediment.</li> <li>- In addition, carbon can be stored for a long time in mangrove sediments due to the anaerobic conditions of mangrove sediments, which can inhibit the process of organic material decomposition.</li> </ul>
[39]	<ul style="list-style-type: none"> <li>- Sandy sediment has the characteristics of large grains, low density, and high permeability, so that organic material was not easily stored for long.</li> <li>- Sediment carbon stock in the area where propagules grow was <math>506.89 \pm 250.74</math> MgC ha<sup>-1</sup>, whereas the area covered by mangrove seedlings was <math>461.85 \pm 102.23</math> MgC ha<sup>-1</sup>.</li> </ul>
[40]	<ul style="list-style-type: none"> <li>- About 46% of total ecosystem carbon stock was stored in sediment (30 cm sample depth).</li> <li>- Mangrove sediment has the potential to store more carbon in the inner mangrove zone because it has a greater accumulation of litter.</li> </ul>
[41]	<ul style="list-style-type: none"> <li>- The organic carbon stock of the sediment in the proximal zone was <math>171.25</math> Mg C ha<sup>-1</sup>, the middle zone was <math>193.91</math> Mg C ha<sup>-1</sup>, and the distal zone was <math>204.13</math> Mg C ha<sup>-1</sup>.</li> <li>- The higher sediment organic carbon is found at the 0-20cm depth in the distal zone. The decomposition of organic material that settles, accumulates, and is trapped by weak currents is difficult to carry to the open sea in this zone.</li> </ul>
[42]	<ul style="list-style-type: none"> <li>- The total sediment carbon stock obtained was <math>271.66</math> Mg C ha<sup>-1</sup>.</li> </ul>

References	Finding
	- Sedimentary organic carbon was one of the contributors to organic compounds in water.
[43]	- Mangrove sediment carbon stocks were obtained at several locations with a range of 485.56 – 1148.52 Mg C ha <sup>-1</sup> . - The efficiency of carbon storage by sediments is supported by several environmental conditions, such as sediment conditions that were inundated by high tides, and salinity strongly supports the process of carbon burial in sediments in the long term.
[44]	- Organic carbon stocks in oceanic mangroves were higher (Togean Island: 271 - 572 Mg C ha <sup>-1</sup> ) compared to estuarine mangroves (100 - 315 Mg C ha <sup>-1</sup> ). - Mangrove degradation causes a decrease in the organic carbon stock of mangrove sediments. - The combination of ecosystem type (marine and estuarine), degradation, and nutrient dynamics affects the organic carbon stock of mangrove sediments.
[45]	- Differences in physical, chemical and characteristic conditions of mangrove sediments are related to differences in mangrove habitat conditions.

Sediment is a crucial component of mangrove ecosystems as it serves as a carbon sink. Several studies have shown that sediments store significant amounts of carbon, although the values vary spatially. [7] and [36] stated that coastal ecosystems, particularly mangroves, can store approximately 80% of the carbon in their sediment layers. [25] found that more than 60% of the total ecosystem carbon was stored in sediment, and [21] noted that approximately 57% of ecosystem carbon was also located in the sediment. Furthermore, at a depth of 30 cm, mangrove sediments still store approximately 46% of the total carbon at the ecosystem scale. The high carbon content in mangrove sediments contributes to increased aquatic productivity, particularly during the transport of carbon and other organic matter from the sediment to the water column [42].

Carbon stocks in mangrove sediments generally correlate with the condition of the mangrove ecosystem, that is, natural, degraded, or converted for other uses. [16] and [36] found that approximately 80–86% of the total carbon stock in natural mangrove ecosystems is stored in sediments. However, when mangrove ecosystems experience degradation, a significant decline in the carbon stock in the sediment occurs [44]. Furthermore, [16] reported that sediment carbon stocks in former fishpond areas experienced a significant decline compared with those observed in pristine mangrove areas. Rehabilitation efforts through mangrove replanting in former shrimp ponds can gradually increase sedimentary carbon stocks. This was due to the ability of the rehabilitated mangrove vegetation to trap sediment and organic matter. Findings by Jansi *et al* [28] showed that carbon stocks in rehabilitated shrimp ponds were higher (1.01 MgC ha<sup>1</sup>) compared to those found in non-rehabilitated ponds (0.34 MgC ha<sup>1</sup>).

Spatially, carbon stocks in mangrove sediments showed significant variation. The interior mangrove zone generally shows higher sedimentary carbon stocks than the fringe zone [40]. [3] and [32] reported that at sediment depths of up to 50 cm, carbon stocks in the interior mangroves were almost three times higher than those in the fringe and mudflat zones at the front of the mangrove ecosystem. This difference was related to the greater accumulation of litter in the interior zone. This litter was buried in sediment and became a major source of carbon. This organic carbon is then stored for long periods owing to the anaerobic conditions of the sediment, which are degraded slowly [21, 38]. Furthermore, the carbon storage

efficiency in the interior zone is also higher [30,43], as this zone has a lower level of tidal penetration, resulting in less flushing [41, 43]. However, in some cases, such as oceanic mangroves, where the entire mangrove zone is affected by tides, the sediment carbon distribution tends to be homogeneous. [24] found that in the oceanic mangrove area in Wori, North Sulawesi, there was no significant difference in carbon stocks between the foreshore zone near the coast and the zone closer to land.

In addition to ecosystem conditions and spatial differences, several physicochemical and environmental factors also influence carbon stocks in mangrove sediments. These factors include tides, sediment grain texture, sediment bulk density (SBD), and input of organic matter from outside the mangrove ecosystem. In the surface layer of sediment, carbon stocks tend to be lower because of flushing by tides and the influence of sand sediment from the sea carried by currents [20]. Sediment grain texture and size also play important roles in determining the carbon content of mangrove sediments [9, 21, 22, 26]. [22] explained that sediments with a finer texture dominated by silt and clay are more effective in capturing and storing organic carbon [9, 26]. Coarse-grained sediments such as sand have larger pores and tend to release organic carbon more easily when stirred by water movement. Sandy sediments also generally have low SBD and high permeability, resulting in a lower long-term capacity to store organic carbon [39]. Sediment density (SBD) is an important parameter that influences the carbon storage capacity. Sediments with low SBD tend to accumulate more organic carbon [37] because they have a greater number of pores as storage space for organic carbon [35].

In addition to these factors, the input of organic matter from outside the ecosystem also plays a significant role in influencing mangrove sediment carbon stocks. [7] found that sediment carbon stocks in mangrove areas outside conservation areas tended to be higher because of the input of organic matter from land, such as agricultural, mining, and residential activities carried by river flow. [31] also noted the dominance of land-based carbon sources, primarily from terrestrial vegetation and anthropogenic activities, which entered mangrove sediments in the Ngurah Rai Forest Park (Tahura) area, Bali. This dominance was indicated by the high C/N ratio. In general, mangrove sediment carbon sources come from two main categories: the decay of mangrove litter (autochthonous) and external inputs such as river, marine, and terrestrial forest sediments (allochthonous) [3, 15]. Mudflat and fringe mangrove zones are generally dominated by allochthonous carbon sources, whereas interior mangrove zones receive more autochthonous carbon input [3].

## 4 Conclusion

This study provides an integrated overview of mangrove sediment carbon research in Indonesia based on bibliometric and systematic literature reviews. The results revealed that over the past decade, research activity on mangrove sediment carbon has shown a gradual increase, yet remains geographically uneven and methodologically fragmented.

Indonesians rank among the leading contributors in Southeast Asia, but the majority of studies are concentrated in Java. In contrast, islands with large mangrove areas, such as Papua and Kalimantan, remain underrepresented. This spatial imbalance reflects research facilities and knowledge gaps regarding sediment carbon stocks across diverse ecological and coastal geomorphological settings in Indonesia.

Methodologically, most Indonesian studies employ LOI methods, *Walkley-Black* methods, and elemental analyzer techniques for carbon analysis with varying sediment depths (ranging from 15 to 300 cm). Such variation demonstrates the lack of standardization in sampling protocols, which may hinder accurate comparisons across sites and long-term monitoring of sediment carbon dynamics.

From the synthesis of 35 published documents, sediment carbon has consistently emerged as the dominant component of mangrove ecosystem carbon stock, contributing 46 to 80% of total carbon storage. Its variability across sites is influenced by mangrove conditions (natural, degraded, and rehabilitated mangroves), sediment bulk density, texture, and organic matter input. These findings reinforce the crucial role of sediments as a long-term carbon sink.

Therefore, strengthening interdisciplinary collaboration, improving methodological consistency, and expanding research coverage for underrepresented regions are crucial steps in developing a comprehensive national understanding of sediment carbon dynamics in Indonesian mangroves.

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