Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Estimating Mangrove Biomass and Carbon Stocks for Climate Change Mitigation in Sorong City, Southwest Papua of Indonesia

Syaiful Maliki Arief (1) Rima H. Siburian (2), Agustinus Murdjoko (3), Rully N. Wurarah (4)

(1) Universitas Papua, Indonesia; Email: syaifulmalikiarief@gmail.com
(2) Universitas Papua, Indonesia; Email : r.siburian@unipa.ac.id
(3) Universitas Papua, Indonesia; Email: agustinus.murdjoko.papua@gmail.com
(4) Universitas Papua, Indonesia; Email: r.wurarah@unipa.ac.id

ARTICLE INFO

Received: 22 Dec 2024

Revised: 17 Feb 2025

Accepted: 27 Feb 2025

ABSTRACT

Mangrove ecosystems play a crucial role in mitigating carbon emissions through their exceptional capacity to sequester and store large amounts of carbon, both in biomass and soil layers. This study aims to estimate the biomass and carbon stocks of mangrove ecosystems in Sorong City, Southwest Papua—an understudied region with significant coastal ecosystem potential. An allometric approach was applied to calculate Above Ground Biomass (AGB) and Below Ground Biomass (BGB), while laboratory analyses were conducted to determine Soil Organic Carbon (SOC) content. The results revealed a total carbon stocks of 10,925.05 Mg C/ha, with SOC contributing the most (>95%), followed by BGB and AGB. These findings highlight the critical importance of comprehensive mangrove ecosystem management as part of climate change mitigation strategies rooted in blue carbon, and underscore its relevance in strengthening national carbon spatial data in eastern Indonesia.

Keywords: blue carbon, mangrove biomass, Rhizophora mucronata, soil organic carbon, climate mitigation

Introduction

Mangrove ecosystems have a strategic role in mitigating global climate change. Besides functioning as coastal protectors and providers of ecosystem services, mangroves are very efficient for storing carbon, both in vegetation biomass and in soil sediments (Donato *et al.*, 2011). The unique characteristics of complex mangrove roots allow the accumulation and deposition of organic matter over long periods of time, making them one of the most productive natural carbon sinks among terrestrial and marine ecosystems (Alongi, 2012).

Indonesia has the largest mangrove area in the world, covering more than 3.3 million hectares, and contributing more than 30% of of the world's total mangrove ecosystems (Kusumaningtyas *et al.*, 2019). However, most blue carbon studies in Indonesia are still focused on western regions such as Sumatra and Java. Information on the potential for carbon stores in the eastern region, especially Southwest Papua, is still lacking despite its high geophysical and biodiversity characteristics, which potentially support greater carbon accumulation.

Studying biomass and carbon stocks in mangrove ecosystems is crucial to support mitigation strategies based on Ecosystem-based Adaptation (EbA). As part of the global commitment to reduce carbon emissions and the implementation of Nationally Determined Contributions (NDC), mangrove carbon stock estimation can be the basis for coastal protection and restoration policies. Scientific information based on local data is an urgent need as pressure on coastal ecosystems increases due to land conversion, infrastructure development, and climate change.

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

This study was conducted to fill the data gap in the Southwest Papua region, with the aim of estimating the biomass and carbon stocks of mangrove ecosystems in Sorong City. The estimation was carried out using a biometric approach and laboratory analysis of soil organic carbon (SOC). The results of this study are expected to enrich the national blue carbon database and support the development of conservation policies based on scientific evidence that are locally relevant but have a global impact. Sorong City as a coastal area in Southwest Papua has a mangrove area that has not been widely studied in terms of its ecosystem function as a carbon sink. Therefore, this study aimed to calculate the biomass and carbon stocks of vegetation and soil, and compared them with previous studies as a basis for climate mitigation-based management.

Materials and Method

The study was conducted in 2024 at three mangrove locations in Sorong City: Klablim, Klamana, and Klawalu. Study sites were selected purposively by considering the representation of mangrove cover. The materials used in this study included tree diameter measuring instruments (calipers), measuring tapes, GPS, soil drills, sample bags, labels, and laboratory chemicals for soil analysis, such as $K_2Cr_2O_7$ solution, concentrated H_2SO_4, $FeSO_4$, ferroin indicators, and distilled water. The soil was dried in the open air and filtered with a 2 mm sieve before being analyzed. Vegetation measurements were carried out on 20×20 m plots to facilitate recording individual trees and collecting stand structure data. In each observation plot, a center point was made as a reference for the north-south and east-west directions.

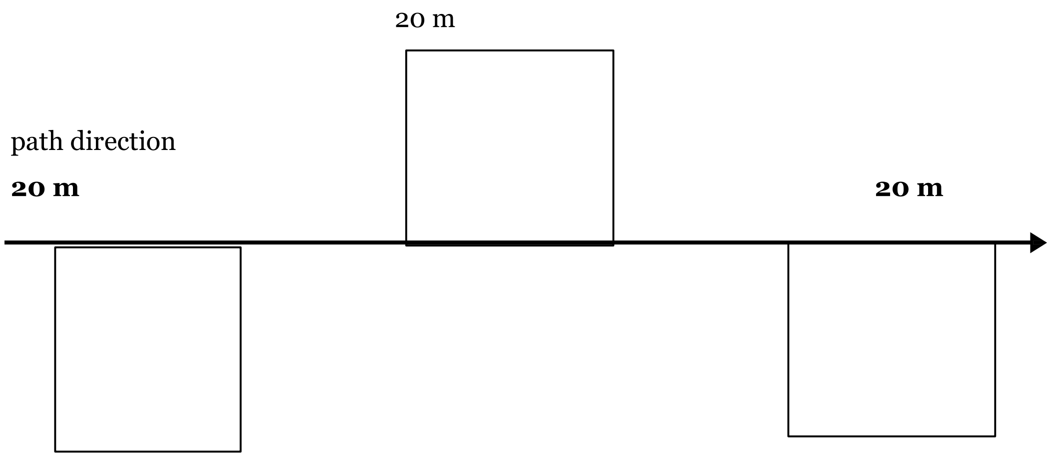

Figure 1. Observation plot design measuring 20 m x 20 m

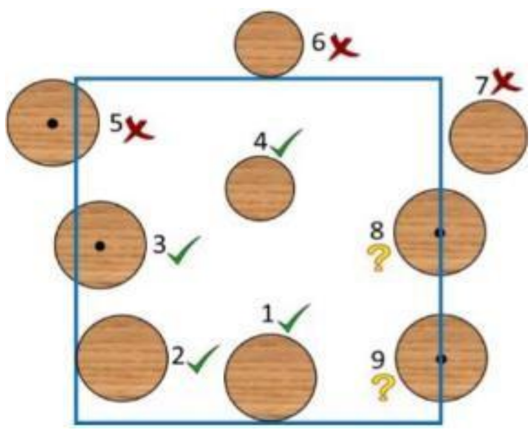

Figure 2. Top view of tree positions, including those inside and outside the plot (DLH Surabaya. 2023)

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

Figure 3. Illustration of mangrove sediment sampling points

Soil samples were taken from three points in each plot, namely the upper left corner, the center, and the lower right corner. These three subsamples were then combined into a single composite sample for laboratory analysis.

For AGB, the allometric equation of Komiyama *et al.* (2005) was used as follows:

$$AGB = 0.251 \times \rho \times D^{2.46},$$

where ρ is wood density (g/cm^3) and D is the stem diameter (cm). BGB was calculated using the root-to-stem ratio of 0.39 (Kauffman *et al.*, 2011). Carbon from biomass was calculated by converting biomass × 0.47 according to IPCC guidelines (2006). Soil samples were analyzed for organic C content using the Walkley-Black method. Subsequently, the bulk density was calculated by drying the fixed volume soil (ring sampler) in a 105°C oven for 48 hours. The SOC value was then calculated using the formula:

$$SOC = \text{Organic C (\%)} \times BD\ (g/cm^3) \times \text{depth (cm)}$$

SOC values were expressed in kg/m^2 and converted to Mg C/ha for spatial comparison purposes.

Total ecosystem carbon was calculated by summing the total carbon from three main compartments: AGB, BGB, and SOC. The total carbon value per hectare was determined by the following formula:

$$C\text{-total} = C\text{-AGB} + C\text{-BGB} + SOC$$

All measurement results were processed using Microsoft Excel, analyzed descriptively-quantitatively, and displayed in the form of tables and graphs to illustrate the distribution and contribution of each component to the total carbon stock of the ecosystem.

Results and Discussion

Mangrove Species Composition in Sorong City

Table 1. Mangrove Forest Species Composition in Sorong City

No	Species	Station I		Station II		Station III		Number
		Pole	Tree	Pole	Tree	Pole	Tree	
1	*Aegiceras corniculatum*	2	3	1	4	4	2	16
2	*Avicennia officinalis*	2	21	1	3	3	4	34
3	*Bruguiera gymnorrhiza*	3	14	11	21	2	13	64
4	*Bruguiera parviflora*	2	1	2	1	1	4	11
5	*Ceriops tagal*	3	3	28	19	3	4	60
6	*Rhizophora apiculata*	2	32	2	3	1	1	41
7	*Rhizophora lamarckii*	1	1	1	1	2	2	8
8	*Rhizophora mucronata*	3	1	1	35	5	24	69
9	*Xylocarpus granatum*	1	1	1	2	2	3	10
10	*Xylocarpus moluccensis*	2	2	12	6	1	2	25
	Number	**21**	**79**	**60**	**95**	**24**	**45**	338

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

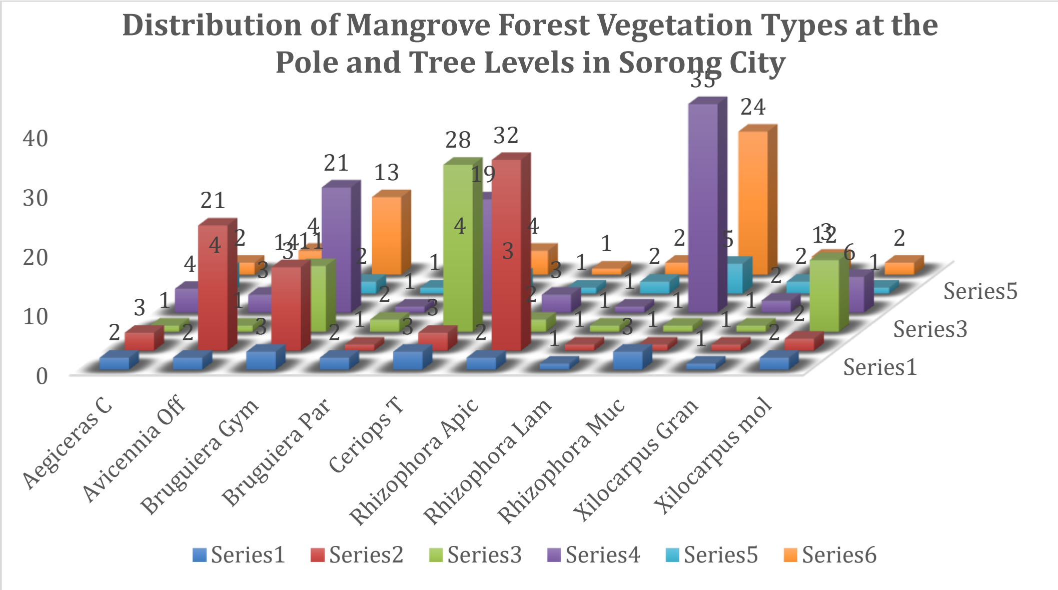

Figure 3. Distribution of Mangrove Forest Vegetation Types at the Pole and Tree Levels in Sorong City

Estimation of Above Ground Biomass (AGB)

Table 2. Above-ground carbon biomass values of each species at three stations

No	Species	AGB st1 (kg)	AGB St2 (kg)	AGB St3 (kg)	Total AGB Carbon (kg)
1	*Aegiceras corniculatum*	28.57	5.94	8.28	42.79
2	*Avicennia officinalis*	21.14	2.87	60.58	81.72
3	*Bruguiera gymnorrhiza*	39.08	19.27	144.13	202.48
4	*Bruguiera parviflora*	2.59	0.56	3.51	6.66
5	*Ceriops tagal*	27.32	9.85	45.72	82.89
6	*Rhizophora apiculata*	52.94	4.25	60.37	117.56
7	*Rhizophora lamarckii*	1.25	1.34	2.55	5.14
8	*Rhizophora mucronata*	45.99	26.97	511.75	584.71
9	*Xylocarpus granatum*	8.38	2.44	5.47	16.29
10	*Xylocarpus moluccensis*	9.28	2.91	2.75	14.94
	Total	**236.54**	**73.53**	**845.11**	**1155.18**

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

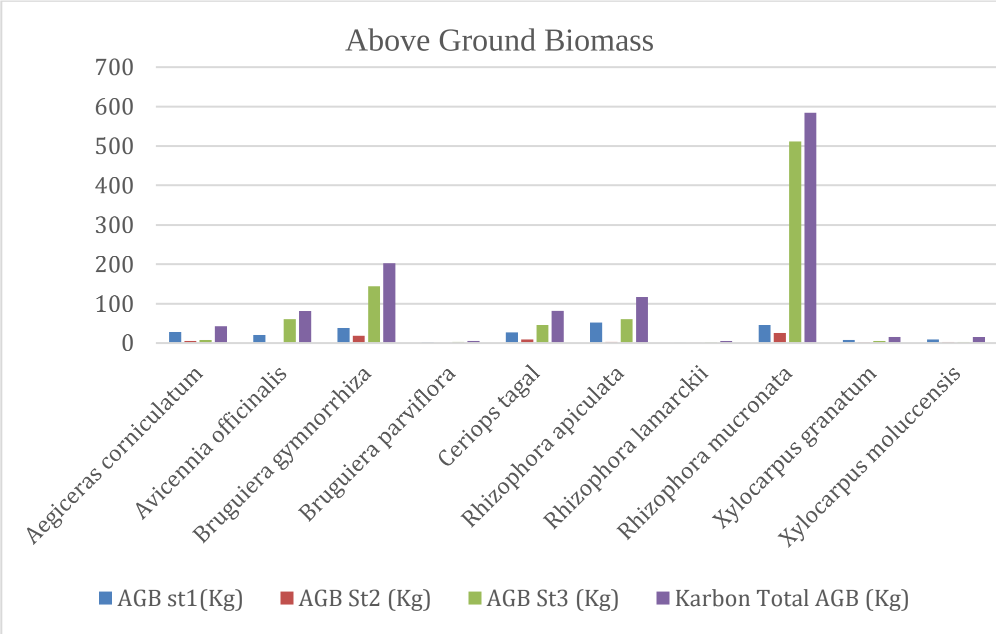

Figure 4. AGB values per species

Estimation of Below Ground Biomass (BGB)

Table 3. Below-ground carbon biomass values of each species at three stations

No	Species	Diameter (cm)	Bellow Ground Biomass			Total BGB
			BGB I	BGB II	BGB III	
1	*Aegiceras corniculatum*	30	23.69	8.03	13.21	44.93
2	*Avicennia officinalis*	28	17.07	3.72	72.62	93.41
3	*Bruguiera gymnorrhiza*	40	58.36	29.08	229.93	317.37
4	*Bruguiera parviflora*	20	2.64	0.37	3.84	6.85
5	*Ceriops tagal*	25	15.61	4.15	37.88	57.64
6	*Rhizophora apiculata*	45	62.97	7.63	160.45	231.05
7	*Rhizophora lamarckii*	15	0.97	0.24	1.83	3.04
8	*Rhizophora mucronata*	50	78.9	53.94	371.57	504.41
9	*Xylocarpus granatum*	35	15.16	4.88	19.57	39.61
10	*Xylocarpus moluccensis*	20	5.12	1.57	6.24	12.93
	Total		**256.8**	**105.58**	**903.93**	**1266.31**

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

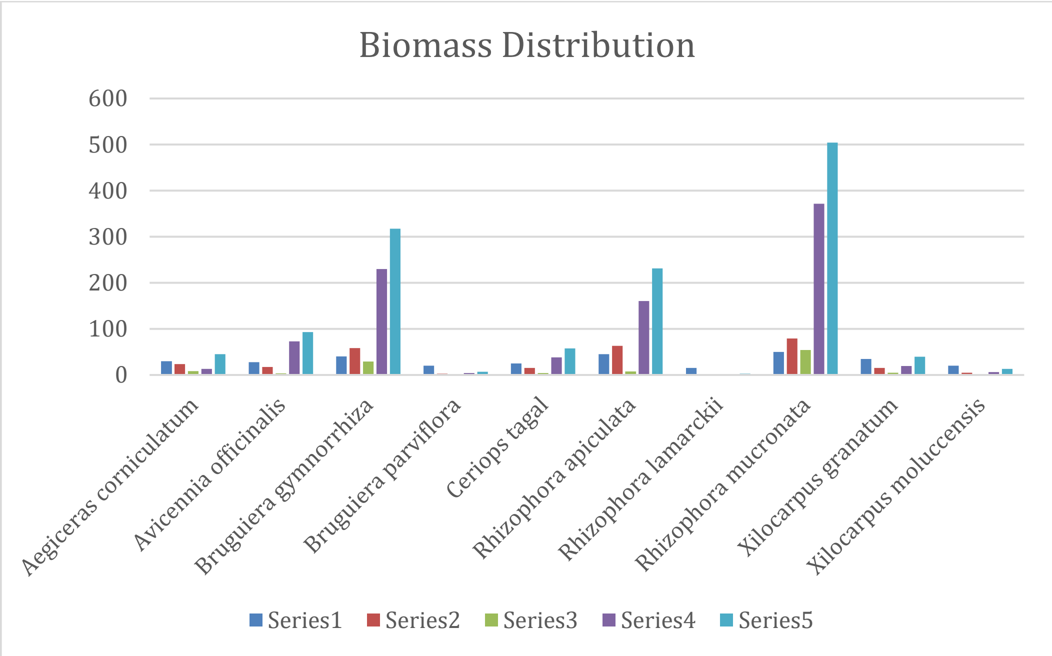

Figure 5. BGB biomass per species

Estimation of Soil Organic Carbon (SOC)

Tabel 4. Average organic C content, bulk density, and SOC

No	Code	Organic C (%)	Bulk Density (g/cm3)	Volume (cm3)	Soil Organic Carbon (kg/m2)
1	L1P11	20.54	0.602	166.07	2053.47
2	L1P12	17.11	0.666	150.12	1710.66
3	L1P13	15.52	0.7	142.81	1551.49
4	L1P21	16.48	0.679	147.22	1647.38
5	L1P22	17.41	0.66	151.51	1740.94
6	L1P23	17.29	0.662	150.95	1727.77
7	L1P31	17.94	0.65	153.96	1795.33
8	L1P32	18.52	0.638	156.64	1850.82
9	L1P33	17.02	0.668	149.71	1702.11
10	L1P41	17.56	0.657	152.2	1755.92
11	L1P42	18.12	0.646	154.79	1811.9

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

12	L1P43	18.03	0.66	151.46	1802.34
13	L1P51	17.4	0.655	152.62	1739.41
14	L1P52	17.65	0.671	149.06	1765.34
15	L1P53	16.88	0.599	166.91	1687.65
16	L1P61	20.72	0.644	155.34	2072.81
17	L1P62	18.24	0.598	167.2	1823.74
18	L1P63	20.78	0.583	153.36	1857.92
	Total	302.67	11.036	2605.86	**32097**

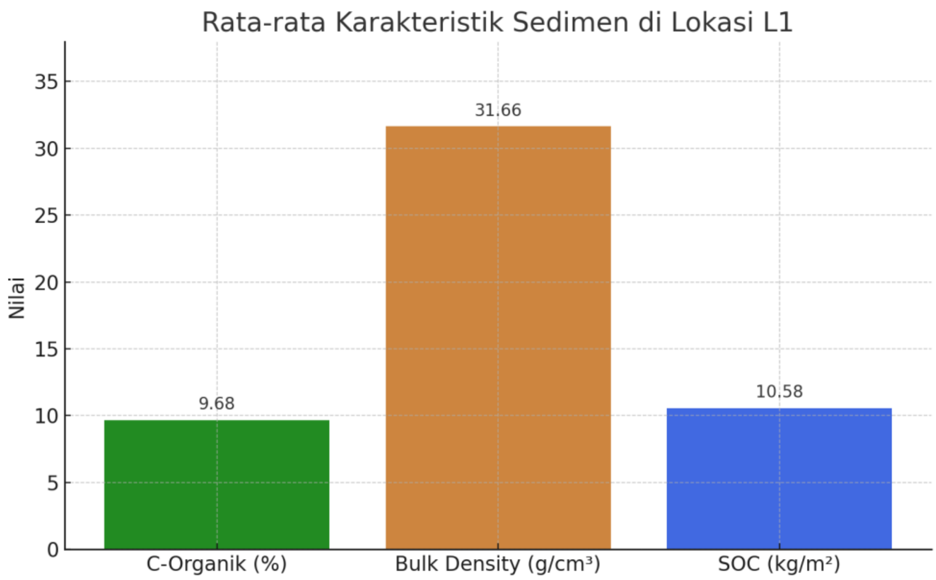

Figure 6. Average organic C content, Bulk Density, and SOC

Table 5. Soil organic carbon value per station

No	Code	Soil Organic Carbon			Total
		Station I	Station II	Station II	SOC
1	P1L1	2053.47	1795.33	1739.41	5588.21
2	P1L2	1710.66	1850.82	1765.34	5326.82
3	P1L3	1551.49	1702.11	1687.65	4941.25
4	P1L4	1647.38	1755.92	2072.81	5476.11
5	P1L5	1740.94	1811.9	1823.74	5376.58
6	P1L6	1727.77	1802.34	1857.92	5388.03
	Total	10431.71	10718.42	10946.87	**32097**

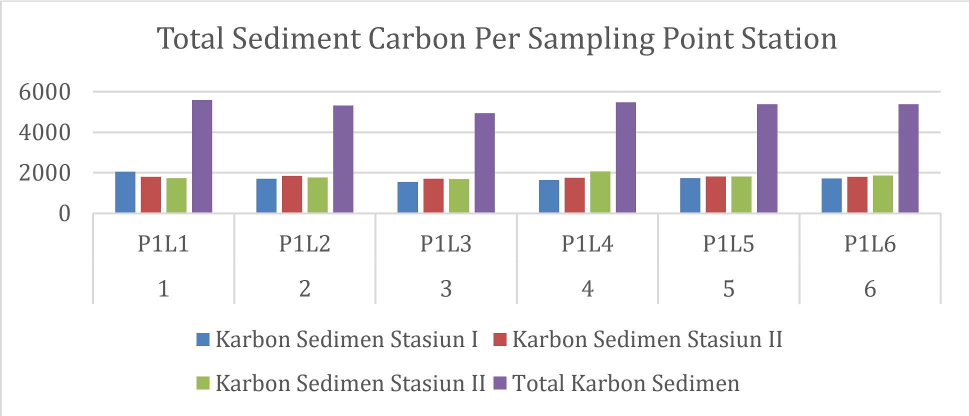

Figure 7. Average distribution of Sediment Carbon (SOC) values per station

Total Carbon Stocks

Table 6. Total carbon value per station

Location	AGB (Mg C/ha)	BGB (Mg C/ha)	SOC(Mg C/ha)	Total Carbon (Mg C/ha)
Station 1	236.54	256.8	10431.71	10925.05
Station 2	73.53	105.58	10718.42	10897.53
Station 3	845.11	903.93	10946.87	12695.91
Total	**1155.18**	**1266.31**	**32097**	**34518.49**

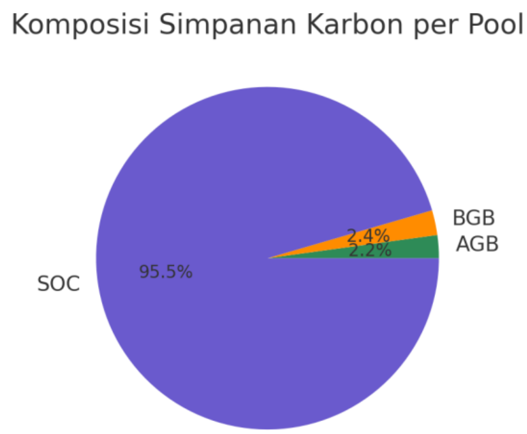

Figure 8. Carbon stock composition per pool (AGB, BGB, SOC)

The results of the study indicate that the mangrove ecosystems in Sorong City have a very high carbon storage capacity, with soil organic carbon (SOC) contributing more than 95% of the total ecosystem carbon. These findings reaffirm the role of the mangrove ecosystems as effective natural carbon sinks,

Journal of Information Systems Engineering and Management
2025, 10(44s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

in line with the results of global studies reporting that mangrove sediments store 3–5 times more carbon than aboveground vegetation (Taillardat *et al*., 2018; Donato *et al*., 2011).

The large contribution of SOC to total carbon also reflects favorable local environmental conditions, such as high organic matter supply, litter accumulation from dominant vegetation such as *Rhizophora mucronata*, and low anthropogenic disturbance. The high soil organic C content (up to 20.78%) and relatively low bulk density (average 0.61 g/cm^3) support the conclusion that the soil in this area acts as a stable long-term carbon store. Similar studies by Breithaupt *et al*. (2012) in Florida and Cairo *et al*. (2021) in Kenya also reported the pattern of soil carbon dominance in tropical mangrove systems.

The dominance of *Rhizophora mucronata* in AGB and BGB suggests that this species is a key in biomass accumulation. With an extensive root system and adaptive to tidal fluctuations, the genus *Rhizophora* has been shown to be efficient in biomass and litter production that contributes to soil organic enrichment (Alongi, 2012). The AGB biomass of *R. mucronata* reaches more than 500 kg per plot, far exceeding other species, thereby supporting its use in blue carbon-based restoration programs.

However, the imbalance between the contribution of SOC and vegetation biomass indicates that ecosystem carbon management cannot only focus on tree stands. Research by Lovelock *et al*. (2017) shows that disturbances to sediments such as erosion, reclamation, or land use changes can cause large releases of carbon that have been stored so far. Therefore, mangrove-based climate change mitigation strategies must include comprehensive protection of vegetation and soil compartments.

The consistency of data at the three locations shows that the characteristics of the ecosystem in Sorong City are generally stable in supporting high carbon storage. This is an important finding considering that eastern Indonesia is often underrepresented in national carbon spatial maps. In line with the idea expressed by Pham *et al*. (2019), regional carbon stock mapping is a strategic step in strengthening the national carbon information system and determining priority conservation areas.

This study also highlights the importance of an ecosystem-based adaptation (EbA) approach in coastal management. In the context of climate change, the existence of mangroves not only offers mitigation functions, but also adaptation through coastal protection, pollutant filtering, and increasing fisheries productivity (Kauffman *et al*., 2016; Ghosh *et al*., 2021). Therefore, the results of this study should be integrated into the development of local policies that integrate mangrove conservation into coastal spatial planning.

Another finding that needs to be underlined is that the total carbon value in Sorong City (up to 12,695.91 Mg C/ha) far exceeds the national average (9,000–10,000 Mg C/ha), as reported by Kusumaningtyas *et al*. (2019). This emphasizes that the Southwest Papua region has untapped blue carbon potential, and contributes significantly to Indonesia's NDC (Nationally Determined Contributions) target in reducing greenhouse gas emissions.

By considering all carbon compartments, this study provides a complete and comprehensive picture of the carbon storage capacity of the mangrove ecosystem in Sorong City. The methodological approach used—a combination of biomass estimation and SOC laboratory analysis—ensures data accuracy and comparability with international studies. In addition, these results are very relevant as a basis for formulating evidence-based conservation and adaptation policies in coastal areas of eastern Indonesia.

Most studies on carbon stocks of mangrove ecosystems in Indonesia are still focused on the western regions, such as the coasts of Sumatra, Kalimantan, and Java, with relatively abundant data that have been used in formulating national conservation policies (Kusumaningtyas *et al*., 2019; Alongi, 2012). However, the eastern region of Indonesia—including Southwest Papua—has received less attention, both in terms of spatial mapping of carbon stocks and the influence of geomorphological characteristics on carbon accumulation. In fact, studies by Boone and Bhomia (2017) and Kauffman *et al*. (2016) show that local factors such as sedimentation rates, low anthropogenic pressure, and species diversity can actually produce higher carbon stocks in these areas. This information gap is a challenge in developing a spatially representative national blue carbon database. Several previous studies have also not holistically integrated the three main carbon compartments (AGB, BGB, and SOC), or have only focused on vegetation stands without considering the more dominant soil carbon (Donato *et al*., 2011; Taillardat *et al*., 2018).

This study fills the gap in spatial and methodological data by providing a comprehensive estimation of total carbon stocks—including aboveground vegetation, belowground roots, and soil organic carbon content—in three representative locations in Sorong City. With a combination of allometric and laboratory analysis approaches, the results of this study not only show high carbon values, but also reinforce the importance of simultaneous protection of vegetation and soil substrates in ecosystem-based climate change mitigation strategies.

This study also addresses the knowledge gap related to mangrove carbon stocks in eastern Indonesia, especially Southwest Papua, which until now has not been widely used as an object of scientific study. Previous studies focused more on western Indonesia such as Sumatra and Java (Kusumaningtyas *et al*., 2019), while information from areas such as Sorong City remains very limited. In fact, according to Boone and Bhomia (2017), the typical environmental characteristics in Papua, such as low levels of disturbance and high sedimentation, have the potential to produce significant carbon storage values. Thus, this study provides an important scientific contribution in enriching the national blue carbon map and strengthening the basis for local data-based policy making.

Conclusion

The results of this study indicate that the mangrove ecosystem in Sorong City, Southwest Papua, has significant potential as a blue carbon storage, with the majority of carbon stored in the soil organic carbon (SOC) compartment. The total carbon stock estimate reached 10,925.05 Mg C/ha, most of which (>95%) is stored in sediment. These findings indicate that mangrove conservation is not only important for maintaining vegetation but also maintaining the stability of soil substrates that store carbon in the long term. *Rhizophora mucronata* plays a dominant role in the accumulation of biomass and carbon, both above and below ground, confirming the ecological and economic value of this species in the restoration and management of mangrove forests. Considering the high carbon value in this area, mangrove ecosystem conservation and restoration strategies need to be prioritized in ecosystem-based adaptation (EbA)-based climate change mitigation planning both nationally and locally. These results are also an important contribution in strengthening the national database of blue carbon stocks, as well as providing relevant scientific evidence for policy makers to determine priority conservation areas, especially in eastern Indonesia where spatial data on coastal ecosystems remain limited.

References

[1] Azzahra, R. (2020). Estimasi Karbon pada Ekosistem Mangrove Desa Bedono, Demak. *Jurnal Ilmu Lingkungan*, 18(2), 110–118. https://doi.org/10.14710/jil.18.2.110-118

[2] Boone, K., & Bhomia, R. (2017). Mangrove carbon stock assessment in West Papua. *Journal of Coastal Conservation*, 21, 23–32. https://doi.org/10.1007/s11852-016-0465-3

[3] Donato, D. C., et al. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293–297. https://doi.org/10.1038/ngeo1123

[4] IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories*. Volume 4. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[5] Komiyama, A., et al. (2005). General allometric equations for estimating biomass in mangrove forests. *Journal of Tropical Ecology*, 21(4), 471–477. https://doi.org/10.1017/S026646740500247X

[6] Kauffman, J. B., et al. (2011). Ecosystem carbon stocks of mangroves across broad environmental gradients. *Ecological Applications*, 21(2), 457–467. https://doi.org/10.1890/10-1454.1

[7] Kusumaningtyas, M. A., et al. (2019). Carbon stock potential in Indonesian mangroves. *Forest Ecology and Management*, 448, 323–332. https://doi.org/10.1016/j.foreco.2019.06.005

[8] Taillardat, P., et al. (2018). Blue carbon of mangrove forests: Global patterns. *Nature Climate Change*, 8, 865–871. https://doi.org/10.1038/s41558-018-0286-6

[9] Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon Management*, 3(3), 313–322. https://doi.org/10.4155/cmt.12.20

[10] Azzahra, R. (2020). Estimasi Karbon pada Ekosistem Mangrove Desa Bedono, Demak. *Jurnal Ilmu Lingkungan*, 18(2), 110–118. https://doi.org/10.14710/jil.18.2.110-118

[11] Boone, K., & Bhomia, R. (2017). Mangrove carbon stock assessment in West Papua. *Journal of Coastal Conservation*, 21, 23–32. https://doi.org/10.1007/s11852-016-0465-3
[12] Breithaupt, J. L., Smoak, J. M., Smith, T. J., Sanders, C. J., & Hoare, A. (2012). Organic carbon burial rates in mangrove sediments: Strengthening the global budget. *Global Biogeochemical Cycles*, 26(3). https://doi.org/10.1029/2012GB004375
[13] Chen, L., Zeng, X., & Yang, X. (2018). Above- and below-ground biomass and carbon stocks in subtropical mangrove plantations. *Forest Ecology and Management*, 417, 168–174. https://doi.org/10.1016/j.foreco.2018.03.003
[14] Donato, D. C., et al. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293–297. https://doi.org/10.1038/ngeo1123
[15] Ghosh, T., et al. (2021). Spatio-temporal carbon stock dynamics in Indian Sundarbans mangrove forests. *Wetlands Ecology and Management*, 29(5), 843–857. https://doi.org/10.1007/s11273-021-09825-3
[16] IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories*. Volume 4. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[17] Kairo, J. G., Bosire, J., & Macharia, D. (2021). Blue carbon in mangrove systems: Kenya's experience. *Estuarine, Coastal and Shelf Science*, 256, 107302. https://doi.org/10.1016/j.ecss.2021.107302
[18] Kauffman, J. B., et al. (2016). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. *CIFOR Working Paper 125*. https://doi.org/10.17528/cifor/005485
[19] Komiyama, A., et al. (2005). General allometric equations for estimating biomass in mangrove forests. *Journal of Tropical Ecology*, 21(4), 471–477. https://doi.org/10.1017/S026646740500247X
[20] Kusumaningtyas, M. A., et al. (2019). Carbon stock potential in Indonesian mangroves. *Forest Ecology and Management*, 448, 323–332. https://doi.org/10.1016/j.foreco.2019.06.005
[21] Lovelock, C. E., et al. (2017). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature*, 526(7574), 559–563. https://doi.org/10.1038/nature15538
[22] Pham, T. D., et al. (2019). Mapping of tropical mangrove forest biomass using Sentinel-1 data: Case study in the Mekong Delta, Vietnam. *Remote Sensing*, 11(8), 983. https://doi.org/10.3390/rs11080983
[23] Taillardat, P., et al. (2018). Blue carbon of mangrove forests: Global patterns and opportunities. *Nature Climate Change*, 8, 865–871. https://doi.org/10.1038/s41558-018-0286-6
[24] Tiolong, A. B., Maramis, D., & Dondokambey, A. (2019). Analisis simpanan karbon pada ekosistem mangrove di Kota Bitung. *Jurnal Ilmiah Platax*, 7(3), 123–132. https://doi.org/10.35800/jip.7.3.2019.25550