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Carbon Stock in Sediments of Mangrove Ecosystems in Pangkalan Jambi Village, Bengkalis Regency

Cadangan Karbon pada Sedimen di Ekosistem Mangrove Desa Pangkalan Jambi Kabupaten Bengkalis

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ABSTRACT

The study on carbon reserves in sediment within Pangkalan Jambi Village, Bengkalis Regency's mangrove ecosystem, was conducted from June to 2024. This research aimed to analyze carbon reserves in the sediment of the mangrove ecosystem in Pangkalan Jambi Village, Bengkalis Regency, Riau Province. The study employed field survey methods and laboratory analyses, focusing on three stations with varying mangrove densities. Results revealed nine mangrove species, dominated by *Rhizophora mucronata*. The average mangrove density was 2,611 individuals/ha, with a carbon reserve of 43.25 tons/ha across all stations. The study found a positive correlation (r = 0.528) between mangrove density and carbon reserves, explaining 27.98% of the total variation. Furthermore, carbon reserves showed no significant differences across sediment depths. These findings emphasize the importance of mangrove conservation for carbon storage, contributing to climate change mitigation. Further biomass and species-specific carbon storage research is recommended to optimize mangrove management strategies.

Keywords: Mangroves, Carbon Stock, Sediment, Pangkalan Jambi

ABSTRAK

Penelitian cadangan karbon pada sedimen di ekosistem mangrove Desa Pangkalan Jambi Kabupaten Bengkalis dilakukan pada bulan Juni s/d 2024. Penelitian ini bertujuan untuk menganalisis cadangan karbon pada sedimen di ekosistem mangrove Desa Pangkalan Jambi, Kabupaten Bengkalis, Provinsi Riau. Penelitian dilakukan dengan metode survei lapangan dan analisis laboratorium, dengan fokus pada tiga stasiun dengan kerapatan mangrove yang bervariasi. Hasil menunjukkan terdapat sembilan jenis mangrove, didominasi oleh *Rhizophora mucronata*. Rata-rata kerapatan mangrove adalah 2.611 individu/ha, dengan cadangan karbon sebesar 43,25 ton/ha di seluruh stasiun. Studi ini menemukan korelasi positif (r = 0,528) antara kerapatan mangrove dan cadangan karbon, yang menjelaskan 27,98% dari total variasi. Selain itu, cadangan karbon tidak menunjukkan perbedaan signifikan pada berbagai kedalaman sedimen. Temuan ini menegaskan pentingnya konservasi mangrove untuk penyimpanan karbon, yang berkontribusi pada mitigasi perubahan iklim. Penelitian lebih lanjut tentang biomassa dan penyimpanan karbon spesifik per jenis mangrove direkomendasikan untuk mengoptimalkan strategi pengelolaan mangrove.

Kata Kunci: Mangrove, Cadangan Karbon, Sedimen, Pangkalan Jambi

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INTRODUCTION

Global warming refers to the phenomenon of increasing average global surface temperatures caused by greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions, primarily from human activities, including transportation, industry, agriculture, and deforestation, trap heat in the atmosphere through the greenhouse effect. According to Jones et al. (2023), global temperature changes affect the intensity of storms, rainfall patterns, and the length of seasons in various regions. Another significant impact is rising sea levels due to melting polar ice, leading to coastal erosion and saltwater intrusion in Java, Sumatra, and Bali (Susanto et al., 2023). In addition, temperature increases and altered rainfall patterns threaten mangrove ecosystems, particularly in Sulawesi and Kalimantan, reducing their capacity to sequester carbon and protect coastlines from extreme wave action (Rahmawati et al., 2022).

Mangrove ecosystems are unique coastal environments that thrive in muddy soils with high salinity. Sianturi & Maisyah (2018) highlighted the ecological importance of mangroves, including their role in protecting coastlines from erosion and strong waves, providing habitats for coastal biota, and absorbing carbon dioxide (CO_2) through photosynthesis. Harahap et al. (2022) stated that Indonesia's mangrove forests can absorb more carbon than terrestrial ecosystems, with a carbon storage capacity of 1,000–1,200 tons per ha in certain regions (Handayani et al., 2023). Species such as *Rhizophora* sp. and *Avicennia* sp. can store 200–300 tons of carbon per ha (Setiawan et al., 2023), making them one of the most effective natural carbon sinks. Mangroves store carbon in their biomass such as trunks, roots, and leaves and in soil sediments, where it can remain sequestered for hundreds of years (Khairunnisa et al., 2018).

Mangrove forest management is an essential strategy for mitigating climate change. This approach includes sustainable forest management, preventing deforestation, restoring peatlands, and rehabilitating mangrove forests. Fitriani et al. (2022) further noted that mangroves in coastal areas of Sumatra and Java contribute significantly to reducing greenhouse gas emissions, supporting Indonesia's efforts to combat global climate change. According to the Ministry of Environment and Forestry, Indonesia's mangrove forest area reached 3.36 million hectares in 2021, covering regions in Sumatra, Kalimantan, Papua, and Sulawesi, accounting for 25% of the world's total mangrove coverage. In Riau Province alone, mangrove forests span 224,895 ha across several districts, making it a strategic area for conservation and climate change mitigation.

Mangrove ecosystems are one of the most effective natural solutions for reducing atmospheric carbon emissions by ensuring the sustainability of mangrove forests through rehabilitation and proper management. As the country with the largest mangrove forests in the world, Indonesia holds significant potential for mitigating climate change. According to data from the Ministry of Environment and Forestry, Indonesia's mangrove forests span 3.36 million ha, with Riau Province contributing approximately 224,895 ha of this area. Pangkalan Jambi Village, located in Bengkalis Regency, is one of the regions with a pristine mangrove ecosystem rich in carbon storage potential.

However, research on carbon storage estimation in the mangrove forests of Pangkalan Jambi Village remains limited. Yet, understanding the carbon sequestration potential of this area is crucial as a basis for mangrove management and conservation while supporting climate change mitigation policies. Based on this background, this study aims to (1) analyze mangrove species and density, (2) measure carbon content in sediments, and (3) evaluate the relationship between mangrove density and carbon storage in sediments in Pangkalan Jambi Village.

The results are expected to contribute not only scientifically to the field of mangrove ecology but also practically as a reference for sustainable coastal ecosystem management. Consequently, the mangrove forests in Pangkalan Jambi Village can be optimally managed to support climate change mitigation efforts and environmental sustainability. This study aims to analyze mangrove species and density, assess carbon stock in mangrove sediment in Pangkalan Jambi Village, evaluate the relationship between mangrove density and sediment carbon stock, and compare carbon stock across different sediment depths.

MATERIALS AND METHOD

The research was conducted from June to July 2024 in the mangrove forest area of Pangkalan Jambi Village, Bengkalis Regency, Riau Province. Sample analysis was conducted at the Marine Chemistry Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Science, Universitas Riau.

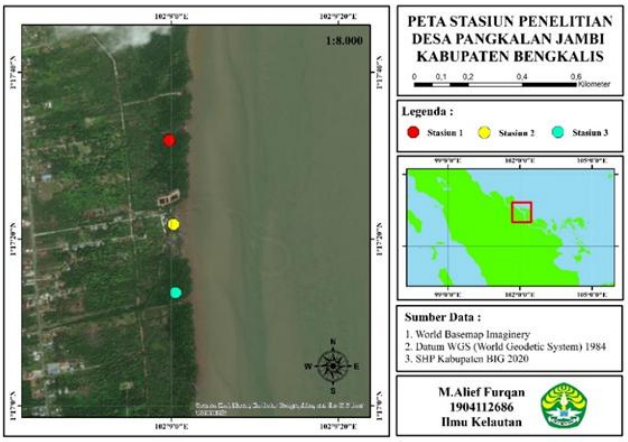

Figure 1. The mangrove area of Pangkalan Jambi Village as the research

Research methodology

A survey method was applied in this research, involving direct observation and sediment sampling at the research site. The sediment samples were analyzed in the Marine Chemistry Laboratory, Faculty of Fisheries and Marine Science, Universitas Riau, using the Loss on Ignition (LOI) method to measure organic carbon content.

The research was conducted in the mangrove area of Pangkalan Jambi Village, Bengkalis Regency. The determination of three stations was based on different conditions: Station 1: A pristine mangrove area with no human interference; Station 2: A mangrove area developed as a tourist site; Station 3: A mangrove area located near residential settlements. A transect approximately 100 meters long was established at each station, with 10 × 10 m² quadrat plots placed along the transect to represent mangrove density levels. Water quality measurement was conducted as supporting data, including temperature, salinity, and pH, measured in situ during high tide.

Vegetation data were collected from observation plots, focusing on tree trunks with a diameter of ≥4 cm. Mangrove density was calculated based on the number of trees per unit area (ind/ha).

Sediment samples were collected at three stations, with three points designated for each mangrove density level (high, medium, and low). Samples were taken at three depth intervals: 0–10 cm, 11–20 cm, and 21–30 cm, resulting in 27 samples; each sample weighs 50 g.

After collecting all data and samples in the field, analyses were carried out on the collected samples. Organic matter analysis was conducted following the Pett (1993) method. The procedure involved drying sediment samples in an oven at 105°C for 24 hours, followed by combustion in a furnace at 550°C for 3 hours. The weight of the samples was then measured to determine the organic matter content. Carbon content analysis was carried out using the Loss on Ignition (LOI) method Howard et al. (2014). This process involved drying sediment samples in an oven at 60°C for 48 hours, grinding them to ensure homogeneity, and then burning them at 450°C for 4 hours. The final step involved re-weighing the samples to calculate the carbon content accurately.

The analyzed data included soil density, carbon density, carbon estimation, and organic carbon percentage. Calculations were performed using the formulas provided by Howard et al. (2014).

$$BD = \left(\frac{g}{cm^3}\right) \quad (1)$$

$$\%BO = \left(\frac{(w_0 - w_t)}{w_0}\right) \times 100 \quad (2)$$

$$\%C = (0{,}580 \times \%BO) \quad (3)$$

$$\text{Soil C Density} = (\%C \times BD) \quad (4)$$

$$\text{Soil C} = (D \times SDI \times \%C) \quad (5)$$

Description:

BD	=	Bulk density (g/cm³)
g	=	Oven dry mass
cm³	=	Sample volume
%BO	=	Percentage of organic matter in sediment lost during the combustion process
Wo	=	Dry weight before combustion (g)
Wt	=	Final weight after combustion (g)
%C	=	The carbon content of organic sediment material
%BO	=	Percentage of organic matter in sediment (ignition)
0.580	=	Constantly convert % organic matter to % organic C.
Soil C	=	The carbon content of sediment
SDI	=	Sample Depth Interval (cm)

RESULT AND DISCUSSION

Water quality measurement

Water quality plays a crucial role in supporting mangrove ecosystems and coastal biota. Poor water quality, caused by pollutants such as excess nutrients or sediment, can be mitigated by mangroves through nutrient absorption, sediment deposition, and natural filtration. Mangroves can gradually improve water quality through these mechanisms, although the type and pollution level limit their effectiveness. The water quality parameter measurement data can be found in Table 1.

Table 1. Average measurement of water quality parameters

No.	Station	Parameter		
		Salinity	pH	Temperature (°C)
1	Station 1	24,6	6,46	29,96
2	Station 2	21,1	6,33	31,33
3	Station 3	23,0	6,43	30,33

Water quality influences mangrove ecosystems and coastal biota. This study measured salinity, pH, and water temperature. Salinity ranged from 21.1-24.6 ppt, with the highest at Station 1 (24.6 ppt) and the lowest at Station 2 (21.1 ppt) due to drainage channels at the tourist site. pH ranged from 6.33-6.46, with the highest at Station 1 (6.46) and the lowest at Station 2 (6.33), influenced by the mixing of seawater and freshwater from small river estuaries. Water temperature ranged from 29.96-31.33°C, highest at Station 2 (31.33°C) and the lowest at Station 1 (29.96°C) due to more shaded conditions. According to marine biota standards, all parameters are within acceptable limits to support mangrove ecosystems.

Identification of mangrove species and density

Nine mangrove species were identified in Pangkalan Jambi Village, consisting of true and associated mangroves. *R.mucronata* was the most dominant species, while *Nypa fruticans* and *Lumnitzera littorea* were rarely found. Mangrove density ranged from 1300-4300 ind/ha, classified as dense according to the Minister of Environment Decree No. 201 of 2004 (>1500 ind/ha). The highest density was at Station 1 (minimal human activity), moderate at Station 3 (near residential areas), and lowest at Station 2 (affected by coastal abrasion). *R. mucronata* dominated due to extensive planting since 2022 and its use as traditional medicine. The species composition and individual count of mangrove vegetation are presented in Table 2.

Table 2. Mangrove vegetation density (ind/ha)

Species	Station 1			Station 2			Station 3		
	1	2	3	1	2	3	1	2	3
R.mucronata	2300	900	700	1400	400	600	700	700	100
R.apiculata	500	200	1200	0	200	100	1200	600	300
Nypa fruticans	400	200	100	0	0	0	0	0	200
A.alba	300	900	600	0	0	300	400	0	0
X.granatum	500	100	700	500	300	200	700	0	100
S.alba	0	400	100	400	100	0	0	100	0
L.littorea	100	300	300	0	200	0	0	0	0
E.agallocha	100	0	300	0	0	700	0	200	400
S.caseolaris	100	0	0	100	400	0	0	400	200
Total	4300	3000	4000	2400	1600	1900	3000	2000	1300
Average		3766			1966			2100	

The average mangrove density at the study site was 2611 ind/ha, lower than the Mangrove Conservation Area in Tarakan (11,700 ind/ha) (Salim et al., 2019) but higher than Kayu Ara Permai Village (2166 ind/ha) (Dewi et al., 2021). The well-preserved mangrove ecosystem results from community efforts to combat coastal abrasion.

Sediment organic matter content

The average organic matter content in the sediment of the mangrove ecosystem in Pangkalan Jambi Village ranges from 5.3% to 9.1%, with an average of 6.14%. The lowest organic matter content was found at Station 1, with high mangrove density, while the highest was at Station 2, with low mangrove density (Table 3).

Table 3. Average organic matter content (%) and ± standard deviation (± Std)

Station	Average (%) ±Standard Deviation (± Std)
1	5,67 ± 0,27428
2	6,68 ± 2,16042
3	6,08 ± 0,17243
Average	6,14%

Carbon reserves in the sediment are influenced by organic matter content, substrate type, and station location. Station 2, with low mangrove density and a more open area, tends to have higher organic matter content than Station 1 and Station 3, which have high and medium densities. This is due to the input of organic matter carried by currents, supported by the presence of trimba (Triangle Mangrove Barrier) that prevents organic matter from being taken back to the water. Moreover, the organic content in soil, including sediment, is highly sensitive to various factors such as climate, topography, soil type, crop management, and other anthropogenic conditions (Iman et al., 2017).

Carbon stock content in sediments

The calculated carbon stock content in sediments by plot and station in the mangrove ecosystem of Pangkalan Jambi Village, Bengkalis Regency, can be seen in Table 4.

Table 4. Average sediment carbon stock content

Station	Plot	Carbon Stock Content	Average (ton/ha) ±Standard Deviation (±Std)
	1	45,68	
1	2	45,95	45,50 ± 0,56765
	3	44,86	
	1	40,84	
2	2	40,33	41,88 ± 2,24598
	3	44,45	
	1	41,10	
3	2	44,42	42,38 ± 1,78360
	3	41,63	
Total Average Content			43,25 ton/ha

In Table 4, it is shown that the lowest carbon stock content was found at Station 2, with the lowest mangrove density, at 41.88 tons/ha. This is because Station 2 is more open, allowing currents to carry sediment during high tide, and the role of the Triangle Mangrove Barrier (trimba) in retaining sediment during low tide enables sediment to mix with the previous surface layer. The highest carbon stock content was found at Station 1, with the highest mangrove density, at 45.50 tons/ha, with a total carbon content of 129.77 tons/ha and an overall average of 43.25 tons/ha.

This result is lower than the study by Azzahra et al. (2020) in Bedono Village, Demak, at 480.608 tons/ha but higher than the study by Pangestika et al. (2023) in the mangrove forest of Ayah Subdistrict Kebumen Regency, at 30.43 tons/ha. The average carbon stock content distribution varies across each station in the study area, influenced by soil density and mangrove canopy cover at each location. According to Hickmah et al. (2021), organic carbon storage is determined by density, organic matter content, and sample depth.

The average carbon storage in the mangrove ecosystem of Pangkalan Jambi Village is 43.25 tons/ha. This result is higher compared to the study by Pangestika et al. (2023) in the mangrove forest of Ayah Subdistrict, Kebumen Regency, which recorded 30.43 tons/ha. However, this result is relatively low when compared to the study conducted by Azzahra et al. (2020) in the Bedono Demak Village, with total carbon storage of 480,608 tons/ha, and much lower compared to the study by Lestariningsih et al. (2018) in the mangrove area of Timbulsloko Village, Demak, Central Java, with total carbon storage of 12,370.8 tons/ha.

The differences in total sediment carbon content in mangrove areas are due to variations in mangrove cover conditions, mangrove species growing at each site, and the characteristics of the sediment structure at each location. The lower carbon content in mangrove sediments can be attributed to various human activities, with land use changes for settlement and shrimp farming potentially disturbing the mangrove ecosystem as a carbon sink.

Marbun et al. (2020) state that mangrove forests can store a large amount of carbon, both in biomass and sediment. Furthermore, Mahasani et al. (2016) stated that several factors influence carbon storage in soils, including environmental factors such as land use and physicochemical aspects of the soil such as temperature, pH, pore size, texture, bulk density, and others. This is further supported by Hickmah et al. (2021), who add that organic carbon storage is also influenced by sediment pH, particle size, and type.

The relationship between mangrove density and carbon stock in sediments

The simple linear regression analysis results show that the relationship between carbon stock and mangrove density is moderate, with the regression equation Y = 36.878 + 0.0019x (Figure 2). The r value is 0.528. The analysis of the relationship between density and carbon stock shows a coefficient of determination $R^2 = 0.279$, meaning that 27.98% of the total carbon stock is influenced by density, while other factors affect the remaining 72.02%. The significance value is 0.143 ($p > 0.05$).

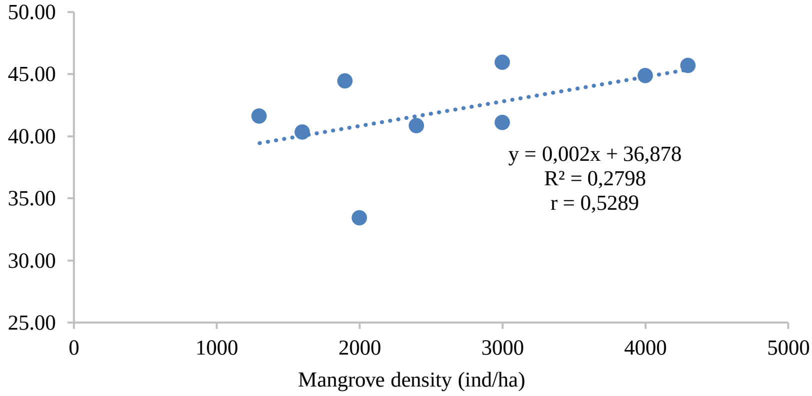

Figure 2. The relationship between mangrove density and carbon stock

The results obtained in this study align with the statement of Rahmat et al. (2022), which suggests that the amount of carbon stored in mangrove stands is strongly influenced by the density of mangrove vegetation. The results of this study indicate that mangrove density does not affect organic matter content. This may be due to several factors, such as most of the mangroves being newly planted in 2021 and not yet developed into mature trees. However, the findings of this study are contrary to those of Pangestika et al. (2023), who stated that density does not significantly affect the amount of carbon stored.

Comparison of carbon stock stored at different depths

The calculation results of carbon stock content in sediments based on depth in the mangrove ecosystem of Pangkalan Jambi Village, Bengkalis Regency, can be seen in Table 5.

Table 5. Carbon stock at different depths (ton/ha)

Station	Depth		
	0-10cm	11-20cm	21-30cm
1	46,85	43,61	45,45
2	41,34	41,64	42,65
3	40,75	45,11	41,61
Average	42,98	43,43	43,23

Based on Table 6, the average carbon stock content at three different depths shows similar values at each depth. Meanwhile, the lack of significant differences between Station 2 and Station 3 is suspected to be due to several factors, one of which is frequent abrasion or wave effects that may cause sediments to mix back to the surface, leading to uniform carbon distribution at each depth. Additionally, the trimba (Triangle Mangrove Barrier) along the coastline supports the even distribution of carbon within the sediment.

CONCLUSION

The research in the mangrove forest area of Pangkalan Jambi Village revealed the presence of 9 mangrove species with an average density of 2,611 individuals per hectare. The highest density was observed at station 1, where human activity is minimal. The average sediment carbon content in the mangrove area is 43.25 tons/ha, with the highest concentration also found at station 1, correlating with higher mangrove density. A moderate relationship ($r = 0.528$) was identified between mangrove density and sediment carbon content, indicating that mangrove density contributes to carbon storage. Moreover, no significant differences were found in sediment carbon storage across different depths (0–10 cm, 11–20 cm, and 21–30 cm), with stable carbon values across all layers ($p > 0.05$).

REFERENCES

Azzahra, F., Suryanti, S., Febrianto, S., 2020. Carbon absorption estimation in the mangrove forest of Bedono Village, Demak, Central Java. *Journal of Fisheries and Marine Research,* 4(2): 308-315.

Dewi, D., **Efriyeldi, E., Amin, B.,** 2021. Estimation of carbon reserved in mangrove forest of Sungai Apit District, Siak Regency, Riau Province. *Asian Journal of Aquatic Sciences*, 4(3): 197-207.

Fitriani, A., Prasetyo, D., Hidayah, T., 2022. Mangrove ecosystems and greenhouse gas emission reduction. *Jurnal Lingkungan dan Pesisir,* 6(2): 140-153.

Handayani, S., Setiawan, L., Putri, M., 2023. Mangrove forest carbon storage in Indonesia. *Jurnal Kehutanan Indonesia,* 18(1): 112-128.

Harahap, R., Setiawan, T., Budi, A., 2022. Mangroves and carbon sequestration: A comparative study with terrestrial ecosystems. *Jurnal Biologi Tropis,* 15(2): 120-135.

Hickmah, N., Maslukah, L., Wulandari, S.Y., Sugianto, D.N., Wirasatriya, A., 2021. Study of organic carbon stock in sediments in the mangrove vegetation area of Karimunjawa. *Indonesia Journal of Oceanography* 3(4): 419-426.

Howard, J., Hoyt, S., Isensee, K., Telszewski, M., Pidgeon, E., 2014. Coastal blue carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses. https://www.unep.org/resources/publication/coastal-blue-carbon-methods-assessing-carbon-stocks-and-emissions-factors

Iman, M.I., Riawan, E., Setiawan, B., Abdurahman, A., 2017. Air tanah untuk adaptasi perubahan iklim di Malang, Jawa Timur: penilaian risiko penurunan ketersediaan air. *Riset Geologi dan Pertambangan*, 27(1): 47-64.

Jones, L., Lee, H., Kim, S., 2023. Impacts of global warming on weather patterns. *Nature Climate Change,* 13(5): 569-577.

Khairunnisa, K., Setyobudiandi, I., Boer, M., 2018. Carbon stock estimation of seagrasses in the eastern coast of Bintan Regency. *Jurnal Ilmu dan Teknologi Kelautan Tropis,* 10(3): 639-650.

Lestariningsih, W.A., Soenardjo, N., Pribadi, R., 2018. Carbon stock estimation in the mangrove area of Timbulsloko Village, Demak, Central Java. *Buletin Oseanografi Marina* ,7(2): 121-130.

Mahasani, I.G.A.I., Karang, I.W.G.A., Hendrawan, I.G., 2016. Karbon organik di bawah permukaan tanah pada kawasan rehabilitasi hutan mangrove, Taman Hutan Raya Ngurah Rai, Bali. *Prosiding Seminar Nasional Kelautan*.

Marbun, A., Rumengan, A.P., Schaduw, J.N., Paruntu, C.P., Angmalisang, P.A., Manopo, V.E., 2020. Analysis of carbon stocks in mangrove sediments in Baturapa Village, Lolak Subdistrict, Bolaang Mongondow Regency. *Jurnal Pesisir dan Laut Tropis,* 8(1): 20–30.

Pangestika, M.A., Soenardjo, N., Pramesti, R., 2023. Estimation of sediment carbon storage in the mangrove forest of Ayah Subdistrict, Kebumen Regency. *Journal of Marine Research,* 12(1): 89-94.

Pett, R.J.A., 1993. Collection of laboratory methods for selected water and programs at Australian Universities and College. PT. Hasfarm Dian Konsultan, 20p.

Purnobasuki, H., 2012. The utilization of mangrove forests as carbon storage. *Buletin PSL Universitas Surabaya* 28: 3-5.

Rahmat, N., Pratikto, I., Suryono, C.A., 2022. Carbon storage in mangrove vegetation stands in Pasar Banggi Village, Rembang. *Journal of Marine Research*, 11: 506-512.

Rahmawati, S., Nurhidayah, H., Suparno, L., 2022. Mangrove ecosystems and climate change. *Jurnal Ekologi Pesisir,* 7(1): 91-104.

Salim, G., Rachmawani, D., Agustianisa, R., 2019. Hubungan Kerapatang mangrove dengan kelimpahan gaastropoda di Kawasan Konservasi Mangrove dan Bekantan (KKMB) Kota Tarakan. *Jurnal Harpodon Borneo*, 12(1).

Setiawan, H., Suhendar, M., Rakhmawati, I., 2023. Carbon content of mangrove vegetation in coastal areas. *Jurnal Ilmu Lingkungan*, 19(1): 99-11.

Sianturi, R., Masiyah, S., 2018. Estimation of mangrove carbon stock in the Kumbe River Estuary, Malind District, Merauke Regency. *Musamus Fisheries and Marine Journal*, 24-32.

Susanto, A., Lestari, Y., Haryono, T., 2023. Rising sea levels and coastal threats. *Jurnal Kelautan Indonesia* 10(1): 25-38