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Community Structure and Carbon Stock of Mangrove Sediments in Sembilang National Park Area

Muhammad Fadlurrohman Ash Raffi[1]*, Taryono[2], Ali Mashar[2]

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ABSTRACT

Increased greenhouse gas emissions have led to climate change. Indonesia plans to reduce greenhouse gas emissions by 140 million tons of CO_2-equivalent (CO_2e) by 2030. One strategy for achieving this goal is to conserve mangrove habitats. However, unsustainable activities continue to jeopardize the survival of these mangroves. The purpose of this study was to investigate the community structure and sediment carbon content of mangrove ecosystems in Sembilang National Park. Data was obtained at three stations using 100-m transects extending inland from the seashore or riverbank. The sediment carbon analysis was carried out utilizing the Loss on Ignition (LOI) method. Excoecaria agallocha had the highest Importance Value Index (IVI) at the Sungai Barong station, followed by Rhizophora apiculata in the Sungai Sanjang and Birik stations. The mangrove ecosystems at the study sites were characterized as moderately dense. The investigation revealed that the carbon store in mangrove sediments was 1294.14 t/ha, with an average of 431.38 t/ha. Mangrove ecosystems must be managed and protected to ensure that they continue to provide ecological and economic advantages.

Keywords: carbon stock, climate change, mangrove

INTRODUCTION

Mangrove ecosystem conservation is one of the most important measures for reducing carbon emissions due to its high carbon storage capability. Bachmid *et al.* (2018) revealed that mangroves may absorb up to 77.9% of CO_2 and store it in their stems, leaves, and sediment. Donato *et al.* (2012) observed that the sediment contains most of the carbon stock in the mangrove ecosystem.

Sembilang National Park is a mangrove habitat that helps to store carbon and regulate the climate. However, the pressures of diverse human activities pose a major threat to its viability. Unsustainable use has increased stress on the park's mangrove environment, including illegal logging, land conversion for residence, agriculture, aquaculture, and natural calamities like forest fires. Between 2014 and 2019, land clearing for settlements and the conversion of mangrove lands into aquaculture ponds reduced mangrove cover by 4,145 ha (Febrianto *et al.* 2022). Such land modification lowers mangroves' ability to absorb carbon and contributes to the release of previously stored carbon into the atmosphere.

Mangrove ecosystem management is critical for avoiding unsustainable use, mitigating degradation effects, and meeting emission reduction targets. In this context, the mangrove ecosystem in Sembilang National Park has the potential to act as a carbon pool, providing a feasible alternative to help achieve national emission reduction goals. This study looks at the community structure and sediment carbon potential of mangrove forests in Sembilang National Park. The findings are expected to give useful information on mangroves' carbon storage capability, particularly for park managers and others interested in meeting emission reduction targets.

METHODS

Research Site and Time

This investigation was carried out from March to May 2024 in Sembilang National Park, Banyuasin Regency, South Sumatra (Figure 1). The observation sites represent various levels of mangrove ecosystem usage and have been grouped into three study stations. Station 1 (Sungai Barong) was close to aquaculture activity; Station 2 (Sungai Sanjang) was next to Sembilang Hamlet; and Station 3 (Sungai Birik) was further distant from human use activities.

Instruments

The instruments utilized in this investigation were designed to make data collecting and laboratory analysis more efficient. These comprised stationery,

[1] Graduate School, Program Study Coastal and Marine Resource Management, IPB University, Bogor 16680, Indonesia
[2] Department of Aquatic Resource Management, Faculty of Fisheries and Marine Sciences, IPB University, Bogor 16680, Indonesia
* Corresponding Author:
Email: ashraffimf313@gmail.com

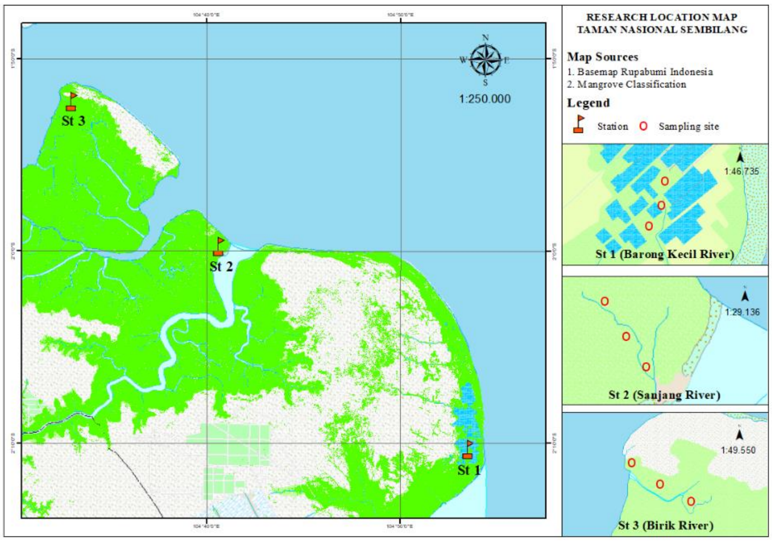

Figure 1 Research site.

sample plastic bags, core pipes, measuring tape, raffia string, analytical balance, oven, petri dishes, GPS map device, muffle furnace, and porcelain crucibles.

Data Collecting

This study's primary data comprised of mangrove structure and sediment data collected through firsthand observation. The mangrove vegetation sample method employed was the line transect, and quadrat plot method outlined by Bengen (2001), which was carried out at three research sites along 100-m transects extending seaward or landward. Each transect had three sample plots based on Agustini *et al.* (2016), with sizes of 10 ×10 m for trees, 5 × 5 m for saplings, and 1×1 m for seedlings (Figure 2). Following Azzahra *et al.* (2020), mangrove diameter was measured at breast height (DBH), which is approximately 1.3 m above the ground level. The Importance Value Index (IVI) was generated to offer a summary of each mangrove species' role and dominance at the study sites. Sediment sampling was carried out using the Verisandria *et al.* (2018) approach, with a PVC pipe or corer inserted vertically to a depth of 100 cm and samples collected at three distinct depth intervals.

Data Analysis

1. Mangrove Vegetation Analysis

The mangrove vegetation was analyzed by identifying mangrove species using Sembilang National Park's Mangrove Species Guidebook (Sarno *et al.* 2018). The following formula was used to determine various ecological parameters: species density (D_i), relative density (RD_i), species cover (C_i), relative cover (RC_i), species frequency (F_i), relative frequency (RF_i), and the Importance Value Index (IVI).

$$\mathrm{IVI_i} = \mathrm{RD_i} + \mathrm{RC_i} + \mathrm{RF_i}$$

where:
RD_i: Relative density
RC_i: Relative cover
RF_i: Relative frequency

2. Soil Carbon Stock Mangrove Analysis

In this study, mangrove sediment carbon stock was analyzed using the Loss on Ignition (LOI) method, as described by Howard *et al.* (2014). This method includes measuring bulk density, organic matter content, and calculating sediment carbon stock. The analysis was carried out using the following steps:

a) Bulk density:

$$Bulk\ density\ (g/cm^3) = \frac{Oven-dried\ sample\ mass\ (g)}{Sample\ volume\ (cm^3)}$$

b) Dry ignition (*loss on ignition*) was calculated using:

$$\%\ LOI = \left(\frac{Wo - Wt}{Wo} x\ 100\right)$$

where:
LOI : Loss on ignition (%)
Wo : Dry mass before combustion (g)
Wt : Dry mass after combustion (g)

c) Conversion of organic matter percentage to carbon percentage was calculated using:

$$\%\ C = (0.580)\ \times\ \%\ LOI$$

where:
LOI : Loss on ignition (%)
%C : Organic carbon content (%)
0.580 : Conversion factor from organic matter to organic carbon

d) Carbon density was calculated using:

$$Soil\ carbon\ density\ \left(\frac{g}{cm^3}\right) = (\%\ C)\ \times\ Bulk\ density\ (g/cm^3)$$

e) Soil carbon content was estimated by using:

$$\text{Soil carbon } (\text{Mg ha}^{-1}) = \text{Bulk density} \times \text{Soil depth interval} \times (\%\text{C})$$

RESULTS AND DISCUSSION

Mangrove Vegetation Analysis

Observations of the mangrove ecosystem in Sembilang National Park revealed seven species: *Rhizophora* apiculata, *R. mucronata*, *Bruguiera gymnorhiza*, *B. sexangula*, *Avicennia marina*, *Excoecaria agallocha*, and *Xylocarpus granatum* (Table 1). The species composition at the study sites was largely comparable, as most of the sampling plots were in the intermediate zone and, to a lesser extent, landward. According to Bengen (2001), mangrove zonation in Indonesia typically contains a seaward zone dominated by Avicennia, followed by Sonneratia associations, a middle zone dominated by Rhizophora, followed by Bruguiera species, and a landward zone that transitions into lowland forest. The species discovered in this study follow that trend, showing that the study location is situated in the mangrove ecosystem's intermediate and landward zones.

Excoecaria agallocha exhibited the highest density of any mangrove species at Station 1 (622 individuals per hectare) (Figure 3). This is most likely because of the species' excellent adaptability to landward settings and high salinity tolerance. According to Noor *et al.* (2006), E. agallocha requires a substantial amount of freshwater throughout the year and is commonly found along the landward border of mangrove zones. At Stations 2 and 3, Rhizophora apiculata had the highest species density, with 389 and 433 individuals per hectare, respectively. Station 3 (Sungai Birik), on Alanggantang Island, has the maximum mangrove density of 1344 individuals per hectare (Figure 4). Sungai Birik's very high density may be ascribed to its remote location and lack of human disturbance or resource exploitation. In contrast, the low density recorded at Sungai Barong could be attributed to its proximity to aquaculture facilities. The mangrove densities in Sungai Birik, Sungai Sanjang, and Sungai Barong are classified as medium density under Minister of Environment Decree No. 201 (2004), which establishes Standard Criteria and Guidelines for Determining Mangrove Degradation.

The Importance Value Index (IVI) can be used to analyze the role of individual mangrove species in comparison to others (Table 2). At Station 1, Excoecaria agallocha had the highest IVI of 147.76%. at a prior study conducted at Sembilang National Park by Sarnubi *et al.* (2020), E. agallocha had an IVI of 72.53%. This variance could be due to several causes,

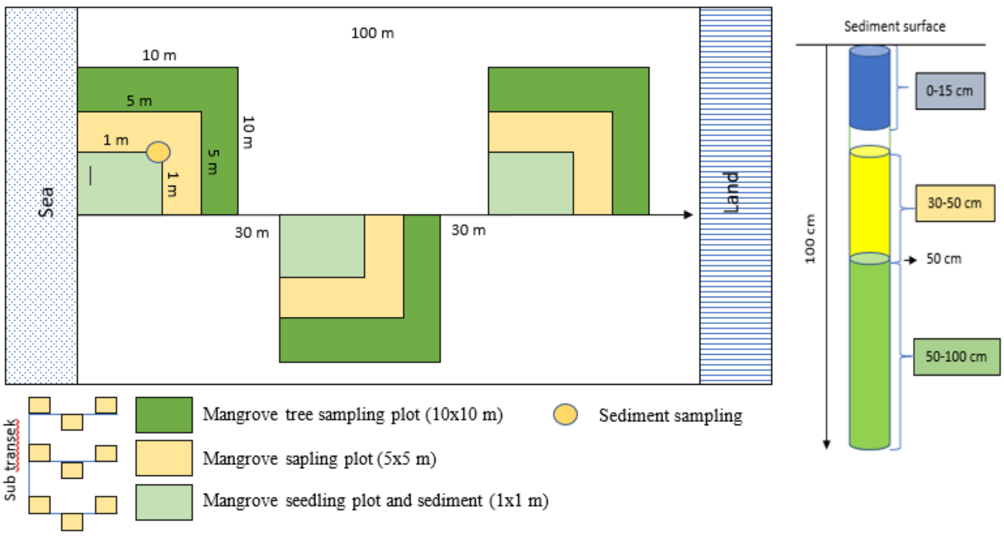

Figure 2 Sampling method.

Table 1 Distribution of mangrove species at research site

Mangrove species	Mangrove distribution		
	S1	S2	S3
Avicennia marina	+	–	–
Bruguiera gymnorhiza	+	+	+
B. sexangula	+	+	–
Rhizophora apiculata	+	+	+
R. mucronata	–	+	+
Excoecaria agallocha	+	+	+
Xylocarpus granatum	–	–	+

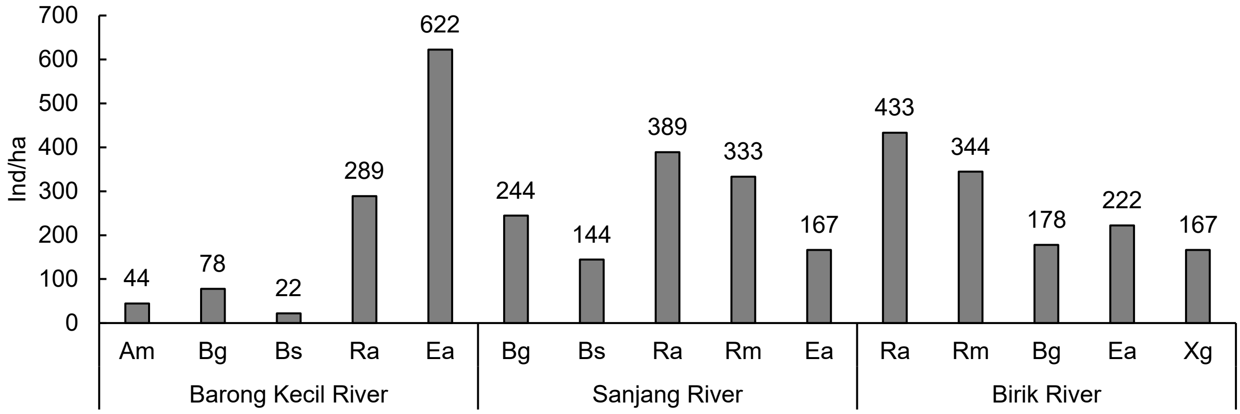

Figure 3 Mangrove density.

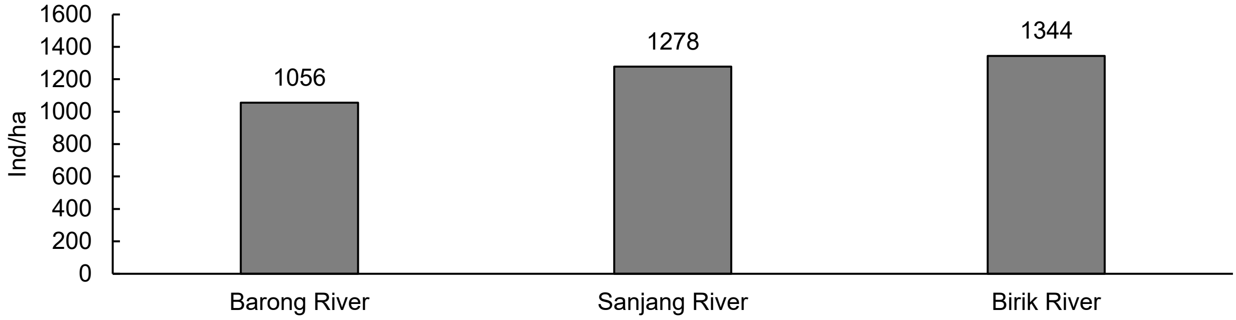

Figure 4 Mangrove density in the study area.

Table 2 Mangrove community structure

Station	Species	%Rdi	%Rfi	%Rci	IVI
I	*Avicennia marina*	4.21	5.56	19.44	29.21
	Bruguiera gymnorhiza	7.37	11.11	3.47	21.95
	B. sexangula	2.11	5.56	3.96	11.62
	Rhizophora apiculata	27.37	33.33	28.76	89.46
	Excoecaria agallocha	58.95	44.44	44.37	147.76
Total	S. Barong Kecil	100	100	100	300
II	*Bruguiera gymnorhiza*	19.13	18.18	19.13	56.4
	B. sexangula	11.30	9.09	11.30	31.7
	Rhizophora apiculata	30.43	36.36	30.43	97.2
	R. mucronata	26.09	22.73	26.09	74.9
	Excoecaria agallocha	13.04	13.64	13.04	39.7
Total	S. Sanjang Sembilang	100	100	100	300
III	*Rhizophora apiculata*	29.91	25.00	29.91	84.8
	R. mucronata	26.50	20.00	26.50	73.0
	Bruguiera gymnorhiza	13.68	15.00	13.68	42.4
	Excoecaria agallocha	17.09	30.00	17.09	64.2
	Xylocarpus granatum	12.82	10.00	12.82	35.6
Total	S. Birik P. Alanggantang	100	100	100	300

one of which is the ecological state of the study site, which is near aquaculture ponds. Anthropogenic disturbances sometimes only promote mangrove species that are tolerant of environmental stress, such as E. agallocha, resulting in dominance and higher IVI. In contrast, Sarnubi *et al.* (2020) conducted their research in a model arboretum area, a managed restoration zone with a more balanced vegetation composition because of human participation in planting and maintenance activities. This is congruent with arboretums' purpose as educational and ecotourism facilities. According to their findings, Avicennia marina had the highest IVI (74.08%), indicating that this species is well-suited for growing in the arboretum of Sembilang National Park.

At Stations 2 and 3, Rhizophora apiculata had the highest IVI, with 97.2% and 89.3%, respectively. According to Hutasoit *et al.* (2017), R. apiculata dominates the mangrove species composition in Sembilang National Park, with the highest IVI of any species at 44.49%. This species' dominance can be due to favorable environmental circumstances that encourage Rhizophora growth. Ulqodry *et al.* (2020) reported that Rhizophora species dominate practically the entire mangrove area in Sembilang National Park due to the abundance of muddy substrates that give ideal circumstances for the genus' growth and development.

Mangrove Sediment Carbon

Soil Bulk Density

The analysis findings show that soil density levels range from 0.48 to 0.93 g/cm³. All research sites had an average soil density of 0.691 g/cm³, indicating the presence of organic materials. According to Hardjowigeno (2003) and Tarigan *et al.* (2015), organic soil has a lower density (0.1−0.9 g/cm³) than mineral soil (1−0.7 g/cm³). Soil density increases with depth (Figure 5). This is thought to be because the surface layer contains more organic matter, such as leaves, branches, fruits, or the remains of other living organisms, which act as a source of organic material in the sediment. Damayanti *et al.* (2012) stated that the presence of organic matter causes the topsoil to have a lower soil density value than the subsurface.

The results of the difference test on soil density values show that there is no significant difference between each station (p = 0.526), implying that bulk density variation among sample collecting locations is rather uniform. The depth test yields a p value of 0.078, near to the significance criterion (p < 0.05), indicating a potential difference in bulk density across depths. The mean rank of bulk density rises with depth, from 9.89 at the initial depth to 13.78 and 18.33 for the successive depths, possibly reflecting an increase in sediment density in deeper layers.

%C Organic

The content of organic carbon in the research area ranges from 6.12% to 12.61%, with an average of 10.04%. This value is slightly lower than those reported by Marbun *et al.* (2020), who found organic carbon (%C) levels ranging from 8.05% to 16.17%, with an average of 10.57%. Organic carbon percentage variances are influenced by various factors such as substrate type, litter production, tidal impacts, meteorological conditions, fertility, and human activities. Station 3 had the highest concentration of organic carbon at a depth of 75−80 cm, while Station 1 had the lowest percentage at a depth of 5−10 cm (Figure 6). Organic carbon values vary by depth and tend to rise as sediment depth increases. The variation in organic matter concentration stems from a lack of oxygen in the deeper sediment layers. Oxygen is involved in the decomposition of organic matter; thus, the oxygen level of deeper soil layers might influence this process. As a result, low oxygen levels in deeper soil layers may impact this process, resulting in higher organic carbon content in the sediment.

The Kruskal-Wallis test on organic carbon content (%C) shows significant variations between stations (Asymp. Sig. = 0.014 < 0.05). Station 3 has the greatest mean rank (Mean Rank = 18.67), followed by Station 2 (15.33), while Station 1 has the lowest (8.00). This suggests that the %C of silt varies greatly between sampling sites. Meanwhile, the difference in %C by depth is not significant (Asymp. Sig. = 0.163 > 0.05), but there is a tendency of increasing mean rank values from depth 1 to depth 3 (10.33 to 17.44). These findings demonstrate that depth does not have a significant influence on the fluctuation of %C in sediment.

The Mann-Whitney test revealed significant statistical differences in organic matter concentration (%C) between Stations 1 and 2 (p = 0.031) and Stations 1 and 3 (p = 0.009). This suggests that Station

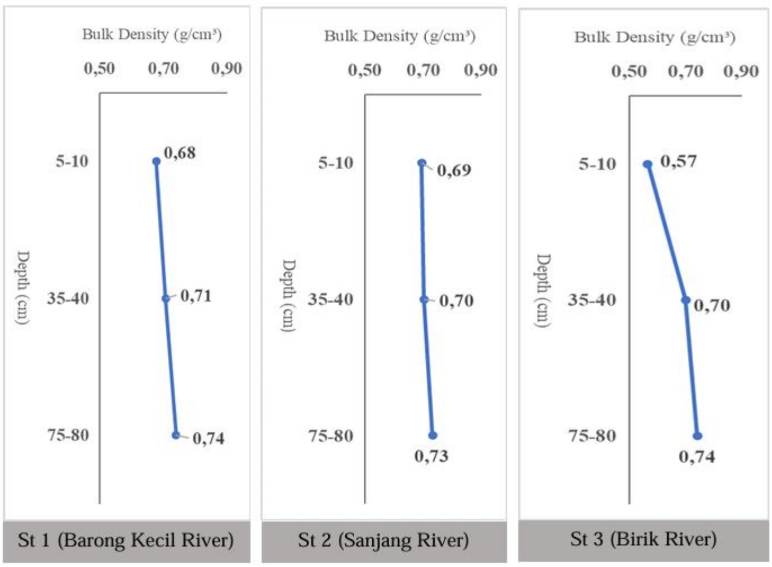

Figure 5 Bulk density by depth.

1 has a much lower %C level than the other two stations. In contrast, no significant difference was discovered between Stations 2 and 3 ($p = 0.270$), indicating that the %C content of these two stations is generally similar.

Carbon Storage in Sediment

The carbon storage capacity of mangrove sediments in the Sembilang National Park region is 1294.14 tons of carbon per hectare (ton C/ha), with an average of 431.38 ton C/ha (Table 3). The average carbon storage value yields a CO_2 absorption rate of 1581.73 t/ha. Station 3, located on the Birik River, has the highest carbon storage value at 466.64 ton C/ha. Differences in sediment carbon content can be impacted by mangrove cover conditions and density levels at each research location. Station 3 has a higher density level than the other sites, resulting in greater sediment carbon storage. Amanda *et al.* (2021) complement this finding, stating that higher mangrove density levels effect differences in soil carbon reserves.

Station 3 is located away from community activity, near the flow of minor rivers, and very far from the ocean. This situation is one of the variables that contribute to the high sediment carbon storage value at this site. The distribution of organic carbon content is primarily impacted by the vicinity of organic material sources, with higher levels near the river mouth and lower levels offshore (Wahyuningsih *et al.* 2020). Nainggolan *et al.* (2022) discovered that regions furthest from the coast have the highest carbon storage levels. Furthermore, Senger *et al.* (2021) stated that tidal conditions can raise oxygen levels, prompting microorganisms to oxidize carbon and then release it into the environment via respiration. This effect is thought to lead to lower carbon content levels in coastal areas. The quantity of sediment carbon storage value depends on the sampling location's proximity to the river flow. According to Hickmah *et al.* (2021), the average organic carbon storage in areas near river flows is larger, at 172.72 t/ha, than in places further away from the flow, where the average organic carbon storage is 76.17 t/ha.

Carbon storage levels grow as the sampling interval deepens (Figure 7). This finding is consistent with Aldiano *et al.* (2022), that the average estimated carbon storage value in sediments was highest at depths of 60−100 cm and concluded that the deeper the sediment, the higher the average carbon value. Mckee *et al.* (2007) and Razaan *et al.* (2024) discovered that the deeper the mangrove sediment layers, the greater the carbon storage values. Sediment deposition rates are one factor that influences vertical variation in carbon storage, as

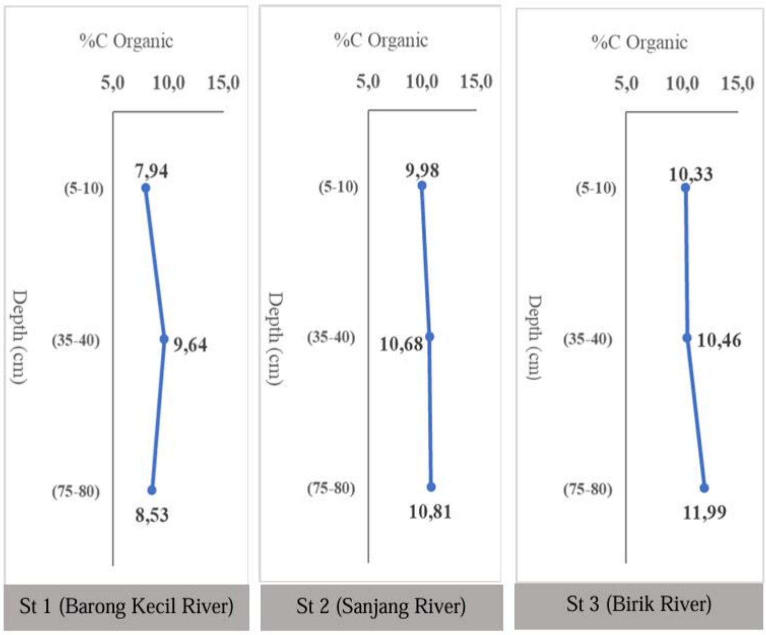

Figure 6 C organic (%) by depth.

Table 3 Sediment carbon stock

Station	C Core section(g/cm³)	Total C Station (MgC/ha)	Average C Station (mgC/ha)
1	3.75	374.83	124.94
2	4.53	452.85	150.95
3	4.66	466.46	155.49
		1294.14	431.38

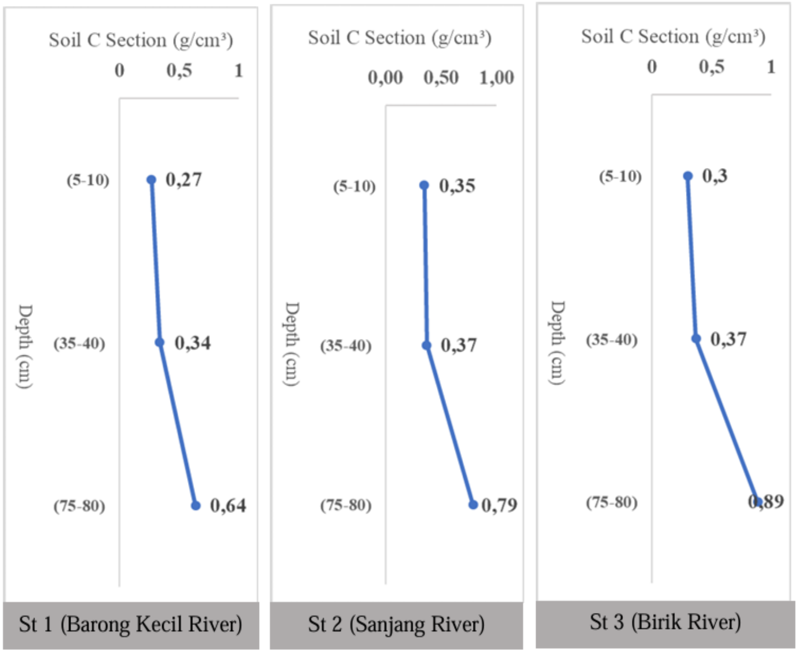

Figure 7 Sediment carbon stock by depth.

sediment depth can alter the deposition rate of organic material from mangrove plants or other sources.

The Kruskal-Wallis test findings showed that the carbon content of the sediments did not change substantially between stations (p = 0.717). However, there were substantial changes in carbon concentration at different depths (p = 0.000). The average rank value for carbon increased with depth, from 7.78 at depth 1 to 22.89 at depth 3. This trend points to a large rise in carbon concentration in deeper sediment layers. In contrast, the mean rank values between stations were very similar, showing that location had no major effect on carbon concentration in sediments.

The Mann-Whitney test results demonstrate that the sediment's carbon concentration varies dramatically with depth. There is no significant difference in carbon content between depths of 0−15 cm and 35−40 cm (p = 0.171), indicating that the upper layers are essentially comparable. However, there is a significant difference between depths of 0−15 cm and 70−80 cm (p = 0.000), as well as depths of 35−40 cm and 70−80 cm (p = 0.000). The much higher mean rank value at 70−80 cm depth implies that carbon content increases dramatically in deeper sediment layers, which supports the earlier Kruskal-Wallis test results.

CONCLUSION

This study identifies seven distinct types of mangroves in the Sembilang National Park ecosystem, indicating a rather high level of species diversity. Mangrove density is modest at all observation stations, with the maximum density observed at Birik River Station 3 (1,344 individuals per hectare). *Excoecaria agallocha* is the most ecologically prominent plant at Station 1, whereas *Rhizophora apiculata* dominates at Stations 2 and 3. The average sediment carbon storage rate is 431.38 t/ha, resulting in a total value of 1,294.14 t/ha. These findings indicate that species composition and site characteristics have a major impact on carbon storage capability, emphasizing the need of preserving diverse mangrove stands with complex structures as part of blue carbon efforts.

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