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COMMUNITY STRUCTURE AND CARBON STOCK POTENTIAL OF MANGROVE ECOSYSTEMS IN THE COASTAL AREA OF BANGKO SUBDISTRICT, ROKAN HILIR REGENCY

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ABSTRACT

The objectives of this study were to analyze mangrove community structure, estimate carbon storage and CO_2 sequestration potential, assess the economic value of CO_2 sequestration, and formulate management strategies for mangrove forests in the coastal area of Bangko Subdistrict, Rokan Hilir Regency. This research was conducted in October 2024 in the coastal area of Bangko Subdistrict, Rokan Hilir Regency, Riau Province. The method applied was a survey-based approach. Sampling stations were determined using purposive sampling. Mangrove community structure data were collected using 10 m × 10 m quadrat transect plots. A total of six observation stations were established, with three plots per transect. The potential carbon stock of the mangrove ecosystem was calculated based on carbon content from trunk biomass, roots, litter, and sediment. Biomass carbon estimation utilized species-specific allometric equations. The results recorded seven mangrove species: *Avicennia alba, A. eucalyptifolia, A. lanata, Bruguiera parviflora, Rhizophora apiculata, R. mucronata,* and *Sonneratia alba.* The highest relative density and the highest relative frequency were recorded for *A.alba* at Station I (75%) and Station II (42.86%). The highest relative dominance was recorded for *Sonneratia alba* at Station V (52.05%). The highest Importance Value Index (IVI) was observed for *Avicennia alba* at Station I (151.15%). The mangrove ecosystem in the coastal area of Bangko Subdistrict has an average carbon stock potential of 382.37 tons/ha, with an estimated CO_2 sequestration potential of 1,277.21 tons per hectare, totalling 15,893,618.87 tons. The estimated average economic value of carbon sequestration is IDR 1,081,274,726/ha, equivalent to IDR 13,455,438,919,367. Sustainable mangrove ecosystem management as a contribution to climate change mitigation can be implemented through the following strategies: ecosystem rehabilitation and protection, strengthening governance and law enforcement, community empowerment and alternative livelihood development, increased awareness and cross-sectoral coordination, and continuous monitoring and research.

Keywords: Mangrove, Carbon Sequestration, Economic Value, Mangrove Management

1. INTRODUCTION

The Mangrove forests are recognized as highly efficient carbon sinks and play a critical role in the global carbon cycle. Within this system, mangrove ecosystems store a substantial amount of biomass, with approximately 50% of the forest's carbon being retained within mangrove vegetation. Consequently, the degradation or loss of mangrove forests may significantly reduce

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carbon sequestration capacity and lead to decreased CO_2 absorption.

Rokan Hilir Regency, located in Riau Province, is recognized as one of the regions with the most extensive mangrove coverage in Indonesia. According to Warningsih et al.[1], the mangrove area in this regency is estimated at 16,276.80 ha and is distributed across three administrative districts: Bangko, Pasir Limau Kapas, and Sinaboi. Over the past several decades, however, the mangrove ecosystem along the coastal zone of Rokan Hilir has experienced a continuous decline, primarily driven by intensive and unsustainable human activities. This has resulted in significant ecological degradation.

Spatial data reported by Safitri[2] indicate a consistent reduction in mangrove extent over time, decreasing from 31,550 ha in 1994 to 28,370 ha in 2004, 23,357 ha in 2007, and 19,724 ha in 2017. These values reflect an overall loss of approximately 11,826 ha within 23 years. Bangko District is among the most severely affected areas. In 2007, mangrove cover in this district was recorded at 14,191 ha; however, by 2017 it had decreased to 11,165 ha[2], and further declined to 10,340.40 ha in 2020[1].

The coastal zone of Bangko District is part of the Berkey Island Nature Reserve, which was formally designated under the Decree of the Minister of Forestry (No. SK.3570/Menhut-VII/KUH/2014). This decree established a total of 8,277.67 ha of protected forest within Rokan Hilir Regency, Riau Province. The management of mangrove ecosystems in Indonesia is regulated under Presidential Regulation No. 73 of 2012 concerning the National Strategy for Mangrove Ecosystem Management (SNPEM). Within this regulation, sustainable mangrove ecosystem management is defined as all efforts related to the protection and sustainable utilization of mangroves to ensure the long-term ecological functionality of mangrove ecosystems for human well-being. Interviews conducted with coastal communities in Bangko District, Rokan Hilir Regency, indicated that current mangrove conditions have undergone significant degradation and decline in forest cover. This degradation has primarily been driven by mangrove logging for construction materials, land conversion for settlements, the establishment of shellfish aquaculture ponds, and the expansion of oil palm plantations.

The ecological consequences of mangrove degradation include a reduction in habitat availability for marine species, with potential impacts on the spawning grounds of up to 40% for commercially important fish species, such as Lates calcarifer. Socioeconomically, this degradation has contributed to a decline in local fishery yields, with an estimated 30% reduction in fishermen's catch[1]. Additionally, the loss of mangrove cover compromises ecological functions, including biomass production and carbon storage capacity.

Given these impacts, conservation and restoration efforts are crucial to support the sustainability of mangrove ecosystems and contribute to mitigating global climate change. Maintaining mangrove ecosystems also ensures the continued availability of economically valuable marine organisms whose life cycles depend on mangrove habitats, enabling long-term and sustainable utilization.

2. RESEARCH METHOD

Time and Place

The study was conducted in October 2024 at designated mangrove sampling sites along the coastal area of Bangko District, Rokan Hilir Regency. Laboratory analyses of mangrove detritus and sediment samples were performed at the Marine Chemistry Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Riau.

Method

The research employed a survey-based method, in which Bangko District, Rokan Hilir Regency, was designated as the study area and mangrove ecosystems served as the primary research object. Sampling stations were selected using purposive sampling, based on specific field considerations and site conditions. The determination of sampling points was conducted using a geospatial approach, based on satellite imagery obtained from the Forest Management Unit (UPT KPH) in Bagansiapiapi. The spatial dataset utilized included mangrove ecosystem distribution maps. Geographic Information System (GIS) analysis was applied to identify areas that met defined research criteria, including sparse, moderate, and dense mangrove vegetation cover. Site selection was carried out through an overlay between satellite imagery and thematic datasets from UPT KPH Bagansiapiapi. Preliminary validation was conducted through visual interpretation and land cover classification analysis, followed by ground checks to ensure alignment between spatial data and actual field conditions.

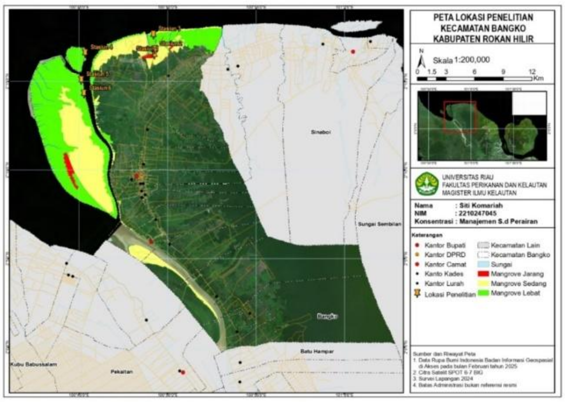

Figure 1. Research location in Bangko subdistrict, Rokan Hilir district

Mangrove community structure analysis included calculations of relative density, relative frequency, relative dominance, and the importance value index (IVI). Biomass estimation of tree stems and roots was performed using allometric equations based on stem diameter, and the resulting biomass values were subsequently converted into carbon stock estimates. Mangrove detritus biomass was quantified using the dry weight measurement method, while sediment carbon content was determined using the Loss on Ignition (LOI) method.

Procedures

Determination of Research Stations

A total of six observation stations were established within the mangrove ecosystem of Bangko District, Rokan Hilir Regency, based on the evaluation of spatial data and in situ field verification. Station selection was carried out using representativeness criteria that considered variations in mangrove stand density as well as proximity to human settlements.

Station I was located in the upstream section of the Serusa River, nearest to settlement areas, and characterized by low mangrove density, with *A. alba* as the dominant species. Station II was positioned in the downstream section of the Serusa River, in proximity to residential and agricultural activities, and was also classified as a low-density mangrove area. Station III, located farther downstream along the Serusa River, represented relatively undisturbed conditions and was categorized as moderate-density mangrove. Station IV was situated on Serusa Island, a landform formed through sedimentation processes, and was likewise classified as a moderate-density mangrove. Stations V and VI were located within the Berkey Island Nature Reserve and represented high-density mangrove stands.

Transect and plot deployment

Mangrove community structure data were collected using a transect line plot method following the protocol described by Bengen[4]. In this method, a transect line was established perpendicular to the shoreline, extending from the seaward edge toward the landward area. Along the transect, the first plot measuring 10 × 10 m was established, positioned parallel to the transect line. Within each main plot, a subplot measuring 0.5 × 0.5 m was placed for mangrove detritus sampling. Subsequently, the second and third plots of the exact dimensions were established along the transect, with an interval distance of 10 m between adjacent plots.

Identification of Mangrove Species and Measurement of Stem Diameter

Data collection for mangrove vegetation structure was conducted through direct field observations, including species identification, enumeration, and measurement of tree diameter. Mangrove individuals with a stem diameter ≥ 5 cm were measured following the procedure described by Komiyama et al.[5]. Species identification was carried out based on morphological characteristics, including leaf structure, stem characteristics, and floral traits. The identification results were then verified using a standardized mangrove identification reference compiled by Noor et al.[3].

Measurement of Mangrove Litter Carbon

The quantification of mangrove litter was conducted using the dry-weight method. Prior to analysis, the litter samples were cleaned of residual sediment and homogenised using a mortar and pestle. A representative subsample of 30 g was then placed into aluminium foil and oven-dried at 105 °C for 48 hours to achieve a constant weight. After drying, the samples were cooled in a desiccator and subsequently weighed to determine their dry mass. The final dry-weight values were calculated following the procedure outlined by Ashton et al.[6].

Measurement of Mangrove Sediment Carbon

Sediment carbon measurement in mangrove ecosystems was conducted using the Loss on Ignition (LOI) method. The analytical procedure involved weighing 30 g of sediment samples and placing them into aluminium foil containers, followed by oven drying at 105°C for 48 hours. The samples were then weighed and recorded as a constant dry weight. Subsequently, the samples were combusted in a furnace at 550°C for 4 hours. In the final step, the samples were reweighed and recorded as the final weight. This method refers to the protocol described by Helrich[7].

Data Analysis

Analysis of Mangrove Community Structure

According to Bengen[4], the structure of mangrove communities can be assessed through the calculation of the Importance Value Index (IVI), which comprises relative density (RDi), relative frequency (RFi), and relative dominance (RCi). Density is defined as the number of individual mangrove trees within a sampling plot, representing the total number of trees contributing to the stand structure. Density is calculated using the following formula:

$$\text{Density}=\frac{\text{The number of individuals of each species}}{\text{The total number of sampling plots}}$$

$$\text{Relative density}=\frac{\text{Density of a species}}{\text{Total species density}}\ \text{x}100\%\ \text{x}$$

Species frequency (Fi) is defined as the probability of encountering species *i* across all sampling plots compared to the total number of established plots[4]. Species frequency is calculated using the following formula:

$$\text{Species frequency}=\frac{\text{Total individuals of a species}}{\text{Total of sampling plots}}$$

$$\text{Relative frequency}=\frac{\text{Frequency of a species}}{\text{Total frequency of all species}}\ \text{x}100\%$$

Dominance represents the extent to which a species occupies spatial cover within a sampling plot. This parameter is determined by calculating the basal area of each species and dividing it by the total area of the sampled plot.

$$\text{Species dominance}=\frac{\text{Basal area of a species}}{\text{Total area of all sampling plots}}$$

$$\text{Relative dominance}=\frac{\text{Dominance of a species}}{\text{Total dominance of all species}}\ \text{x}\ 100\%$$

The Importance Value Index (IVI) represents the degree of ecological dominance or contribution of each vegetation species within a given area. The IVI is calculated using the following formula:

$$\text{IVI} = \text{RD} + \text{RF} + \text{RC}$$

Description:
RF = Relative Frequency
RC = Relative Dominancy
RD = Relatif Density

Assessment of Carbon Stock in Mangrove Stands

Mangrove stand biomass constitutes a significant carbon pool that requires a quantitative assessment. In this study, biomass estimation was conducted using a non-destructive method by measuring the diameter at breast height (DBH), defined as 1.3 m above ground level, and then applying species-specific allometric equations. The carbon stock stored in mangrove biomass was then calculated by multiplying the estimated biomass value by a carbon fraction, following the standard formula established in SNI 7724:2011, as follows:

$$C = 0{,}47 \times B$$

Description:
C = Carbon stock
B = Biomass
0,47 = Carbon fraction

Assessment of Carbon Stock in Mangrove Roots

The analysis of below-ground carbon storage (roots) in mangroves was conducted using an allometric approach. The stem diameter of each mangrove tree was measured at breast height (1.3 m above ground level). Root carbon stock was then estimated using the same calculation approach applied for above-ground biomass, following the standardized equation provided in SNI 7724:2011.

Assessment of Carbon Stock in Mangrove Litter

The carbon stock of mangrove litter was assessed by measuring the dry weight of the samples and converting it into biomass values8. Biomass can be determined using the following formula:

$$\text{Biomass} = \frac{\text{BK sample (g)}}{\text{BB sample (g)}} \text{ x total BB sample}$$

Description:
BK = Dry mass
BB = Fresh mass

The carbon stock of mangrove litter was estimated by measuring the dry weight of the samples and converting the values into biomass[8]. The biomass was calculated using the following formula:

Carbon estimation = Biomass x Organic carbon content

Analysis of Mangrove Sediment Carbon Stock

The analysis of mangrove sediment carbon stock was conducted based on sediment sample depth, carbon density, soil (sediment) bulk density, estimated carbon content, and the percentage of organic carbon in the sediment. The calculations followed the formula described by Howard et al.[9] as follows:

The soil bulk density (BD) of each sample was calculated using the following formula:

$$\text{Bulk density} = \frac{\text{Dry mass of the sample}}{\text{sample volume}}$$

Next, the percentage of organic matter lost during dry ashing (Loss on Ignition, LOI) was determined using the following formula:

$$\%\ BO = \left(\frac{wo - wt}{wo} \text{ x } 100\right)$$

Description:

% BO	=	The percentage of organic matter lost during combustion.
Wo	=	Initial mass of the sample (g)
Wt	=	Final mass of the sample after combustion (g)

Subsequently, the percentage of organic matter was converted to the percentage of sediment carbon using the following formula:

$$\%\ C = (1/1{,}724) \text{ x } \%\ BO$$

Description:

%C	=	Percentage of carbon in sediment organic matter.
1,1724	=	A constant used to convert the percentage of organic matter into the percentage of organic carbon

The carbon density in mangrove sediments was calculated using the following formula:

Carbon density = %C x BD

The mangrove sediment carbon stock was estimated using the following formula:
Carbon stock= BD x SDI (Depth interval) x %C

Analysis of CO_2 Sequestration Capacity

The CO_2 sequestration capacity was obtained by calculating the carbon content and converting it into CO_2 equivalent[10]. The formula used is as follows:

$$CO_2 = (MrCO_2/Ar.C) \times Cn$$

Description:

CO_2	=	CO_2 Sequestration
$Mr.CO_2$	=	Relative molecular mass of the compound CO_2 (44)
Ar. C	=	Relative atomic mass of carbon (12)
Cn	=	Karbon stock

3. RESULT AND DISCUSSION

Structure of Mangrove Communities

During the study, a total of seven mangrove species were identified, namely *Avicennia alba*, *A. eucalyptifolia*, *A. lanata*, *Bruguiera parviflora*, *Rhizophora apiculata*, *R.mucronata*, and *Sonneratia alba*. The spatial distribution of these mangrove species along the coastal area of Bangko Subdistrict is presented in Table 1.

Table 1. Distribution of mangrove species

No	Species	Local Name	Station (Ind)					
			I	II	III	IV	V	VI
1	*Avicennia alba*	Api-api Putih	12	16	13	14	6	4
2	*A. eucalyptifolia*	Api-api Hitam	3	2	13	16	5	8
3	*A. lanata*	Api-api	1	6	7	9	3	2
4	*Bruguiera parviflora*	Lenggade	-	-	-	-	13	13
5	*Rhizophora apiculata*	Bakau Putih	-	1	3	2	1	2
6	*R. mucronata*	Bakau Hitam	-	2	3	2	2	2
7	*Sonneratia alba*	Perepat	-	-	-	-	5	8
Total			199					

Notes: (-) = species not observed

Based on Table 1, the species with the highest occurrence across the stations was *A. alba*. As a pioneer species, *A. alba* plays a crucial ecological role and is well-suited for coastal restoration due to its rapid growth and high adaptability. This species inhabits intertidal areas on muddy substrates and exhibits a high tolerance to salinity. Its root system functions as a sediment trap, with complex, thin, finger-like pneumatophores. The mangrove species *A. alba*, *A. eucalyptifolia*, and *A. lanata* were observed at all research stations, reflecting favourable environmental conditions that support their adaptation. These species are capable of surviving in extreme coastal environments, such as high salinity, muddy soils, and tidal fluctuations.

The mangrove community density along the coastal area of Bangko Subdistrict was considered moderate, with an average total density of 1,105 individuals per hectare. The highest total mangrove density was recorded at Station IV, with 1,433 individuals per hectare, while the lowest density was observed at Station I, with 533 individuals per hectare. At Station IV, the most dominant species was *A. eucalyptifolia*, with a density of 533 individuals per hectare, representing approximately 37.21% of the total mangrove population at that station. This suggests that *A. eucalyptifolia* is a pioneer species capable of optimal growth under the environmental conditions present at this station.

The low density observed at Station I was attributed to pressures from local community activities, such as logging and land-use changes. It should be noted that density values do not always directly correspond to the visual thickness or canopy density of mangrove vegetation. This discrepancy may arise because tree size (diameter and height), species age, and canopy cover also influence the perceived vegetation density, not merely the number of individuals per unit area. Additionally, environmental factors and the level of anthropogenic disturbance influence species distribution and dominance. These findings are consistent with Alongi[11], who stated that interactions between biotic and abiotic factors strongly influence mangrove community structure, and that the number of individuals does not necessarily represent the overall stand structure.

The condition of the mangrove forest, based on relative density, relative frequency, relative dominance, and the importance value index of each mangrove species at the observation stations, is presented in Table 2.

Table 2. RDi, RFi, RCi, and IVI of mangrove species at the observation stations

St	Spesies	RDi	RFi	RCi	INP
I	*Avicennia alba*	75,00	42,86	33,29	151,15
	A. eucalyptifolia	6,25	28,57	49,29	84,11
	A. lanata	18,75	28,57	17,42	64,74
	Jumlah	100	100	100	300
II	*Avicennia alba*	59,26	27,27	19,88	106,42
	A. eucalyptifolia	7,41	18,18	38,83	64,42
	A. lanata	22,22	27,27	26,13	75,63
	R. apiculate	3,70	9,09	6,53	19,33
	R. mucronata	7,41	18,18	8,62	34,21
	Total	100	100	100	300
III	*A. alba*	33,33	20	29,39	82,72
	A. eucalyptifolia	33,33	20	30,35	83,68
	A. lanata	17,95	20	27,93	65,88
	R. apiculate	7,69	20	5,92	33,61
	R. mucronata	7,69	20	6,41	34,10
	Total	100	100	100	300
IV	*A. alba*	32,56	27,27	31,08	90,91
	A. eucalyptifolia	37,21	27,27	35,25	99,73
	A. lanata	20,93	27,27	24,10	72,31
	R. apiculate	4,65	9,09	3,97	17,71
	R. mucronata	4,65	9,09	5,60	19,34
	Total	100	100	100	300
V	*A. alba*	17,14	17,65	16,88	51,67
	A. eucalyptifolia	14,29	17,65	11,33	43,27
	A. lanata	8,57	17,65	7,59	33,81
	B. parviflora	37,14	17,65	0,92	55,71
	R. apiculate	2,86	5,88	9,07	17,81
	R. mucronata	5,71	5,88	2,18	13,78
	S. alba	14,29	17,65	52,02	83,95
	Total	100	100	100	300
VI	*A. alba*	10,26	17,65	5,93	33,84
	A. eucalyptifolia	20,51	17,65	21,04	59,20
	A. lanata	5,13	17,65	9,84	32,62
	B. parviflora	33,33	17,65	1,39	52,38
	R. apiculate	5,13	5,88	16,22	27,23
	R. mucronata	5,13	5,88	6,89	17,90
	S. alba	20,51	17,65	38,68	76,84
	Total	100	100	100	300

Note: RDi = Relative Density, RFi = Relative Frequency, RCi = Relative Dominance, IVI = Importance Value Index

Estimation of Carbon Stock

The highest average carbon stock was recorded at Station V, at 307.16 ton/ha, while the lowest was observed at Station I, with 61.98 ton/ha. The average stand carbon stock at Stations II, III, IV, and VI was 101.77, 194.60, 269.98, and 297.92 ton/ha, respectively, in addition to differences in density, average stem size, and mangrove species composition at each observation station. Mangrove stand (stem) carbon stock constitutes one of the main components of carbon storage in coastal ecosystems. High carbon stock values are associated with high biomass in a given area, which is determined by the number of trees, stem diameter, and stand density. The carbon stock of mangrove stands highlights the crucial role of this vegetation in mitigating global climate change. Given their significant potential for carbon sequestration, mangrove forest conservation and restoration represent key strategies for reducing greenhouse gas emissions and achieving carbon neutrality targets.

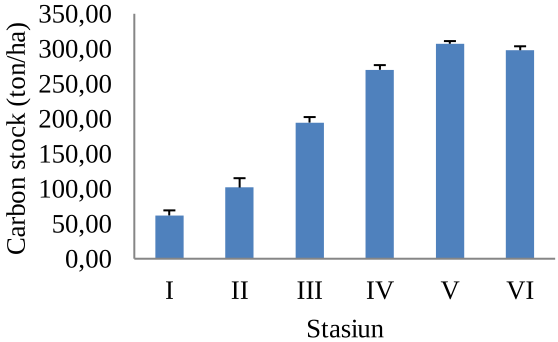

Figure 2. Mangrove stand (stem) carbon stock across observation stations

The average mangrove root carbon stock at each observation station indicates that the highest average was recorded at Station VI, at 289.52 ton/ha, while the lowest was observed at Station I, at 21.25 ton/ha. The average root carbon stock at Stations II, III, IV, and V was 47.28, 106.22, 146.31, and 244.70 ton/ha, respectively. These values reflect differences in station conditions, such as species composition, species abundance, and average stem diameter. The mangrove root carbon stock was estimated using allometric models based on the stem diameter of each mangrove species.

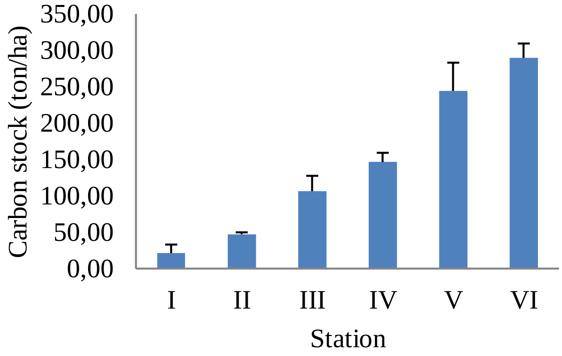

Figure 3. Mangrove root carbon stock across observation stations

The number of mangrove species present at the station likely influences the highest mangrove root carbon stock observed at Station VI. Station VI harbours seven mangrove species: *A. alba*, *A. eucalyptifolia*, *A. lanata*, *B. parviflora*, *R. apiculata*, *R. mucronata*, and *S. alba*. Among these, *B. parviflora* exhibits high density (Table 2), which contributes to an increased root carbon stock. The combination of species richness and high density, particularly of *B. parviflora*, is a key factor driving the elevated mangrove root carbon stock at Station VI. Although the average stem diameter is relatively small, the allometric calculations used for estimating root carbon are influenced by species-specific root morphology. Ati et al.[12] reported that higher mangrove population density leads to increased biomass and carbon stock.

Based on Figure 4, the highest average mangrove litter carbon stock was recorded at Station I, at 0.18 ton/ha, while the lowest average carbon stock was observed at Stations II and III, both at 0.10 ton/ha. Although Station I had the lowest number of mangrove stems compared to the other stations, a substantial amount of shrub vegetation was present, contributing to the increased mangrove litter carbon at this station. The prevalence of shrub vegetation is influenced by minimal seawater intrusion. Emrinelson & Warningsih[13] reported that shrub vegetation can impede the growth of true mangroves, as it grows rapidly and produces a large number of leaves, thereby shading sunlight essential for propagule development of true mangroves.

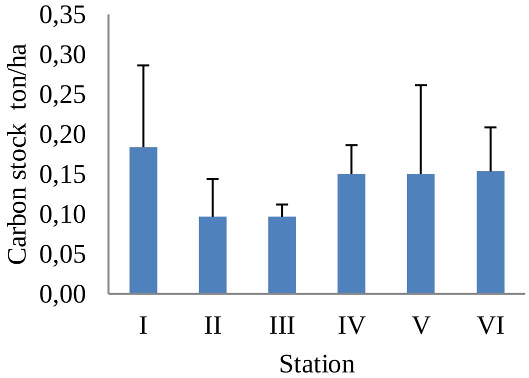

Figure 4. Mangrove litter carbon stock across observation stations

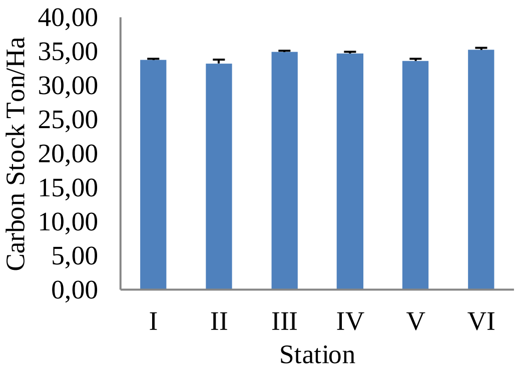

Figure 5. Mangrove sediment carbon stock across observation stations

Based on Figure 5, the highest average mangrove sediment carbon stock was observed at Station VI, at 35.21 ton/ha, while the lowest average was recorded at Station II, at 33.22 ton/ha. The sediment carbon stocks at Stations I, III, IV, and V were not significantly different, with values of 33.73, 34.91, 34.68, and 33.58 ton/ha, respectively. The high sediment carbon stock at Station VI is likely associated with the highest root carbon stock at the same station. The high density and species richness of mangroves at Station VI provide a substantial source of organic matter for the sediments. According to Hasidu et al.[14], high sediment carbon stocks result from mangrove necromass buried within the sediment, and decomposed litter accumulates in the sediment over time. The process of CO_2 sequestration by sediments occurs indirectly: CO_2 absorbed by vegetation is first stored as biomass, which is then deposited into the sediment, forming a carbon stock. Therefore, the CO_2 sequestration potential of mangrove sediments is directly proportional to the sediment carbon stock.

Total Carbon Stock

The average carbon stock for each carbon pool indicates that the majority of carbon in the mangrove forests of Bangko Subdistrict is stored in the stand (stem) component, at 205.57 ton/ha. In contrast, the lowest carbon stock is found in mangrove litter, at 0.14 ton/ha. The total carbon stock per hectare of mangrove forest was estimated at 382.37 tons/ha. With a total mangrove area of 12,444.052 ha, the total estimated carbon stock amounts to 4,758,255.11 tons.

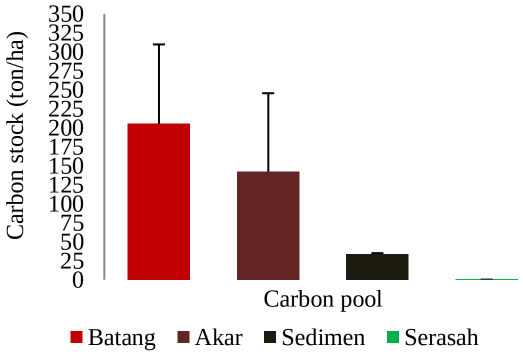

Figure 6. Carbon stock for each carbon pool

The relatively high average carbon stock in mangrove stems is attributed to the dense woody tissue. Stands with larger stem diameters generally have considerably higher carbon stocks compared to smaller-diameter stems. Murdiyarso et al.[15] noted that, compared to density, stem diameter has a significant influence on carbon stock values because biomass carbon is estimated using allometric equations, which are affected by species-specific stem diameter and wood density.

Estimated CO_2 Sequestration Potential

The estimation of carbon dioxide (CO_2) sequestration potential by the mangrove ecosystem is based on the carbon stock present in mangrove stems and roots, as these components continue to sequester carbon through plant tissues. Carbon sequestration is the process by which carbon is absorbed from the atmosphere and stored in plant biomass.

Based on Table 3, the average CO_2 sequestration potential of the mangrove forest in Bangko Subdistrict indicates that stems can sequester 754.55 tons/ha, while roots can sequester 522.75 tons/ha. The total CO_2 sequestration per hectare is 1,277.19 ton/ha, resulting in an estimated total CO_2 sequestration potential of 15,893,618.87 ton for the mangrove forest in Bangko Subdistrict. The CO_2 sequestration estimate was calculated by multiplying the carbon stock by 3.67, which is the molar mass ratio of CO_2 to carbon (C)[10]. According to Alongi[11], the carbon stored in mangrove stems and roots represents the accumulation of carbon from photosynthesis that has been converted into biomass. Stems store the majority of above-ground carbon, while roots store the majority of below-ground carbon.

Table 3. Estimated CO_2 sequestration potential of mangrove forests in Bangko Subdistrict

No.	Carbon Pool	Carbon Stock (ton/ha)	Sequestration CO_2 (ton/ha)	Mangrove (12.444,052 ha)
1	Stem	205,57	754,44	15.893.618,87
2	Root	142,44	522,75	
Total		348,01	1.277,19	

Estimated Economic Value of Carbon Sequestration

This study utilised the Social Cost of Carbon (SCC) to estimate the economic value of carbon stored in mangrove forests. The SCC represents an economic metric used to assess the social, environmental, and economic impacts of each ton of carbon dioxide (CO_2) emitted into the atmosphere. The estimated economic value of CO_2 sequestration by the mangrove forest in Bangko Subdistrict is presented in Table 4.

Table 4. Estimation of the economic value of CO_2 sequestration in mangrove forests

Carbon pool	CO_2 Sequestration (ton/ ha)	USD ($)	IDR	Mangrove (12.444,052 ha)
Stem	754,44	38.476,54	638.710.513	IDR 13.455.438.919.367
Root	522,75	26.660,49	442.564.214	
Total	1.277,19	65.137,03	1.081.274.726	

Note: Currency exchange rate applied at the time of the study: 1$ = IDR 16.600 (Mei, 2025)

Based on Table 4, the estimated economic value of CO_2 sequestration by the mangrove forest in Bangko Subdistrict indicates that the economic value of carbon stored in mangrove stems is IDR 638,710,513/ha. In contrast, the value for mangrove roots is IDR 442,564,214/ha. The economic value of carbon stock was calculated by multiplying the Social Cost of Carbon (SCC) by the carbon sequestration values of stems and roots. According to the Environmental Protection Agency (EPA), the current SCC value is USD 51. The estimated economic value of CO_2 sequestration by the mangrove forest was derived from the average CO_2 sequestration by stems and roots. This average value was then multiplied by the current SCC price of USD 51 and subsequently converted to Indonesian Rupiah at an exchange rate of IDR 16,600 per USD (as of May 2025). The resulting value was then multiplied by the total mangrove area in Bangko Subdistrict, resulting in IDR 1,081,274,726/ha. The total economic value of carbon in the mangrove forest of Bangko Subdistrict was estimated at IDR 13,455,438,919,367. Considering that Indonesia's current global carbon economic value is USD 248 billion, or approximately IDR 3,540 trillion, the economic contribution of Bangko's mangrove forest represents about 1.21% of the Gross Regional Domestic Product (GRDP) of Riau Province.

Management of Mangroves in Bangko Subdistrict

The mangrove ecosystem along the coast of Bangko Subdistrict, Rokan Hilir Regency, was found in this study to have a total carbon stock of 389.58 tons/ha across a total mangrove area of 12,444.052 ha. This highlights its potential contribution to mitigating climate change. The area represents a vital asset in global efforts to reduce greenhouse gas emissions. Healthy, mature, and undisturbed mangroves are reported to have total carbon stocks ranging between 500 and 1,000 tons C/ha [16,9]. The carbon stock value of mangroves in the Bangko coastal area falls into the "moderately good" category when compared to the global maximum potential of mangrove carbon reserves. While higher than severely degraded mangroves, there remains substantial potential for improvement through sustainable mangrove management efforts. The optimal carbon storage potential in mangrove ecosystems can exceed 600 tons C/ha[16].

According to Atmawati[17], regarding the sustainability status of mangrove ecosystem management in Kepenghuluan Serusa, Bangko Subdistrict, the overall sustainability of the mangrove ecosystem was classified as "moderately sustainable" (54.70%). Sustainable management of mangrove forests in this subdistrict is crucial to protect carbon storage assets and maximise their role in mitigating climate change. Sustainable mangrove management in Bangko Subdistrict, Rokan Hilir Regency, aimed at contributing to climate change mitigation, can be implemented through a comprehensive strategy, including ecosystem rehabilitation and protection, strengthening governance and law enforcement, community empowerment and provision of alternative livelihoods, increasing awareness and cross-sectoral coordination, as well as continuous monitoring and research.

4. CONCLUSION

The community structure is dominated by *A. alba*, with an INP value of 151.15, indicating resistance to anthropogenic pressure; however, this reduces aquatic biodiversity, as observed in a comparative study at station VI. The mangrove ecosystem in Bangko District has an estimated total carbon stock of 382.37 tons/ha, with the most significant contribution coming from stem biomass (54%). The estimated CO2 absorption capacity of mangrove forests in Bangko Subdistrict is 15,893,618.87 tons. This value can still be increased, considering that the mangroves in Bangko Subdistrict are classified as staked and seeded and also have a relatively high density.

Economic Value of Carbon: The estimated economic value of carbon in the mangrove forest is on average IDR 1,081,274,726 per hectare, totalling IDR 13,455,438,919,367, demonstrating that the mangroves in Bangko Subdistrict are eligible for inclusion in the national carbon trading scheme. This economic value is derived solely from carbon stock, while mangrove forests provide additional direct and indirect benefits.

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