Estimation of Carbon Stock of Sediment in Mangrove Ecosystem of Apar Village, North Pariaman Sub-District, West Sumatra

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ABSTRACT

Global warming is one of the issues in the world today, characterized by an increase in the earth's temperature due to greenhouse gases. Mangrove forests are one of the blue carbon parameters that can utilize CO_2 for photosynthesis and store it in the form of biomass and sediment well. Sediments serve as a growing medium and a place to accumulate various components, including carbon. Carbon stored in mangrove sediments tends to be greater than in other types of forests. The study aimed to determine sediment carbon stocks based on density and the relationship between mangrove density and estimated carbon stocks in sediments in the mangrove ecosystem of Apar Village, North Pariaman District. Mangrove sediment sampling was carried out using the Purpose Sampling technique, and the data obtained were analyzed using the Loss on Ignition method. The results showed that the highest average carbon stock in sediments was found at station 2 with medium density, which was 215,03 tonnes/ha, followed by station 3, which had a high density, with a value of 197,98 tonnes/ha, and the lowest average carbon stock was found at station 1 with medium density, which was 132,43 ind/ha. Future research is expected to observe carbon stocks in mangrove stands and litter in the Apar Village mangrove ecosystem to obtain more detailed information.

Keywords: Apar Village, Carbon Stock, Los on Ignition, Mangrove Sediment

1. INTRODUCTION

The issue of climate change has been affected by many people (Adrian et al., 2011). One of the causes of climate change is large amounts of greenhouse gases in the atmosphere. Greenhouse gases can cause an increase in the earth's surface temperature or what is commonly called global warming (Yan et al., 2016). The contribution of CO_2 to the earth's atmosphere is the most dominant due to increased human activities in forests, which in turn can cause the greenhouse effect (Amanda et al., 2021). Reducing CO_2 emissions through forest vegetation is necessary, such as maintaining the integrity of natural forests and increasing the population density of trees outside the forest. This is because plants can absorb charcoal acid gas (CO_2) from the air through photosynthesis, which is then converted into carbohydrates, spread throughout the plant body, and finally deposited in the plant body.

Mangroves are one of the parameters of blue carbon because they utilize CO_2 for photosynthesis and store it in biomass and sediments (Ati et al., 2014). The optimal function of carbon sequestration by mangroves reaches up to 77.9%, where the sequestered carbon is stored in mangrove biomass in several parts, such as stems, leaves, and sediments (Bachmid et al., 2018). Sediment carbon is derived from all organic matter in the soil, including roots and small litter with a diameter of less than 2 mm (IPCC, 2006). Sediments serve as a growing medium and a place to accumulate various components, including carbon.

In coastal ecosystems, the ability of sediments to store carbon is estimated to be more than 50% (Donato et al., 2011). The carbon stored in mangrove sediments tends to be greater than in other types of forests. Sediment type is a limiting component for mangrove growth (Kauffman & Donato, 2012). If the sediment composition is more clay and silt, then the stand becomes denser. Conversely, if the substrate is sandy or sandy with a combination of coral pieces, mangrove density will be low because the substrate cannot capture or hold the fallen mangrove fruit, so the regeneration process does not occur (Pratama et al., 2023).

The area with a mangrove forest ecosystem in West Sumatra Province is one in

Pariaman City. The coastal area of Pariaman City has a very high level of physical vulnerability. The concentration of settlements along the coastal area, the beach's gentle slope, and the high abrasion trigger this condition (Amanda et al., 2021). This damage will undoubtedly have an impact on the reduction in density levels as well as the reduction in carbon stocks in mangrove forests, causing the carrying capacity of mangrove forests to absorb carbon dioxide to decrease. On that basis, researchers are interested in estimating carbon stocks stored in mangrove forests in Apar Village, North Pariaman District, Pariaman City, West Sumatra Province.

2. RESEARCH METHOD

Time and Place

The research was conducted in March 2024 in the Mangrove Ecosystem of Apar Village, Pariaman Utara District, Sumatra Barat Province. Total sediment analysis was performed at the Marine Chemistry Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Riau.

Method

The method used in this study is a survey method, namely the observation of mangrove density and sediment sampling in the field (Yaqin, 2022). Determination of the station is done purposively, namely, the location of the station based on the density of mangroves in the study site that has been measured previously.

Procedures

Determination of Research Station

Purposive sampling methods were used to determine the research station, where the research station represented the research area as a whole. The research site was divided into three stations with a distance of 100 m between stations. Each station was drawn along 100 m from the sea to the mainland. Each line has three plots that are 35 m apart. An illustration of the position of transects and plots at the research site can be seen in Figure 1.

Sediment Samples

Sediment sampling was carried out on each plot contained in the research station. Sediment sampling refers to Indraiswari & Putra (2019), namely sediment samples taken are divided based on depth intervals into 3, 0-15 cm, 15-30, and 30-50 cm. So, the total samples obtained were 27 samples.

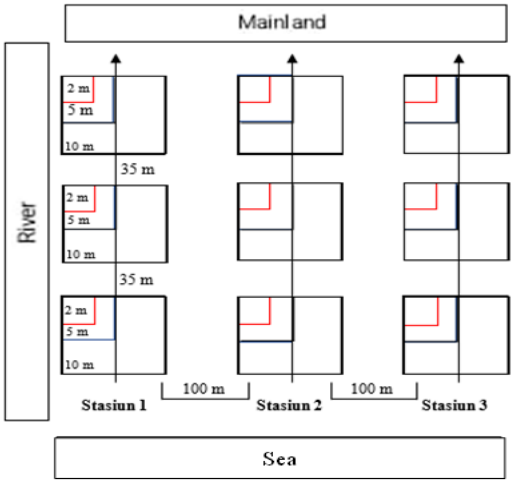

Figure 1. Illustration of transect and plot positions

Mangrove Density

Mangrove density data were observed in predetermined plots at three stations. Data were collected using transects measuring 10 m x 10 m for tree observations with tree trunk diameter ≥ 10 cm and height > 1.5 m. The plot size of 5 m x 5 m was used to observe saplings with a diameter < 10 cm and a height of 1.5 m. For the observation of seedlings with a height < 1.5 m, a plot size of 2 m x 2 m was used. Measure mangrove tree trunk circumference, which is done at an adult's chest height.

Furthermore, the data obtained were analyzed quantitatively, and the calculation of mangrove density with the formula (Howard et al., 2014):

$$\text{Density} = \frac{\text{Number of Individuals of a species}}{\text{Sampled Area}}$$

Mangrove vegetation density refers to the Decree of the Minister of Environment No. 201 Year 2004 on Standard Criteria and Guidelines for Determination of Damage (Table 1).

Table 1. Criteria for vegetation density

Criteria		Coverage	Density (Tree/ha)
Good	Tight	≥ 75%	≥ 1500
Medium	Medium	≥ 50% - < 75%	≥ 1100 - < 1500
Damaged	Rare	< 50 %	< 1000

Sediment Sample Handling

To determine the estimation and percentage of organic carbon stocks in sediments, the things that need to be considered are the depth of the sediment samples to be taken, the depth interval of the samples taken, and the sediment density (Verisandria et al., 2018). To find out this, the stages of work carried out are as follows:

Before conducting sediment sampling, the sediment sampling area is cleaned of organic waste and living leaves. Then, coring is done vertically, inserting the core into the sediment to a certain depth. Then, the core is rotated to cut the roots in the soil. Then, the corer is pulled while rotating to maintain the amount of sediment taken. After the corer is lifted, it is split and divided based on three depths, namely depths of 0-15 cm, 15-30 cm, and 30-50 cm. The samples obtained were then put into a plastic-coded sample to facilitate laboratory observation and analysis. The samples obtained were then put into an ice box to survive during the laboratory study.

Data Analysis

Carbon in Sediment Samples

The organic carbon content of sediment samples was analyzed in the laboratory using the Loss on Ignition (LOI) method. The LOI method is a method used to measure organic content in sediments by weighing the weight of the sample lost after combustion (Mahasani et al., 2015). How to extract carbon in mangrove sediments is by dry ignition oven furnace using a temperature of 450℃ for 3 hours. The goal is that the carbon in the sediment burns perfectly. Before the oven, the sample was weighed first (W1), and after the stove, it was weighed again (W2) to determine the carbon stock of biomass.

Data Processing

Calculations and data analysis refer to Howard et al. (2014) as follows: Soil Density is the weight of the particles per unit volume of soil and its voids. The formula used to calculate soil density is as follows:

$$\text{Soil Density (BD)} = \frac{g}{cm^3} = \frac{oven\ dry\ mass\ (g)}{sampel\ volume\ (cm^3)}$$

Description:

Soil Density (BD)	:	Fill content of sludge substrate (g/cm^3)
Oven-dried mass	:	Mass of dried sample (g)
Sample volume	:	Sample volume (cm^3)

Organic matter (BO) was calculated using the following formula

$$\%BO = \frac{wo - wt}{wo}\ x\ 100$$

Description:

%BO	:	Percentage of sediment organic matter lost in the combustion process.
Wo	:	Dry weight before combustion (g)
Wt	:	Final weight after combustion (g)

The conversion of organic matter percentage to carbon percentage was calculated using the following formula:

%C = (0,580 x %BO)

Description:

%C	:	The carbon content of organic sediment material
%BO	:	Percentage of sediment organic matter (ashing)
0.580	:	constant to convert % organic matter to %C organic

The carbon density content of the soil was estimated using the following formula:

Soil C Density = (%C x BD)

Description:

Soil C Density	:	Carbon density (g C cm-3)
%C	:	The carbon content of organic sediment material
BD	:	Soil density (g/cm^3)

Calculate the total carbon content using the following formula

Soil C = (BD x SDI x %C)

Description:

Soil C (MgC/ ha)	:	Estimated carbon storage
BD	:	Soil Density (g/cm^3)
SDI	:	Sample depth interval (cm)

Data Analysis

Data obtained from field and laboratory measurements were then processed using Microsoft Excel to get the results of carbon stock estimation and carbon uptake between stations. A simple linear regression test determined the relationship between mangrove density and carbon stock estimation. Meanwhile, the One-way ANOVA test was conducted to determine the difference in carbon stocks between stations and depth.

3. RESULT AND DISCUSSION

General Conditions of the Research Location

Geographically, Apar Village borders the

Indian Ocean to the west, Tanjung Sabar Village to the east, Ampalu Village to the south, and Mangguang Village to the north. This mangrove area was managed initially by the Tabuik Diving Club (TDC) but is now managed by BUMDES (Village-Owned Enterprise) with the help of Pokdarwis (Tourism Awareness Group). The area is also traversed by a small river whose flow comes from anthropogenic activities, affecting the condition of the mangrove forest.

Environmental quality parameters are one of the factors that support mangrove growth. Environmental quality is considered in terms of temperature, salinity, water pH, and soil pH. Environmental parameter data obtained at each station are presented in Table 2.

Table 2. Environmental quality parameters

Station	Water quality			
	Salinity (ppt)	Water pH	Soil pH	Temperature (^{0}C)
1	4	7,18	5,4	28,7
2	4	7,47	4,5	29,5
3	4	7,3	5	30

Based on Table 2, The salinity value at the three stations has the same salinity of 4 ppt. The location of the mangrove ecosystem adjacent to the river influenced the salinity values obtained at the three stations. This causes the salinity of the waters in the mangrove ecosystem to be slightly saltier than fresh water but does not reach complete salt levels of seawater. The quality of water relatively affects the density of mangrove species. Based on this statement and the results of water quality measurements, it can be said that fluctuations in nutrients required by mangroves are likely to occur in natural mangrove areas at each observation station.

This is suspected because natural mangrove areas near river mouths cause water quality fluctuations to happen effectively. These fluctuations occur through river water flow during tidal cycles. This water condition allows mangroves to have a high species density. However, this condition does not happen in rehabilitated mangrove areas, as high mangrove density is intentionally achieved through planting. Nevertheless, water quality parameters relatively affect the survival of mangroves (Susiana, 2015).

The pH value of water at the three stations ranged from 7.3 to 7.47, indicating that the water was neutral to slightly alkaline. Soil pH values obtained varied from 4.5 to 5.4. Meanwhile, the water temperature in the mangrove ecosystem at the three stations ranged from 28.70 – 30°C. Overall, the environmental quality parameters at the three stations still fulfill the criteria for seawater quality standards for biota. Based on the Decree of the Minister of Environment number 51 of 2004, the quality standard values for biota are temperature ranging from 25-32°C, salinity quality standard values reaching 34 ppt, and pH quality standard values of 7-8.5.

Table 3. Types of mangroves in the mangrove ecosystem of Apar Village

Jenis mangrove	Station								
	1			2			3		
	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3
Rhizophora apiculata	-	-	-	-	-	-	-	-	+
Rhizophora mucronata	+	+	+	+	+	+	+	+	+
Sonneratia caseolaris	-	-	-	+	+	-	+	-	-
Sonneratia alba	+	+	+	-	-	+	-	+	+
Nypa fruticans	-	+	+	+	+	+	+	+	+
Acanthus ilicifolius	-	+	+	-	+	-	-	-	-

Description : (+) = Found, (-) = Not-Found, (T) = Sampling Point

Mangrove Species Composition

Data collection of mangrove species was carried out at three stations, namely at station 1, which was in the back area of Turtle conservation; station 2, which represented the middle area of the mangrove ecosystem; and station 3, which was near the river. The identification results found six types of mangroves in the mangrove ecosystem of Apar Village.

Table 3 shows that *Rhizophora apiculata* is only found in station 3, *R. mucronata* is found in all research stations, *Sonneratia caseolaris* is found in stations 2 and 3, *Nypa fruticans* is found in all stations, and *Acanthus ilicifolius* is found in stations 2 and 3.

Mangrove Vegetation Density

Mangrove vegetation density was calculated in this study to classify mangrove vegetation into tree, sapling, and seedling categories. The results of the calculation of mangrove vegetation density in the tree category are presented in Table 4

Table 4. Mangrove vegetation density of Apar Village

Station	Species	Species Density (ind/ha)		
		Seedling	Sapling	Tree
1	*R. apiculata*	-	-	-
	R. mucronata	2500	3466,67	400
	S.caseolaris	-	-	-
	S.alba	-	400	666,67
	N. fruticans	-	-	333,33
	A. ilicifolius	833,33	-	-
Jumlah		3333,33	3866,67	1400,00
2	*R. apiculata*	-	-	-
	R. mucronata	3333,33	2166,67	33,33
	S.caseolaris	-	233,33	466,67
	S.alba	833,33	-	200
	N. fruticans	5833,33	-	700
	A. ilicifolius	1666,67	833,33	-
Jumlah		11666,67	3233,33	1400,00
3	*R. apiculata*	-	-	33,33
	R. mucronata	2500	5333,33	300
	S.caseolaris	-	933,33	433,33
	S.alba	833,33	400	133,33
	N. fruticans	2500	1333,33	866,67
	A. ilicifolius	-	-	-
Jumlah		5833,33	8000,00	1766,67

Table 4 shows that the highest density of mangrove vegetation in the tree category is found at station 3, which has a density of 1766.67 ind/ha and is dominated by *N. fruticans.* At the same time, the lowest density is found at stations 1 and 2, with a density of 1400 ind/ha, dominated by *S. alba* and *S. caseolaris.* Mangrove vegetation in the sapling category has the highest density at station 3, 8000 ind/ha, dominated by *R. mucronata.* The lowest density is found at station 2, 3233.33 ind/ha, where *R. mucronata* dominates. Meanwhile, the highest density in the seedling category was found at station 2, which had a density of 11666.67 ind/ha and was dominated by *N. fruticans.* In contrast, the lowest density was found at station 1, with a 3333.33 ind/ha density, which *R. mucronata* dominated.

Soil Density

From the results of the analysis, it is known that the soil at each depth has a different density value. The sample volume is obtained by measuring the height of the sample interval and the diameter of the corer. Stations 1 and 2 contain soil density data from mangrove areas with moderate density, and Station 3 contains soil density data from high mangrove density. The average results of soil density can be seen in Table 5.

Based on Table 5, the average sediment density at station 1 is lowest in transect 3 with a 22 g/cm3 value, followed by transects 1 and 2 with 23 g/cm^3 values. At station 2, the highest average sediment density value is found in transect 1 with a value of 32 g/cm^3, followed by transect 3 with a value of 28 g/cm^3, and the lowest is found in transect 2 with a value of 22 g/cm^3 Meanwhile, at station 3, the highest average sediment density value is found in transects 1 and 2 with a value of 29 g/cm^3 and the lowest is found in transect 3 with a value of 24 g/cm^3.

Table 5. Average sediment density in the mangrove ecosystem

Transect	Station 1	Station 2	Station 3
1	0,23	0,32	0,29
2	0,23	0,22	0,29
3	0,22	0,28	0,24
Average	0,22	0,27	0,27
STDEV	0,0027	0,0503	0,0289

Sediment Organic Matter

The percentage value of organic carbon is obtained from the soaking results to determine organic matter and convert it to organic carbon. Station 1 contains data on organic matter from moderate-density mangrove areas, and Stations 2 and 3 contain organic matter content from high mangrove density. Based on the calculation results, the value of organic matter at each station is different. The average value of organic matter is presented in Table 6.

Table 6. Average sediment organic matter content in mangrove ecosystems

Transect	Station 1	Station2	Station3
1	21,33	25,22	24,33
2	22,44	26,11	33,33
3	15,44	30,00	18,22
Average	19,74	27,11	25,29
STDEV	3,76	2,54	7,60

Based on Table 6, the highest average organic matter content at station 1 is found in transect 2 with a value of 22.44%, followed by transect 1 with a value of 21.33%, and the lowest is found in transect 3 with a value of 15.44%. At station 2, the highest average value of organic matter is found in transect 3, with a value of 30.00%, followed by transect 2, with a value of 26.11%, and the lowest is found in transect 1, with a value of 25.22%. Meanwhile, at station 3, the highest average value of organic matter is found in transect 2 with a value of 33.33%, followed by transect 1 with a value of 24.33%, and the lowest is found in transect 3 with a value of 18.22%

Carbon Stocks Across Depths

Calculating mangrove carbon stocks is necessary due to the importance of mangrove ecosystems in the carbon cycle in coastal areas. Carbon content in plants can be known by calculating biomass because most plant biomass is carbon content (Prakoso et al., 2017). The sediment density and soil depth value determine high and low carbon content in sediments. The thicker the soil density, the higher the carbon stock on the land (Prayitno et al., 2013).

Based on carbon stock analysis, the average carbon stock value distribution at each depth is different. This is influenced by soil density at each depth, which is different, and mangrove density at each station, which also affects the distribution of carbon content. The study was divided into three depth intervals, namely 0-15 cm, 15-30 cm, and 30-50 cm. The average value of carbon stock at each depth interval is presented in Table 7.

Table 7. Average carbon stock at each depth interval

Depth Interval	Station 1	Station 2	Station 3
0-15 cm	167,33	183,46	179,14
15-30 cm	126,99	255,69	260,33
30-50 cm	102,97	172,57	154,45
Average	132,43	203,91	197,97
STDEV	32,52	45,17	55,39

Based on Table 7, the average carbon stock value at a depth of 0-15 cm is highest in station 2, which has a moderate mangrove density with a value of 183.46 tonnes/ha, followed by station 3, which has a high mangrove density category with a value of 179.14 tons/ha. At a depth of 15-30 cm, the highest average carbon stock value is found at station 3, with an average value of 260.33 tons /ha, followed by station 2, with a value of 255.69 tons /ha, and the lowest is found at station 1 with a value of 126.99 tons/ha. This value is lower than the results of research by Mahasani et al. (2016) in the mangrove forest of Ngurah Rai Grand Forest Park, Bali, which ranged from 830.46 - 1963.9 tons/ha. Meanwhile, the amount of carbon content in this study is almost the same as the results of research conducted by Heriyanto et al. (2017) in the area of Sandy Beach Kawal Village, Bintan Regency, with an average mangrove carbon of 182.821 tons /ha.

The difference in the value of mangrove sediment carbon content at each station that has different mangrove density categories is thought to be influenced by the type of mangrove that grows in each location and also the characteristic structure of soil sediments at each location (Suryono et al., 2018). The greater the organic matter content in the sediment, the greater the organic carbon content stored. Otherwise, the sediment's organic carbon content is low due to the low content of organic matter in the sediment (Mahasani et al., 2016).

Based on Table 7, the vertical distribution shows that the value of carbon stock is getting smaller in the lower layers, namely at a sediment depth of 30-50 cm. This is thought to be related to the decomposition process and sedimentation rate. The low organic carbon in the lower layer is associated with the decomposition process, which is higher than that of the sedimentation process. The decomposition process causes organic material to be decomposed into simpler compounds, including nutrients.

Carbon Stock between Stations

Based on carbon stock analysis, the distribution of average carbon stock values at each station differs. This is influenced by soil density at each station, which is different, and mangrove density at each station also affects the distribution of carbon content. Stations 1 and 2 contain carbon stock data from mangrove areas with medium density, and Station 3 contains carbon stock content data from high mangrove density. The average value of carbon stock at each research station is presented in Table 8.

Table 8. Average carbon stock

Transect	Station 1	Station 2	Station 3
1	144,26	228,59	203,98
2	149,63	171,74	265,89
3	103,41	244,75	124,06
Average	132,43	215,03	197,98
STDEV	25,27	38,34	71,1

Based on Table 8, the average value of carbon stock at station 1 is lowest in transect 3 with a value of 103.41 tonnes/ha, followed by transect 1 with a value of 144.26 tonnes/ha, and the highest is in transect 2 with a value of 149.63 tons/ha. At station 2, the lowest average carbon stock value was found in transect 2 with a value of 171.74 tons /ha, followed by transect 1 with a value of 228.59 tons /ha, and the highest was found in transect 3 with a value of 244.75 tons /ha. Meanwhile, at station 3, the lowest average carbon stock value was found at transect 3 with a value of 124.98 tons /ha, followed by transect 1 with a value of 203.98 tons/ha, and the highest was found at transect 2 with a value of 265.89 tons /ha.

The National Standardisation Agency (2011) states that the amount of carbon stock is directly proportional to mangrove density. This means that the denser the mangrove, the greater the carbon stock. However, the study showed that mangrove density in the medium category had the highest carbon stock content. Soil density conditions also influence factors affecting carbon stocks other than mangrove density in each location and location conditions at the station. High and low carbon content in the soil is determined by the value of soil sediment density and soil depth in each sample. The thicker the soil density is, the higher the carbon stock on the land will be.

Relationship between Mangrove Density and Carbon Stock in Sediment

The results of simple linear regression analysis showed that the relationship between carbon stock and mangrove density has a low relationship with a value of r = 0.1283 with a coefficient of determination (R^2) = 0.0164, which means that 1.64% of the amount of carbon stock is influenced by mangrove density, while other factors influence 98.35%. The results of the linear regression analysis are presented in Figure 2.

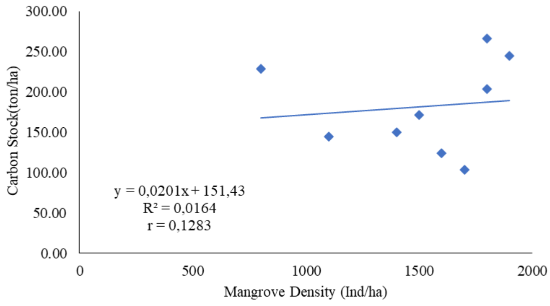

Figure 2. Comparison of average carbon stock

This is supported by the statement of Suryono (2018), which states that carbon storage in plants is influenced by several factors, among others, the age of the plant, the level of soil fertility or habitat where it grows, and the plant distance or density. Mangrove species composition greatly influences the relationship between these two parameters. Morphologically, the size of mangroves varies between types, causing carbon stocks to vary. Thus, the dominant mangrove species determines the amount of carbon stock. It is likely that the relationship between density and carbon stock is stronger in monospecies mangrove vegetation.

Based on the regression test results, it can be seen that carbon stocks are influenced by mangrove density, but the effect is not very significant or does not always show a strong relationship. Other factors, such as sediment density and the characteristic structure of soil sediments at each location, are suspected to affect the high and low carbon stock content. The higher the soil density, the higher the organic content of the sediment.

4. CONCLUSION

The average carbon stock calculation results in the mangrove ecosystem of Apar Village show that the highest carbon stock is found at station 2 with medium density, amounting to 215.03 tons/ha, followed by station 3 with high density at 197.98 tons/ha. The lowest average carbon stock is at station 1, which has medium density, at 132.43 tons/ha. The linear regression test results indicate a weak relationship between mangrove density and carbon stock value. Carbon stock at each station shows a significant difference.

Future research is expected to analyze carbon stock in the sediment, as there is a large opportunity to observe carbon stock in mangrove stands and the relationship between mangrove stands and carbon stock at the site. Additionally, research on carbon stock in litter within the mangrove ecosystem of Apar Village is necessary to obtain more detailed information.

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