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Carbon Estimation in Mangrove Forests of The East Coast of North Sumatra

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Abstract

Mangrove forests are important ecosystems, providing various ecological, economic, and social benefits. They serve as habitats for a wide range of species, act as natural barriers against coastal erosion, and play a key role in carbon sequestration, which helps to reduce the impacts of climate change. This study used surveys to tree biomass growth and quantify the carbon stocks trapped in this ecosystem. The methodology applied in measuring carbon in mangrove forests is similar to that used in primary forests, although some unique aspects need to be considered, such as the accumulation of non-biodegradable debris. Aspects that need to be considered, such as litter accumulation cannot be included in technical carbon calculations. included in technical carbon calculations. The condition of mangrove forests in North Sumatra shows a significant decline, with a 61.21 % significant decline, with a in primary mangrove area between 1990 to 2015, mainly due to land conversion for aquaculture and agriculture. Carbon sequestration in mangrove forests is crucial to mitigating climate change, with their capacity to store carbon in biomass and sediment. Rehabilitation efforts, such as propagation planting and seedlings, showed expected survival rates and large carbon storage potential, with total carbon stocks reaching 558.07 mgC ha-1. It is important to understand carbon storage dynamics and influencing factors, such as duration and nutrient inputs, for effective management and conservation strategies

Keywords: *Blue Carbon; Carbon Estimation; Mangrove Biomassa*

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INTRODUCTION

Mangrove forests are vital ecosystems that provide many ecological, economic, and social benefits. They serve as critical habitats for diverse species, act as natural barriers against coastal erosion, and play an important role in carbon sequestration, thereby mitigating climate change (Rull, 2024; Wirasatriya et al., 2022). In addition, mangroves support local economies through fisheries and tourism, while also offering resources for construction and medicine (Ersan et al. 2022; Hidayati et al., 2023; Waleed et al. 2023). Their unique microbial diversity contributes to nutrient cycling and pollution remediation, improving overall ecosystem health (Waleed et al. 2023; Suardana et al., 2023). However, mangrove ecosystems are under threat from land conversion and pollution, leading to biodiversity loss and negative impacts on coastal communities (Saragih et al. 2022; Hidayah et al., 2022; Utary, 2024). To ensure its sustainability, conservation efforts, and community involvement are essential to restore degraded areas and raise awareness of their ecological importance (Utary, 2024; Ainindiya et al., 2024).

Mangrove forests in North Sumatra are significantly degraded, with primary mangrove areas declining by 61.21 % due to aquaculture and land conversion for agriculture (Sulistiyono, 2018). The eastern coastal area experienced a 59.68 % decrease in mangrove cover, driven by similar factors (Onrizal, 2010). Rehabilitation efforts, such as planting propagules and seedlings, have shown promising survival rates of 69.42 % and 86.38 %, respectively, while the potential for carbon storage remains large, with the total ecosystem carbon stock reaching 558.07 mgC ha^{-1} (Amelia et al., 2023). The level of sedimentation in these mangrove ecosystems is critical to their sustainability, with mudflats and fringes increasing at a rate that can offset sea level rise (Malik et al., 2023; Aulia et al., 2022; Murdiyarso et al., 2018). Overall, the condition of mangrove forests in North Sumatra highlights the urgent need for conservation and restoration initiatives to combat ongoing environmental threats (Syahrial et al., 2023).

Carbon sequestration in mangrove forests is essential for climate change mitigation due to its significant capacity to store carbon in both biomass and sediments. Mangroves act as effective carbon sinks, with studies showing that they can absorb large amounts of carbon dioxide (CO_2) over long periods of time, thereby reducing atmospheric CO_2 levels (Awad et al., 2023; Cuenca-Ocay, 2024). For example, mangrove forests in Egypt show an average carbon sequestration rate of 81.87 g C org m^{-2} $year^{-1}$ (Awad et al., 2023). In addition, the preservation and restoration of these ecosystems not only increases carbon storage but also provides coastal protection against storms and erosion (Cuenca-Ocay, 2024; Cotovicz, et al., 2024). However, methane emissions from mangrove forests may offset some of the benefits of carbon sequestration, especially in areas affected by freshwater (Cotovicz, et al., 2024). Therefore, understanding the dynamics of storage carbon and the factors that affect it, such as inundation duration and nutrient inputs, are critical to effective management and conservation strategies (Xie et al., 2023; Jones et al., 2020). Overall, safeguarding mangrove ecosystems is essential to maximize their role in mitigating climate change and improving coastal resilience (Sulistiyono. 2018; Ocay. 2024). From the background above, the aim of this study is to find out more about Carbon Estimation in the Mangrove Forest of the East Coast of North Sumatra.

METHOD

Types and Approaches of Research

This investigation uses an analytical descriptive methodology, specifically emphasizing the identification and examination of existing problems during the conduct of the research, followed by the processing and analysis of the findings to reach conclusions. The selection of locations in each location is carried out through a purposeful sampling technique. The survey was carried out to assess the biomass of mangrove trees to measure sequestered carbon stocks.

Basically, the methodology used for carbon measurement and quantification in mangrove ecosystems is not much different from that used in other environments, such as primary forests. Only a few aspects need to be considered, as they may not be included in the technical parameters of carbon accounting; One of these aspects is the accumulation of waste. The presence of waste in mangrove forests cannot be accounted for and is excluded from the technical calculation of carbon due to the impact of tidal fluctuations.

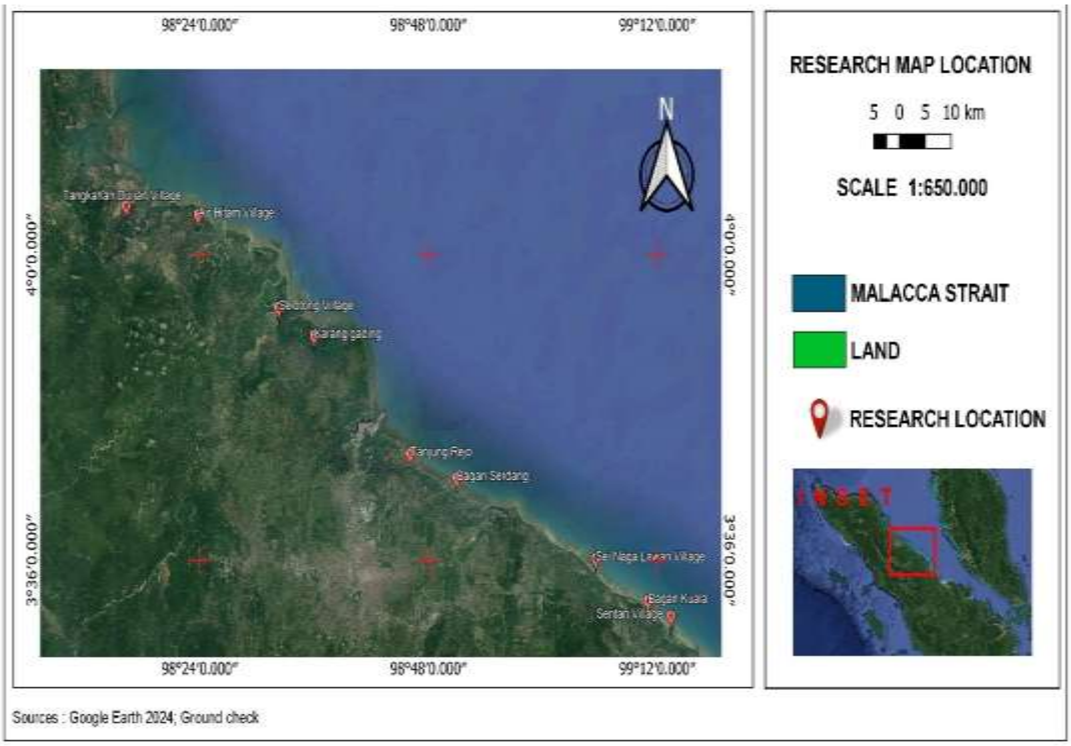

Figure 1. Mangrove Area Research Location on The East Coast of North Sumatra

Time and Location of Research

This research was conducted in 3 mangrove areas on the east coast of North Sumatra, namely Deli Serdang, Serdang Bedagai, and Langkat. With the first area point of Deli Serdang there are 3 sub-districts, namely Percut Sei Tuan District, Labuhan Deli District, and Pantai Labu District; while the second area of Langkat the research location point is 3 sub-districts, namely Gebang, Secanggang, and Pangkalan Brandan districts from June to October 2023.

Tools and Materials

The tools and materials used in this study include stationery to record data in the field, record paper to record mangrove data, global positioning system (GPS) for determining coordinate points, digital cameras as documentation tools, Roll Meter to measure plots observations, measuring tape for measuring the circumference of tree trunks, raffia ropes as a plot boundary mark Observation.

Research Methods

Determination of Sampling Location

The mangrove samples taken include tree trunk samples. Sampling is carried out By creating a mangrove plot refers to a simple sampling method according to (Manuri & Warren, 2011). Simple sampling is one of the common sampling techniques conducted on mangrove carbon analysis. This method is used in areas where the initial data Estimates of the distribution of carbon stocks are not available. This method does not classify the sample population based on certain considerations so that the variation between plots becomes greater (Manuri & Warren, 2011). The mangroves observed for carbon stock analysis in this study focused on mangroves with a stem size of 5 cm in diameter (Komiyama et al., 2005). Data grouping trees are carried out following (Manuri & Warren, 2011) and SNI No. 7724 of 2011 to make it easier to record data in the field.

Field Data Collection

The first observation of the mangrove community by determining the sampling location refers to the simple sampling method, then installing a plot with an area of 20 meters x 20 meters against the tree category at each location. Field observations using sample plots. The position of each plot is adjusted to the condition of the mangrove vegetation in the field based on density criteria. The placement of each plot is 20 x 20 m, where each sub-district has 3 (three) stations with a distance of 8 m each, at each station there are 3 (three) plots or three repetitions So that the total number of observation locations is 27 stations (Figure 1).

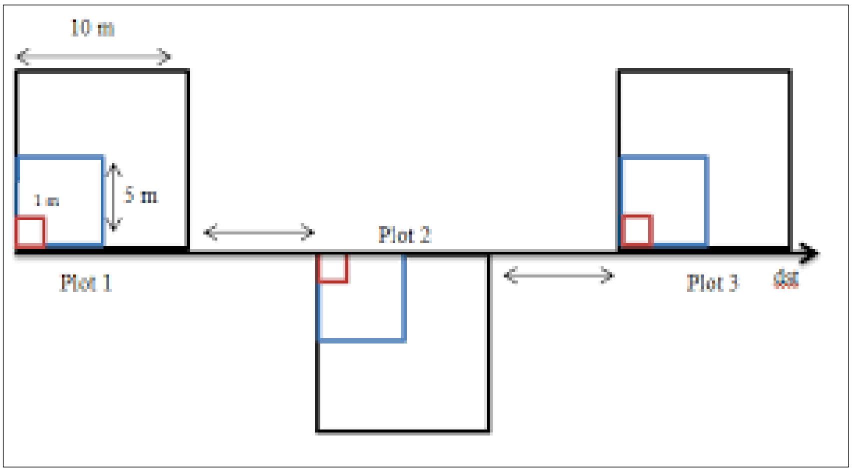

Figure 1. Direction of the Transverse Line Parallel to the Sea

The next step is to identify all types of mangroves in the plot, then calculate the number of tree stands (Bengen, 2001) and measure the trunk circumference of each tree where the diameter of the tree trunk is measured at the height of an adult's chest (DBH = diameter at breast height = 1.3 m from the ground level). Each rod is measured using a measuring tape and then given a number or mark and recorded for each type. Measurements are carried out by wrapping a measuring tape around the tree trunk, with the position of the tape parallel in all directions, so that the data obtained is the circumference/circumference of the trunk. To find out the diameter of the tree, the tree circumference/circumference data is divided by the value of π (3.14), as shown in the equation below referes to Rull (2024):

$$d = k/\pi \quad (1)$$

Where: d = diameter of the tree; k = tree circumference; π = 3.14

The condition of the mangrove ecosystem is represented by the condition of type density (Di), biomass, and estimated carbon reserves at the research site. Type i (Di) density is the number of type i stands in an area (Bengen, 2001), which can be written with the formula:

$$Di = ni/A \quad (2)$$

Where:
Di = Type density i (Ind/m^2);
ni = Total number of type I stands;
A = Total area of the sampling area.

Biomass Data Collection and Carbon Stock Estimation are determined from mangrove biomass. The procedure for measuring mangrove biomass in the tree category is carried out in a non-destructive way, namely, the determination of tree biomass is determined based on the data from the measurement of the circumference of the tree trunk with the record that the type of plant measured is already known the allometric formula. In this case, the procedure for measuring biomass above the ground level uses the procedure according to (Komiyama et al., 2005). Analysis of estimation of mangrove vegetation biomass above ground level using allometric equations based on mangrove plant species. The tree trunk diameter data obtained from mangrove vegetation measurements is used for the purpose of calculating biomass for tree categories and which will then be included in the allometric equation for each type of mangrove. To determine the value of biomass, an allometric equation is used. Allometric equations for some types mangroves are presented in the following Table 1.

Table 1. Tree Biomass Allometric Equation Model

Types of mangrove	Biomass	Previous Research
Avicennia alba	$Wr = 0{,}079211 * DBH^{2{,}470895}$	Poedjirahajoe et al., 2017
Avicennia marina	$Wr = 0{,}2901 * DBH^{2.2605}$	Dharmawan, 2010
Rhizophora apiculata	$Wr = 0{,}043 * DBH^{2.63}$	Amira, 2008
Rhizophora mucronata	$Wr = 0{,}1466 * DBH^{2{,}3136}$	Dharmawan, 2010
Bruguiera cylindrica	$Wr = 0{,}251 * \rho * DBH^{2.46}$	Komiyama et al., 2005
Bruguiera gymnorhiza	$Wr = 0{,}0754 * D^{2.505} * \rho$	Kauffman & Donato, 2012
Sonneratia alba	$Wr = 0.3841 * D^{2.101} * \rho$	Kauffman & Donato, 2012

Note: B = Plant biomass (kg/m^2); ρ = Specific gravity of the plant ($grams/cm^3$); D = Diameter of the tree trunk (cm); ρ *Bruguiera cylindrica* = 0.749; ρ *Bruguiera gymnorhiza* = 0.699; ρ *Sonneratia alba* = 0.475

To obtain the value of stored carbon in each type of mangrove, the biomass value obtained from the allometric formula is multiplied by the concentration of organic carbon in each type of tree based on the following equation of Estimated Carbon Reserves SNI 7724-2011 (Syahrial, 2023) :

$$Ctop = 0.47 \times Wtop \quad \ldots (3)$$

Where:
Ctop = Carbon reserves at the top of the soil surface (kg);
Wtop = Plant biomass at the top of the soil surface (kg)

RESULT AND DISCUSSION

Based on the results of the identification carried out, it is known that the mangrove species that live in the study site are *Rhizophora apiculata, Rhizophora mucronata, Avicennia alba, Avicennia marina, Bruguiera gymnorhiza, Bruguiera cylindrica, Sonneratia alba.* Mangrove species found at Deli Serdang, Serdang Bedagai, and Langkat Regency Stations are found in the following table 2.

Mangrove density is an important factor affecting the health and sustainability of coastal ecosystems, with various studies highlighting its significance in different regions. In Pariaman, West Sumatra, a study revealed that of the 10 hectares of mangrove area, 88.8% showed very high density, indicating strong ecological health (Fajri, 2024). In contrast, in Sorong City, the Klawalu Mangrove Tourism Park shows a more varied density distribution, with 47.71% classified as very dense and 2.42% as very rare, reflecting the impact of human use on mangrove resources (Tjolli, 2024). Furthermore, a study in Langsa City found densities between 675 and 1,541 trees per hectare, positively correlated with the efficiency of sediment traps, which are essential for coastal protection (Gusnita, 2022).

Table 2. Composition of Mangrove Types Found at Each Station

Species	**Deli Serdang**			**Serdang Bedagai**			**Langkat**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Rhizophora apiculata	√		√	√	√	√		√	√
Rhizophora mucronata	√		√	√	√	√		√	√
Avicennia alba		√	√	√			√		
Avicennia marina		√	√	√			√	√	
Bruguiera gymnorhiza				√					
Bruguiera cylindrical				√					
Sonneratia alba					√				

The species density for the tree category obtained at the research site showed mixed results. Based on the calculation of density values, Deli Serdang Regency, Serdang Bedagai Regency, and Lalat Regency are included in the Very dense category. The density of each station type for the tree category is presented in Table 3.

Table 3. Total Density Value of each location

Location	**Total Density (ind/Ha)**	**Category (KEPMEN LH No. 201/2004)**
Deli Serdang	5283.33	Very Dense
Serdang Bedagai	9625.00	Very Dense
Langkat	6900.01	Very Dense

The density of trees included in the category of Very dense in Deli Serdang district is 5283.33 ind/ha, in Serdang Bedagai 9625.00 ind/ha, and in Langkat Regency 6900.01 ind/ha (Table 3). Based on the mangrove density standard issued by KEPMEN LH No. 201 of 2004, mangrove areas are said to be in the rare category if the density value is less than 1000 individuals per hectare (<1000 ind/ha). Research in Jakarta showed a two-decade decline in mangrove density, with densities ranging from 440 to 1,250 trees per hectare, underscoring degradation concerns (Usman et al., 2023). Mangrove ecosystems exhibit significant diversity and species composition, which vary across different geographic locations. For example, Lepar Island hosts 11 species from five families, with *R. apiculate*, and *B. gymnorrhiza* being very dominant (Henri et al., 2024). In Dafi Village, seven species were identified, with *B. gymnorrhiza* again showing the highest density and value of importance (Manumpil, 2023). The Philippine Barangay Ata-Atahon recorded 19 species of mangroves, with *Ceriops decandra* being the most abundant. In India, the mouth of the Kali River documents 14 species of true mangroves, with *Avicennia officinalis* being the most prominent (Hondappanavar, 2024).

Table 4. Mangrove content and density

Location		Stations	Species	Total (Individu)	Diameter Average	Biomassa (kg/m²)	Carbon Stock (kg/m²)
Deli Serdang	1	Tanjung Rejo Village Percut Sei Tuan District	*R. apiculata*	79	10.83	226.12	106.27
			R. mucronata	106	11.02	377.78	177.56
	2	Karang Gading Village Labuhan Deli District	*A. alba*	75	24.84	2218.66	1042.77
			A. marina	51	17.29	1508.93	709.19
	3	Bagan Serdang Village Beach Labu District	*R. apiculata*	204	4.90	28.17	13.24
			R. mucronata	88	4.78	54.63	25.68
			A. alba	26	12.32	392.64	184.54
			A. marina	5	15.29	1128.95	530.61
Serdang Bedagai	4	Bagan Kuala Village Tjg Beringin District	*A. marina*	129	17.94	1645.00	773.15
			A. alba	28	21.66	1580.74	742.95
			B. gymnorhiza	37	11.15	203.81	95.79
			B. cylindrical	35	10.19	568.04	266.98
			R. apiculata	56	17.29	774.58	364.05
			R. mucronata	33	22.93	2058.55	967.52
	5	Sentang Village Sialang Buah District	*R. apiculata*	176	9.11	143.48	67.43
			R. mucronata	145	10.06	306.28	143.95
			S. alba	128	9.65	213.60	100.39
	6	Sei Naga Lawan Village Perbaungan District	*R. apiculata*	273	7.64	9.05	4.25
			R. mucronata	115	6.15	9.79	4.60
Langkat	7	Air Hitam Village Gebang District	*A. alba*	127	8.92	176.48	82.95
			A. marina	101	9.55	373.68	175.63
	8	Selotong Village Secanggang District	*R. apiculata*	167	8.50	119.75	56.28
			R. mucronata	125	7.32	14.69	6.90
			A. marina	104	6.78	166.9571	78.47
	9	Tangkahan Durian Village Pangkalan Brandan District	*R. apiculata*	126	24.52	1940.948	912.25
			R. mucronata	78	21.34	1742.786	819.11

Based on the results of carbon stock calculations, it is known that *A. alba* has the highest carbon content of 1042.77 kg/m^2 in Deli Serdang district. Carbon stock calculations in Serdang Bedagai District showed *R. mucronata* with the highest carbon stock of 967.52 kg/m^2. Meanwhile in Langkat District *R. apiculata* became the species with the highest carbon stock content of 912.25 kg/m^2(table 4).

CONCLUSION

Mangrove forests are highly effective carbon sinks, able to absorb large amounts of carbon dioxide (CO_2) over a long period. For example, mangrove forests in Egypt have been reported to absorb an average of 81.87 g C org m^{-2} year^{-1}, underscoring their role in reducing atmospheric CO2 levels, The degradation of mangrove forests, particularly in areas such as North Sumatra, is alarming. From 1990 to 2015, the primary mangrove area decreased by 61.21 %, mainly due to aquaculture and agricultural land conversion. This loss affects not only carbon storage but also biodiversity and coastal protection. Despite the degradation, rehabilitation initiatives such as planting propagules and seedlings have shown promising survival rates of 69.42 % and 86.38 %, respectively. This shows that restoration efforts have the potential to increase carbon storage capacity, with the total ecosystem carbon stock reaching 558.07 mgC ha^{-1}. The level of sedimentation in mangrove ecosystems is critical to its sustainability, as it can offset sea level rise. This aspect is very important to maintain the ecological function of mangrove forests, including their carbon storage capabilities. Beyond carbon storage, mangrove forests provide many ecological, economic, and social benefits. They serve as critical habitats for a variety of species, protect coastlines from erosion, and support local economies through fisheries and tourism.

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