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Estimation of subsurface carbon stock of mangrove on Takari Beach, Rebo Village, Merawang District, Bangka Regency

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A B S T R A C T

The Bangka Belitung Islands Province has a mangrove ecosystem covering an area of 273,692.81 hectares. These ecosystems play a crucial role in mitigating greenhouse gas emissions through the sequestration mechanism, which involves absorbing carbon from the atmosphere and storing it in the form of biomass. Human activities around these areas, such as the flow of tailings from artisanal mining (TI), have caused damage to these ecosystems, leading to a reduction in one of the primary carbon dioxides (CO^2) absorbers. This study aims to support the sustainable management of mangrove conservation areas in efforts to reduce the impact of global warming. Sampling stations were determined using purposive sampling, with the collection of substrate carbon, biomass, and carbon samples, as well as water quality parameters at Takari Beach. The results showed that the water temperature was 28°C, salinity ranged from 25 to 27 ppt, and pH ranged from 5 to 8,5. Four mangrove species were found at two stations: *Rhizophora mucronata, Rhizophora apiculata, Sonneratia alba*, and *Lumnitzera littorea,* totaling 185 trees. The mangrove biomass was measured at 27,10636 tons/ha, and the below-ground carbon stock was recorded at 12,74 tons/ha.

Keywords: Biomass; carbon; mangrove types

1. INTRODUCTION

Climate change has become a profound global challenge, with widespread impacts on the environment, economy, and quality of life. One potential nature-based solution for climate change mitigation is the conservation and restoration of mangrove ecosystems. Mangroves have a remarkable capacity to sequester vast amounts of carbon, directly contributing to the reduction of greenhouse gas emissions. Research shows that mangrove ecosystems store significantly more carbon than terrestrial tropical forests, making them highly effective in mitigating global warming (Duke et al., 2017). Mangroves not only protect coastal areas from erosion but also play a crucial role in climate change mitigation through carbon storage (Wahyudin et al., 2024).

Indonesia, as an archipelagic nation with the largest mangrove area in the world, holds a strategic position in global mangrove ecosystem management. However, Indonesia continues to face serious challenges such as deforestation, land conversion, and mining activities that threaten the sustainability of this ecosystem (Farhaby & Anwar, 2021). At the local level, the Bangka Belitung Islands Province also faces similar challenges, with many coastal areas degraded by human activities. Takari Beach, Bangka Regency, is one example of a mangrove ecosystem experiencing degradation, with its health condition classified as moderate to poor (Farhaby & Anwar, 2023). This degradation reduces the mangroves' capacity to protect the coast and store carbon, impacting their biodiversity and ecological function (Slamet et al., 2024).

Research on mangrove carbon stocks in the Takari Beach rehabilitation area is still very limited, highlighting a gap in scientific understanding of the role of mangroves in climate change mitigation in the area. Previous research has underemphasized the importance of carbon stock estimation as an indicator of the success of mangrove rehabilitation and its contribution to carbon emission reduction (Pramono & Alyodya, 2024). Therefore, a more in-depth study of local mangrove carbon estimation is essential to support evidence-based decision-

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making. This study aims to address this gap by analyzing mangrove species and density in Takari Beach, as well as measuring biomass and carbon stocks in mangrove stands in the area (Harefa et al., 2024).

This research is also important considering that mangrove species play a significant role in the amount of carbon that can be stored, as each species has different growth characteristics, such as stem size, roots, and lifespan. Some mangrove species are capable of storing greater amounts of carbon due to their greater biomass, while others may have a lower capacity (Wahyudin et al., 2024). Therefore, understanding the mangrove species present in the study area will help in calculating the different carbon storage capacities between species. Furthermore, mangrove density (the number of trees per unit area) is directly related to the total amount of biomass and carbon that can be stored in a mangrove ecosystem. The denser the mangrove population, the greater the total biomass and carbon stored. Therefore, measuring mangrove density in this area will provide a more accurate picture of the existing carbon stock (Slamet et al., 2025).

The results of this study are expected to provide more accurate data on carbon stocks at Takari Beach and can be used as a reference in mangrove ecosystem management policies in the coastal areas of Bangka Belitung. Furthermore, the results of this study will make an important contribution to developing mangrove-based blue carbon projects in Indonesia, which can support the achievement of national greenhouse gas emission reduction targets. Practically, the data obtained will support mangrove conservation and rehabilitation policies at Takari Beach and other coastal areas in Bangka Belitung. Theoretically, this study will also enhance scientific understanding of mangrove carbon stocks in coastal areas of Indonesia, particularly in Bangka Belitung, which is still limited (Hanifa et al., 2024).

2. MATERIALS AND METHODS

2.1 Study area

This research was conducted in the Takari Beach Mangrove Area, Rebo Village, Bangka Regency. The research consisted of three main stages: field survey, research data collection, and data processing and analysis. The field survey was conducted in August 2023 to determine the initial conditions of the research area and prepare equipment for data collection. Data collection took place in August 2023 in the Takari Beach Mangrove Area, and was then processed and analyzed from October to November 2023.

Figure 1. Research location

Determination of station points using the purposive sampling method, namely the deliberate selection of locations by considering the following criteria:

Mangrove Species Diversity: Stations were selected based on the diversity of existing mangrove species and their high carbon storage potential. Mangrove species diversity significantly influences the ecosystem's capacity to store carbon, as different species have different biomass and carbon absorption capabilities (Henri

et al., 2023). Selecting locations with diverse mangrove species also aims to provide a more representative picture of the carbon potential in mangrove ecosystems and improve the accuracy of research results related to carbon sequestration in various mangrove species (Pandeirot et al., 2020).

Mangrove Ecosystem Condition: The selected location must represent the condition of a mangrove ecosystem that is still maintained or requires rehabilitation to determine its carbon storage capacity under different conditions. Locations with varying ecosystem conditions provide a more complete picture of carbon storage potential, especially regarding the condition of degraded and well-maintained mangroves (Tahir et al., 2023). Selecting a location that represents these conditions is important because it can influence the level of carbon storage, considering that well-maintained mangroves have a higher carbon storage potential than degraded ones (Prasetya et al., 2021).

Accessibility: Station locations were selected with ease of access for sampling. Accessibility is a crucial factor in site selection to ensure effective and efficient data collection while minimizing disruption to the ecosystem or causing unintended damage. This also reduces the risk of disturbance to protected mangrove ecosystems and facilitates smooth research (Putro et al., 2018).

2.2 Materials

The tools and materials used are: Mobile phone, stationery, GPS, raffia rope, thermometer, worksheet, sewing meter, label paper, sample plastic, oven, refractometer, mortar, core sampler, spray paint, personal protective equipment (PPE), digital scales, DO meter, porcelain cup, muffle sampler, cable ties, soil pH, dark bottle, mangrove identification guide.

2.3 Methods

2.3.1 Measurement plot construction

The plot size used in this study was 10 x 10 meters per station, according to the Indonesian National Standard (SNI 7724:2011). This plot size was chosen because it has proven effective in monitoring mangrove vegetation density and providing representative data for biomass and carbon stock analysis.

2.3.2 Mangrove vegetation collection

Tree stem diameter (DBH) measurements were taken at a height of 1,3 meters above ground level for each mangrove tree found within the plot. Trees sampled in this category had a tree stem diameter (dbh) of ≥ 4 cm and included counting the number of stands, diameters, and species within the plot (Nuraini et al., 2021).

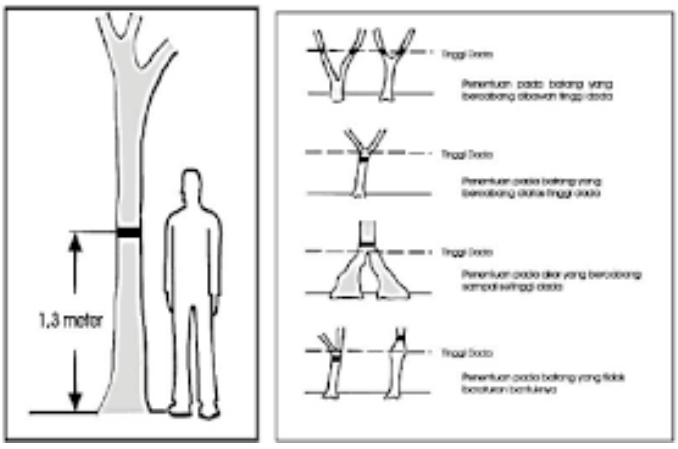

Figure 2. Illustration of measuring tree diameter at breast height (DBH) (Farhaby, 2019)

2.3.3 Soil sampling

Soil samples were taken at a depth of 0-30 cm, divided into three depth intervals: 0-10 cm, 10-20 cm, and 20-30 cm, by the procedures in SNI 7724:2011. Three replicates per station were collected to ensure a better representation of soil conditions. These soil samples were used to measure bulk density, soil depth (Kd), and soil organic carbon (C-organic). After collection, the soil samples were oven-dried at 105°C until they reached constant weight, then incinerated at 550°C to measure organic carbon content using the Loss on Ignition (LoI) method.

2.3.4 Water quality parameter collection

Water quality was measured to determine factors that can influence mangrove growth and development, such as temperature, pH, salinity, and dissolved oxygen (DO). Measurements were conducted at each station using the following procedures:

- Temperature: Water temperature was measured using a standard thermometer placed at specific depths at the research site. Measurements were conducted periodically at each station to obtain representative data (Akhter et al., 2018).
- pH: Water pH was measured using a pH meter that had been calibrated with a pH buffer standard. Measurements were taken at a depth of approximately 10 cm from the water surface at each station (Fatema et al., 2015).
- Salinity: Salinity was measured using a salinity refractometer or digital salinity sensor. Measurements were taken at the same points as pH and temperature measurements and were conducted periodically to monitor changes in water salinity (Yusop et al., 2013).
- DO (Dissolved Oxygen): Dissolved oxygen content was measured using a DO meter, which measures dissolved oxygen concentration in mg/L. Measurements were taken at a depth of approximately 10 cm from the water surface at each station (Sarker et al., 2012).

2.4 Data analysis

2.4.1 Mangrove species density

Mangrove species density is the number of individual mangrove species within a specific area. To calculate mangrove species density in the study area, a formula is used that refers to the number of individual species found within an observation area. The formula used to calculate mangrove species density refers to (Nuraini et al., 2021):

$$K = \frac{ni}{A} \quad (1)$$

Description:

K : Species density (ind/ha)

ni : Total number of stands of species i

A : Total plot area (ha)

2.4.2 Mangrove carbon

Carbon stock calculations refer to SNI 7724:2011, which provides a forest carbon measurement methodology based on guidelines from the National Standardization Agency (BSN). The formulas used to calculate carbon content in various carbon pools, such as aboveground and belowground biomass and soil organic matter, follow this standard to ensure accuracy in carbon stock estimates.

2.4.3 Calculation of mangrove below-ground biomass

Each mangrove species was measured using an allometric model tailored to the species present. Table 1 is the allometric model for below-ground biomass (roots) used in this study.

Table 1. Allometric equation model for below-ground biomass

Mangrove types	Allometric model	Source
Rhizophora apiculata	$B = 0{,}00698*DBH^{2,61}$	Komiyama et al., (2008)
Rhizophora mucronata	$B = 0{,}199p^{0.899}*DBH^{2.22}$	Komiyama et al., (2008)
Sonneratia alba	$B = 0{,}199*p^{0.899}DBH^{2.22}$	Komiyama et al., (2008)
Lumnitzera littorea	$B = 0{,}045^{*}DBH^{2,48}$	Komiyama et al., (2008)

Where DBH is Diameter at Breast Height (tree trunk diameter at a height of 1,3 meters) and p is the root length in certain species.

2.4.4 Carbon calculation from biomass (Cb)

After calculating the mangrove biomass, the carbon content of the biomass is calculated using the formula referred to in SNI 7724:2011:

$$Cb = B \times \%C_{org} \quad (2)$$

Description:
Cb : Carbon content of biomass (Kg)
B : Total biomass (Kg)
$\%C_{org}$: Percentage value of carbon content (0,47)

2.4.5 Soil carbon calculation (Ct)

To calculate soil carbon, use the formula based on SNI 7724:2011, with parameters including soil sample depth (Kd), bulk density (ρ), and % organic carbon:

$$Ct = Kd \times p \times \%C_{org} \quad (3)$$

Description:
Ct : Soil carbon content (g/cm^2)
Kd : Soil sample depth (cm)
P : Bulk density (g/cm^3)
$\%C_{org}$: Percentage value of carbon content (0,47)

2.4.6 Calculating carbon stocks in plots (C_{plot})

The calculation of total carbon stocks in plots is done by accumulating carbon from aboveground biomass (C_{bap}), belowground biomass (C_{bbp}), and soil carbon (C_{soil}). The formula used is:

$$C_{plot} = (C_{bap} + C_{bbp} + C_{soil}) \quad (4)$$

Description:
C_{plot} : Total internal carbon content plot (ton/ha)
C_{bap} : Total upper carbon content of the ground surface in the plot (ton/ha)
C_{bbp} : Total bottom carbon content of the ground surface in the plot (ton/ha)
C_{soil} : Total soil carbon content per hectare in plot (ton/ha)

2.4.7 Calculating carbon stocks in a stratum ($C_{stratum}$)

Calculating carbon stocks in a forest stratum is done by summing the carbon stocks of each plot within that stratum. The formula used is:

$$C_{stratum} = \sum C_{plot} \times L_{stratum} \quad (5)$$

Description:
$C_{stratum}$: is the total carbon stock within the stratum, expressed in tons.
C_{plot} : is the carbon stock in plots within the stratum.
$L_{stratum}$: is the stratum area calculated in hectares (ha).

2.4.8 Calculating total carbon stock in an area (C_{total})

Total carbon stock in an area is calculated by summing the carbon stocks in all strata. The formula used is:

$$C_{total} = \sum C_{stratum} \quad (6)$$

Description:
C_{total} : carbon stock in an area, expressed in tons.
$C_{stratum}$: total carbon stock in a stratum.

3. RESULTS AND DISCUSSION

3.1 Environmental parameters

The parameters measured during the research at Takari Beach, Rebo Village, Merawang District, Bangka Regency, are as follows:

Table 2. Water quality parameters

Station	Water quality parameter			
	Do (mg/L)	Soil pH	Salinity (ppt)	Temperature (°C)
1	3.5 mg/L	2	27 ppt	28°C
2	-	5	25 ppt	28°C

Observations at Station 1 showed a DO level of 3,5 mg/L, supporting mangrove root respiration and healthy mangrove vegetation growth. A sufficiently high DO level allows mangrove roots to respire optimally, thus supporting mangrove productivity and survival. According to Indriyani et al. (2020), mangroves require a DO level in the range of 2-7 mg/L to support efficient root respiration. Conversely, at Station 2, no dissolved oxygen was detected due to anaerobic environmental conditions. This occurred because at the time of sampling, the area was not inundated with seawater and did not experience tidal fluctuations. The absence of dissolved oxygen indicates adverse conditions for mangrove root respiration, which negatively impacts plant growth. Decreased DO levels can limit the survival of coastal ecosystems, including mangroves, which are highly dependent on adequate oxygen levels in their roots (Indriyani et al., 2020; Sapkale et al., 2023).

Salinity at Station 1 was recorded at 27 ppt, while at Station 2 it was recorded at 25 ppt. The ideal salinity for mangrove growth ranges from 15-35 ppt, so the salinity at both stations is still within the range that supports mangrove growth, although slightly higher at Station 1. The higher salinity at Station 1 supports mangrove species that are more tolerant of these conditions, while the slightly lower salinity at Station 2 allows different types of mangroves to thrive, as explained by Lusiana et al. (2020).

The soil pH at Station 1 was recorded at 2, indicating highly acidic soil conditions that can inhibit mangrove growth. The optimal soil pH for mangroves ranges from 5 to 8 (Bersaldo et al., 2022). Very low soil pH can reduce mangrove species diversity and affect nutrient availability and the activity of decomposing microorganisms in the soil. At Station 2, the soil pH was recorded at 5, indicating more neutral soil conditions that support better mangrove growth.

The water temperature recorded at both stations was 28°C, which is within the optimal temperature range for mangrove growth, which is between 25-32°C (Hendy et al., 2021). This stable temperature supports photosynthesis and metabolism of mangrove plants, allowing them to thrive at both stations.

As a result, water quality at both stations exhibits diverse conditions, which impact the health and sustainability of the mangrove ecosystem. Optimal water quality parameters, such as DO in the range of 2-7 mg/L, salinity 15-35 ppt, soil pH between 5-8, and water temperature between 25-32°C, support optimal mangrove growth and survival. An imbalance or mismatch in any of these water quality parameters can hinder the functioning of the mangrove ecosystem, affecting species diversity and productivity.

3.2 Mangrove ecosystem characteristics

Observations of the mangrove ecosystem at two stations showed that Takari Beach has four mangrove species: *Rhizophora mucronata, Rhizophora apiculata, Sonneratia alba,* and *Lumnitzera littorea*. A total of 185 mangrove trees were found at the two stations (Table 3).

Table 3. Below carbon table

Station	Location	Range DBH (cm)	Number of Trees (ind)	Density (ind/ha)	Below Ground Biomass (ton/ha)		Below Ground Carbon	
					Root Biomass	Soil Organic	Below Carbon (ton/ha)	Soil Carbon
1	Takari	0,96 - 20,70	117	1901,10	40,66	0,28	19,11	323,10
2		1,27 - 16,88	68	1104,90	13,55	0,28	6,37	286,18
TOTAL			185	3005,98	54,21	0,55	25,48	609,28
Mean (Ton/ha)			92,5	1502,99	27,10636	0,28	12,74	304,64

3.3 Mangrove biomass

The results of the mangrove biomass calculation showed a biomass content of 27,11 tons/ha. Station I had the highest biomass at 19,11 tons/ha. This is because Station I is dominated by *Rhizopora apiculata* and *Rhizopora mucronata*. *Rhizophora* sp. mangroves grow in muddy areas with adaptations in the form of stilt roots. One of the functions of stilt roots in this mangrove species is to absorb air in oxygen-poor conditions; lower oxygen levels increase the number and height of stilt roots (Soenardjo et al., 2018). The lowest biomass value was found at station II, at 13,55 tons/ha (Below-Ground Biomass). This occurs because the diameter (diameter at breast height, DBH) at location II is smaller compared to the other locations. The biomass value is not only influenced by tree density but also by the diameter of the tree itself, because the larger the diameter of a tree, the greater the biomass value will be (Program et al., 2016).

The types of *Rhizophora mucronata, Rhizophora apiculata, Sonneratia alba,* and *Lumnitzera littorea* found at the research location had DBH values ranging from 0,96 – 20,70 at station 1 and 1,27 – 16,88 at station 2, with a total number of 185 individuals. This is by the statement of Henri et al. (2023) regarding differences in tree biomass per species influenced by several factors, namely the number of individuals and tree size (tree diameter).

3.4 Mangrove carbon stock estimation

According to Ati et al. (2014), carbon stock describes the extent to which a tree stores carbon. The extent of carbon storage in a given vegetation depends on the amount of biomass contained within the mangrove stand, soil fertility, and the vegetation's absorption capacity. Based on calculations, the overall average mangrove carbon stock at Takari Beach, with an average carbon storage per stand, was 12,74 tons/ha. The highest carbon storage was at Station I (19,11 tons/ha), while the lowest carbon storage was at Station II (6,37 tons/ha).

Biomass values based on the number of mangrove trees at each station were 19,11 tons/ha at Station I and 6,37 tons/ha at Station II. Factors thought to influence differences in biomass include the number of trees, tree density, and tree species. Meanwhile, the percentage of carbon content is influenced by mangrove health conditions, organic matter, and substrate type (Lestariningsih et al., 2018). According to Widyastuti et al. (2018), tree biomass is thought to be influenced by mangrove density, and carbon biomass will increase as canopy cover and mangrove density increase. The higher the biomass value, the higher the carbon storage (Program et al., 2017).

4. CONCLUSION

Research at Takari Beach, Rebo Village, Merawang District, Bangka Regency, showed that water quality, including DO, salinity, soil pH, and temperature, affects the health of the mangrove ecosystem. Station 1 had a relatively high DO (3,5 mg/L), supporting mangrove growth, while Station 2 exhibited anaerobic conditions with no DO. Salinity at both stations was still within the optimal range, but the highly acidic soil pH at Station 1 inhibited mangrove growth. Mangrove biomass at Station 1 (19,11 tons/ha) was higher than at Station 2 (13,55 tons/ha), which was caused by differences in tree size and density. Carbon stock estimates showed the largest carbon storage at Station 1 (19,11 tons/ha) and the smallest at Station 2 (6,37 tons/ha). These factors indicate the importance of water quality management and mangrove ecosystems in maintaining the sustainability and function of the ecosystem. The types of mangroves found at the two stations were 4 types of mangroves, namely *Rhizophora mucronata, Rhizophora apiculate, Sonneratia alba,* and *Lumnitzera littorea*, with a total of 185 trees. Mangrove biomass was 27,11 tons/ha. The calculation of carbon stocks below the average carbon storage in the stand was 12,74 tons/ha.

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