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Quantification of Soil Organic Carbon Stocks in the Mangrove Forest of Telaga Tujuh Island, Langsa, Aceh

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ABSTRACT

Mangrove ecosystems are considered highly effective carbon sinks because of their substantial capacity to caputure and store carbon, especially in the form of soil organic carbon. This study aims to quantify the soil organic carbon stock in the mangrove forest of Telaga Tujuh Island, Langsa, using purposive sampling with eight circular plots of 400 m² each. Results showed that the diameter class distribution was dominated by the 10-20cm with 158 individuals. The tree density in this place was 796.88 ind. ha^{-1}. The highest soil organic carbon stock was recorded in Plot 8, with a value of 811.24 Mg C ha^{-1}. The mean of soil organic carbon stock was 635.28 ± 110.46 Mg C ha^{-1}. Overall, the total soil organic carbon stock of Telaga Tujuh Island was estimated at 22,234.86 ± 3,866.20 Mg C ha^{-1}. These results highlight the significant role of Telaga Tujuh mangroves as a carbon sink and their contribution to national carbon emission mitigation strategies.

Keywords: Circular Plot, Mangrove, Soil Organic Carbon Stock, Telaga Tujuh, Tree Density

1. Introduction

Mangrove forests are coastal ecosystems that play vital ecological and economic roles, one of which is serving as an effective carbon sink. Their capacity to sequester and store carbon dioxide (CO_2) from the atmosphere makes them one of the most important natural solutions for mitigating climate change. Climate change itself is a result of global warming, which is primarily caused by anthropogenic activities, including industrial processes, fossil fuel combustion, and the u se of synthetic chemicals such as those present in refrigerants. [1] reports mangrove store a mean of 738.9 Mg C ha^{-1}, representing 17% of total tropical marine carbon stocks. Mangroves capture carbon through multiple mechanisms: storing carbon in living biomass and sediments, trapping carbon-rich particles and facilitating sediment accretion [2].

Carbon reserves in mangrove forests are stored within various components, including tree biomass, litter, roots, and soil. Among these components, below-ground carbon reserves stored in roots and soil are generally considered more stable and long-lasting than above-ground carbon reserves (trees and litter). This is because the decomposition of organic matter below the soil surface occurs much more slowly, allowing carbon to remain stored for longer periods and reducing the likelihood of it being released back into the atmospheric [3]. Information on below-ground carbon reserves is essential for developing sustainable mangrove forest management strategies. This includes implementing carbon conscious harvesting practices, where harvesting intensity is adjusted based on the forest's carbon storage capacity, as well as restoring degraded mangrove areas to enhance their carbon sequestration potential. Indonesia has committed to reducing greenhouse gas emissions, and mangrove forests with high below-ground carbon reserves can play a key role in achieving these emission reduction targets. Data on these carbon reserves can assist the government in formulating effective policies and strategies for sustainable mangrove management and contribute to the attainment of national emission goals.

A study quantifying soil organic carbon stock in mangrove forests was conducted on Telaga Tujuh Island, located in Langsa Barat District, Langsa. This island is a small barrier characterized by relatively well-preserved and lush mangrove vegetation, making it strategic site for blue carbon research. Unlike inland mangroves, this island is situated at the interface of the Langsa river estuary and the Malacca Strait. This unique hydro-oceanographic position facilitates high rates of sediment accretion and organic matter trapping, which are critical drivers for soil carbon burial. According to [4] Telaga Tujuh Island is located on the seaward-facing western side of the mangrove complex. The study aimed to quantify the amount of soil organic carbon stock stored within this vital ecosystem.

While recent studies in Telaga Tujuh Island, such as [5], have primarily focused on vegetation biomass, and [6] concentrated on vegetation analysis. Although [4] estimated total carbon stocks, the scope of the study was board covering the entire Langsa. There is a distinct scarity of data specifically quantifying soil organic carbon stocks, despite soil representing the largest carbon pool in this ecosystem. Therefore, this study offers a novel contribution by isolating the soil carbon dynamics in this specific estuarine-island setting, providing a critical baseline for 'Blue Carbon' accounting admit rising ecotourism development.

2. Method

2.1 Research Overview

This research was carried out from June to August 2024. The study site was located in the mangrove forest of Telaga Tujuh Island, Langsa Barat (4°33'30.7" N, 98°03'32.7" E). The following figure (Figure 1) shows the map of the research area and the placement of the sampling plots. Soil carbon content and bulk density were evaluated at the Laboratory of Soil Chemical, Faculty of Agriculture, Universitas Syiah Kuala. The tools used in this study included a soil auger, plastic clips, GPS device, writing instruments, gloves and another tools and materials used for bulk density and soil carbon content analysis.

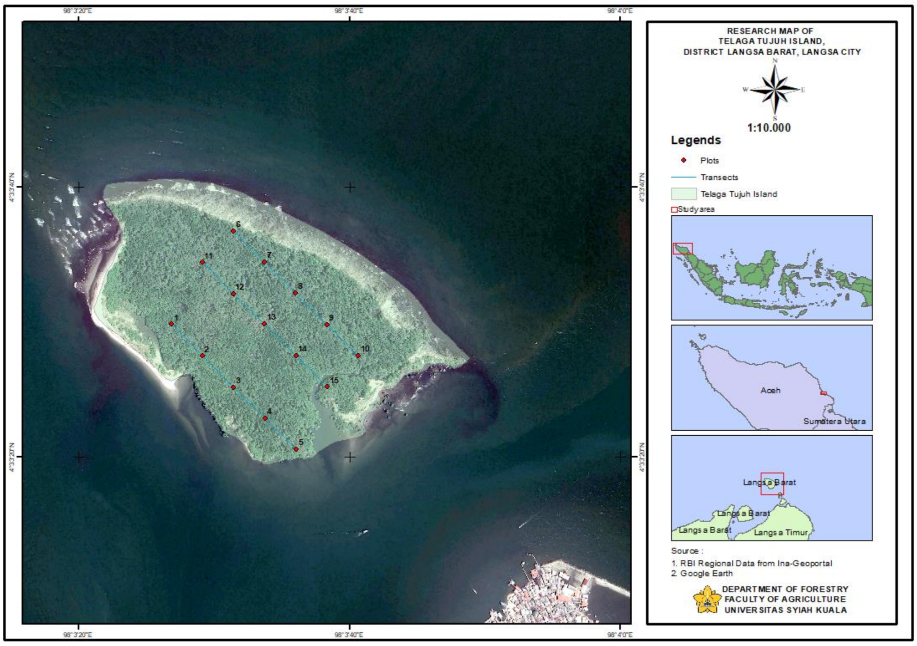

Figure 1. Research location

2.2 Data Collection

2.2.1. Preparation stage

This phase involved preliminary site surveys, administrative approvals, and material setup. The research was undertaken in collaboration with the Region III Regional Forest Management Unit (UPTD KPH) and the Langsa-based NGO Balee Juroeng.

2.2.2. Selection of starting point and plot establishment

The transect starting point was strategically positioned in high-density mangrove areas using a purposive sampling approach. Circular plots with an 11.3-meter radius (400 m^2 $plot^{-1}$) were established across Telaga Tujuh Island (35 ha), representing a 0.91% sampling intensity. From the 15 originally mapped plots, 8 representative plots (Plots 1, 3, 5, 6, 8, 12, 13, and 15; located within 4°33'25.8"–4°33'29.0" N, 98°03'30.7"–98°03'34.6" E) were selected for soil organic carbon stock analysis. While [7] utilized all 15 plots for above-ground carbon evaluation, this 8-plot subset was specifically chosen to accurately characterize the entire 35-hectare ecosystem. Mangrove vegetation was measured at the tree level (diameter ≥ 10 cm) within these 11.3 m radius subplots. Figure 2 illustrates the plot layout.

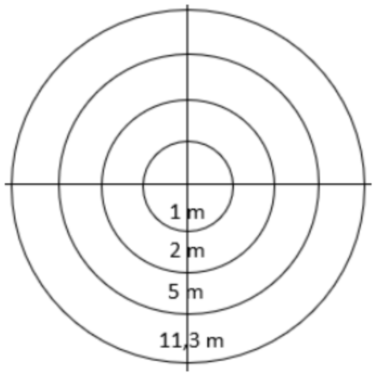

Figure 1. The design of research plot

2.2.3. Soil sampling technique

Soil samples were collected within each observation plot (radius 11.3 m) of plot 1, 3, 5, 6, 8, 12, 13, and 15. Sampling points were determined at the center of the plot. Samples were collected at 0-50 cm depth using a soil auger [8]. Each soil sample was placed into a labeled plastic bag indicating the plot number, sampling point, and depth. Samples were preserved in a cool, dry environment prior to the laboratory for analysis.

2.2.4. Analysis of bulk density (g cm^{-3})

Initial weighing: the soil sample within the core ring was weighed to obtain the wet weight. Drying process: samples were oven-dried at 105°C for approximately 24 hours until reaching a constant weight. Final weighing: after cooling in a desiccator, the dried sample was reweighed to obtain the oven-dry weight. Calculation of bulk density: the bulk density was determined using equation:

$$BD = \frac{Wd}{V} \tag{1}$$

Where:

BD : Bulk density (g cm^{-3})
Wd : Oven-dry soil weight (g)
V : Volume of the core ring (cm^3)

2.2.5. Analysis of soil carbon content (%)

Initial drying: the crucible containing the sample was oven-dried at 105°C for 24 hours to remove moisture. The sample was weighed to obtain the initial dry weight (W1). Ignition Process: The sample was combusted in a muffle furnace at 550°C for 4 hours to burn off organic matter. Cooling and Final Weighing: The crucible was cooled in a desiccator and reweighed to obtain the post-combustion weight (W2). Calculation of Carbon Content: The percentage of soil organic matter and carbon content were calculated using equation (2):

$$\%C = (W1 - W2)/W1 \times 58\% \quad (2)$$

2.3. Data Analysis

Soil organic carbon stock was calculated form bulk density and carbon content analysis as follows: [9]

$$Ct = BD \times D \times \%\ C\ Organic \quad (3)$$

Where:

Ct : Soil carbon stock (g cm^{-2})
BD : Bulk density (g cm^{-3})
D : Depth of the soil layer (cm)
% C : Persentage of soil carbon content (%)

The calculation of below-ground carbon stock in ha [9]:

$$C = Ct \times 100 \quad (4)$$

Where:

C : Soil carbon stock (Mg ha^{-1})
Ct : Soil carbon stock (g cm^{-2})
100 : convertion from g cm^{-2} to Mg ha^{-1}

3. Results and Discussion

Figure 3 illustrated the diameter class distribution, which was dominated by the 10-20 cm with 158 individuals, followed by the 21-30 cm class (74 individuals). In mangrove ecology, this class often represented the primary vegetation layer that forms the main canopy and contributed significantly to the forest's basal area and carbon sequestration capacity. The abundance of trees in the 10-20 cm and 21-30 cm suggests that the forest is in a vigorous growth phase. This confirms that the ecosystem is stable, productive and successfully occupying the available growing space without signs of degradation. According to [10], the abundance of trees in the 10-20 cm diameter class suggests a vigorous growth phase, indicating a stable and productive ecosystem with successful conservation of tree species.

Conversely, the largest diameter class (41-50 cm) was the least represented, comprising only 5 individuals. The relatively lower number of large trees (> 40 cm, 5 individuals) is typical for mangrove ecosystems, where extreme diameter growth is often limited by substrate instability or historical harvesting. The limited number of large trees can be attributed to substrate instability [11] and historical harvesting [12], which restrict diameter growth.

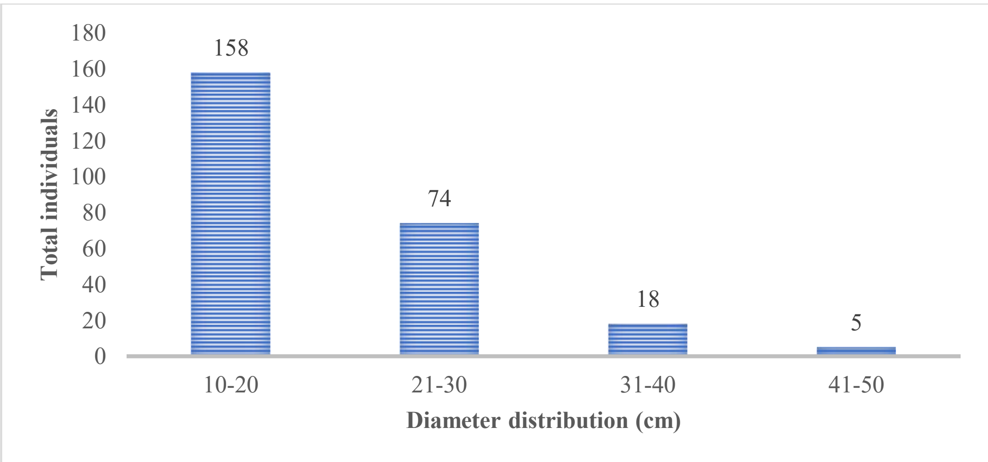

Figure 3. Diameter distribution (cm) of eight plots

Table 1 showed that plot 3 recorded the highest abundance with 42 individuals, closely followed by plot 4 (41 individuals). Plot 4 is attributed to the large number of trees present 41 individuals, including two trees with diameters of 46.15 cm and 41.38 cm, respectively. The higher abundance of individuals may be attributed to micro site variations, such as the presence of canopy gaps. In mangrove ecology, the mortality of large tree creates a gap that allows sunlight to penetrate the forest floor stimulating the rapid recruitment of saplings and poles to fill the available space. [13] demonstrate that saplings are most abundance in gaps, with long term survival depending on both light conditions and sediment disturbance.

Table 1. Total individuals (ind. plot^{-1}), tree density (ind. ha^{-1}) and soil organic carbon stocks (Mg C ha^{-1})

Variables	The Number of Plot								Total	Tree density (ind. ha^{-1})
	1	2	3	4	5	6	7	8		
Total individuals (ind.)	30	33	42	41	24	28	24	33	255	796.88
Soil organic carbon stock (Mg C ha^{-1})	748.76	525.21	663.29	595.79	687.76	518.64	531.56	811.24	5,082.25	
Mean ± SD of soil organic carbon stock (Mg C ha^{-1})									635.28 ± 110.46	

The tree density in this place was 796.88 ind. ha^{-1}. This indicated a mature stand structure dominated by large diameter trees. This forest had undergone natural self thinning, where lower density correlated with higher individual biomass and canopy cover, characteristic of stable, old growth ecosystem. [14] demonstrates that mangrove density and species age significantly influence biomass, with density ranging from 1,460 to 2,128 ind. ha^{-1} and corresponding biomass variations from 206.77 to 293.73 Mg C ha^{-1}.

The soil in Telaga Tujuh Island was characterized as high density mineral soil (bulk density 0.89 to 1.06 g cm^{-3}. Laboratory analysis showed that Plot 8 had the lowest bulk density value among all eight observation plots, at 0.890 g cm^{-3}, while its organic carbon content (%C) was the highest, reaching 18.23%. This demonstrates that the higher the organic carbon content, the lower the bulk density value. Soils that are frequently water-saturated or flooded tend to become soft and less dense, causing the decomposition of organic matter to proceed more slowly. This is supported by research conducted by [15] which stated that soil bulk density is one of the factors that can affect the amount of carbon stored in sediments. The higher bulk density value, the greater the soil compaction, which in turn enhances the soil's capacity to store carbon.

Table 2 also showed that the highest total carbon stock was found in Plot 8, amounting to 811.24 Mg C ha^{-1}. The mean of soil organic carbon stock was 635.28 ± 110.46 Mg C ha^{-1}and the total stock for 35 ha was 22,234.86 ± 3,866.20 Mg C. In addition, soil conditions and bulk density are also suspected to influence the high total carbon stock observed in Plot 8. According to [16] carbon stocks in mangrove ecosystems are the sum of carbon stored in tree trunks and canopies, roots, fallen wood, and soil. Among these components, soil is the most important, contributing more than 50% of the total carbon stock in mangrove ecosystems.

4. Conclusion

The conclusion of this study was that Telaga Tujuh Island possessed soil organic carbon stock of 22,234.86 ± 3,866.20 Mg C. It is recommended that efforts for conservation and restoration be strengthened to maintain and enhance belowground carbon reserves. Mangrove forest management practices should take into account their carbon storage capacity to ensure that resource utilization does not reduce the existing carbon stock. Continued research is necessary to monitor the carbon reserve dynamics and the factors influencing them, including the impacts of climate change and anthropogenic activities. Additionally, community awareness and involvement in mangrove forest management should be enhanced to preserve the ecosystem and its ecological benefits.

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