Estimation of aboveground biomass and carbon storage in mangroves along the coast of Banda Aceh City

Harum Farahisah[1*], *Muhammad* Nanda, *Yudi* Haditiar, and *Khairunnisa*

[1]Marine Sciences Department, Faculty of Marine and Fisheries Universitas Syiah Kuala Banda Aceh 23111, Indonesia

Abstract. One of the ecosystem services provided by mangroves is carbon absorption and storage, known as blue carbon. The coastal area of Banda Aceh has significant potential for mangrove forests as carbon stocks. This study aimed to estimate the carbon storage in mangrove vegetation along the Banda Aceh coast. The objectives were to calculate the density, aboveground biomass, and carbon storage of mangroves in this area. Data collection was conducted at four stations, namely Station 1 in Meuraxa District, Station 2 in Kuta Raja District, Station 3 in Kuta Alam District, and Station 4 in Syiah Kuala District, using a 100 m² quadrat transect method. Data processing involved allometric equations to determine aboveground biomass and carbon storage. Three mangrove species were identified: *Rhizophora mucronata*, *Avicennia marina*, and *Nypa fruticans*. The average mangrove density at Stations 1, 2, 3, and 4 was 0.50/m², 0.18/m², 0.17/m², and 0.32/m², respectively. The average aboveground biomass and carbon storage in the coastal area of Banda Aceh were 1450.18 kg/100 m² and 68.16 tons of carbon per hectare. This study underscores the potential of mangroves along the Banda Aceh coastline as carbon sinks, contributing to climate change mitigation.

1 Introduction

Coastal areas have the potential to reduce carbon emissions, often referred to as blue carbon. Blue carbon refers to organic carbon captured and stored by oceans and coastal ecosystems, particularly by coastal ecosystems such as seagrass, tidal marshes, and mangrove ecosystems [1, 2]. Efforts to reduce carbon emissions and address global warming involve controlling carbon emission production as well as preserving ecosystems capable of absorbing carbon. Mangrove ecosystems provide ecosystem services, including microclimate regulation, erosion prevention, coastal protection, and serving as habitats for aquatic species [3, 4]. Understanding the impacts of climate change on blue carbon ecosystems and identifying effective management actions are crucial for advancing research in this field.

* Corresponding author: harumfarahisah@usk.ac.id

Mangrove ecosystems can sequester and store carbon. The connection between carbon dioxide absorption and tree biomass is strong. Through photosynthesis, trees absorb CO_2 from the atmosphere and convert it into organic carbon in the form of carbohydrates, which is then stored in the tree's biomass [5]. As trees age, the amount of carbon stored tends to increase [6]. The coastline of Banda Aceh has several mangrove ecosystem areas in four districts: Meuraxa District, Kuta Raja District, Kuta Alam District, and Syiah Kuala District.

Previous studies have examined carbon storage in mangrove ecosystems, such as in Gampong Jawa and Lambaro Skep, Banda Aceh [7], where *Rhizophora apiculata* and *Rhizophora mucronata* were found to absorb comparable amounts of carbon. Carbon storage in mangrove ecosystem sediments in Masjid Raya Subdistrict, Aceh Besar, was also studied by Farahisah and Siregar [8]. Additionally, research on carbon stock estimation in the mangrove ecosystem of Kutaraja Subdistrict was also conducted by Dewiyanti *et al.* [9]. The result was found that mangrove trees have a highest carbon stock followed by mangrove root, deadwood, and soil, whith the total carbon stock was 81.37 ton/ha. The research related to carbon stocks in Banda Aceh is still scattered across several locations, and there has not been a comprehensive study; thus, this research aims to analyze the above-ground biomass and carbon storage of mangroves along the coast of Banda Aceh. This study is expected to enhance the role of mangroves in efforts to mitigate climate change in the coastal areas of Banda Aceh specifically, and Indonesia in general.

2 Method

This research was conducted in the coastal area of Banda Aceh City, Aceh Province in August 2024 (Figure 1).

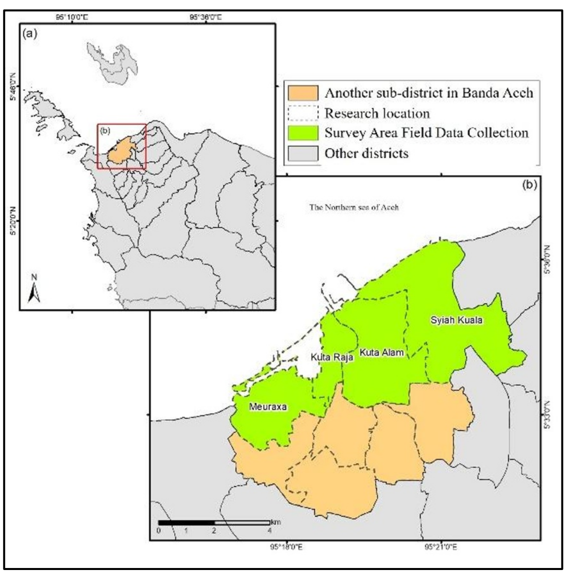

Fig. 1. Map of research location.

2.1 Field data collection

Sampling was conducted using a purposive sampling method representing districts along Banda Aceh's coast. Data collection occurred at four stations: Meuraxa, Kuta Raja, Kuta Alam, and Syiah Kuala. A 10 × 10 m plot transect was applied at each sampling point with three repetitions. Within each transect, tree species, coordinates, and tree diameters (≥ 5 cm) were recorded [10]. Soil samples were collected at each station to analyze texture and organic carbon content in the Soil Laboratory of FP USK.

2.2 Biomass and Carbon Calculations

Aboveground mangrove biomass was calculated using allometric equations (Table 1). Subsequently, carbon stock, CO_2 absorption, and O_2 production were calculated using the following formulas [11].

Table 1. Allometric equation mangrove species.

Species	Allometric Equation
R. mucronata (Dharmawan, 2013)	$B = 0.1466*D^{2.3136}$
A. marina (Dharmawan and Siregar, 2008)	$B = 0.1848*D^{2.3524}$

Carbon Stock analysis, $C = B \times 0.47$ (1)
CO_2 uptake estimation, $CO_2 = C \times 3.67$ (2)
O_2 production estimation, $O_2 = CO_2 \times 0.73$ (3)

Where B represent mangrove biomass (kg); D is the diameter at breast height (dbh) (m); 0.47 is the carbon fraction; 3,67 is the atomic ratio CO_2 to C; and 0.73 is the atomic ratio O_2 to CO_2.

3 Result and discussion

3.1 Mangrove density

There are three types of mangroves found at the research location, namely *Rhizophora mucronata, Avicennia marina,* and *Nypa fruticans*. The mangroves in the coastal area of Banda Aceh are dominated by the species *Rhizophora mucronata*, with a total of 328 trees found across all stations, followed by *Avicennia marina* with 14 trees and *Nypa fruticans* with 8 trees. The highest mangrove density was found at the Meuraxa station with a value of 0.5 ind/m², followed by Syiah Kuala station at 0.32 ind/m², Kura Raja at 0.18 ind/m², and Kuta Alam at 0.17 ind/m² (Table 1). In comparison to Farahisah's research in Ruyung Village, Aceh Besar, the average mangrove density is 0.25 ind/m² [8], which is almost the same as the research location at 0.29 ind/m².

Table 1. Mangrove density.

Station	Species	Density (ind/m^2)
Meuraxa	*R. mucronata*	0.50
Kuta Raja	*R. mucronata*	0.18
	A. marina	
	N. fruticans	
Kuta Alam	*A. marina*	0.17
	R. mucronata	
Syiah Kuala	*R. mucronata*	0.32

The dominant genus of mangroves in the research location is the Rhizophora genus. This is consistent with Dewiyanti's research in Kutaraja [9], Banda Aceh, and in Ruyung Village, Aceh Besar. Rhizophora propagules are better suited for long-distance dispersal and have an advantage for establishment in the lower part of the intertidal zone [12]. In addition to mangroves, the coastal vegetation commonly found in the coastal area of Banda Aceh includes ‘pinus’ and ‘bintaro’ species.

3.2 Biomass and carbon stock mangrove

The mangrove biomass analysed refers to the aboveground biomass of mangroves using allometric equations. Aboveground biomass (AGB) is in line with carbon stock, where higher biomass indicates higher carbon storage. The research results show that the mangrove biomass and carbon storage, from highest to lowest, are found at Kuta Raja station, Meuraxa, Syiah Kuala, and Kuta Alam. The mangroves at Kuta Raja station have a greater number of trees and larger diameters compared to other stations, resulting in higher biomass and carbon. In contrast, mangroves in Kuta Alam subdistrict tend to have smaller tree diameters, leading to this station having the lowest biomass and carbon storage. The aboveground biomass of mangroves is also influenced by environmental conditions. Higher tidal amplitudes, river discharge, temperature, direct rainfall, and decreased potential evapotranspiration contribute to increased mangrove aboveground biomass [13].

Table 2. Biomass and carbon stock mangrove.

Station	Biomass ($kg/100m^2$)	Carbon (ton/ha)	CO_2 uptake estimation (ton/ha)	O_2 production estimation (ton/ha)
Meuraxa	1130.27	53.12	194.78	141.66
Kuta Raja	3411.14	160.32	587.85	427.53
Kuta Alam	570.35	26.81	98.29	71.48
Syiah Kuala	688.98	32.38	118.73	86.35
Average	1450.18	68.16	249.91	181.76

The average carbon storage at the research site is 68.16 tons/ha, which is lower compared to the mangrove carbon uptake in Demak, which is 190,257 ton carbon/ha [14]. Although the mangrove species at both locations are the same, namely *R. mucronata* and *A. marina*, the number of stands and density are higher in Demak, resulting in greater carbon storage. Besides storing carbon, the mangrove ecosystem on the coast of Banda Aceh can also absorb carbon dioxide and produce oxygen. The Kuta Raja station shows the highest potential in terms of biomass, carbon storage, CO_2 absorption, and oxygen production compared to other stations. Stations with larger biomass tend to have higher capacities for carbon absorption and oxygen production, which is crucial in the context of climate change mitigation and ecosystem conservation. Kuta Alam, despite having the lowest biomass and carbon absorption capacity still makes a significant contribution on climate change mitigation. The highest averages were found at Kuta Raja station, with values of 587.85 CO_2 tons/ha and 427.53 O_2 tons/ha.

3.3 Carbon organic in sediment

In addition to estimating carbon in mangroves, an analysis of organic carbon and sediment texture was also conducted at the research site (Table 3). The sediment texture in the Meuraxa and Syiah Kuala subdistricts is sandy loam, while in Kuta Raja and Kuta Alam it is loam. The sediment in the mangrove ecosystems along the coast of Banda Aceh predominantly consists of sand and silt. The highest average organic carbon content in the sediment is found in Meuraxa subdistrict at 2.09%, and the lowest at Syiah Kuala station at 0.95%. The average organic carbon content along the coast of Banda Aceh is lower than that in Ruyung village, Aceh Besar. The low soil carbon stock in the study area is assumed to be because the location is close to the sea and influenced by tides, which increases the sand composition compared to dust and silt. The sand fraction has a limited capacity to stabilize organic compounds compared to silt and clay soils [30], due to the greater porosity of sand [9]. Soil texture significantly affects organic carbon levels in mangrove ecosystems, with silt and clay particles positively correlated with carbon, while sand particles show a negative correlation [15]. Mangrove ecosystems store large amounts of organic carbon in sediments, with variations in carbon stocks and accumulation rates among estuarine and marine mangroves due to environmental settings and conditions [16].

Table 3. Texture and carbon organic sediment

Station	Sand (%)	Silt (%)	Clay (%)	Texture	Organic C (%)
Meuraxa	55	33	13	Sandy Loam	2.09
Kuta Raja	45	48	8	Loam	2.06
Kuta Alam	42	46	12	Loam	1.08
Syiah Kuala	63	27	10	Sandy Loam	0.95

4 Conclusion

Carbon storage in the mangrove ecosystem can be estimated using the allometric equation for aboveground biomass. The average aboveground biomass of mangroves along the coast of Banda Aceh was 1450.18 kg/100 m^2, with carbon storage of 68.16 tons/ha. The Kuta Raja station shows the highest potential in terms of biomass, carbon storage, CO_2 absorption, and oxygen production compared to other stations. Based on the research conducted, mangroves along the Banda Aceh coastline have the potential to act as carbon sinks and contribute to climate change mitigation

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