Carbon stock estimation of mangrove ecosystem in the Kuta Raja Subdistrict, Banda Aceh, Aceh Province

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Abstract. Mangroves play a crucial role in maintaining the environmental balance through their ability to absorb and store carbon. This study aimed to analyze carbon storage in mangrove ecosystems, including aboveground biomass, belowground biomass, deadwood biomass, and organic soil material. The sampling method used in this research was purposive sampling to select three observation stations. The results of this research indicate that the biomass of mangrove tree stems in the Kuta Raja Subdistrict, Banda Aceh, was 117.9 tons/ha, which was the highest value compared to the roots at 47.2 tons/ha, and deadwood at 2.2 tons/ha, as part of carbon storage in mangrove plants. The carbon stock at the research site was highest in mangrove tree at 55.43 tons/ha, followed by mangrove root at 22.17 tons/ha, and deadwood at 1.04 tons/ha, and organic soil material at 2.7 tons/ha. The total carbon stock of the mangrove ecosystem was 81.37 tons/ha.

1 Introduction

Mangrove ecosystems can protect coastal environment from severe impact of natural climates [1], high productivity through nutrients recycle, and reduce pollution and erosion [2]. Another advantage of mangroves is that they can reduce carbon through a sequestration mechanism or absorb carbon from the atmosphere, which is then stored as biomass and soil organic matter [3;4]. Mangroves can reduce carbon through a mechanism of sequestration or absorption of carbon from the atmosphere, which is then stored in mangrove parts such as plants, litter, and soil organic matter to prevent an increase in carbon dioxide [5;6]. This absorption occurs through photosynthesis, and plants absorb carbon in the form of CO_2 [7]. Global warming is an increase in atmospheric temperature caused by greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N2O), perfluorocarbon (CFCS), and sulphur hexafluoride (HFCS) [8]. Global warming causes extreme weather, increasing the Earth's temperature so that it can melt polar ice. Carbon dioxide has a greater influence than other greenhouse gases [9].

Mangrove biomass is high and is considered to contribute significantly to global carbon fluxes because it can store large amounts of carbon [10]. Mangrove as biofilter can maintain balance in aquatic environments [11]. The city of Banda Aceh has an area of

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mangroves that remained after the tsunami disaster in 2004, spread over 4 sub-districts and has a carbon potential of 78.73 tonnes/ha [12]. Estimating carbon stores in mangrove forests is a forest-conservation effort [13]. It can be used as a strategy by managers to carry out mangrove forest conservation efforts. Several studies have been conducted on carbon estimation, such as that conducted by Dewiyanti, et al [7] and Rahmah, et al [12] in Banda Aceh, Aceh Province.

Kuta Raja is one of the sub-districts in Banda Aceh which has a mangrove ecosystem covering an area of 47.9 ha in 2015 after the tsunami disaster [14]. It is located in the community and on roads crossed by many vehicles. The existence of this ecosystem is very good for environmental balance; therefore, it must be maintained. The sustainability of mangrove forests can be implemented in three ways: protection, preservation, and utilization. The aim of this study was to analyze carbon storage in the mangrove ecosystem, including upper surface biomass, lower surface biomass, dead wood, and soil organic matter.

2 Methodology

2.1 Location and time of research

The research was conducted from May until August 2023 in the mangrove forest. There were three stations established using purposive sampling method, namely Gampong Pande as station 1, Gampong Jawa as station 2, and station 3 was in Gampong Peulanggahan, Banda Aceh, Aceh Province, Indonesia. The soil samples were analysed in Soil and Plant Research Laboratory, Faculty of Agriculture, Universitas Syiah Kuala, included drying, and the bulk density.

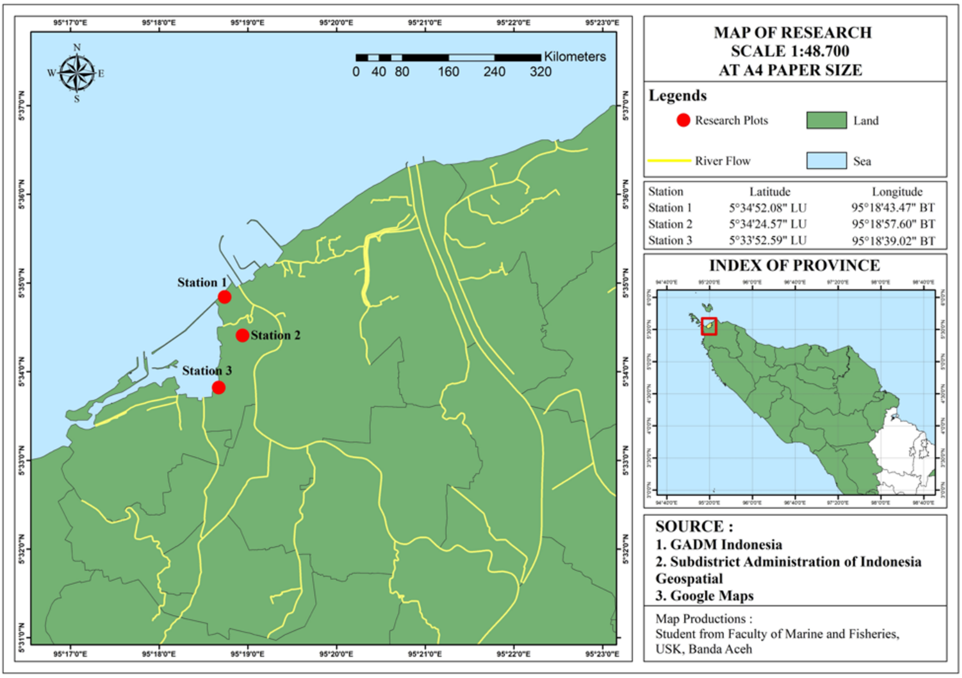


Fig. 1. Map of research locations

2.2 Tools and materials

The main tools used in this study were ropes for transects, measuring tape, sacks, Global Positioning System (GPS), and digital scales. Meanwhile, the material used was soil from the mangrove ecosystem as a sample.

2.3 Research methods

2.3.1 Determining research locations

Research location determine by considering the mangrove dominance, density, and diameter in 3 station. The station was a square with dimensions of 10 m × 10 m. Based on the Indonesian National Standards [15], measuring and calculating carbon reserves in mangrove forests was carried out using field measurements by calculating carbon reserves from the carbon pool or carbon storage section, which consists of surface biomass, namely trees, subsurface biomass, namely roots, dead wood, and soil organic matter. .

2.3.2 Tree biomass data

Tree biomass measurements were carried out by identifying the type of tree, measuring the diameter at breast height (DBH), and recording the data. The tree biomass was calculated using an allometric equation.

Table 1. Allometric Equations

Type	Biomass	Source
Rhizophora apiculate	B = 0.043 D2.63	Amira, 2008
Rhizophora mucronata	B = 0.1466 D2.3136	Dharmawan, 2010
Avicennia alba	B= 79211D2.470895	Tue et al., 2014
Rhizophora stylosa	B = 0.0139D2.1072	Clough & Scott 1989
Avicennia marina	B = 0.1848D2.3524	Dharmawan & Siregar, 2008
Sonneratia alba	B =0.258D2.287	Kusmana et al., 2018
Xylocarpus Granatum	B = 0, 1832D2,21	Tarlan, 2008

B=Biomass and D=Diameter

Mangrove biomass carbon was calculated based on the Indonesian National Standard [15] as follows:

$$Cb = B \times \% \, C \text{ organic}$$

Where:
Cb = carbon content of biomass (kg)
B = total biomass (kg)
%C organic = percentage value of carbon content, equal to 0.47.

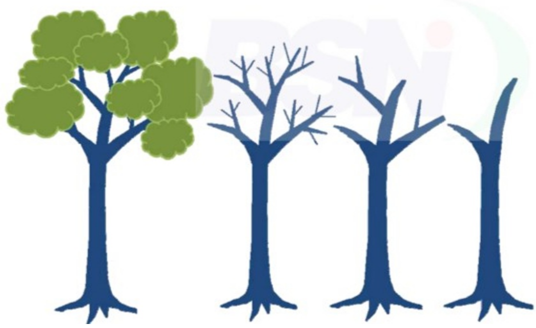
The carbon content of the biomass per hectare was calculated using the following equation:

$$C_n = \frac{C_x}{1000} \times \frac{10000}{l_{plot}}$$

Where:
C_n= carbon content per hectare in each carbon pool of each plot (ton/ha)
C_x = carbon content in each carbon pool in each plot (kg)
l_{plot}= Plot area of each carbon pool (m^2)

2.3.3 Dead Tree Biomass Data Collection

Dead trees were measured by measuring DBH and determining the integrity of the dead tree. The dead tree biomass was calculated using the allometric equation and multiplied by a correction factor for the level of dead tree integrity.



(a) b) (c) (d)

Fig.2. Level of tree integritySource: Indonesian National Standard 7724:2011

Caption:
a: living tree
b: dead tree (correction factor 0.9)
c: dead tree without leaves and twigs (correction factor 0.8)
d: dead tree without leaves, branches, or twigs (correction factor: 0.7)

2.3.4 Root biomass measurement

Root biomass measurements are calculated using the following formula:

$$B_{bp} = NAP \text{ X } B_{ap}$$

Information:
B_{bp} = biomass below ground level (kg)
B_{ap} = biomass above ground /mangrove tree (kg)
NAP = root–shoot value, equal to 0.40. Based on Indonesian National Standard 7724 [15], the shoot root value for the
mangrove ecosystem is 0.40.

2.3.5 Measurement of soil carbon content

Measurement of soil organic carbon content in the mangrove ecosystem was measured using five soil sample points (four corners of the station and one in the middle of the station). Soil samples were taken at a depth of 21 cm. The samples were weighed by wet weight and then taken to the Soil and Plant Research Laboratory, Faculty of Agriculture, Universitas Syiah Kuala to be dried, then weighed by dry weight and the "bulk density" value was calculated (weight of dry soil mass per unit volume) [16]. The calculation of soil carbon adopted the loss on ignition (LOI) method, which involves weighing the weight of the sample that is lost after burning. The samples were dried in an oven at 60^0C for 48 hours [17].

Soil carbon calculations based on the Indonesian National Standard [15] are as follows:

$$C_t = Kd \times \rho \times \% \text{ C organic}$$

Where:
C_t = soil carbon content (g/ cm^2)
Kd = sampling depth (cm)
ρ = bulk density (g/cm^3)
% C organic = percentage value of carbon content, equal to 0.47.

The calculation of soil organic carbon content per hectare was calculated using the following equation:

$$C_{soil} = Ct \times 100$$

Where:
C_{soil} = soil organic carbon content per hectare (tons/ha)
C_t = soil carbon content (g/cm^2)
100 the conversion factor from g/cm^2 to tonnes/ha

3 Results and discussion

3.1 Composition of mangrove vegetation

Four species of mangroves were found at three research location, there were *Rhizophora mucronata*, *R. stylosa, R. apiculata*, and *Xylocarpus granatum*. *R. apiculata* was found at stations 1 and 2, the number of trees were 3 trees/100 m^2 and 44 trees/100 m^2, respectively. Furthermore, *R. mucronata* was found at station 3 as many as 12 trees/100 m^2. At station I, three mangrove species were found, there were *R. apiculata* with a number vegetation of 3 trees/100 m^2, *R. stylosa* (11 trees/100 m^2), and *X. granatum* with 2 trees/100 m^2 (Table 2). In general, the research location was dominated by *Rhizhopora* sp., this species has the ability to adapt in the varied coastal environment condition. According to Kolinug et al. [18] and Srikanth et al. [19], *Rhizophora* sp. can adapt to high salinity and has supporting roots that can absorb air in muddy substrates. *Rhizophora* is mangrove type that can live in various types of substrate and higher ability to survive than other mangrove type [20], and *Rhizophora* from Rhizophoraceae family had wide distribution and tends to adapt well in the environmental condition of mangrove community [21]. Moreover, Canizares et al. [22] reported that Rhizophoraceae is most important and widespread mangrove species in the Pacific.

3.2 Mangrove vegetation biomass

Biomass is expressed as the amount of organic compounds present in the plants. Determination of biomass uses a destructive method which is carried out without damaging the plants, namely by using the allometric equation. At the research location, *R. mucronata* has a higher tree biomass than other species found at the research location with a total biomass of 194.45 tons/ha because it has the highest average diameter value. Table 2 shows the biomass of each species mangrove vegetation. *R. mucronata* has a higher biomass than the other mangrove types [23]. Mangrove plant biomass is influenced by mangrove type, tree diameter, and tree density [24]. *R. mucronata* also had the largest average diameter compared with the other types found at the research site.

Table 2. Average diameter and total biomass of mangrove species

Station	Location	Species	Average diameter (cm)	Tree (stem) biomass (tons/ha)	Root biomass (ton/ha)	Dead Tree Biomass (tons/ha)
I	Gampong Pande	*R. apiculata*	5.45	19.08	7.63	3.69
		R. stylosa	6.63	4.12	1.65	0
		X. granatum	5.8	1.84	0.74	0
2	Gampong Jawa	*R. apiculata*	9.1	80.58	32.23	2.97
3	Gampong Pelanggahan	*R. mucronata*	10.7	194.45	77.8	0

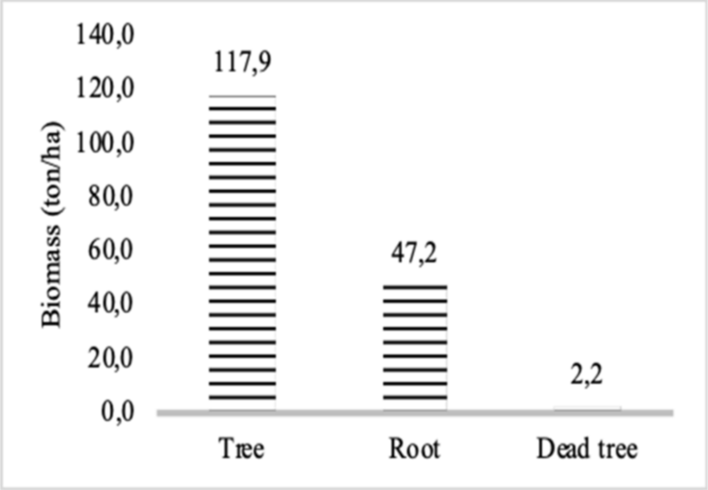


Fig. 3. Biomass of mangrove vegetation

The root biomass of mangrove plants is directly proportional to the tree biomass. The greater the value of tree biomass, the greater the root biomass of mangrove plants [14]. At the research location, the highest biomass was in mangrove tree (stem), and followed by root, and dead tree, the value were 117.9 tons/ha, 47.2 tons/ha, and 2.2 tonnes/ha, respectively. Dead tree biomass at the research location was obtained with a correction factor of 0.7 according to the condition of the tree, which only left a few branches [15]. The total biomass at the research location was 167.3 tons/ha. Rahmah et al. [12] reported that the mangrove ecosystem in coastal area, Banda Aceh, Aceh Province Indonesia has net production value because it has a biomass tree vegetation was ranged between 62.9–398.8 tons/ha.

3.3 Mangrove vegetation carbon stock

The carbon stock of mangrove plants was higher in station 3 at tree level as much as 91.4 tons/ha than station 1 (37.0 tons/ha) and station 2 (37.87), it means that this station stored the most carbon in plants compared to other locations due to the high vegetation biomass at this location. According to Indonesian National Standard [15], 47% of tree biomass is in the form of carbon. Therefore, the greater the biomass value, the higher the carbon stock stored [25]. Nedhisa and Tjahjaningrum [26] argued that most of the biomass from plants is carbon; therefore, biomass greatly influences the carbon stock that can be stored by mangrove plants. Biomass stored in mangrove vegetation of Kerala, southwest coast of India is 117.11 ± 1.02 tons/ha [27]. Furthermore, the mangrove ecosystem in the Anambas Islands Marine Tourism Park, Indonesia has a biomass of 574. According to Indonesian National Standard [15], the carbon stock of mangrove plants consists of carbon stock stored in the tree trunk as the top surface (above ground), roots as part of the lower surface (below ground) apart from soil carbon, and dead trees found in the ecosystem [28]. Mangrove tree trunks store the most carbon compared to other parts. This is supported by research conducted by Rahmah et al. [12], where tree trunk estimated carbon stock of 270.12 tons/ha. Carbon stock has positively correlation with mangrove density and size, where the higher the mangrove density, the more carbon stock tends and the larger tree size will produce higher biomass and carbon stores [29].

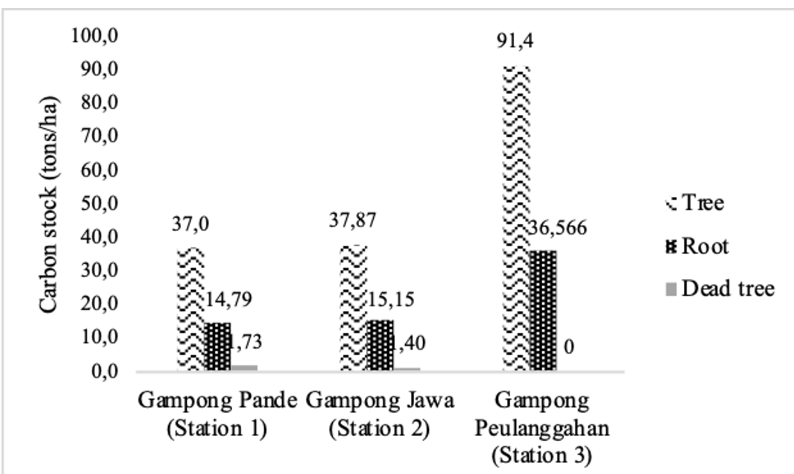


Fig. 4. Carbon stock of mangrove vegetation in each station

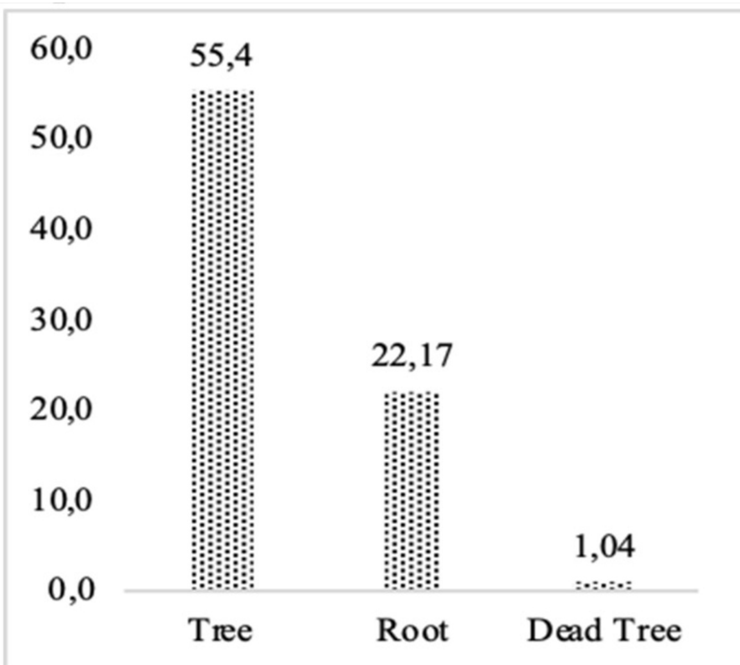


Fig. 5. Carbon stock of mangrove vegetation in each component of mangrove

3.4 Mangrove soil carbon stock

The soil carbon stock in station 1, 2, and 3 were 2.18 tons/ha, 4.22 tons/ha, and 4.54 tons/ha, respectively. In total, the soil carbon stock at the research location was 10.94 tons/ha. The soil carbon stock at the study area is less than the result reported by Rahmah et al. [12] in Banda Aceh, Aceh Province which has a soil carbon stock of 14.84 tons/ha at a soil depth of 15-30 cm. Low soil carbon stock in study area assumed because the location is close to the sea and influenced by tides, therefore, the composition of sand is higher than dust and silt. The sand fraction has a limited capacity to stabilize organic compounds compared to silt and clay soil [30] due to the greater porosity of sand. Several studies show that changes in organic carbon in soil are related to sand fraction, and it have the greatest influence on the Carbon cycle [30; 31]. The soil content of the dust fraction is positively correlated with organic matter, high organic carbon because the soil content of the dust fraction is also high [32]. C-organic at the research location was classified as very low, with an average of 0.99%, organic C is low with a range of <1.00%, low 1.00-2.00%, medium 2.01-3.00%, and high >5.00%, respectively [33].

Total carbon stock in study area included above ground carbon stock (tree), and below ground carbon stock consisted by root, dead tree, and soil organic was 89.58 tons/ha (Table 3). The total above and below ground carbon stock were 55.43 tons/ha and 34.15 tons/ha. The result of this study in line with result reported by Rahmah et al. [12], mangrove carbon stock in Banda Aceh is 89.24 tons/ha. Harefa et al., [34] reported that mangrove carbon stock ini Deli Serdang, Indonesia more than 58.87 tons/ha dominated by *Rhizophora apiculata*. Some biology parameters of mangrove vegetation can influence the carbon stock, for example stem diameter, species density, and diversity of tree species are parameters that affect the biomass and carbon content an ecosystem [35].

Table 3. Total carbon stock in study area

Stock Carbon (tons/ha)				Total Carbon Stock (tons/ha)
Tree	**Root**	**Dead tree**	**Soil**	
55.43	22.17	1.04	10.94	89.58

4 Conclusion

Carbon stock can be determined by above and below ground biomass. The above ground carbon stock is higher than the below ground in mangrove ecosystem Kuta Raja Subdistrict, Banda Aceh, Aceh Province. In term of tree component, the greatest biomass and carbon stock were found in tree (stem) compared to root and dead wood. Whereas the lowest carbon stock was in dead wood. Soil organic matter as below ground stores 10.94 ton/ha of carbon. The total carbon stock of the mangrove ecosystem is 89.57 tons/ha, which includes tree (stems), roots, dead wood and soil.

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