Carbon Stock Analysis in Mangrove Vegetation on Dompak Island, Riau Islands

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Abstract. Mangroves play an important role in providing protection for coastal areas and mitigating climate change simultaneously. The mangrove ecosystem is potentially a carbon sink but can also be a significant source of carbon emissions if wrongly managed. Degradation of the mangrove ecosystem occurs globally, including on Dompak Island, Indonesia. This research aimed to determine carbon stock in above-ground and below-ground biomass of mangroves on Dompak Island to estimate the carbon loss due to degradation reported. The result shows that carbon stock in mangrove vegetation on Dompak Island ranges from 21.11-82.03 tons C/ha. The degradation of the mangrove ecosystem on Dompak Island was estimated to have caused 983.94-3,823.2 ton/ha carbon loss between 2007-2018. Based on one-way ANOVA analysis, above-ground organic carbon stocks and underground organic carbon stocks between stations were found to be significantly different ($p < 0.05$).

Keywords: Mangrove, Carbon Stock, Above Ground, Below Ground, Biomass

1 Introduction

The mangrove ecosystem is an essential ecosystem for small islands. Indonesia has 17,000 islands and many of them are small islands. The mangrove ecosystems provide ecological functions to reduce waves and prevent beaches from erosion because mangroves have a strong root system. A study reported that the extent of the mangrove ecosystem significantly affects the vulnerability of small islands to marine action [1]. An island that has a mangrove width of 400 times the wave height that hits the area tends to be able to reduce the height of tidal inundation, currents, and hydraulic forces to 0%. The vulnerability of small islands can increase due to the increase in global temperature, which causes sea level rise.

Mangroves play a vital role in mitigating global climate change. It absorbs carbon in the atmosphere and stores it in biomass and sediment. Indonesia's mean mangrove ecosystem C stock was reported to be 1,083 ± 378 MgC ha^{-1} [2]. Unfortunately, the Indonesian mangrove deforestation rate from 1980 to 2005 was 52,000 ha yr^{-1} [2] and led to a significant annual loss of carbon to the atmosphere, ranging from 0.96 Pg CO_{2e} yr^{-1} to 0.19 Pg CO_{2e} yr^{-1} [3]. It makes

MaCiFIC 2022, September 28-October 01, Tanjungpinang, Indonesia

DOI 10.4108/eai.28-9-2022.2328376

mangroves not only potential as a carbon sink but also possible to be a significant source of carbon emission.

Degradation of the mangrove ecosystem also occurs on Dompak Island. Mangrove forest area decreased by 34.19%, or around 46.61 ha, due to land conversion (office area, community housing, road construction, and supporting infrastructure) and logging from 2017-2018 [4]. Due to the loss, data related to carbon stock in Dompak Island has yet to be found. This data is important to be obtained to plan sustainable development on the island.
This study aimed to determine the value of above-ground and below-ground carbon stock from the mangrove ecosystem on Dompak Island, Tanjungpinang City, Riau Islands Province, with an allometric analysis approach to estimate the carbon loss due to degradation reported.

2 Method

2.1 Location

Location. This research was conducted on Dompak Island, Tanjungpinang City, Riau Islands Province. The map of the research location can be seen in **Figure 1**. The coordinates of the sampling points are shown in **Table 1**.

Fig. 1. Research location; DU as North Station; DT as East Station; DS as South Station; DBA as West Station.

Table 1. The coordinate points of sampling locations

Locations	Coordinate Points
North	104° 27' 55.595"E; 0° 52' 39.572"N
East	104° 28' 59.444"E; 0° 52' 11.690"N
South	104° 27' 0.500"E; 0° 52' 3.770"N
West	104° 26' 14.114"E; 0° 52' 53.184"N

2.2 Material and Equipment

Material. Mangrove samples were divided into three groups based on their diameter. The first group is a tree group with a diameter of >10 cm. The second group is a sapling group with a diameter of 2-10 cm, and the third group is a seedling group with a diameter of <2 cm.

Equipment. GPS was used to record location coordinate, and research was documented using a camera. A roll meter and rope were used to draw the line transects and sample plots. Tree's DBH was measured using a measuring tape.

2.3 Sampling and Measurement Method

Sampling method. Mangrove vegetation was sampled using the line transect method and sample plots, following the Decree of the Indonesian Minister of Environment and Forestry No. 201 of 2004 concerning Standard Criteria and Guidelines for Determining Mangrove Damage.

Measurement method. Mangrove stands were measured in diameter at breast height (DBH) to calculate the mangrove carbon stock above ground level. The DBH of all trees found in the plot was measured. At each transect, data were collected using a 10 x 10 m sample plot for groups of trees >10 cm in diameter placed along the transect line. The sapling group was taken on a 5 x 5 m plot, and the seedling group was taken on a 1 x 1 m plot.

2.4 Biomass and Carbon Content Analysis

Biomass. Tree biomass was calculated using the allometric equation, divided into above-ground and below-ground biomass. The above-ground allometric equation based on tree species is shown in **Table 2**. Below-ground biomass is calculated by the following equation (1) [5]:

$$BGB = 0.199 \text{ x } \rho^{0.899} \text{ x } D^{2.22} . \quad (1)$$

Where:
ρ: tree density

Table 2. Allometric equation calculation of above-ground biomass

Species	Equations	References	Wood Specific Density (gr/cm^3)
Bruguiera gymnorhiza	$0.0754*\rho*D^{2.505}$	Kauffman and Cole (2010)	0.741
Ceriops decandra	$0.251*\rho*D^{2.46}$	Komiyama et al. (2005)	0.725
Ceriops tagal	$0.251*\rho*D^{2.46}$	Komiyama et al. (2005)	0.8859
Rhizophora apiculata	$0.043*D^{2.63}$	Amira (2008)	0.8814
Rhizophora mucronata	$0.128*D^{2.60}$	Fromard et al. (1998)	0.8483
Rhizophora stylosa	$0.105*D^{2.68}$	Clough and Scott (1989)	0.94
Sonneratia alba	$0.3841*\rho*D^{2.101}$	Kauffman and Cole (2010)	0.6443
Xylocarpus granatum	$0.1832*D^{2.2}$	Tarlan (2008)	0.6721

Carbon Content. Above-ground and below-ground biomass were converted into carbon content of biomass using equation (2) [6].

$$Cb = B \text{ x } \%C \text{ organic.} \quad (2)$$

Where:

Cb	: carbon content of biomass, expressed in kilograms (kg)
B	: total biomass, expressed in kilograms (kg)
%C organic	: the percentage value of carbon content of 0.47

3 Results

3.1 Mangrove Vegetation Structure

Mangrove Vegetation Structure. There are eight mangrove species found in sampling locations. They are *Rhizophora apiculata*, *Rhizophora mucronata*, *Xylocarpus granatum*, *Ceriop tagal*, *Sonneratia alba*, *Ceriops decandra*, *Rhizophora stylosa* and *Bruguiera gymnorrhiza*. Six species are from the Rhizophoraceae family, one from the Sonneratiaceae family and one from the Meliaceae family. A previous study reported that there are ten mangrove species on Dompak Island [7], while the identification results from a study conducted in 2021 found 14 mangrove species on Dompak Island [4]. Species frequency, dominance, density and Importance Value Index (IVI) of mangroves from each station are shown in **Table 3**.

The mangrove species with the most distribution is *Rhizophora mucronata*, with a relative frequency of 29.17%, followed by *Rhizophora apiculata* and *Xylocarpus granatum*, with the same relative frequency, which is 22.22%. The least mangrove species found were *Ceriop tagal*, *Sonneratia alba* and *Rhizophora stylosa*. The relative frequency for those mangrove species is 1.39%. *Ceriops decandra* has a relative frequency of 18.06%, while *Bruguiera gymnorrhiza* has a relative frequency of 4.17%.

The results of the analysis obtained on the structure of mangrove vegetation in the mangrove forest ecosystem on Dompak Island show that the diameter of the stems varies in each station. This study's smallest DBH of trees was in the range of 12-15 cm and dominance in every station. The DBH were also found in 16-19 cm, 20-23 cm, 24-27 cm and the largest was 31-101.91 cm from species *Sonneratia alba* and *Xylocarpus granatum*. Trees with large DBH values were only located in the North and West station.

Table 3. Mangrove species frequency, dominance, density and Importance Value Index (IVI)

Station	No.	Species	Relative Frequency (%)	Density (ind/ha)	Relative Density (%)	Relative Dominance (%)	IVI
North	1	*Xylocarpus granatum*	**33.33**	2,600	42.07	31.34	106.74
	2	*Rhizophora mucronata*	29.63	**2,810**	**45.47**	**40.87**	**115.97**
	3	*Rhizophora apiculata*	18.52	580	9.39	17.51	45.41
	4	*Ceriops decandra*	18.52	190	3.07	10.28	31.88
	5	*Ceriops tagal*	0.00	0	0.00	0.00	0.00
	6	*Sonneratia alba*	0.00	0	0.00	0.00	0.00
	7	*Rhizophora stylosa*	0.00	0	0.00	0.00	0.00
	8	*Bruguiera gymnorrhiza*	0.00	0	0.00	0.00	0.00
		Total	**100.00**	**6,180**	**100.00**	**100.00**	**300.00**
East	1	*Xylocarpus granatum*	22.73	1,100	20.91	0.79	44.43
	2	*Rhizophora mucronata*	22.73	420	7.98	0.16	30.87
	3	*Rhizophora apiculata*	22.73	**2,660**	**50.57**	1.34	74.63
	4	*Ceriops decandra*	18.18	220	4.18	0.02	22.38
	5	*Ceriops tagal*	0.00	0	0.00	0.00	0.00
	6	*Sonneratia alba*	0.00	0	0.00	0.00	0.00
	7	*Rhizophora stylosa*	0.00	0	0.00	0.00	0.00
	8	*Bruguiera gymnorrhiza*	13.64	860	16.35	**97.69**	**127.68**
		Total	**100.00**	**5,260**	**100.00**	**100.00**	**300.00**

South	1	*Xylocarpus granatum*	10.00	20	0.50	1.27	11.77
	2	*Rhizophora mucronata*	30.00	1,740	43.28	13.73	87.01
	3	*Rhizophora apiculata*	**50.00**	**2,200**	**54.73**	**84.80**	**189.52**
	4	*Ceriops decandra*	10.00	60	1.49	0.20	11.69
	5	*Ceriops tagal*	0.00	0	0.00	0.00	0.00
	6	*Sonneratia alba*	0.00	0	0.00	0.00	0.00
	7	*Rhizophora stylosa*	0.00	0	0.00	0.00	0.00
	8	*Bruguiera gymnorrhiza*	0.00	0	0.00	0.00	0.00
		Total	**100.00**	**4,020**	**100.00**	**100.00**	**300.00**
West	1	*Xylocarpus granatum*	8.33	20	0.86	0.01	9.20
	2	*Rhizophora mucronata*	**41.67**	1,800	**77.59**	0.12	**119.38**
	3	*Rhizophora apiculata*	16.67	120	5.17	0.00	21.84
	4	*Ceriops decandra*	16.67	120	5.17	0.02	21.85
	5	*Ceriops tagal*	0.00	0	0.00	0.00	0.00
	6	*Sonneratia alba*	8.33	20	0.86	0.14	9.33
	7	*Rhizophora stylosa*	8.33	240	10.34	**99.71**	118.39
	8	*Bruguiera gymnorrhiza*	0.00	0	0.00	0.00	0.00
		Total	**100.00**	**2,320**	**100.00**	**100.00**	**300.00**

Based on the relative density value, it is known that there are 3 species of mangroves that have high species density. *Rhizophora mucronata*, *Rhizophora apiculata* and *Bruguiera gymnorrhiza* have the highest relative density among other species. Species density is influenced by the number of individuals of a species found in the area of the sample plot. Based on the number of individuals in each station, all stations were categorized as mangrove forests with very dense densities (>1,500). The North station has the highest value density, and the West station has the lowest value density, respectively 6,180 and 2,320.

The dominance of mangrove species was also different at each station. *Rhizophora mucronata* species dominates the North station. *Rhizophora apiculata* species dominates the South station. The *Bruguiera gymnorrhiza* species dominated the East station, and the *Rhizophora stylosa* species dominated the West station. The dominance of the species is influenced by the circumference of the tree trunks found at the observation site. The Importance Value Index shows that *Rhizophora mucronata* is an essential mangrove species for North and West stations, *Bruguiera gymnorrhiza* for East stations and *Rhizophora apiculata* for South stations.

3.2 Carbon stock

Carbon stock. Carbon stock was determined using the non-destructive method, where tree biomass was calculated based on the allometric equation of each species. As shown in **Table 4**, carbon stocks in the above-ground biomass at each station varied. Mean C-organic in above-ground biomass with the highest to lowest values were 52.37 tonsC/ha, 24.49 tonsC/ha, 12.60 tonsC/ha and 9.58 tonsC/ha. The largest above-ground carbon stock was at the West station and the smallest at the East station. Mean C-organic in the below-ground at North and South stations were known to have almost the same value, namely 16.94 tonsC/ha and 16.24 tonsC/ha. The largest below-ground carbon stock was at the West station and the smallest was at the East station, 29.66 tonsC/ha and 11.53 tonsC/ha. Total C-organic of mangrove vegetation on Dompak Island ranged between 21.11-82.03 tonC/ha.

Table 4. ABG and BGB carbon stock of Mangroves on Dompak Island, Riau Islands

Stations	Mean C-organic in Above Ground Biomass (tonC/ha)	Mean C-organic in Below Ground (tonC/ha)	Total C-organic (tonC/ha)
North	24.49	16.94	41.43
West	52.37	29.66	82.03
South	12.60	16.24	28.84
East	9.58	11.53	21.11

4 Discussion

Plant biomass consists of various elements, including oxygen, hydrogen, and the most dominating element, carbon (C), which results from the plant's photosynthesis process [8]. Plants need CO2, which is needed in the photosynthesis process. It can be obtained by absorbing CO2 from the air and converting it into organic material, which is then helpful for the plant's growth process.

Mangrove ecosystems are essential in mitigating the climate crisis because of their greater ability to absorb carbon than other forest ecosystems. Mangroves, as carbon dioxide absorbers, store carbon in above-ground and below-ground biomass. Several studies have shown that the carbon content of above-ground biomass is generally higher than below-ground carbon, but it can also be lower [8], [9], [10]. This situation was found in the carbon stock content at the North and West stations, which had higher above-ground carbon stocks than the below-ground carbon stocks, and at the East and South stations, where the opposite happened.

Carbon content is directly proportional to the basal area, canopy cover, and vegetation density. The higher the value of these components, the higher the carbon content stored in the biomass [9], [11]. According to previous studies, the lower carbon content values at the East and South stations were assumed to be caused by the low vegetation density and the smaller DBH class, where DBH affected the basal area value. Environmental conditions influence the density of mangrove vegetation. Environmental conditions limiting mangroves' distribution and density are substrate characteristics, salinity, temperature, pH, and freshwater input. The mangrove density at the seedling level is more significant than that at the sapling and tree levels [12].

The high carbon content at the North and West stations compared to the other two stations was assumed to be due to the high number of individuals of *Rhizophora* sp. located at the observation site. The carbon content at the West station became the highest carbon stock due to the presence of the mangrove species *Rhizophora stylosa*, which had the highest density and also mangrove tree with high DBH value. *Rhizophora* sp. has a higher density than other mangrove species. Based on the allometric equation, the density and DBH of the tree affect the biomass value, so it affects the results of the carbon calculation.

The carbon value of mangrove biomass in Dompak Island was lower than the biomass carbon stock studies in the previous study which was 233.24-376.30 tons/ha and 12.67-138.25 tons/ha, respectively [9], [11]. However, the total organic carbon stock of biomass at the West station is higher than the value of organic biomass carbon in a study conducted in Sungai Haji Dorani, Selangor, Malaysia [13]. In general, organic carbon stocks in Dompak Island are also higher than in the research conducted in Ujung Piring, Jepara, Central Java [14]. The total mangrove area in Dompak Island was reported to decrease from 136.31 to 89.7 ha in 11 years between 2007-2018 [4]. According to that study and vegetation carbon assessment results in this study, anthropogenic activities on Dompak Island caused 983.94 – 3,823.2 ton/ha carbon loss. The remaining mangrove area on Dompak Islands was estimated to store 1,893.57 – 7,358.10 tons of carbon in the vegetation biomass.

5 Conclusion

The highest to the lowest organic carbon stocks on Dompak Island was 82.03 tonsC/ha, 41.43 tonsC/ha, 28.84 tonsC/ha and 21.11 tonsC/ha, respectively. Total C-organic of mangrove vegetation on Dompak Island ranged between 21.11-82.03 tonC/ha. The highest total carbon stock is located at the West Station, and the lowest at the East Station. The degradation of the mangrove ecosystem on Dompak Island was estimated to have caused 983.94 – 3,823.2 ton/ha carbon loss between 2007-2018. Based on one-way ANOVA analysis, above-ground organic carbon stocks and underground organic carbon stocks between stations were found to be significantly different ($p < 0.05$).

Acknowledgements. This research is part of the Bintang Project, which was conducted by the Ecology Division and was funded by the Carbon Ethics Indonesia Foundation. The authors would like to thank Eka Cahyaningrum, Grace Easteria, Muhammad Halim, Alfat Naufin Nazmi, and Rabiansyah for research support and help during fieldwork.

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