

# Relationship analysis of vegetation structural properties and the aboveground carbon stock of mangrove forest

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**Abstract.** Mangrove forests have important ecological functions as a controller of environmental quality in coastal areas and absorber of atmospheric carbon. The mangrove ecosystem has a unique vegetation structure which form vegetation zonation that consists of different forest stands characteristics and tree species. This study aims to analyze the relationship between vegetation structural properties and the estimated aboveground carbon (AGC) stock of mangrove forest in Bedul mangrove, Banyuwangi, East Java, Indonesia. The study was conducted by field observation at some purposively selected sample locations. Field measurement was aimed to collect data about mangrove tree diameter at breast height (DBH), species, tree height, and fractional canopy cover. Mangrove biomass was indirectly calculated by allometric method based on mangrove species to estimate AGC in mangrove stands. The highest total AGC found in this study was 114.09 tons/ha at *Rhizophora mucronata* dominated forest, while the lowest total AGC was 12.86 tons/ha with *Ceriops tagal* as the dominant species. The AGC estimation in mangrove stands correlated positively with DBH and tree height. However, the biomass content and AGC are affected by the number of mangrove stands. The difference in the number of stands affect the amount of carbon content at each sample point.

## 1 Introduction

Climate change occurs because of an increase in carbon dioxide (CO<sub>2</sub>) content in the atmosphere. The CO<sub>2</sub> content in the air increases with the development of human activities. Global warming has an impact on living things such as increased temperatures, sea levels and disruption of food availability. In this context, vegetation plays an important role in absorbing carbon in the atmosphere and reducing the effects of global warming. The amount of carbon stored between land covers varies, depending on the diversity and density of existing plants, the type of soil, and how they are treated. Apart from the well-recognized role of terrestrial forests as carbon sinks, several studies have shown that carbon can be stored in the biomass and sediment of tidal swamp vegetations such as mangroves and seagrass beds [1–3].

The potential of forest resources in Indonesia is very abundant, one of which is mangrove forest resources. Indonesia has the largest area of mangrove forests in the world [4]. Mangrove forests in Indonesia accounted for 23 % of the total area of the world's mangrove ecosystems, with a total area of 1 671 140.75 ha in good condition, while in a damaged area of 1 817.99.93 ha [5]. Mangrove forests have an ecological function as a controller of environmental quality in coastal areas and a role in the absorption of atmospheric carbon.

Mangroves able to absorb and bury carbon in sediments [2, 6]. As an ecosystem, mangroves become

a place to live various types of biota. In addition, mangrove functions as a provider of environmental services because it is the most effective blue carbon sink [1, 2]. Damaged mangrove forests will affect the ability of mangrove forests in carbon sequestration. The existence of mangroves must continue to be preserved and improved, both the quality and quantity of the forest so that it functions properly in reducing global warming. Information about carbon produced by a vegetation or forest stand can be obtained by estimating the vegetation biomass. Therefore, measurements of biomass are needed to find out how much carbon is stored in forests and their effects on global warming and as an approach to calculate the amount of carbon that can be renewed in the atmosphere.

The mangrove ecosystem has a unique vegetation structure, arranging several characteristics in sequence such as trees, saplings, poles, seedlings, and germination to form a series of specific zones. Mangrove forests are generally composed of vegetation zoning from the coast towards the mainland. The zoning pattern is closely related to ecological conditions, especially those related to the ability of the life of its constituent plant species. Therefore, the characteristics vary in different locations, can overlap between zones, or even reduce zones due to abnormal conditions of several growth-supporting factors.

This study aims to analyze the relationship between vegetation structural properties and the estimated aboveground carbon (AGC) stock of mangrove forest in

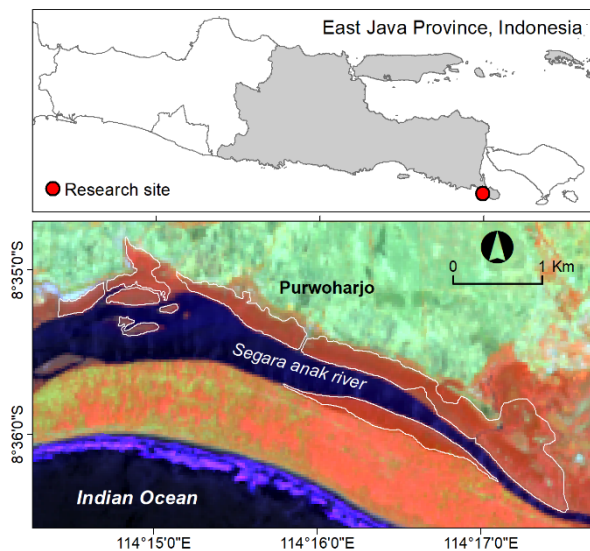
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Bedul mangrove, Banyuwangi, East Java Province, Indonesia. The structural characteristics of vegetation stands referred to in this study includes, dominant species, fractional canopy cover (Fcover), tree height, tree diameter at breast height (DBH), and aboveground biomass (AGB).

## 2 Research methods

### 2.1 Study site

This study was conducted at the Bedul mangrove complex in Banyuwangi, East Java Province, Indonesia, which is managed by Alas Purwo National Park (TNAP). This location is a natural conservation area that has a unique landscape or vegetation formation. One specific type of vegetation in Alas Purwo National Park is the formation of mangrove forests. The study site located in Grajagan Bay along the mouth of the Segara Anak river. Geographically it is located at longitude of 114°13'20.2"-114°20'459.7" East and latitude of 8°35'52.7"-8°37'28.6" South (Figure 1).



**Fig. 1.** Study site visualized with Landsat 8 OLI image false color composite; the mangrove forest boundary is indicated by white polygons.

### 2.2 Field data collections

Determination of sample points was done by looking at the characteristics of mangrove objects that appear on Landsat 8 OLI image. We used purposive sampling method to determine the sample locations in the field. The sample location determined based on the distribution pattern of the object under study, ease of access, and homogeneity of the sample. Technically, the field sampling was done by box plots. Each plot size was used to measure the diameter of different trees. Plots of 20 m × 20 m were used to measure tree diameter more than 20 cm, plots of 10 × 10 meters were used to measure tree diameter of 10 cm to 20 cm, and plots of 5 m × 5 m were used to measure tree diameter less than 10 cm [7]. In each plot, observation of objects and measurement tree diameter at breast height (DBH),

identification of mangrove species, measurement of average tree height using laser range finder, and acquisition of fractional canopy cover data using a hemispherical camera system.

### 2.3 Data processing and statistical analysis

The mangrove biomass calculated in this research was the aboveground biomass (AGB). The calculation of mangrove biomass was done by allometric method based on mangrove species in the Bedul Mangrove Area, Banyuwangi. This study uses allometric equations developed by Komiyama et al. [8] because the equation was built based on Asian mangroves. The value of AGC was then derived from the AGB values. According to Indonesian National Standard number 7724: 2011 [7], AGC can be calculated from AGB using the following formula:

$$C_b = B \times \% \text{ organic C} \quad (1)$$

Where  $C_b$  is carbon content of biomass (kg),  $B$  is total biomass (kg), and % organic C is percentage value of carbon content, amounting to 0.47 or using the value of percent carbon obtained from measurements in the laboratory.

The fractional canopy cover shows the percentage of canopy cover on a certain land area [9]. This data was calculated using CAN-EYE software (<https://www.paca.inrae.fr/can-eye>). CAN-EYE is a free software devoted for extracting canopy-related information from hemispherical photos taken from fieldwork. The statistical analysis conducted in this study was correlation and regression to determine the strength, shape, and direction of the relationship between each structural parameter of vegetation and mangrove AGC.

## 3 Result and discussions

### 3.1 Fieldwork results

Fieldwork was conducted from 30 January to 3 February 2020. The number of sample points obtained from field work were 20 sample points. This sample amount is below the initial plan, which was 35 sample points. The number of initial sample points was not met due to the difficult access to the sample locations and extreme tidal fluctuation. However, we tried to maintain the collected samples to cover most of the mangrove structural properties variation exist in Bedul mangrove.

Most types of mangroves grow well on muddy soils, especially in areas where silt accumulates. In Segara Anak river the depth of the mud varies from 0.14 m to 2.1 m at each location along the 15 km of stream. The conditions and types of substrates in Segara Anak river are mud and some sandy mud. Based on the results of identification carried out by Alas Purwo National Park researchers, they found 27 species of true mangroves. These mangrove species are as follow: *Acrostichum Aureum*, *Ac. speciosum*, *Aegiceras corniculatum*, *Ae. floridum*, *Avicennia alba*, *A. marina*, *A. lanata*, *A.*

*officinalis*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *B. sexangula*, *Ceriops decandra*, *C. tagal*, *Excoecaria agallocha*, *Heritiera littoralis*, *Lumnitzera rasemosa*, *Lumnitzera littorea*, *Nypa Pempsis acidula*, *Rhizophora apiculata*, *R. mucronata*, *Scyphiphora hydrophyllacea*, *Sonneratia alba*, *S. caseolaris*, *Xylocarpus granatum*, *X. molluccensis*, and *X. rumphii*. Of the 27 species, 24 species can be found around the Segara Anak river, which is dominated by *Rhizophora mucronata*, *Ceriops tagal* and *Bruguiera gymnorrhiza*. From our fieldwork, we found 14 species of mangroves distributed along the Segara Anak river (Table 1).

**Table 1.** Mangrove species found during fieldwork.

No	Mangrove Species	No	Mangrove Species
1	<i>Avicennia alba</i> (AA)	8	<i>Lumnitzera racemosa</i> (LR)
2	<i>Avicennia marina</i> (AM)	9	<i>Rhizophora apiculata</i> (RA)
3	<i>Avicennia officinalis</i> (AO)	10	<i>Rhizophora mucronata</i> (RM)
4	<i>Bruguiera gymnorrhiza</i> (BG)	11	<i>Sonneratia alba</i> (SA)
5	<i>Ceriops tagal</i> (CT)	12	<i>Sonneratia caseolaris</i> (SC)
6	<i>Ceriops decandra</i> (CD)	13	<i>Xylocarpus granatum</i> (XG)
7	<i>Excoecaria agallocha</i> (EA)	14	<i>Xylocarpus moluccensis</i> (XM)

### 3.2 Mangrove AGB and AGC

The mangrove AGB was calculated using allometric equations based on species referring to the allometric equation by Komiyama et al. [8]. In allometric equation, the parameters included in the calculation is the diameter at breast height (DBH) obtained from the field work. After the biomass content was known, then the biomass yield was multiplied by 0.47 based on SNI 7724: 2011 [7] or in other words 47 % of the biomass content is carbon value. Table 2 below shows the result of the calculation of mangrove AGB and AGC.

Mangrove biomass can be calculated using several variables such as diameter and height data. In this study, the calculation of mangrove tree biomass data was not done destructively but was estimated indirectly using allometric equation. The largest proportion of carbon storage on land is generally found in the tree component. To reduce destructive actions during measurement, tree biomass can be estimated using allometric equations based on stem measurements [10].

Based on the results of the statistical analysis, the higher the biomass the higher the carbon stock at each sample point. Field sample point number 4 has the highest value compared to other samples. While point number 14 has the lowest value of carbon stocks, which is only 12.86 t ha<sup>-1</sup>. The assumption underlying the preparation of the biomass estimation model is the close relationship between tree dimensions (diameter and height) and biomass.

Carbon content in plants illustrates how large the plant can sequester CO<sub>2</sub> from the air. The estimated carbon calculated increases proportionally with the increase in tree biomass. The carbon content is directly

proportional to the biomass content. This is consistent with Hairiah and Rahayu [10], that the potential of carbon stocks can be seen from the existing stand biomass. The amount of carbon in each part of the tree is influenced by biomass. Therefore, any increase in biomass will be followed by an increase in carbon content. This shows that the amount of biomass affects the carbon content.

**Table 2.** Mangrove AGB and AGC.

Sample ID	AGB (ton/ha)	AGC (ton/ha)
1	193.53	90.96
2	114.18	53.66
3	210.71	99.03
4	242.75	114.09
5	121.23	56.98
6	123.41	58.00
7	109.09	51.27
8	133.77	62.87
9	113.95	53.56
10	137.76	64.75
11	108.16	50.84
12	45.35	21.32
13	63.94	30.05
14	27.36	12.86
15	234.01	109.98
16	154.00	72.38
17	69.58	32.70
18	53.01	24.92
19	70.73	33.24
20	38.10	17.91

### 3.3 Relationship between vegetation structure and AGC

The measurement results based on parameters used in this study show different results at each point of the observation location. The parameters used include the average tree DBH, tree height, fractional canopy cover and dominant species (Table 3). From Table 3, it is evidence that *Rhizophora mucronata* and *Rhizophora apiculata* are the dominant species at all sample points. These species also have largest AGB and AGC values across sample points. The AGB and AGC for *Rhizophora mucronata* are 114 and 242.75 tons/ha, respectively; and for *Rhizophora apiculata* are 109.98 and 234.01 tons/ha, respectively. This is in accordance to finding from Suryono et al. [11] that the biomass and carbon stock of *Rhizophora sp.* higher than other species.

The lowest AGC was found at sample point 14 with a total AGC of 12.86 t ha<sup>-1</sup> with the dominant species of *Ceriops tagal*. The low AGC value is presumably because this mangrove species has a low average trunks diameter, besides being high and canopy density is also low compared to the others. In addition, at sample point

20 with the dominant species *Ceriops decandra* was included in the low AGC value, which is 17.91 t ha<sup>-1</sup> with an average tree diameter of 22.8 cm.

**Table 3.** Field measurement results.

ID	Average DBH (cm)	Average Tree Height (m)	Fcover	AGC ton/ha	Dominant Spesies
1	27.8	10.8	0.40	90.96	RM
2	29.3	11.7	0.34	53.66	EA
3	40.9	14.5	0.33	99.03	RM
4	54.8	23.1	0.14	114.1	RM
5	39.2	17.6	0.18	56.98	RM
6	45.0	13.6	0.22	58.00	AO
7	40.9	18.9	0.21	51.27	RA
8	50.6	18.8	0.09	62.87	RA
9	47.9	11.9	0.05	53.56	RA
10	47.1	23.3	0.21	64.75	RA
11	38.5	15.9	0.31	50.84	RM
12	28.2	8.2	0.18	21.32	CD
13	36.3	14.1	0.29	30.05	SA
14	22.6	5.7	0.09	12.86	CT
15	48.8	19.5	0.20	109.9	RA
16	48.2	16.7	0.17	72.38	RA
17	41.3	19.1	0.15	32.70	SA
18	34.2	16.1	0.27	24.92	SA
19	35.3	10.8	0.15	33.24	SA
20	22.8	5.9	0.18	17.91	CD

These AGC value difference between these mangrove species was due to the difference in average tree diameter at breast height (DBH). AGC in tree stands is thought to be affected by diameter, biomass density and canopy cover. The existence of trees with a diameter of more than 30 cm provides a significant contribution to AGC based on tree biomass. Therefore, more mangrove trees with diameter more than 30 cm will result in higher AGC value [12]. The higher value of the biomass content and carbon stock at each sample point is obtained in trees over 35 cm in diameter. This is because biomass is closely related to the process of photosynthesis, biomass increases because plants absorb carbon dioxide from the air and convert it into organic compounds through photosynthesis. The results of photosynthesis are used by plants to grow horizontally and vertically.

A large increase in tree diameter is positively correlated with an increase in the amount of biomass and AGC. Table 4 shows that these parameters are having moderate degree of correlation at values of 0.63. The age of mangrove stands will be directly proportional to the biomass content. This is in accordance with Adinugroho and Sidiassa [13] statement, that the diameter of the trunk diameter is directly proportional to the value of biomass, the higher the DBH, it indicates that the tree is older and has more carbon stocks. In addition, the description of the age of

the population is often expressed in diameter, so the more age of the plant, the greater the biomass content in the soil [14].

The parameters of tree height and Fcover in this study were not very significant in influencing biomass and carbon content, that are 0.56 and 0.22 respectively (Table 4). According Dharmawan and Siregar [15], 98.7 % of biomass is affected by diameter at breast height (DBH) and the number of trees used will also be influential because the determination of the amount of biomass in this study uses the allometric equation which is strongly influenced by the number and diameter of trees. Based on the results table, there are several sample points, for example sample points 1 and 5, the results do not have a positive correlation between the diameter of the tree and the carbon content. This is possible because of the number of trees taken during fieldwork, because the number of trees identified from each sample point in this study is different. That is because of the limited time and terrain during fieldwork.

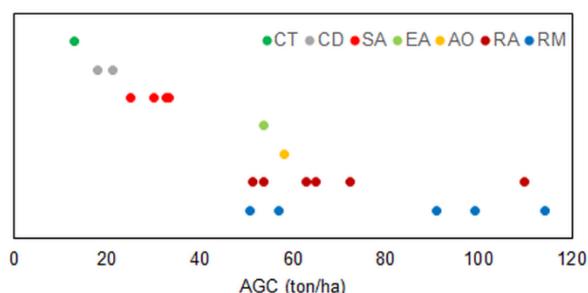
**Table 4.** Correlation between mangrove structural parameters to the AGC.

Parameters	DBH	Tree Height	Fcover	AGB	AGC
DBH	1				
Tree Height	0.82	1			
Fcover	-0.32	-0.04	1		
AGB	0.63	0.56	0.22	1	
AGC	<u>0.63</u>	<u>0.56</u>	<u>0.22</u>	<u>1</u>	1

In addition, based on these results some sample points do not correlate well with the mangrove Fcover with AGC, for example at sample points 1 to 4. The mangrove Fcover at point 1 is higher than point 4. However, the carbon content at point 4 is much higher compared to point 1. This is possible because of differences in classification and parameters used when processing in CAN-EYE software. However, the average tree diameter at point 4 is greater than point 1. This is in accordance with the statement that the diameter of the trunk is directly proportional to the value of biomass, the higher the DBH indicates the older the tree and has more carbon reserves. According to Table 4, AGB and AGC have similar correlation value to DBH, tree height, and Fcover. The correlation between AGB and AGC also positive 1. This is because the value of AGC was derived directly from AGB as mentioned in Section 2.3.

Figure 2 is a plot diagram showing the clustering of AGC value for each mangrove tree species samples identified in the field. Each line and dot color represents the mangrove tree species and the X axis indicates the AGC of each sample in ton/ha. From this figure, *Rhizophora apiculata* (RA) and *Rhizophora mucronata* (RM) are dominating the moderate and high value of AGC. These two species also have the widest range of AGC in the study site, approximately from 50 to 114 ton/ha. From Table 3, it is evidence that these species have relatively larger tree DBH and taller tree height compare to other species. *Excoecaria agallocha* (EA) and *Avicennia officinalis* (AO) found to have moderate

AGC value at about 50 t ha<sup>-1</sup> to 60 t ha<sup>-1</sup>. While, *Ceriops tagal* (CT), *Ceriops decandra* (CD), and *Sonneratia alba* (SA) tend to have low AGC value at approximately 10-35 ton/ha. These three mangrove tree species are relatively shorter and have smaller DBH than the other.



**Fig. 2.** Association between mangrove tree species and aboveground carbon in Bedul mangroves.

## 4 Conclusions

Based on the results of our study conducted in Alas Purwo National Park, it can be concluded that we found 14 species of mangroves around the Segara Anak River. The highest AGC was in sample point 4 with a total carbon stock of 114.09 t ha<sup>-1</sup> and the dominant species is *Rhizophora mucronata*. While, the lowest AGC was in sample point 14 with a total carbon of 12.86 tons/ha and the dominant species is *Ceriops tagal*. The greater the diameter value of a tree, the greater the AGB content and AGC stock. However, the number of trees identified will affect the biomass content and carbon stock at each sample point. In this study, tree height and Fcover did not significantly influence the biomass and carbon content.

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