Carbon Stock Analysis of Mangrove Ecosystems in Paliat Island Sumenep East Java

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Abstract. Mangroves have important roles in the coastal environment. They enrich coastal waters with nutrient, protect coastlines from abrasion and sea level rise as well as support coastal fisheries. Another function of mangroves that are less known is their role in carbon (C) sequestration and storage. Previous studies reveal that mangrove forests contain some of the highest carbon stocks per unit area compared to other forest types. However, that information is not widely available, particularly in Indonesia. This study aimed to determine distribution and community structure of mangroves ecosystem and to estimate carbon stock stored in the mangrove forest of Paliat Island Sumenep East Java. The data collection was conducted on the island, starting from July to September 2017 using harvesting sampling method. Furthermore, to discriminate carbon stock from different parts of mangrove vegetation, One Way ANOVA statistical analysis was employed. The results showed that there were 4 dominant mangrove species on the island namely Rhizophora mucronata, Bruguiera gymnorrhiza, Rhizophora stylosa, and Rhizophora apiculata. The total mangrove biomass of the study area was approximately 21.59 ton/Ha with an estimated carbon stock around 10.80 ton/Ha. Further analysis explained that there was a significant difference in carbon stock between various parts of mangrove vegetation (One Way ANOVA, F=220, df1=4, df2=85, p<0.05).

Keywords: Mangroves, Paliat island, biomass, carbon stock.

1. Introduction
Mangroves are typical vegetations that can be found along the coast of tropical regions and small islands. The term of mangroves refers to a group of halophytic species from 12 genera in eight families [1]. A more explicit definition explains mangroves as a vegetation which commonly grows in tropical and sub-tropical estuaries, mostly located in the intertidal zone. Due to their habitat, mangroves distribution and growth are influenced by tides. In some regions, mangroves can also be found in semi-closed beaches, flat deltaic lands, and sandy or rocky coastlines around small islands [2,3].

Mangroves have essential roles for the coastal environment that directly provide advantages for biodiversity and human society. Several important functions of mangroves ecosystems have been widely known. The primary service of mangroves is to provide shelter for numerous terrestrial and aquatic biota as feeding, spawning, and nursery ground for many fish, crustacean, and mollusk species [4,5]. Mangroves that grow along the coastline act as a natural barrier and protect the land from...
erosion. Their extensive and sophisticated root system trap particulate matter and bind soil particles [6]. Furthermore, mangroves also protect coastlines and human settlements against severe waves and cyclone during extreme weather events [7,8]. Mangroves have a significantly important function not only to support fisheries but also act as natural barriers for the coastal environment. Through the biochemical process, fallen mangrove leaves are converted into nutrients. These nutrients are essential components in the coastal food chain.

Around 69 mangrove species are already identified. Worldwide, mangroves are distributed along tropical coastlines between 25 °N and 25 °S. However, due to unique warm water movement from the equator mangroves can live beyond those zones. For example, mangroves can exist 10-15° past their typical zones as far as the east coast of Africa, Australia, and New Zealand. Whereas, in other locations such as in Japan, the Red Sea, and Florida mangroves can live about 5-7° farther south [9]. The total area of mangroves forest worldwide is approximately 138,000 km² [10]. Indonesia hosts about 3.5 million Ha of mangroves area. This amount is equivalent to 23% of the world's mangrove ecosystem. Despite its significant ecological values, mangrove forests are threatened by human and natural causes. In the past 25 years, vast areas of mangrove in Indonesia have been changed and modified for aquaculture and settlements, consequently altering the natural function of the habitat. The latest data released by the Ministry of Environment and Forestry stated that in 2017 only 1.67 million Ha of mangroves in Indonesia was detected in good condition [11]. Annual deforestation rates of mangrove forest globally were estimated at 0.13% from 2001–2012; this rate was five times higher compared to the loss of tropical forest in the world [12,13].

Besides, their important ecological role, mangroves also have a significant function in carbon storage and sequestration. However, studies on carbon stock of mangrove are not as popular as research on their ecological function for coastal ecosystem services such as fisheries, shoreline protection and bioremediation of wastes [14]. While information on mangrove’s distribution in Indonesia is relatively easy to obtain, studies on the amount of mangrove’s biomass and carbon stock are not widely available. Based on previous studies, investigation of mangrove’s carbon storage was mainly focused on above ground biomass [15], the concentration of Carbon stored in mangrove’s soil [16], the ratio of below-ground and above-ground biomass [17] and high rates of carbon sequestration [18]. With mangrove’s ability to store and sequester large quantities of Carbon, they become highly important for conservation use to reduce greenhouse gasses (GHG) effect as well as minimize the impact of climate change. According to that statement, to reduce GHG emissions in the atmosphere, mangroves conservation is the main alternatives [19]. Furthermore, to formulate conservation strategies, it is important to quantify existing carbon stocks to fulfill the standard of monitoring, verification, and reporting [6]. Therefore, this research is intended to determine distribution and community structure of mangroves ecosystem and to estimate carbon stock stored in the mangrove vegetation of Paliat Island Sumenep East Java.

2. Research Methodology

2.1. Study Area

This research was conducted in Paliat Island, start from July to September 2017. Paliat Island is located approximately 80 nautical miles east of the main island of Madura (Figure 1). The coordinate of the island is 06°57’30” S and 115°34’30” E. It takes about 7-8 hours to reach the island using a commercial ferry. There are nearby islands close to Paliat namely Kangean, Sepanjang, and Sapeken Island. The island was chosen because it has better mangrove’s condition and more natural situation compare to other islands within the area.

2.2. Establishment of sampling plots and measurements

A purposive sampling was employed in the study area. Quadratic transect measuring 10x10 m² weras set-up to areas with sufficient mangrove cover along the landward, middle ward, and seaward. In each transect, mangroves were counted and identified respectively. Basic vegetation parameters were
measured for each identified species including (a) diameter at breast height (DBH) in cm, (b) basal area in meter, (c) density.

2.3. Vegetation analysis
A series of general vegetation analysis was performed to provide information regarding the distribution and community structure of mangroves on the island. These analyses included the calculation of population density ($D_i$), frequency ($F_i$), coverage ($C_i$), relative density ($RDi$), relative frequency ($RFi$), relative coverage ($RCi$) and the importance value index ($IVI$).

\[D_i = \frac{\sum ni}{A}\]
\[RDi = \frac{ni}{\sum n_i} \times 100\%\]
\[F_i = \frac{\sum F_i}{\sum F}\]
\[RFi = \frac{F_i}{\sum F_i} \times 100\%\]
\[C_i = \frac{\sum BA_i}{A}\]
\[RCi = \frac{C_i}{\sum C_i} \times 100\%\]

![Figure 1. Research Location Paliat Island East Java](image)

2.4. Biomass and Carbon Stock Analysis
The calculation of mangrove’s biomass was conducted using destructive sampling method by harvesting several mangroves vegetation in the transect area. The total dry weight from different parts of mangroves samples (trunks, roots, leaves, branches) was measured. Next, biomass data from mangroves samples were analyzed to obtain the value of carbon concentration from different parts. According to IPCC (2006) the carbon concentration contained in organic matter was around 50%, so the estimated amount of carbon stored was estimated as in the following equation:

\[C = B \times 0.47\]

where C: Carbon Stock (kg)  
B: Biomass (kg)
Furthermore, the conversion of carbon stock to total CO$_2$ uptake can use the relative atomic mass ratio of C (12) with the relative molecular of CO$_2$ (44), formulated as follow:

$$W_{CO_2} = \frac{Mr_{CO_2}}{Ar_C} \times C_n$$

where $W_{CO_2}$: CO$_2$ Absorption (kg)  
Mr: Relative Molecular  
Ar: Relative Atom  
Cn: Carbon Stock

3. Results and Discussion

3.1. Mangroves community structure

Mangrove identification was conducted by observing specific characteristic of roots, flowers, leaves, and stems, and then compared with identification book [20,21]. The results showed that 4 mangroves species were found on the island, namely *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Rhizophora stylosa*, and *Rhizophora apiculata*. The distribution of mangroves at the different site indicated that *Bruguiera gymnorrhiza* can be found in 5 locations, followed by *Rhizophora mucronata* in 4 locations while the other two species were found in 3 locations. Table 1 below describes the distribution of mangroves species across study locations. One of the main indicators of ecosystem health in the wetland area is the increase in the number of plant species [22]. In the case of mangroves, a physical parameter such as salinity and competition with other vegetation determine their distribution [23].

| Species            | Family            | Station 1 | Station 2 | Station 3 |
|--------------------|-------------------|-----------|-----------|-----------|
|                    |                   | 1 2 3     | 1 2 3     | 1 2 3     |
| *Rhizophora mucronata* | Rhizophoraceae    | + + + - - - + + - |                     |
| *Bruguiera gymnorrhiza* |                 | - + + + + + - + - - |                     |
| *Rhizophora stylosa*    |                   | - - - + + + - - - |                     |
| *Rhizophora apiculata*  |                   | - - - - - - + + + |                     |

+ : present  - : absent

| Species            | No of Individual | Density (ind/100 m) | Density (ind/Ha) |
|--------------------|------------------|---------------------|-----------------|
| *Rhizophora mucronata* | 36               | 0.36                | 3600            |
| *Bruguiera gymnorrhiza* | 8                | 0.08                | 800             |
| *Rhizophora stylosa*    | 34               | 0.34                | 3400            |
| *Rhizophora apiculata*  | 26               | 0.26                | 2600            |

The density values (Table 2) shows that among 4 species of mangroves in Paliat Island, *Rhizophora mucronata* has the highest stem density (3600 ind/Ha), followed by *Rhizophora stylosa* (3400 ind/Ha) and *Rhizophora apiculata* (2600 ind/Ha). The lowest density was *Bruguiera gymnorrhiza* with only 800 ind/Ha. Based on the classification from the Ministry of Environment and Forestry, mangroves in Paliat Island can be categorized as a medium to high-density level.

Moreover, calculation of Important Value Index (IVI) was done to measure the species dominance in a specific location. IVI in this study was calculated for every species found in each study sites. Obtaining IVI is important to understand the ecological importance of a particular species as well as to
formulate their conservation and management strategies. The IVI for mangrove species was calculated as the sum of relative density (RDI), relative frequency (RFI) and relative coverage (RCI). The results of the IVI calculation in this study are presented in Table 3.

Table 3. IVI Calculation

| No | Mangrove Species          | Parameters |  |  |  |  |
|----|--------------------------|------------|---|---|---|---|
|    |                          | RDI (%)    | RFI (%) | RCI (%) | IVI |
|----|--------------------------|------------|---------|---------|-----|
|    |                          |            |         |         |     |
| 1. | Rhizophora mucronata     | 73.68      | 40      | 31.95   | 145.63 |
| 2. | Brugueira gymnorhiza     | 10.53      | 60      | 68.05   | 138.58 |
|----|--------------------------|------------|---------|---------|-----|
|    |                          |            |         |         |     |
| 1. | Rhizophora stylosa       | 56         | 16.67   | 1.73    | 74.40 |
| 2. | Brugueira gymnorhiza     | 4          | 50      | 95.24   | 149.24 |
| 3. | Rhizophora aciculata     | 18         | 33.33   | 3.03    | 54.36 |
|----|--------------------------|------------|---------|---------|-----|
|    |                          |            |         |         |     |
| 1. | Rhizophora aciculata     | 61.11      | 28.57   | 63.51   | 153.20 |
| 2. | Rhizophora mucronata     | 11.11      | 28.57   | 29.55   | 69.23 |
| 3. | Brugueira gymnorhiza     | 11.11      | 42.86   | 6.94    | 60.91 |

According to Table 3, the IVI composition throughout the entire location was different. At the first station, IVI for Rhizophora mucronata and Brugueira gymnorhiza was not significantly different. Meanwhile, at the second station, IVI for Brugueira gymnorhiza was beyond the other two species. A similar condition also occurred at station 3, where IVI for Rhizophora aciculata was more than doubled compared to Rhizophora mucronata and Brugueira gymnorhiza. The results indicate that Rhizophora stylosa was the least dominant mangrove species of Paliat Island. The domination of Rhizophora species in mangrove ecosystems of coastal and small island regions was also reported by other studies, for example in Labuhan Lamongan district [24], Rawa Timur Central Java [25], and Panjang Island Jepara [26]. In general, Rhizophora grows in groups. Living on riverbanks, flat coast, and tidal floods area. Compared to other mangrove species, this type of mangrove appears to be more tolerant of inundation. According to the Wetland Organization, Rhizophora was also described as vegetation that grows on muddy soil, smooth, deep, and flooded during normal tides. Rhizophora faces some challenges to grow in areas far from tides. Rhizophora has a flowering season that occurs throughout the year. Therefore, the reproduction process continues to happen all over the year. It makes Rhizophora, one of the most widespread types of mangrove worldwide.

3.2. Above ground biomass and carbon stock analysis

Biomass is the total weight or volume of living material in a particular area [27]. Biomass can be estimated from tree density, tree height, and stem diameter. There is a close correlation between biomass and tree diameter. The process of adding mass is caused by photosynthesis. Photosynthesis results in the form of cellulose and wood-forming substances, which will be used for growth, are then stored as biomass.

Above ground biomass (AGB) of mangroves in this research was gained by harvesting 36 mangroves trees with diameter > 10 cm, and then dry weight of each mangrove components such as stems, roots, leaves, and branches were measured. An aground survey was conducted in a total of 9 plots. Samples were collected from 36 mangrove trees with Average DBH = 34.79 ± 8.07 cm. The total Mangroves AGB from the study was 24.40 ton/Ha; therefore, total carbon stock was estimated around 12.2 ton/Ha. The calculation of AGB and Carbon stock in Paliat Island is explained in Table 4.

Similar to other tree, mangroves assimilate atmospheric CO into organic compounds to produce leaves, roots, branches, and stem tissue; maintain existing tissue; create storage reserves; and develop chemical defenses [15]. Living in extreme soil condition, mangroves develop a biological mechanism to minimize water loss and maximize carbon gain. Adaptation allows mangroves to be highly efficient
in water use and transpiration and by exhibiting physiological plasticity concerning changes in environmental conditions [26].

Table 4. AGB and Carbon Stock Analysis

| No | Calculation    | Stem  | Roots | Leaves | Branches | Total  |
|----|----------------|-------|-------|--------|----------|--------|
| 1  | ADW (gr)       | 135.01| 98.61 | 67.5   | 115.56   | 21.59  |
| 2  | AGW (gr)       | 200   | 52.06 | 6.97   | 17.98    | 21.59  |
| 3  | SGW (gr)       | 100   | 100   | 100    | 1000     | 21.59  |
| 4  | Total Biomass (gr) | 1662.24 | 455.26 | 42.04  | 95.28    | 21.59  |
| 5  | Total Carbon (gr)  | 831.12  | 227.63 | 21.02  | 47.64    | 10.80  |
| 6  | Total CO2 (gr)  | 3047.44 | 834.64 | 77.06  | 174.69   | 39.59  |
| 7  | Total Biomass (ton/Ha) | 16.62   | 4.55  | 0.42   | 0.000095 | 21.59  |
| 8  | Total Carbon (ton/Ha) | 8.31    | 2.28  | 0.21   | 0.000048 | 10.80  |
| 9  | Total CO2 (ton/Ha) | 30.47  | 8.35  | 0.77   | 0.000175 | 39.59  |

Mangrove ecosystem at the study site has a total biomass content of 21.59 ton/Ha. The potential of biomass at the study site is lower compared to previous study in Bekasi (108.66 ton/Ha) and North Sumatra Gembong estuaries (49.13 ton/Ha). Low quantity of biomass is caused by non-optimum photosynthesis ability, light intensity, the age of the plants, and the content of nutrient in the soil. Furthermore, the total carbon content (C) in the study area was 10.80 ton/Ha. IPCC data (2006) states that average carbon content in many Asian coastal estuaries can reach 180-225 ton/Ha. Looking at the IPCC data above, it means that the total carbon storage in the study area was relatively low. The concentration of carbon in vegetation depends on biomass, carbon absorption, soil fertility, plant diversity and density [28].

Plants absorb carbon using leaf and then distributed to other parts, mainly used for stem growth. The stem has a high carbon content compared to other parts of mangroves vegetation because carbon content in the upward (end) part of the tree such as branches, twigs, and leaves is getting smaller. Further analysis explained that there was a significant difference in carbon stock between various parts of mangrove vegetation (One Way ANOVA, F=220, df1=4, df2=85, p<0.05). Woody component is a place to store food reserves. Therefore, the highest carbon content can be found in part with a high concentration of xylem. Besides, along with increasing age, cellulose substances, as well as wood-forming substances, filled up a lot in the stem. Cellulose and lignin are positively correlated with carbon content, where high cellulose and lignin can increase carbon content in the stem. Carbon content in cellulose and lignin is approximately 44.44% and 67.50% [29]. CO2 absorption by mangrove ecosystems is greater than that of ordinary terrestrial plants [30]. In total, mangroves in Paliat Island can absorb around 39.59 ton/Ha CO2. The ability of leaves to absorb CO2 in the air depends on the uncovered response of stomata and influenced by the enzymatic ability of each type of mangrove in photosynthesis [31]. Mangroves density is considered to be the main factor that influences the quantity of biomass in the study area. The alteration of mangroves density could cause a negative impact on the entire ecosystem and disturb mangrove’s ability to absorb CO2 from the atmosphere. Besides density, other important factors that have an impact on the rate of biomass addition are species composition, vegetation structure, and environmental quality.

3.3. Allometric equations

Allometric is defined as a method to study the relationship between tree size (diameter) and several parameters such as the biomass of tree parts, wood volume, and carbon stock. The allometric equation in this study was determined by comparing DBH values and C levels in each mangrove’s component.
using several regression models including linear, logarithmic, polynomial and power (Figure 2). The best regression model can be used to estimate the DBH and carbon content of mangrove trees. Many other studies choose to use allometric equation instead of harvesting mangrove vegetation to estimate carbon stock. Nonetheless, this study tried to produce a particular equation based on actual data of DBH and Carbon concentration. The results are presented in Table 5.

Table 5. Allometric Equations of DBH and Carbon Concentration

| No | Mangroves Part | Allometric Equation | $R^2$ |
|----|----------------|---------------------|------|
| 1  | Stems          | $y = 0.045x^2 - 1.638x + 47.88$ | 0.950 |
| 2  | Roots          | $y = -0.013x^2 + 1.022x - 5.911$ | 0.423 |
| 3  | Leaves         | $y = -0.007x + 1.336$ | 0.352 |
| 4  | Branches       | $y = -0.004x^2 + 0.348x - 3.819$ | 0.714 |

![Figure 2. Allometric Equations from Different Parts of Mangroves of Paliat Island](image)

According to Table 5, polynomial equations for stems and branches provide higher $R^2$ in comparison with allometric equations for roots and leaves. It means that the most reliable equation that can be used to predict concentration of Carbon were equations for stems and branches. However, more evaluation is needed to use these equations outside the study area. Despite harvesting and measuring Carbon concentration in mangroves provide the actual data, destructive sampling as in use in this study is not highly recommended. An extensive mangrove forest may contain over 10 species, nonetheless, to formulate species-specific allometric equations to estimates forest carbon stocks is not necessary. It is suggested to group all species together and use generalized allometric equation using DBH value to generate reliable calculation of carbon stock, it. This value is known to its function which can explain more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions. Moreover, to check the validity of an allometric equation for specific locations, cutting down 2-3 large trees should be efficient enough [32,33]. There are variations in producing allometric equations especially for Carbon estimation in mangroves. Some of the equations were provided for specific species or certain parts of mangroves vegetations, while the others were used for the general. Allometric equations from other studies that have been widely used to estimate total Carbon storage in mangroves is provided in Table 6.
Table 6. Examples of Allometric Equations for Carbon Estimation in Mangroves

| No | Allometric Equations | Explanation | Source |
|----|----------------------|-------------|--------|
| 1  | Y = 0.1848 × DBH^{2.3524} | Specific for Avicennia marina | Dharmawan, 2010 |
| 2  | Y = 0.1466 × DBH^{2.3136} | Specific for Rhizophora mucronata | Dharmawan & Siregar, 2008 |
| 3  | Y = 0.0275 × DBH^{1.22} | Specific for Rhizophora apiculata | Pambudi, 2011 |
| 4  | Y = 0.251p × DBH^{2.46} | Specific for Avicennia | Komiyama et al (2005) |
| 5  | Y = 0.105 × DBH^{2.48} | Specific for Rhizophora | Komiyama (2008) |
| 6  | Y = 0.186 × DBH^{1.31} | Specific for Brugueira | Komiyama (2008) |
| 7  | Y = 0.186 × DBH^{2.34} | Specific for Ceriops | Komiyama (2008) |

3.4. The importance of carbon stock information for mangroves conservation

Providing complete information for the government and society regarding mangroves role against global climate change by absorbing a large quantity of CO$_2$ is important. Mangroves, seagrasses, and salt marshes are widely recognized for their important functions and capacities to sequester CO$_2$ from the atmosphere. Over 55% of biological carbon (green carbon) is captured by mangroves and their related environments [34]. Together with coral reefs and seagrasses, mangrove ecosystems form the most productive ecosystems on the coastal environment. They provide not only natural benefits but also social and economic advantages to coastal communities. In the last decade, many studies have been conducted to measure and quantify economic benefits that mangroves provide for the coastal environment, generally known as total economic valuation (TEV). Mangrove total economic value is a calculation of the primary function of mangrove ecosystems that have direct or indirect for the environment and the people living in the coastal regions. The examples of this method including EOP (Effect on Productivity), TCM (Travel Cost Method), and CVM (Contingent Valuation Method) [35].

TEV approach encompasses several important functions of mangroves and converts it into currency. However, the role of mangroves as Carbon storage, absorbing CO$_2$ and provide protection against climate change was not considered. Complementing TEV model with the calculation of carbon stock should provide complete estimation and a better understanding of the role of mangroves for the coastal community. As a consequence, public awareness of mangroves protection and conservation could increase significantly.

4. Conclusion

The results from the field observation of mangroves ecosystem in Paliat Island revealed that there were 4 species of mangroves on the island, namely Rhizophora mucronata, Brugueira gymnorhiza, Rhizophora stylosa, and Rhizophora apiculata. According to the community structure analysis, Rhizophora apiculata was the most dominant mangroves species (IVI = 153.20). Using destructive sampling method, it was estimated that mangroves ecosystem at the study site has a total biomass content and carbon stock of 21.59 ton/ha and 10.80 ton/ha respectively. Further, the calculation explained that mangroves in Paliat Island could absorb around 39.59 ton/ha CO$_2$. There was a significant difference in carbon stock between various parts of mangrove vegetation (One Way ANOVA, F=220, df$_1$=4, df$_2$=85, p<0.05). Polynomial equations for stems and branches were sufficient as a regression model to calculate the quantity of carbon stock based on DBH ($R^2 > 0.70$). The total carbon stock estimation should be included in the TEV model to provide a more comprehensive approach in economic valuation of mangroves.

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