A Study of Carbon Sequestration Potency of *Rhizophora mucronata* Lamk. in the Mangrove Conservation Forest of Baros Beach, Bantul, Yogyakarta

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Abstract. Mangrove forests provide components of blue carbon reservoirs, warranting their preservation to mitigate climate change. *Rhizophora mucronata* is the dominant species in mangrove conservation forest at Baros Beach. This research was aimed to assess the carbon sequestration, relative density, and substrate acidity (pH) related to the growth of *R. mucronata*. The methods were: sampling points determination based on map area; establishing 10 m x 10 m measurement plots (PU); growth parameter measurements, canopy area, and soil samples collection. The results showed a correlation between substrate acidity and *R. mucronata* relative density. Relative density reached 100% in PU 4 and 5, where the substrate's pH is neutral, whereas in PU 2 and 1 relative density was less and it correlated with high acidity of substrate. The carbon sequestration potential of mangroves in PU 2 and 3 was the highest, the values are 95.60 kgC/m^2 and 95.72 kgC/m^2, respectively. This was consistent with the biomass values obtained, suggesting a correlation between carbon sequestration potential and biomass. PUP 10 had the lowest carbon sequestration levels, primarily attributed to its comparatively smaller canopy coverage compared to others. Potential carbon storage of *R.* mucronata at the mangrove ecosystem in the Pantai Baros area was from 16.95 to 95.72 kgC/ m^2 which is influenced by the growth of mangrove trees.

Keywords: carbon sequestration, climate change, mangrove, *Rhizophora mucronata*, Baros Beach

1 Introduction

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Recently, temperature increase occurred in many towns of Indonesia and it reached around 33ºC to 36ºC in Yogyakarta Special District, whereas in other towns it was reported that the increase in temperature reached to 40ºC in surrounding Central Java. This increase in temperature is one of greenhouse effects which caused global climate change. Anthropogenic activities such as change in land use, continual burning of fossil fuels including crude oil, natural gas and coal caused a significant increase in the level of greenhouse gases such as CO_2 and CH_4 in atmosphere[1]. Mangrove possesses an important role in the mitigation of climate change because they can absorb CO_2 and store it as a biomass. It has been reported that mangrove can absorb around 46.02 - 55.54% of CO_2 and these values were greater compared to other tropical plants[2]. Mangrove conservation area in Baros beach, Yogyakarta is one of conservation areas that is aimed to reduce the impact of land use change which leads to significant loss of stored carbon[3]. Beside carbon reduction, mangrove conservation areas also function in resist abrasion as well as other ecological functions[4].

Information about the capacity of the mangrove population in absorbing CO_2 and how they contribute to reduction in global climate change is very important. Carbon storage can be determined from the biomass found above or under the ground. The approach in estimating the carbon storage can be done by calculating the above ground biomass or by measuring plant growth. The greater value of vegetation biomass will cause a greater value of carbon, This means that absorption of CO_2 has a correlation with the plant biomass. The value of mangrove biomass can be calculated by their production and density. Plant production and plant density was calculated from stem and canopy diameter, density of each species and substrate condition[5]. According to Alongi (2008)[6] and Matatula et al. (2019)[7], density and biomass of mangrove are influenced by temperature, rainfall variation, salinity, tide, ocean wave and velocity of river flow. Salinity is one of the environmental factors that determine the growth of Mangrove. Salinity is a content of natrium in water which is stated as per mil (‰) or natrium content in one thousand parts of water. Normally mangrove can grow in saline water or brackish water with salinity value [1]around 11-25‰[8] [9].

One of mangrove species found in Baros Conservation Area is *Rhizophora mucronata*. This species has been normally chosen for rehabilitation of mangrove forest because of its easiness in germination and can stand in both high or low submergence. According to Rachmawati et al. (2014), *R. mucronata* widely found in mud area and it has a higher biomass and carbon content stored compared to other mangrove species such as Avicennia lanata, Bruguiera gymnorrhiza, Bruguiera parviflora, and Rhizopora apiculata4. It is also supported by Iksan et al. (2019) research that *R. mucronata* has the highest biomass and carbon absorption value compared to other species in Mangrove Forests Pohorua Village, Muna Regency. Mangrove conservation area in Baros is predicted to have a great carbon storage potency and it will be useful as a contributor in climate change mitigation. This research was carried out to evaluate the potency of carbon storage and to analyze the relationship between salinity and density of *R. mucronata* Lamk. in mangrove conservation area, Bantul.

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2 Method

2.1 Research Site

This research was conducted in the mangrove conservation area in Baros beach, Bantul, Yogyakarta Special Region. This area is located at 0-6 above sea level, with altitude 8° 0' 48.066'' LS, 110° 17' 9.199'' BT (Look at figure 1). This location is at the meeting point between the southern sea and the mouth of the Opak River. The Baros mangrove forest area is designated as a conservation area with a total area of 132 hectares directly facing the southern coast of Java Island which is famous for strong winds and large waves. This mangrove area is an artificial forest area that was formed in 2003 with the cooperation of the Baros community to overcome environmental problems on the coast of Baros.

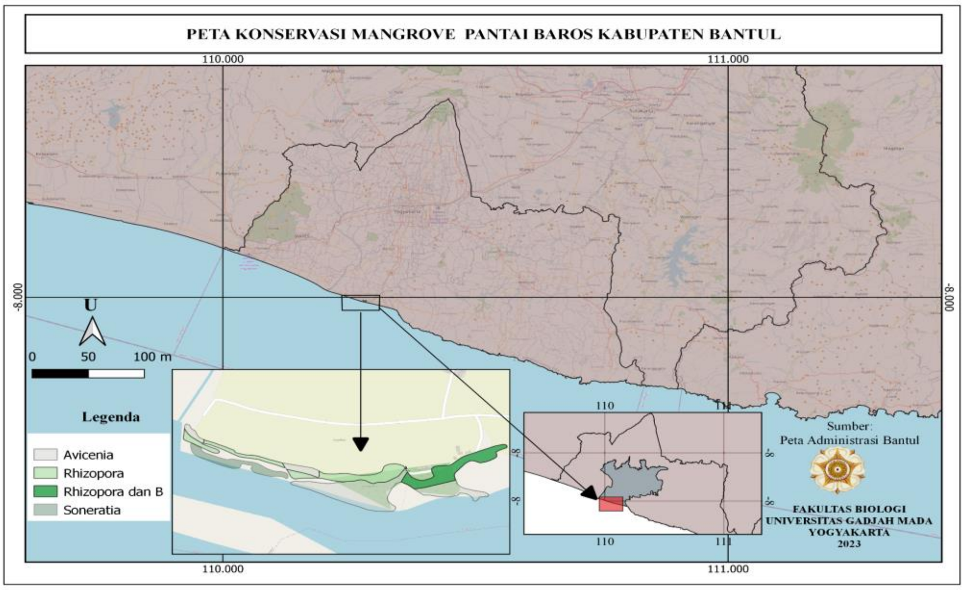

Fig. 1. Map of Mangrove Conservation Area in Baros Beach, Bantul.

2.1.1 Research procedures

a. Establishment the measuring plots (PU)

This research location has a mangrove community that mostly has the same age and has entered the reproductive phase. The decision to establish measuring plots was made in a predominantly *R. mucronata* genus-dominated area. The selection of observation measuring plots was conducted by a random process, followed by the establishment of square measuring plots using red-coloured tape with dimensions of 10 m x 10 m.

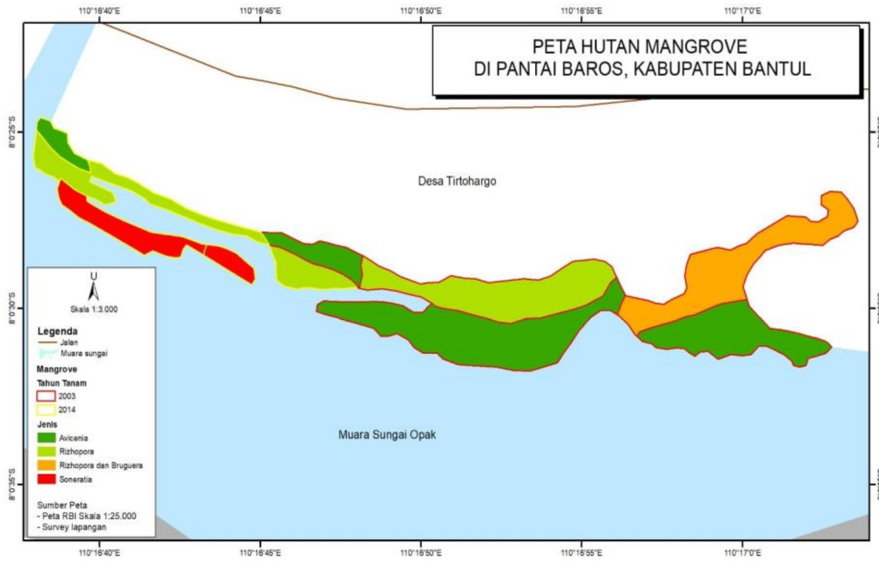

Fig. 2. Measuring Plot Location.

The vegetation parameters that were observed and measured included the species composition, total height, stem diameter (dbh), and crown diameter of all plants within the designated measuring plot. The observations were solely conducted on the specific species of *R. mucronata* within the designated measuring plot. The measurements of overall plant height were conducted using a measuring pole, and measurements of diameter at breast height using a phi band for each individual plant[9].

b. Observation of *Rhizopora mucronata* Density

The density of *Rhizopora mucronata* vegetation was assessed through the utilization of a 10 m x 10 m measuring plot, encompassing all plants inside this plot[9]. The equation used to determine mangrove density is derived from the study conducted by Usman and Hamzah (2013)[10].:

$$Di = \frac{Ni}{A}$$

Di : Species density the-i (ind/m^2)

Ni : Total number of individuals of the i-th species (ind)

A : Total sampling area (m^2)

2

The relative density (RDi) refers to the proportion of species coverage within mangrove regions, determined by comparing the density of species to the overall density of species within the tree category. This calculation is derived from the equation proposed by Usman and Hamzah (2013)[10]:

$$RDi = \frac{Di}{\Sigma Di}\ x\ 100\%$$

RDi : Relative density

Di : Species density

ΣDi : Total number of species

Table 1. Mangrove Density Criteria

	Criteria	Relative Density (%)	Density of Trees (ha^{-1})
Good	Very dense	≥ 75	≥ 1500
	Medium	$\geq 50 - < 75$	$\geq 1000 - < 1500$
Damage	Rare	< 50	< 1000

Source : (Ministry of Environment and Forestry, 2004).

c. Estimation of carbon biomass of *R. mucronata*

The estimation of *R. mucronata* tree biomass was conducted utilizing the expansion factor, which is determined by transforming tree volume into biomass. This method is commonly used to calculate biomass in aboveground conditions. The tree volume value will be multiplied by the wood density value (WD) and the biomass expansion factor (BEF). The wood density value (WD) for *R. mucronata* species is reported as 848.3, according to the data obtained from the World Agroforestry Database (http://db.worldagroforestry.org/wd). Additionally, the biomass expansion factor (BEF) for this species is documented as 1.38 in a study conducted by Krisnawati et al. (2012)[11]. The stem volume is achieved by using data

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on the height and diameter of each individual in the measuring plot. If the wood density for the species to be estimated is not available, then the average value of the wood density of the genus can be used. The value of tree BEF can be obtained by a comparison or ratio between the aboveground tree biomass and the stem biomass. The mathematical equation for biomass calculation used is:

$$\text{Biomass of Tree} = \text{Volume} \times \text{WD} \times \text{BEF}$$

The determination of carbon absorption value, representing the percentage of carbon content present in biomass, involves the conversion of biomass measurements. According to Saifullah et al. (2021)[12], it has been reported that the carbon concentration found in plants is approximately 47%. Hence, the determination of the carbon uptake value is accomplished through the utilization of the following formula:

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

C	:	carbon from biomass (kg)
B	:	Tree biomass (kg)
% C organic	:	Percentage of carbon content of 0.47

Moreover, to ascertain the significance of mitigating carbon dioxide emissions or enhancing CO_2 absorption through mangrove habitats, it is essential to get knowledge regarding the quantity of carbon dioxide assimilated by plants, commonly referred to as carbon sequestration. The calculation of CO_2 sequestration involves the multiplication of the total carbon content by the carbon conversion factor. The carbon conversion factor is 3.67[13]. This factor represents the conversion rate of the element carbon (C) to carbon dioxide (CO_2). It is derived from the atomic masses of carbon (12) and oxygen (16), where the molecular weight of CO_2 is 44. Thus, the conversion ratio is calculated as (44:12) = 3.67. The general equation for carbon uptake is:

$$\text{Sequestration of } CO_2 = 3.67 \times \text{Carbon Content}$$

The determination of the carbon stock within the mangrove ecosystem is achieved by multiplying the area, measured in hectares, with the carbon density of mangrove vegetation, expressed in tonnes of carbon per hectare. The overall carbon storage capacity of mangrove ecosystems is often reported in units of tonnes of carbon.

d. Collection of soil samples

Soil samples were collected at various stages of plant development. The coordinates of the sampling points were determined using Google Maps and 11 samples were taken at a depth of 10 cm from the topsoil layer. Soil samples were taken to the soil laboratory of the Yogyakarta Agricultural Research and Development Agency to be analyzed according to the parameters studied. Soil texture measurements are carried out using a hydrometer. Soil pH tests are carried out with a pH meter. Determination of soil pH is done by inserting 15 grams of soil into a 50 mL vial. Then 20 mL of 0.01 N $CaCl_2$ solution was added and then measured with a pH meter. The DHL test is carried out using the conductometer method. Soil organic carbon use Walky-Black method. Tests were carried out in the laboratory with results as presented in Table 3.

3 Result and discussion

a. *Growth and Density of Rhizophora mucronata*

The field investigations conducted at Baros Beach revealed a diverse array of mangrove species, which is typically inhabited by many plant species, including *Rhizophora mucronata, Avicennia sp., Sonneratia sp., Rhizophora bruguiera, Ceriops* sp., and *Xylocarpus* sp. It was recorded that *R. mucronata* exhibits dominance within the conservation forest. The mangrove conservation forest under consideration is classified as an artificial forest, specifically categorized as ex-situ conservation. Consequently, it is possible to determine the approximate age of the forest stand. This study therefore focused on the examination of *R. mucronata* species by establishing measurement plots that were tailored to the specific geographical distribution of the species. Measurements were conducted on every individual tree to determine the values for height, stem diameter, and crown diameter. The measurement outcomes are displayed in Table 2.

Table 2. Growth and density of *R. mucronata* in mangrove conservation, Baros.

Measuring plot (PU)	Number of principal stems	Average stem diameter (cm)	Average height (m)	Specific density (ind/m^2)	Relative density (%)
PU 1 – 8RB	48 (25 seedlings)	5,98	6,79	0,48	73,85
PU 2 – 5RB	25	12,16	11,06	0,25	78,13
PU 3 – 6RB	64	7,44	9,86	0,64	94,12
PU 4 – 10R	17	5,67	8,48	0,17	100
PU 5 – 2R	10	9,36	9,80	0,1	100

The measurement of mangrove growth, as indicated by stem diameter and tree height, exhibited variability across different measuring plots. The diameter growth of *R. mucronata* exhibits significant variation between different planting units (PU). According to the findings shown in Table 2, the classification of mangrove stands can be delineated based on two distinct criteria: poles, which are characterized by a diameter ranging from 10 to 19 cm, and saplings, which are defined by a diameter less than 10 cm. Primary Unit 1 (PU1) exhibits the highest average diameter (12.17 ± 0.85), indicating a significant carbon storage capacity but limited carbon sequestration capabilities due to a deceleration in growth rate. PU 1, 3, 4, and 5 exhibit a notable capacity for carbon sequestration and storage due to their substantial stem diameter, ranging from greater than 1.5 cm to less than 10 cm[14]. In addition, the diameter of a tree is a determining factor in its potential for carbon storage. An increase in diameter corresponds to an elevated presence of polysaccharide molecules, hence suggesting a greater potential for carbon content. Cell wall is composed of three primary polymeric constituents, namely cellulose (40-50%), hemicellulose (15-25%), and lignin (20-25%), alongside other chemicals (5-10%)[14]. In addition, The age of trees can affect the significance of stem diameter in relation to carbon storage. Older, large-diameter trees have been shown to store disproportionally massive amounts of carbon compared to smaller trees, highlighting their importance in mitigating climate change[31]. Even though PU 1 has the largest number of stands, 25 of them are still seedlings so they are included in the category of plants that are still young and have a smaller diameter. This also affects carbon uptake in PU.

The concept of stand density comprises two components: species density and relative density. Species density refers to the aggregate count of individuals belonging to a certain species within a given sampling area[15]. The findings from the field measurements indicate that there is variation in stand density throughout each measuring plot, as illustrated in Table 2. As an illustration, PU3 exhibits the highest species density of 0.64, implying that the population of *R. mucronat*a trees in PU3 amounts to 64 trees. Conversely, PU5 harbors the lowest recorded count of *R. mucronata* trees..

According to Imra et al. (2021)[13,] relative density was defined as the proportion of species occurrence within mangrove areas, calculated by dividing the density of a particular species by the total density of all species present. PUs 4 and 5 have the highest relative density value of 100% due to the exclusive presence of *R. mucronata* within these particular PUs. The relative density value in PU 1, 2, and 3 did not attain 100% due to the presence of other species, including *Avicennia sp., Hibiscus tiliaceus, Cassia alata, Gliricidia sepium, and Sonnerati*a sp. Consequently, the relative density value was

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diminished. The variations in growth and density of mangroves can be attributed to several factors, including the age of the trees, environmental conditions, and planting techniques. Mangroves are halophytic plants adapted to highly stressful intertidal zones, and their tolerance level for salinity and adaptive characteristics vary from species to species. Climate change, rising sea levels, and fluctuating tidal cycles have influenced the distribution and growth of mangroves. Meanwhile, global warming may promote the expansion of mangrove forests to higher latitudes and accelerate sea-level rise through melting of polar ice or steric expansion of oceans[31].

b. Soil Content Analysis

Soil analysis was performed on each planting unit (PU) in order to assess the soil conditions and their impact on tree growth, as well as their implications for carbon sequestration. Mangroves are arboreal vegetation that thrives in the transitional zone between terrestrial and marine environments, predominantly found in tropical and subtropical areas. Mangroves will thrive in alluvial soils (loose, fine-textured mud or silt, rich in humus). Frequently waterlogged but well-drained soils support good mangrove growth and high species diversity.These plants have adapted to endure challenging ecological conditions characterized by elevated saline levels, fluctuating tides, intense winds, elevated temperatures, and the presence of muddy and oxygen-deprived soils[16]. The composition of soil is composed of varying mixtures of sand, silt, and clay, the abundance of organic matter in mangrove ecosystems can be attributed to the accumulation of mangrove litter and the slow decomposition process facilitated by anoxic soils[17].

Table 3. Soil samples laboratory results for each measuring plot.

No	Parameters	Unit	PU1 (8RB)	PU2 (5RB)	PU3 (6RB)	PU4 (10R)	PU5 (2R)	Method
1	Texture							Hydrometer
	Sand	%	48	51	27	32	42	
	Dust	%	34	30	51	46	33	
	Clay	%	19	19	22	22	25	
2	pH (H2O)		5.03	5.26	6.59	7.55	7.01	pH meter 1:5 IK.5.4.c
3	DHL	(μs/cm)	1263	1291	1150	602	534	Conductometer 1:5
4	C organic	%	2.95	3.95	2.47	1.56	1.45	Walky&Black

5	Organic matters	%	5.08	6.81	4.26	2.69	2.49	Calculation
6	N-NO_3	ppm	352	540	248	50	72	Morgan-Wolf
7	P_2O_5	ppm	41	49	142	75	42	Olsen IK.5.4.h

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Table 3 shows the findings of soil sample analyses conducted on individual PU, revealing that the substrate within the study region has three distinct textures: sand, dust, and clay. The predominant substrate composition of mangrove ecosystems is characterized by the presence of sand and dust particles. However, variations in the relative proportions of these constituents can be observed when comparing different cartographic representations. The sand substrate dominates PU1, PU2, and PU5 successively, with percentages of 48% , 51%, and 42% respectively. The composition of the substrate in PU3 and PU4 is primarily composed of particulate matter in the form of dust. The clay substrate comprises approximately 21% of the overall PU. According to Hossain and Nuruddin (2016)[17], prior studies have indicated that mangrove soil exhibits a wide range of pH levels, which can be either acidic (ranging from 2.87 to 6.40) or alkaline (ranging from 7.4 to 8.22). According to the data presented in Table 3, it can be observed that the pH measurements obtained for each PU indicate an acidic nature. Specifically, PU1 exhibits the highest level of soil acidity, with a pH value of 5.03, while PU4 demonstrates the lowest acidity, with a pH value of 7.55.

Furthermore, according to Astuti (2014)[18], there is a positive correlation between the salinity level of a water body and its DHL (the electrical conductivity) value. This relationship can be attributed to the presence of a greater quantity of ionized dissolved salts in very saline water. Table 3, revealed that PU2 exhibits the highest electrical conductivity, as indicated by its DHL value of 1291 µs/cm. Conversely, PU5 has the lowest electrical conductivity, with a DHL value of 534 µs/cm. Furthermore, the growth of mangroves is intricately linked to the concentration of organic matter present in the soil. The findings of the research indicate that the PU2 substrate exhibited the highest accumulation of carbon (C), nitrogen (N), and other organic elements. In contrast, the PU3 sample had the greatest concentration of phosphate (P), measuring 142 parts per million (ppm).

c. Calculation of potential carbon sequestration

The results of the calculation of carbon biomass, total carbon storage and total carbon sequestration from 5 Measuring Plot (PU) are presented in Table 4 below.

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[18] Astuti, A. D.: Kualitas air irigasi ditinjau dari parameter DHL, TDS, pH pada lahan sawah desa bulumanis kidul kecamatan margoyoso. *Jurnal Litbang*. pp. 35-42(2014)

Table 4. Calculation results of carbon storage and carbon sequestration of *Rhizophora mucronata*species in Baros mangrove conservation forest.

Measuring Plot (PU)	Carbon (kgC/m^2)	
	Carbon storage	*Carbon sequestration*
PU 1 – 8RB	10,83	39,74
PU 2 – 5RB	26,05	95,60
PU 3 – 6RB	26,08	95,72
PU 4 – 10R	4,62	16,95
PU 5 – 2R	12,97	47,61

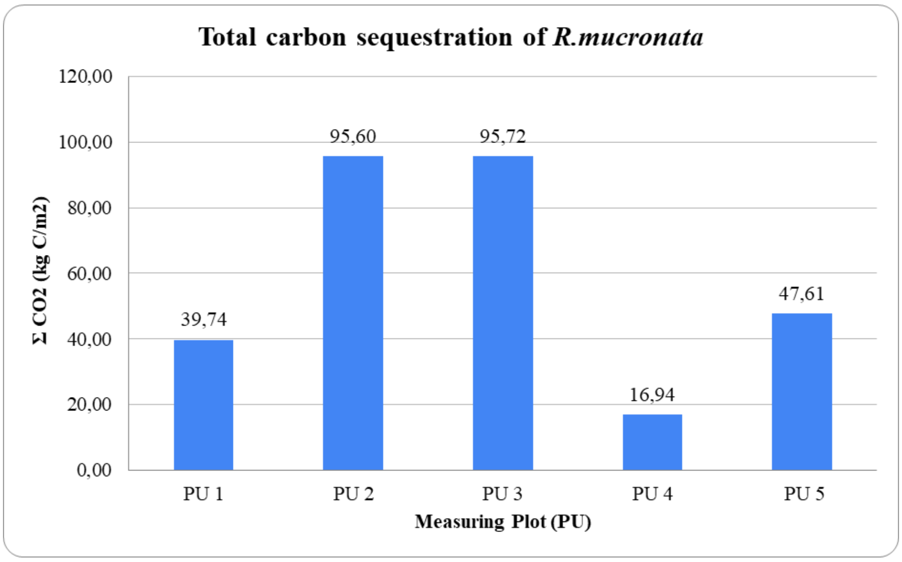

Fig. 3. Total carbon storage of *Rhizophora mucronata* in Baros mangrove conservation forest.

This study determined that there is variability in the quantity of carbon storage in each PU. The variation can be impacted by factors such as the quantity of trees, the number of individuals within the population, the extent of vegetation growth on the trees, as well as the height and diameter of the trees, and the organic matter present in the soil. PU 3 exhibits the most significant carbon sequestration, with a value of 95.72 kgC/m2, when compared to the other PUs. This pertains to the PU3 major trunks with the highest number, as indicated in Table 4, which undoubtedly possess a better capacity for carbon storage compared to other PUs. The carbon sequestration value in PU2 is comparable to that of

PU3, although having only 25 main trunks. However, PU2 has the highest average tree height and stem diameter among the other PUs.

This is consistent with the theory that tree growth is influenced by the absorption of CO_2 during photosynthesis, resulting in biomass and allocation to leaves, branches, trunks, and roots, which play a role in the increase of tree height and trunk diameter, leading to a linear relationship between trunk diameter and biomass and carbon storage[19]. Unlike the vegetation in PU4, which had the smallest average diameter compared to other vegetation, it had the smallest potential for carbon storage, which was 16.95 kgC/m^2. This is consistent with the theory that the larger the diameter, the higher the potential content of polysaccharides, which indicates higher carbon storage[20].

The research results show that the PU with the highest density does not always result in the highest carbon sequestration value, as it can be influenced by other factors. PU4 had the lowest carbon sequestration value compared to other PUs, even though it had a relative density of 100%. This can be associated with the low number of main trunk and trunk average diameter, as these parameters play a role in determining the potential for carbon sequestration, according to the presented theory.

Other environmental factors that influence the growth and development of mangrove vegetation are pH and temperature. The results of the pH measurements of the mangrove forest environment showed a value between 7.5-8.2. According to Auni et al. (2020)[21], water with a pH value of 5-7.8 is considered ideal for mangrove growth and development. pH concentration can affect the absorption of plant nutrients by roots[22].The pH conditions of the mangrove water at the research site varied among different points in different PUs. PU1 had a pH value of 5.03 and PU2 had a pH value of 5.26, indicating that they both had relatively acidic soil. On the other hand, PU3, PU4, and PU5 had basic pH with values of 6.59, 7.55, and 7.01, respectively. This suggests that the water conditions in different PUs.

The research findings showed that pH values of 5.26 and 6.59 had positive correlations with carbon storage on PUs 2 and 3, which had the highest carbon content at 26.05 kgC/m^2 and 26.08 kgC/m^2, respectively. On the other hand, a pH value of 5.03 on PU1 showed relatively low carbon storage at only 10.83 kgC/m^2. Basic pH conditions ranging from 5.26 to 7.55 showed negative correlations with carbon storage, with the highest pH value on PU4 of 7.55 yielding the lowest carbon storage at only 4.62 kgC/m^2, and a pH value of 7.01 on PU5 yielding carbon storage of 12.97 kgC/m^2. The results align with previous research by Zhou et al. (2019)[23] that land carbon, nitrogen, and TC/TN (C/N ratio) negatively correlate with soil pH, and they showed that lower pH levels benefit the accumulation of organic carbon in plants. Moreover, alkaline and relatively high pH levels in soil can negatively affect organic carbon storage in soil[24]. Meanwhile, the result of lowest pH on PU 1 aligned with previous research by Long et al, (2017), the low pH-induced inhibition of growth can cause the combination of H+-toxicity, deficiencies of nutrients, and decreased water uptake. Rapid and temporary changes in pH can impact dissolved organic matter and other chemical attributes, including redox conditions and oxygen levels, which can affect plant growth and carbon uptake[25]. Overall, the relationship between soil pH and plant carbon storage is complex and depends on various factors such as land use, soil type, salinization and other growth factors that influence mangrove. However, based on literature and the study findings, pH levels ranging from 5.26 to 6.59 have high carbon storage indices.

Mangrove ecosystems can be used as a mitigation for global warming[26] due to their ability to increase carbon absorption and storage while preventing erosion (loss of mangrove wetlands). According to Herianto and Subiandono (2016)[27], mangrove has great potential for mitigating global warming by absorbing carbon dioxide (CO_2) from the atmosphere at a higher rate per unit of area as compared to terrestrial forests. Additionally, according to Akbar et al. (2017)[28], mangroves can also prevent erosion by holding and breaking waves, thereby reducing coastal erosion.

4 Conclusions

Based on the results of the research, the mangrove ecosystem in the Pantai Baros area can be concluded to be dominated by the species *Rhizophora mucronata* Lamk. with the greatest carbon storage potential of 95.72 kgC/m^2 in PU3 and the smallest in PU4 of 16.95 kgC/m^2. Overall, the potential for carbon storage is highly influenced by the growth of mangrove trees.

Suggestions. We suggest further research on carbon analysis of *Rhizopora mucronata* species, to obtain the total carbon stock in the area. Investigate other factors that affect carbon storage or explore the potential for mangrove restoration in areas with lower carbon storage potential. In addition, research on carbon analysis of other mangrove species in the mangrove conservation area of Baros can also be conducted.

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