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Analysis of CO_2 Absorption Capacity and Carbon Storage in Mangroves in Kendari Bay Mangrove Tracking Area

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Abstract: Carbon dioxide (CO_2) levels in nature are increasing along with the development of human civilization. On the other hand, mangrove forests can absorb and store carbon in large quantities, and for a long time, so they can play a role in mitigating climate change. This study aimed to determine the potential for CO_2 uptake and carbon storage in the Kendari Bay Mangrove Tracking area, Lahundape Village, West Kendari District, Kendari City. This research was conducted in June 2023 in the Kendari Bay Mangrove Tracking area, Lahundape Village, West Kendari District, Kendari City. The sampling in this study used a purposive sampling method; the determination of sampling was selected systematically with a sampling intensity of 4%. The placement of measuring plots is based on the zoning of 8 (eight) plots of mangrove forests, where each plot is 20 m x 20 m (400 m2). Variables in this study are the diameter at breast height of adults to determine biomass and carbon above ground without cutting trees (nondestructive). Biomass was determined using the Allometric equation. The carbon was determined by ½ of the biomass. The results showed that the potential for CO_2 uptake and carbon storage in the Kendari Bay Mangrove Tracking area, Lahundape Village, West Kendari Subdistrict, Kendari City, has an average CO_2 uptake of 90.99 tons ha-1 and carbon storage of 24.79 tons ha-1. The amount of carbon value is influenced by environmental conditions, type of wood mass, mangrove stem diameter, and the number of species contained in a plot.

Keywords: Mangrove Forest; Carbon Sequestration; Carbon Storage; Kendari Bay.

Introduction

Global warming is the rise in Earth's surface temperature due to greenhouse gases, mainly from CO_2 emissions from fossil fuels and deforestation (Fitria and Dwiyanoto 2021). Carbon emissions, measured in tons of carbon or CO_2 equivalent, leave a carbon footprint from activities like domestic use, transportation, waste management, and building infrastructure. Environmental degradation, such as global temperature increases, is driven by urban energy use, land change, and resource demands, leading to high greenhouse gas emissions. To address this, many cities are adopting low-carbon development to minimize CO_2 emissions, with urban greening through tree planting as a key strategy. Mangrove forests play a crucial role in this effort, as they absorb large amounts of CO_2, helping to reduce the carbon footprint and combat global warming. Like other forest ecosystems, Mangrove ecosystems have a role as a sink (root) of CO_2 from the air (Heriyanto and Subiandono 2012). CO_2 emission is closely related to stand biomass. The total biomass of an area is obtained from the production and density of biomass, which is estimated from the measurements of diameter, height, specific gravity, and density of each tree species.

Biomass and carbon sequestration in mangroves is one of the benefits of mangroves beyond their other biophysical potentials, such as carbon sequestration and storage, to reduce carbon dioxide levels in the air (Rahman et al. 2017). The

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optimal function of mangroves in absorbing carbon reaches 77.9%, where the absorbed carbon will be stored in biomass contained in several parts of the tree, such as trunks, stems, and leaves. Carbon is stored in various parts of the tree, such as stems, leaves, and sediments. Mangrove ecosystems hold significantly more carbon than tropical rainforests, peat swamps, salt marshes, and seagrass beds (Azzahra et al. 2020). Around 40% of tree biomass is carbon, absorbed from CO_2 and stored through photosynthesis. Calculating tree biomass reveals carbon storage and the forest's role in CO_2 reduction. Mangrove degradation, however, can release large amounts of carbon, worsening the greenhouse effect.

Tracking Kendari Bay Mangrove is one of the mangrove forests mangrove forest that began to be developed as a natural tourism area located in Lahundape Village, West Kendari Subdistrict, is a tourist attraction area in Kendari City which was opened in 2017 by the Kendari City Government under Kendari City Tourism Office with an area of ± 8 ha (ArcGis 2023). Density Mangrove density in the Tracking Mangrove Bay Kendari Bay Mangrove Tracking area is relatively thin at 20 to 100 m. Mangrove density is quite high mangrove density is found in locations passed by the river flow, namely around the mouth of the Wanggu River, Kendari Bay, and Kendari Bay. Around the mouth of the Wanggu, Kambu, and Kadia Rivers. Changes in mangrove forest density in Kendari Bay is very significant, whereas in 1990, the mangrove forest on the coast of Kendari Bay had the density of 0.00 - 0.79 and, in 2017, decreased to 0.00 - 0.73 (Ido et al. 2019). The location of this mangrove tracking is on the shoreline of Kendari Bay and around the edge of the highway, a heavy-traffic area that causes an increase in CO_2 generated from transportation activities. An increase in CO_2 is generated from transportation activities. Therefore, Therefore, this research is essential to determine how much the mangrove area can absorb CO_2. can absorb and store CO_2 from the air so that it can support the activities of sustainable management of the area about reducing CO_2 concentrations in the atmosphere.

Materials and Methods

Study area

This research was conducted in June 2023 in the Kendari Bay Mangrove Tracking area, Lahundape Village, West Kendari Sub-district, Kendari City, which is located at coordinates between 3°57'44" - 3°58'23" South latitude and between 122°31'29 "- 122°32'22" East longitude.

procedures

The research procedure consisted of several stages. First, the preparation stage involved conducting a site survey to gather preliminary data and preparing the necessary equipment and materials for field data collection. Next, the research location was selected based on vegetation conditions. After an initial survey to assess the site, eight plots were created, each measuring 20 m x 20 m (400 m²), with 50 m between each plot, applying a 4% sampling intensity and purposive sampling. In the implementation stage, the types of mangrove species within each plot were identified, and using a non-destructive sampling method, the diameter of each plant stem was measured to calculate biomass. These biomass values were converted into carbon absorption and storage data using an allometric equation. Finally, a research report was compiled based on the analyzed data.

Data analysis

Tree Biomass

Mangrove stem diameter data is then processed using the allometric equation to determine stem biomass, presented in Table 1.

Table 1 Allometric equation of mangrove stem biomass Mangrove Type Allometric equation.

Mangrove Type	Allometric equation	Research Source
Rhizophora mucronata	$B = 0{,}1466 \times D^{2{,}3136}$	Dharmawan, 2010
Sonneratia alba	$B = 0{,}3841 \times \varrho \times D^{2{,}101}$ (ϱ=0,078)	Kauffman dan Donato, 2012

Description:
B = Biomass (kg)
D = DBH (cm)
ϱ = Density of wood (gr/m3)

Tree Carbon Uptake

Banuwa et al. (2019) suggested that carbon dioxide uptake can be estimated using the following formula:

$$CO_2 \text{ uptake} = \frac{MrCO2}{\text{ArC}} \text{ x Carbon} \quad (1)$$

Description:

CO_2 uptake = Carbon dioxide (CO2) gas uptake (kg/m^2). $Mr.CO_2$

= Relative molecular mass (44).

Ar. C = Relative atomic mass (12).

Tree Carbon Storage

Above-ground carbon storage can be assumed that 46% of biomass is carbon (Widyastuti et al., 2018). The formula is as follows:

$$C = \text{Biomass x } 0{,}46 \quad (2)$$

Description:

C = Carbon

0,46 = Conversion factor for carbon estimation

Carbon Conversion Calculation

Calculation of carbon stocks per hectare in each plot can use the formula according to SNI from BSN (2011):

$$Cn = \frac{Cx}{1000} \text{x} \frac{10.000}{\text{plot area}}. \quad (3)$$

Results and Discussion

Total Biomassa Mangrove

Total mangrove biomass determined from the number of species and plots showed different values. The total biomass in types and plots can be presented in Table 2.

Table 2. Mangrove biomass based on mangrove species in Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City.

Mangrove Type	Biomass (kg $plot^{-1}$)	Biomass (ton $plot^{-1}$)	Biomass (ton ha^{-1})
Rhizophora mucronata	3.756,43	3,75	9,39
Sonneratia alba	13.489,86	13,49	33,72
Average	8.623	8,62	21,55

Source: Primary *Data*, 2023

Table 2. shows the amount of biomass by mangrove type. The highest biomass is in the type of Sonneratia alba which is 33.72 tons ha-1 while the lowest biomass is in the type of *Rhizophora mucronata* which is 9.39 tons ha-1, so that the average biomass of mangroves based on mangrove types is 21.55 tons ha-1.

The amount of biomass by the plot in the Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City is presented in Table 3.

Table 3. Mangrove biomass by plot in Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City.

Plot	**Biomass (kg $plot^{-1}$)**	**Biomass (ton $plot^{-1}$)**	**Biomass (ton ha^{-1})**
1	2.907,69	2,91	72,70
2	3.395,60	3,40	84,90
3	3.709,67	3,71	92,75
4	1.785,42	1,79	44,62
5	355,43	0,36	8,87
6	1.542,96	1,54	38,57
7	2.704,94	2,70	67,62
8	844,6	0,84	21,12
Average	2.**156**	2,16	54

Source: *Primary Data*, 2023

Table 3 shows different amounts of biomass in each plot. The biomass with the highest value is in plot three, 92.75 tons ha-1, while the lowest value is in plot five, 8.87 tons ha-1, so the average biomass based on the number of plots is 54 tons ha-1.

Mangrove Carbon Uptake

The amount of carbon sequestration based on mangrove types in Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City is presented in Table 4.

Tabel 4. Mangrove carbon sequestration based on mangrove type in Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City.

Mangrove Type	Carbon storage (kg $^{plot-1}$)	Carbon storage (tons $^{plot-1}$)	Carbon storage (tons $^{ha-1}$)
Rhizophora mucronata	6.573,35	6,57	164,33
Sonneratia alba	22.541,85	22,54	563,55
Average	1.455	14,56	363,94

Table 4 shows that the average carbon uptake based on the species found is 363.94 tons ha-1. The highest carbon uptake is in the type of *Sonneratia alba* which is 563.55 tons ha-1. The lowest carbon uptake is in the type *of Rhizophora mucronata* which is 164.33 tons ha-1.

The amount of carbon uptake based on the number of plots in the Kendari Bay mangrove tracking area, Lahundape Village, West Kendari District, Kendari City is presented in Table 5.

Table 5. Mangrove carbon uptake based on plot in Kendari Bay mangrove tracking area, Lahundape Village, West Kendari Sub-district, Kendari City.

Plot	Carbon storage (kg $^{plot-1}$)	Carbon storage (tons $^{plot-1}$)	Carbon storage (tons $^{ha-1}$)
1	4.908,76	4,91	122,71
2	5.732,45	5,73	143,31
3	6.262,66	6,26	156,56
4	3.014,15	3,01	75,35
5	600,04	0,60	15,00
6	2.604,82	2,60	65,12
7	4.566,48	4,56	114,16
8	1.425,85	1.42	35,64
Average	3.639	3,639	90,99

Source: *Primary Data*, 2023

Table 5 shows the amount of carbon uptake in each plot has different values. The highest value of carbon uptake was in the third plot, 156.56 tons ha-1, while the lowest value was in the fifth plot, 15.00 tons ha-1. Thus, the average carbon uptake is 90.99 tons ha-1.

Table 6. Total carbon sequestration based on the study area

Carbon storage (tons ha-1)	Area (ha)
90,99	8
Total	727,92

Source: Primary Data, 2023

Table 6 shows the total carbon sequestration based on the study area is 727.92 tons C.

Mangrove Carbon Storage Potential

Estimation of carbon biomass potential per unit area ton ha-1 can be calculated by entering the diameter at breast height (DBH) value of each plot into the allometric equation for each species with the specific gravity of each tree species. The amount of carbon biomass in each plot is influenced by tree species, tree density, diameter, and total tree height of each species. The following results of this study are presented in Table 7.

Table 7. Mangrove carbon storage by mangrove type in Lahundape Village, West Kendari Sub-district, Kendari City.

Mangrove type	Carbon storage (kg plot-1)	Carbon storage (tons plot-1)	Carbon storage (tons ha-1)
Rhizophora mucronata	1.727,96	1,72	43,20
Sonneratia alba	62.05,339	6,20	155,13
Average	3.966	3,96	99,17

Source: Primary Data, 2023

Table 7 shows that the average mangrove carbon storage based on the types found is 99.17 tons ha-1. The highest carbon storage is in the type of *Sonneratia alba* which is 155.13 tons ha-1. The lowest carbon storage is in the type of *Rhizophora mucronata* which is 43.20 tons ha-1.

The amount of mangrove carbon storage based on the number of plots in the Kendari Bay *mangrove tracking* area, Lahundape Village, West Kendari Subdistrict is presented in Table 8.

Table 8. Mangrove carbon storage based on plots in Kendari Bay *mangrove tracking* area, Lahundape Village, West Kendari Sub-district.

Plot	Carbon storage (kg plot-1)	Carbon storage (tons plot-1)	Carbon storage (tons ha-1)
1	1.337,54	1,33	33,43
2	1.561,97	1,56	39,04
3	1.706,45	1,70	42,66
4	821,29	0,82	20,53
5	163,5	0,16	4,08
6	709,76	0,70	17,74
7	1.244,27	1,24	31,10
8	388,51	0,38	9,71
Average	992	1	24,79

Source: Primary Data, 2023

The highest value of carbon storage is in Table 8. 42.66 tons ha-1, while the lowest value was in plot five at 4.08 tons ha-1. So the average carbon storage is 24.79 tons ha-1.

Table 9. Total carbon storage based on the study area.

Carbon storage (tons ha-1)	Area (ha)
24,79	8
Total	198,32

Source: Primary Data, 2023

Table 9. shows that the total carbon storage based on the study area is 198.32 tons C.

Discussion

The results of the study in Table 3. shows that there are differences in biomass between each type of mangrove. Where the type of *Sonneratia alba* has a higher biomass than the type of *Rhizophora mucronata*. *Sonneratia alba* mangrove species has a biomass value of 33.72 tons ha-1 while *Rhizophora apiculata* species has a biomass value of 9.39 tons ha-1. The biomass content for each type of mangrove vegetation will differ depending on the density of the wood. The higher the wood density, the more biomass content. According to Rachmawati *et al.* (2014) mangrove biomass content is influenced by mangrove density, diameter, type, and *wood density*.

Table 3 shows that there are differences in biomass values between each plot. Plot three has a higher biomass value, while plot five has a lower biomass value than the other plots. The amount of biomass in a field can illustrate the amount of CO_2 in the atmosphere that is absorbed by plants. The ability of mangrove vegetation to absorb biomass in plot three is 92.75 tons ha-1, while plot three has the lowest ability of 8.87 tons ha-1. According to Nedhisa and Tjahjaningrum (2019), differences in biomass in each location are influenced by several factors, these factors include the number and density of trees, tree species, physiological plants and environmental factors which include sunlight, moisture content, temperature and soil fertility.

Table 4 shows that there are differences in carbon sequestration values between each type of mangrove. *Sonneratia alba* mangrove species has a higher carbon sequestration value compared to the type of *Rhizophora mucronata*. The ability of mangrove vegetation in absorbing carbon in the type of *Sonneratia alba* is 563.55 tons $^{ha-1}$, while the type of *Rhizophora mucronata* is 164.33 tons $^{ha-1}$. Table 5 shows that there are differences in carbon sequestration values between each plot. Where in plot three has a higher carbon uptake value, while plot five has a lower carbon uptake value than other plots. Carbon content in plants can be known by calculating biomass, therefore most of the plant biomass is carbon content. The ability of mangrove vegetation to sequester carbon is highest in plot three at 156.56 tons $^{ha-1}$, while plot five has the lowest ability.

which is 15.00 tons $^{ha-1}$. Total carbon uptake in mangroves based on the location area of Kendari Bay *mangrove tracking* area Lahundape Village is shown in Table 6. which amounted to 727.92 tons of carbon. The mechanism of trees is absorbingCO_2 from the air through the leaves, twigs, trunks, and roots which then carry out the photosynthesis process on the leaves, then convert it into organic carbon (carbohydrates) and then store it in the form of biomass on the trunk, leaves, roots, branches, and twigs (Iswandar *et al*., 2017).

The significant correlation between diameter and biomass is thought to be related to the rate of carbon absorption and the physiological process of plants, namely photosynthesis. In the process of photosynthesis, CO_2 in the atmosphere is fixed by plants. The carbon not only serves as chemical energy in plants but also provides a carbon skeleton for organic molecules that make up the structure of plants. In general, carbon, hydrogen, and oxygen assimilated into organic molecules through photosynthesis make up 96% of the total plant biomass. The greater biomass produced from the photosynthesis process will affect plant growth, both primary and secondary growth (Nedhisa and Tjahjaningrum, 2019).

Table 7 shows that the average mangrove carbon storage is 99.17 tons $^{ha-1}$. The biomass content and carbon storage for each type of mangrove vegetation will differ depending on the density of the wood. The higher the wood density, the more biomass content. This is in line with the research of Rahim *et al*. (2018), stating that stored carbon stocks are determined by biomass observed in the field, namely based on tree diameter measurements. An observation *sampling* that has a larger diameter tree than another *sampling* can indicate that the biomass in the sampling is large, so the carbon storage is also large.

The results of the calculation of Kendari Bay mangrove carbon storage by the plot are presented in Table 8. Table 8 shows that the ability of mangrove vegetation to store carbon is highest in plot three at 42.66 tons $^{ha-1}$, while plot five has the lowest ability at 4.08 tons $^{ha-1}$. Mangrove vegetation in plot three has the highest ability to store carbon because the area has a high density of mangrove vegetation and is supported by many mangroves that have a large stem diameter, while in plot five mangrove vegetation density is low and has a small stem diameter. This is reinforced by Mardliyah *et al*. (2019), who that tree diameter has a close relationship with its biomass, where the growth of a tree stand will affect the value of biomass and carbon stored, due to the absorption of CO_2 from the atmosphere through photosynthesis which produces biomass and causes additional diameter and height of a tree. The size of the tree diameter is influenced by the age factor of the tree stand. Total carbon storage in mangroves based on the location area of Kendari Bay *mangrove tracking* area Lahundape Village is shown in Table 9. which is 198.32 tons of carbon. Carbon content in plants illustrates how much the plant can bind CO_2 from the air. Plants absorb CO_2 from the air and then convert it into organic matter through the process of photosynthesis which is used for growth. Based on the results of this study it can be seen, that if the existence of this mangrove area does not exist then carbon by 90.99 tons of carbon will remain free in the atmosphere, and as a result, the carbon content in the atmosphere will increase which will ultimately affect global warming.

Conclusions

Based on the research results, it can be concluded that the average carbon uptake in the Kendari Bay Mangrove Tracking area of Lahundape West Kendari Subdistrict is 90.99 tons ha-1. Average The average carbon storage stored in the Tracking Mangrove area of Kendari Bay, Lahundape Village, West Kendari Subdistrict is 24.79 tons ha-^{1}.

Conflict of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

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