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Article

Measurement of C-Organic Content in Sediment as an Indicator of Carbon Absorption Potential in the Bonto Bahari Mangrove Ecosystem, Maros Regency

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Abstract. Mangrove ecosystems play an important role in mitigating global warming through their ability to absorb and store carbon in biomass and sediment. This research analyzes the organic carbon content and carbon sequestration potential in mangrove sediments in Bonto Bahari, Maros Regency, South Sulawesi. Using purposive sampling method, sediment samples were taken from 9 points with 5 different depths (0-50 cm) and analyzed using the Loss on Ignition (LOI) method. The results showed very low bulk density values (0.01-0.02 g/cm³) with the highest value at a depth of 20-30 cm. Carbon concentrations were relatively uniform (1.5-2.0%) at all depths with the highest concentration at a depth of 40-50 cm (1.93%). The highest carbon content was found at a depth of 40-50 cm (100.667 tons/ha) with carbon sequestration reaching 516.958 tons/ha, while the lowest value was at a depth of 0-10 cm (24.60 tons/ha). There were significant differences ($p<0.05$) in carbon content and sequestration between depths of 0-10 cm and 20-30 cm. This research reveals that deeper sediment layers play an important role in carbon storage in mangrove ecosystems, providing significant implications for sustainable mangrove management and local ecosystem-based climate change mitigation efforts

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1. Introduction

The most concerning environmental problem today is climate change, which causes an increase in global average temperature, especially global warming marked by a continuous increase in the average surface temperature of the earth. Global warming is a consequence of the greenhouse effect caused by increased concentrations of various gases in the atmosphere, including carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O), ozone (O_3), as well ashydrofluorocarbon (HFC) and chlorofluorocarbon (CFC) compounds, which result in solar radiation being trapped in the earth's atmosphere [1]. Global warming is also an urgent problem with profound implications for many aspects of life, including the environment, economy, and public health [2].

Global warming has become a field concern because of its broad and long-term impact on the climate system and life on earth. This phenomenon has prompted the search for solutions that utilize nature's ability to absorb and store carbon [3]. To address this challenge, scientists have identified several key ecosystems that play an important role in the global carbon cycle [4]. Mangrove ecosystems can absorb and accumulate carbon in their biomass and sediment layers, and play an important role in maintaining the balance of the global carbon cycle [5].

Indonesia has a vital role in mitigating global warming through mangrove ecosystems. Indonesia has about 25% of the world's total mangrove area, with carbon stocks reaching 3.14 (Pg) [4]. Global climate change mitigation efforts have identified mangrove ecosystems as one of the promising nature-based approaches. The characteristics of mangrove ecosystems with high biological productivity enable them to function as reservoirs of organic carbon storage in the sediment layer [6]. In addition, the organic C content in sediments can indicate the health of mangrove ecosystems. High organic C content indicates optimal ecosystem productivity and its ability to absorb carbon [7]. Measuring organic C content in mangrove sediments helps identify locations with high sustainable carbon storage potential that maintain and enhance the role of mangroves as carbon absorbers [8].

The ability of mangrove ecosystems to absorb atmospheric carbon through photosynthesis and store it in the form of biomass or sediment per unit area is referred to as the efficiency of carbon absorption and accumulation per unit area. This makes mangroves an extraordinary environment compared to other environments. The presence of mangrove sediments capable of storing large amounts of carbon below the ground makes them a vital component in efforts to mitigate the impacts of climate change [9]. Organic carbon in sediments is one of the main components of organic compounds in aquatic environments, plays a role in improving soil quality, and functions as a carbon store [10].

Mangrove ecosystems are vulnerable to damage caused by human activities and natural processes. Reduction in mangrove area can reduce carbon absorption capacity, which ultimately contributes to global warming [11]. Changes in environmental conditions, such as disturbances due to land use changes, can disrupt the capacity of mangroves to absorb and store carbon, triggering the release of large amounts of greenhouse gases into the atmosphere [12]. Carbon storage in sediments is influenced by its source, including the type of species involved, as well as changes in environmental factors, which can cause fluctuations in the amount of carbon stored [8]. In addition, soil density and depth are very important; thicker sediments generally store more carbon [13].

The carbon content stored in mangrove ecosystems is very vulnerable to changes in environmental conditions, this can affect biogeochemical processes in coastal areas and their significant feedback effects on climate [14]. The carbon content stored in soil or sediment is estimated to be twice as much as the amount of carbon in the atmosphere [15]. Furthermore, carbon storage in mangrove sediments is five times greater than tropical rainforests, making it one of the most effective carbon sinks in the world [16]. Carbon storage refers to the amount of carbon that can be absorbed and stored by soil in the form of organic matter. This carbon serves as an energy source for organisms living in the soil and also acts as a component that contributes to the formation of soil structure [10].

Research on organic carbon content in mangrove sediments has been conducted in several areas in Indonesia. Research related to organic carbon content in mangrove sediments in the Karimunjawa Mangrove Vegetation Area by Hickmah et al., (2021) [6], total organic carbon storage in mangrove sediments in Karimunjawa. Analysis was carried out using the Loss on Ignition (LOI) method to determine organic carbon content, as well as measurements of sediment density, pH, and sediment grain size. The results show that organic carbon storage is influenced by sediment mass density, carbon content, sample depth, sediment pH, as well as size and type of sediment particles. Meanwhile, research conducted by Mashoreng et al., (2022) [17], sediment organic matter content ranged from 5.77% to 7.40%, with a total organic matter of 2,769 tons in an area of 6.5 ha, showing great potential in carbon storage. Research conducted by Hasidu et al., (2023) [5], showed the highest organic carbon content recorded at Station 1 with a value of 233.67 ± 11.90 Mg C ha^{-1}, showing great potential in CO_2 absorption of 856.77 ± 37.66 Mg CO_2 ha^{-1}. Various studies have revealed the important role of mangrove ecosystems in storing organic carbon, most of these studies are still focused on certain regions.

Research on organic carbon content in mangrove sediments provides crucial data to understand the true potential of these ecosystems in long-term carbon absorption. In addition, the location of mangrove ecosystems is generally relatively stable and has a high rate of organic matter accumulation, which allows carbon content analysis to be carried out representatively. South Sulawesi in Maros Regency has a fairly extensive mangrove ecosystem. One of the mangrove ecosystems in Maros Regency, namely Bonto Bahari, still lacks information regarding organic carbon content and carbon sequestration potential in the Bonto Bahari mangrove ecosystem, Maros Regency. This study aims to determine the amount of organic C content and carbon sequestration in the sediments of the mangrove ecosystem in Bonto Bahari and the factors that influence carbon storage in mangrove sediments as well as provide data on the potential for carbon sequestration from measuring organic C content in the sediments of the mangrove ecosystem in Bonto Bahari which can contribute to sustainable mangrove management and support local ecosystem-based climate change mitigation efforts.

2. Experimental Section

2.1. Study site

This research was conducted in 2024 in the mangrove area of Bonto Bahari, Bontoa District, Maros Regency. The sampling location is shown in Figure 1.

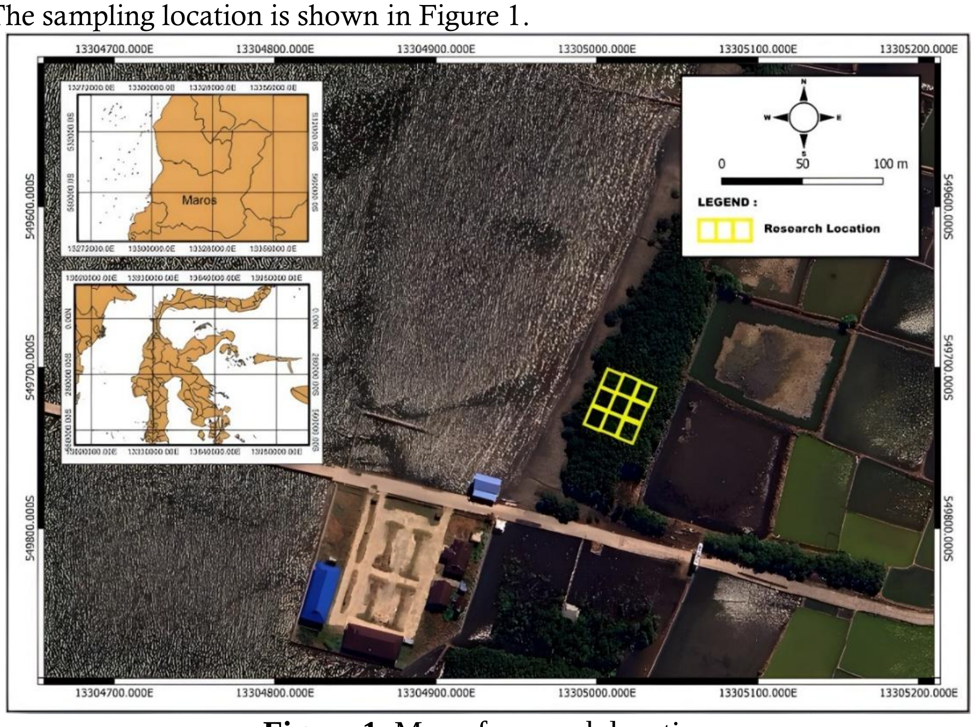

Figure 1. Map of research location

The selection of the mangrove area in Bonto Bahari, Maros Regency, South Sulawesi as a research location is because the mangrove ecosystem in this area has unique characteristics as it is located in the transition zone between the karst formation of Bantimurung - Bulusaraung National Park and the coast of Makassar Strait, creating specific geomorphological and hydrological conditions that potentially affect carbon dynamics. Although mangrove ecosystems have been extensively studied in various regions of Indonesia, there has been no comprehensive study specifically measuring organic C content in sediments and carbon sequestration potential in the Bonto Bahari area.

2.2. Materials

In this research, the tools used include GPS (to determine sampling location coordinates), sedimentcore sampler (to collect sediment samples), plastic bags/sample plastic (to store samples), cool box (to maintain sample temperature), knife/spatula (for cutting and moving samples), analytical balance (to measure sample weight), oven (to dry samples), furnace (for sample burning), and soil sieve (to pulverize samples).

The materials used include sediment samples from mangrove ecosystems, as well as labels and sample storage containers to ensure proper identification during laboratory analysis, and chemical materials such as distilled water, filter paper, and reagents for organic carbon content analysis in the laboratory.The flow diagram for analyzing organic C content and carbon sequestration in mangrove ecosystem sediments is as follows.

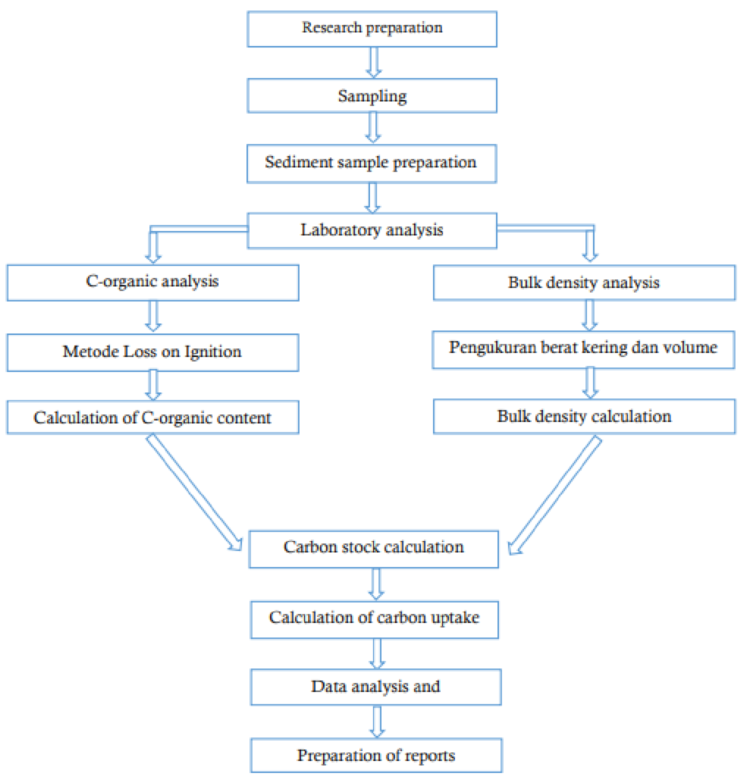

Figure 2. Analysis flow diagram

2.3. Sampling Procedure

The method used in determining sampling points is *purposive sampling method.* Sampling was done at nine points. Sediment samples were taken using *sediment core the sampler* is inserted into the sediment consisting of 5 depths of 10 cm each, namely 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm. Then each depth of sediment sample is inserted into a plastic sample bag and given a name or label on each plastic sample bag to facilitate identification and analysis in the laboratory.

2.4. Sample Analysis

The Chemical Oceanography Laboratory of the Faculty of Marine Sciences and Fisheries at Hasanuddin University conducted testing for organic carbon content in soil and sediment samples using the Loss on Ignition (LOI) Method. Analysis of sediment C-organic was performed using the *loss on ignition* (LOI) method [18]. Limited access to advanced laboratory facilities made the simpler LOI method a more realistic alternative compared to methods requiring complex instrumentation and research in previously unstudied areas; the LOI method offers an optimal balance between ease of implementation and accuracy of results. The weight of material lost after burning is measured as Loss on Ignition (LOI), which is one way to measure organic content in samples such as soil or silt [16]. For the purpose of carbon analysis in sediments, the Loss On Ignition (LOI) technique was used, which involves weighing the sample that is lost after use [19]. Various parameters such as organic carbon concentration, bulk density, carbon content, and carbon sequestration were examined in the samples. One easy way to estimate the organic matter content in soil or sediment samples is through the LOI method. LOI procedure for Loss on Ignition (Equation 1) [8].

$$\%\boldsymbol{LOI} = \frac{(\boldsymbol{Wo}-\boldsymbol{Wt})}{\boldsymbol{Wt}} \times \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where:
Wo : weight of sediment before combustion
Wt : weight of sediment after combustion

Bulk density

Bulk density or soil density was the weight of the dried soil mass per unit volume (Ramanda Reza Aldiano et al., 2023) . The formula used to calculate bulk Soil density (BD) was presented in equation 2 [21]

$$\boldsymbol{Soil\ density} = \frac{\boldsymbol{Oven\ dry\ mass\ (g)}}{\boldsymbol{Sampel\ volume\ (Cm3)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

Where:
Soil density : Content of mud substrate (grams/cm ^{3})
Oven- dry mass : Mass of dried sample (grams)
Sample volume (cm ^{3}) : Sample volume (cm ^{3})

Soil Carbon Content

The carbon content stored in mangrove soil can be calculated after we know the bulk density value. soil density. Calculation of carbon content in mangrove soil was used in equation 3 [22].

$$\mathbf{Ct= Kd\ x\ \rho\ x\ \%\ organic\ (gram/cm^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

Where:
Ct : Soil carbon content (g/cm2)
Kd : Depth of soil sample (cm)
ρ : Bulk density (g/cm3)
% C organic : Percentage value of carbon content, use the carbon percentage determined by laboratory testing.

Calculation of Soil Carbon Content Per Hectare (equation 4)

$$\mathbf{C\text{-}soil= Ct\ x\ 100\ (ton/ha)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(4)}$$

Where:
C_{soil} : Soil organic content per hectare, expressed in tons per hectare (ton/ha)
Ct : Soil carbon content (g/cm ^{2})
100 : Conversion factor from g/cm2 $^-$ ton/ha
(1 g = 0.001 kg = 0.000001 tons)
(1 cm ^{2} = 0.0001 m ^{2} = 0.00000001 ha)

Carbon Absorption

The calculation of carbon absorption uses calculations based on the comparison of the relative atomic mass of carbon (C) with a predetermined formula (5) [23].

$$CO_2 = Cn \times 3.67 \text{ .... (5)}$$

Where:
Cn : Carbon content per hectare in each carbon source in each plot (Ton/ha)
3.67 : Equivalent number or conversion of element C to CO2 (atomic mass of C = 12 and O = 16,
CO2 : (1x12) + (2x16) = 44; the conversion is (44:12) = 3.67)

2.5. Data Analysis

Data analysis was conducted using two approaches. First, using descriptive analysis to provide a general overview of the distribution and characteristics of C-organic content in mangrove sediments. Second, involving inferential analysis using ANOVA to test whether there is a statistically significant difference between the average organic carbon content from several depths of mangrove sediment. One-way ANOVA test was applied to test the significance of differences in mass density and carbon concentration at various depths. Meanwhile, two-way ANOVA testing was carried out using GraphPad Prism 8 to evaluate significant differences in CO_2 storage and absorption at various sediment depths. The significance level was set at $p < 0.05$ and the analysis results were visualized in the form of graphs to show variations in storage and absorption of organic carbon at each depth.

3. Results and Discussion

3.1. Bulk Density

Figure 3 shows the average mass density level of sediments in the Bonto Bahari mangrove ecosystem, which varies at different sediment depths, with values ranging from 0.01-0.02 g/cm³. The highest mass density value is found at a depth of 20-30 cm with a value of 0.017 g/cm³, while the lowest value is found at depths of 30-40 cm and 40-50 cm with a value of 0.011 g/cm³.

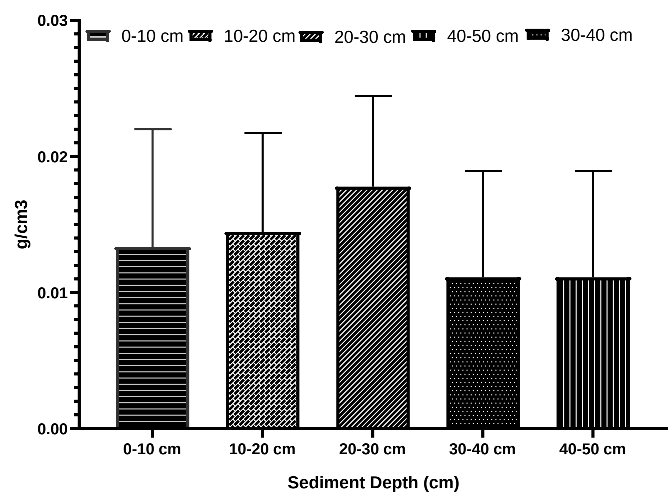

Figure 3. Bulk density graph based on depth levels ($\bar{X} \pm SE, N = 9$)

Statistical test results for mass density did not show any significant variation with depth ($P < 0.05$). Based on the results obtained in the Bonto Bahari mangrove ecosystem, bulk density values ranged from 0.01-0.02 g/cm³, which is classified as very low for sediments in general. At a depth of 0-10 cm, the bulk density value was recorded at 0.013 g/cm³, then increased to reach the highest value of 0.017 g/cm³ at a depth of 20-30 cm. Subsequently, the bulk density value decreased in deeper layers, reaching 0.011 g/cm³ at a depth of 30-50 cm.

The increase in bulk density values from the surface to a depth of 20-30 cm is possibly caused by several factors, including natural sediment compaction, decreased organic matter content with increasing depth, and pressure from the layers above. Meanwhile, the decrease in bulk density values at depths of 30-50 cm may be caused by differences in sediment layers, intensive mangrove root activity at that depth, or anaerobic conditions affecting the decomposition of organic matter.

A bulk density value >1 indicates high density, and <1 indicates low density. This shows that the density of soil or sediment in the Bonto Bahari mangrove ecosystem is very low and less compact, so it can affect organic matter in mangrove sediments in Bonto Bahari. According to research by Sitanggang et al., (2025) [24], it was identified that bulk density is one of the main factors affecting carbon stocks and carbon sequestration rates in mangrove ecosystems. Variations in bulk density can indicate differences in carbon storage capacity between various mangrove habitats. Differences in soil density values are due to several factors, such as differences in intervals used in sampling. Smaller sediment particle sizes result in tighter particle arrangement, thereby increasing sediment density [21]. Conversely, sediments with larger or coarser grains tend to have more space between particles, resulting in lower density. Factors that can influence bulk density include soil composition, land use, and environmental conditions [25].

Statistical testing did not find statistically significant variations in mass density between sediment depths ($p>0.05$). This is possibly because factors affecting mass density, such as sediment composition, organic matter content, and physicochemical processes, provide relatively uniform effects throughout the sediment column. According to Anti et al., (2023) [25], factors influencing mass density include soil composition, land use, and environmental conditions. Additionally, according to Harahap et al., (2021) [26], mass density is influenced by texture, structure, and organic matter content, which causes rapid changes due to soil processing and agricultural practices. This indicates that location has an influence on bulk density values. In addition, low bulk density values can also be caused by increased biomass values and undecomposed organic sediment material [27].

3.2. Carbon Concentration

Figure 4 shows the average level of carbon concentration in sediments of the Bonto Bahari mangrove ecosystem at various sediment depths from 0-50 cm. Carbon concentration values range from 1.5-2.0%.

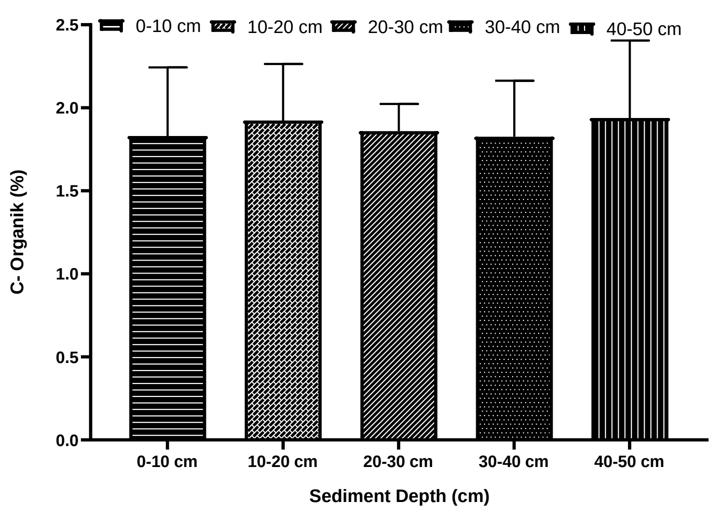

Figure 4. Carbon concentration graph based on depth levels ($\bar{X} \pm SE, N = 9$)

The highest carbon concentration is found at a depth of 40-50 cm with a value of 1.93%. The lowest carbon concentration is found at a depth of 20-30 cm with a value of 1.82%. Overall, the distribution pattern of carbon concentration is relatively uniform at all depths. Statistical testing of carbon concentration did not show significant differences between depths ($P < 0.05$). The highest carbon concentration is found in the deepest analyzed layer at a depth of 40-50 cm with a value of

1.93%. This indicates a significant accumulation of carbon in the deep sediment layer. Meanwhile, the lowest concentration was recorded at a medium depth of 20-30 cm with a value of 1.82%, which is possibly influenced by the dynamics of organic matter decomposition and microorganism activity in that zone. This finding is in line with previous research by Liu et al., (2020) [28], which showed that mangrove expansion in the Nanliu River estuary increased the accumulation of organic carbon in sediments. Deeper sediment layers show higher carbon content, reflecting the process of deposition and preservation of organic matter over a long period of time.

The distribution of carbon at various depths of mangrove sediment was found, and variations in carbon concentration are influenced by environmental characteristics and sedimentation processes. According to Sumarni et al., (2024) [11], the distribution of organic carbon in mangrove sediments shows that carbon concentration tends to increase with increasing depth. The uniformity of carbon distribution observed along the depth profile is supported by the results of statistical tests of carbon concentration which show no significant difference between depths ($P > 0.05$). The distribution of organic carbon in mangrove sediments often shows a uniform pattern at various depths. This finding is supported by analysis of the consistency of carbon concentration between layers which indicates the homogeneity of sediment texture. Research in Selangan Village, East Kalimantan, found that organic carbon concentrations ranged from 1.70% to 4.90% with an average of 2.72 ± 0.20%, and there were no significant differences between sediment layers [29].

3.3 Carbon Content and Carbon Absorption

Figure 5 shows the distribution pattern of carbon content and sequestration at each depth in the Bonto Bahari mangrove ecosystem. For carbon content, values range from 25-100 Tons/ha.

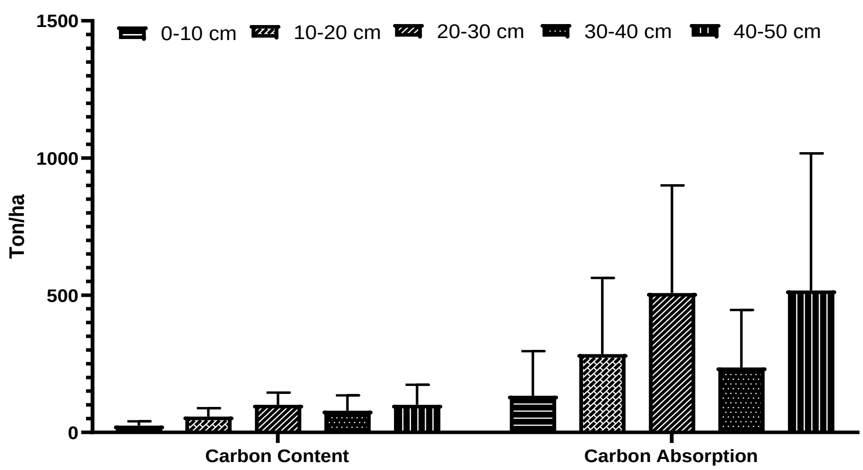

Figure 5. Carbon content and absorption graph based on depth ($\bar{X} \pm SE, N = 9$)

The highest value is found at a depth of 40-50 cm at 100.667 Tons/ha, while the lowest value is found at a depth of 0-10 cm at 24.60 Tons/ha. Carbon sequestration shows greater variation with values ranging from 100-500 Tons/ha. The highest carbon sequestration is found at a depth of 40-50 cm at 516.958 Tons/ha, while the lowest is found at a depth of 0-10 cm at 133.616 Tons/ha.

The results of carbon content and carbon sequestration analysis show a significant difference ($p < 0.05$) in the comparison of depths of 0-10 cm with 20-30 cm for both parameters. Meanwhile, comparisons between other depths did not show significant differences ($p > 0.05$), indicating that variations in carbon content and sequestration are relatively uniform at those depths. These results indicate that a depth of 20-30 cm has significantly higher carbon content and sequestration values compared to a depth of 0-10 cm. In contrast, carbon distribution at other depths tends to be homogeneous. Other research shows significant differences in carbon content and sequestration at various depths of mangrove sediment. At depths from 30-60 cm, carbon storage values reach 5,224.70

tons/ha, for research in Jeruju Besar Village, West Kalimantan [11]. Conversely, the values are lower in the uppermost layer (0-10 cm). Carbon concentration at 50 cm reaches 591.253 tons C/ha, but at 10 cm it is only 519.354 tons C/ha, according to a study in the Tapak mangrove area, Tugurejo Village, Semarang [30].

These differences may be caused by increased particle density and sedimentation of organic matter with increasing depth. In addition, anthropogenic activities such as land conversion and tree cutting can reduce carbon content in the surface layer [31]. Oxygen plays a crucial role in bacterial activity and the decomposition of organic matter. When oxygen availability in sediment is limited, the decomposition process by bacteria can be inhibited. With increasing depth, oxygen levels decrease, resulting in lower organic carbon content in deeper sediment layers [8]. Variations in carbon sequestration include vegetation type and plant root systems. Plant roots that penetrate deeper depths can help influence carbon absorption and increase organic matter content in lower soil layers. Additionally, land use also plays a role in soil carbon distribution [32].

Various factors, including vegetation type, plant root systems, and land use, affect variations in soil carbon absorption. The ability of plant roots to reach deeper soil layers is very important for carbon absorption and organic matter enrichment within them. Number ten. According to research by Mutahharah et al., mangrove roots can absorb 1.60 to 2.64 tons of carbon dioxide per hectare, and their carbon content ranges from 0.44 to 0.72 tons/ha [32]. By understanding the factors that influence the distribution of carbon absorption at various soil depths, sustainable land management can be implemented to increase the soil's capacity to store carbon. This is important in mitigating climate change and maintaining the soil ecosystem's balance.

4. Conclusion

The research results in the Bonto Bahari mangrove ecosystem show an average value in soil density (bulk density) and carbon distribution. Bulk density at this location is very low (0.01-0.02 g/cm^3), with the highest value at a depth of 20-30 cm, although it does not show significant differences between depths. Sediment carbon concentration shows a uniform pattern (1.5-2.0%) in the 0-50 cm depth range, with the highest concentration found at a depth of 40-50 cm (1.93%). Regarding carbon content and absorption, there is an interesting variation where the highest value is found at a depth of 40-50 cm (carbon content 100.667 tons/ha and carbon absorption 516.958 tons/ha), while the lowest value is at a depth of 0-10 cm (carbon content 24.60 tons/ha and carbon absorption 133.616 tons/ha).

Significant differences were found between depths of 0-10 cm and 20-30 cm for both parameters. The distribution of carbon is influenced by several things such as sedimentation, microbial activity, plant root systems, and environmental conditions. This research shows that deeper soil layers are critical in storing carbon in mangrove forests, which has implications for how land is managed to mitigate climate change and maintain the balance of nature.

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