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Biomass and Carbon Stock Estimation in Different Mangrove Areas in Mangunharjo Village, Semarang, Indonesia

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Abstract

Mangroves are one of the coastal ecosystems that play a crucial role in carbon storage. This study aims to determine the differences in biomass and carbon stock values across different mangrove areas, namely natural, mangroves near aquaculture ponds, and rehabilitated mangrove in Mangunharjo Subdistrict, Semarang. The method used in this study was a field survey intended to measure the diameter of mangrove tree trunks as the baseline data for calculating mangrove stand carbon stock. The research was conducted in three areas selected using purposive sampling: natural mangroves, mangroves near aquaculture ponds, and rehabilitated mangroves, with each area consisting of two sampling stations and three transect plots, each. The size of the transect plots used was 10 m × 10 m. Data collection employed a non-destructive method based on allometric equations to estimate mangrove stand biomass. The results showed that the rehabilitated mangrove area had the highest average biomass and carbon stock values, with biomass of 290.47 ± 23.19 tons/ha and carbon stock of 127.60 ± 10.23 tons/ha, followed by the near aquaculture ponds mangrove area with biomass and carbon stock values of 268.39 ± 66.16 tons/ha and 117.63 ± 28.96 tons/ha, respectively. The lowest values were found in the natural mangrove area, with biomass and carbon stock values of 264.25 ± 57.23 tons/ha and 115.85 ± 25.30 tons/ha, respectively. The average carbon stock value in Mangunharjo Subdistrict is greater when compared to the carbon stock value in Mangrove Bay, Australia, which is only 45 tons/ha, but is smaller when compared to the carbon stock value at the mouth of the Batang Apar River, Pariaman, West Sumatra, Indonesia, which has a carbon stock value of 313.52 tons/ha.

1. Introduction

Global warming is one of the issues faced by communities worldwide, characterized by a significant increase in temperature and unpredictable weather conditions due to the rising concentration of greenhouse gases, notably carbon dioxide (Al-Ghussain *et al.*, 2019). The phenomenon of rising temperatures or global warming has negative impacts, one of which is the rise in sea levels. Sea level rise affects the changing conditions of coastal ecosystems and exacerbates coastal flooding and erosion (Tebaldi *et al.*, 2021). One of the efforts to address global warming is to optimize the role of mangrove ecosystems as carbon dioxide absorbers.

Mangroves are one of the ecosystems found in intertidal marine areas, growing in tropical and subtropical regions. Mangroves are known as ecosystems that provide various ecosystem services such as fish habitat, protection for coastal areas, and the capacity to absorb and store large amounts of carbon (Arifanti *et al.*, 2022). Mangrove forests play a critical role in climate change mitigation because they can absorb and store 3–5 times more carbon than other upland forests (Aye *et al.*, 2022). The carbon value contained in mangrove vegetation represents the potential of mangroves in carbon storage (carbon stock) in the form of biomass. Biomass in mangrove stands can be divided into two categories, namely Above Ground Biomass (AGB) and Below Ground Biomass (BGB) (Virgulino-Júnior *et al.*, 2020). Above-ground biomass comes from trunks, leaves, and branches, whereas below-ground biomass comes from roots (Waring and Powers, 2017).

The mangrove area in the Mangunharjo sub-district is one of the ecosystems that contributes to climate change mitigation through carbon storage. This area is located on the coast of Semarang City and has experienced various dynamics in land use changes, one of which is the conversion of land into shrimp farms. The area of mangroves in the Mangunharjo sub-district in 2021 was 60.3 hectares. The lowest mangrove area recorded was in 2022, at only 7.5 hectares, while the highest was in 2017 with an area of 73.4 hectares. The mangrove area in the Mangunharjo sub-district has declined over the period from 2017 to 2021, with a decrease of 12.9 hectares (Saputra *et al.*, 2025).

The presence of aquaculture activities around the mangrove areas is suspected to influence the growth of mangroves, which consequently affects their carbon storage capacity. Nevertheless, some areas of mangrove in Mangunharjo are still well-preserved as natural vegetation and as rehabilitation areas as part of ecosystem recovery efforts. However, the extent of success of these rehabilitation efforts in restoring the ecological functions of mangroves, particularly in terms of carbon storage capacity, remains a question. Therefore, this research was conducted to determine the differences in biomass values and carbon stock of mangrove stands in natural mangrove areas, around the ponds, and rehabilitation areas within the Mangrove Mangunharjo area. The results of this study are expected to provide insights into the contribution of each area in carbon storage and to support policies for sustainable mangrove ecosystem management.

2. Material and methods

2.1 Materials

Mangrove is the object of this study, which was observed in the Mangunharjo sub-district, Semarang City, Indonesia. The primary tools used in this research are GPS (Global Positioning System) for measuring plot coordinates and a tape measure for measuring tree diameter. Environmental parameters were also tested both directly and in the laboratory. Temperature, salinity, and pH were measured in situ using a thermometer, refractometer, and pH meter. Meanwhile, the concentrations of nitrate and phosphate were tested using a spectrophotometer with nitrate reagent (NitraVer 5 Nitrate Reagent Powder Pillows) and phosphate reagent (PhosVer 3 Phosphate Reagent Powder Pillows).

2.2 Methods

2.2.1 Sampling Site

The research was conducted in February 2025 in Mangunharjo Sub-district, Semarang City, Indonesia. The study employed a field survey method to obtain data on species, trunk diameter, and mangrove density in accordance with natural conditions in the field (Dharmawan, 2020). Data collection was carried out in three different areas that were determined purposively, namely the natural mangrove area, around the pond, and the rehabilitation area. Each area consisted of two research stations. Each research station comprised three plots of 100 m². The creation of observation plots was conducted following Aliviyanti *et al.* (2020), by establishing plots measuring 10 m × 10 m, which were placed parallel to the shoreline with a distance of 10 m between each plot. The research location map is presented in Figure 1.

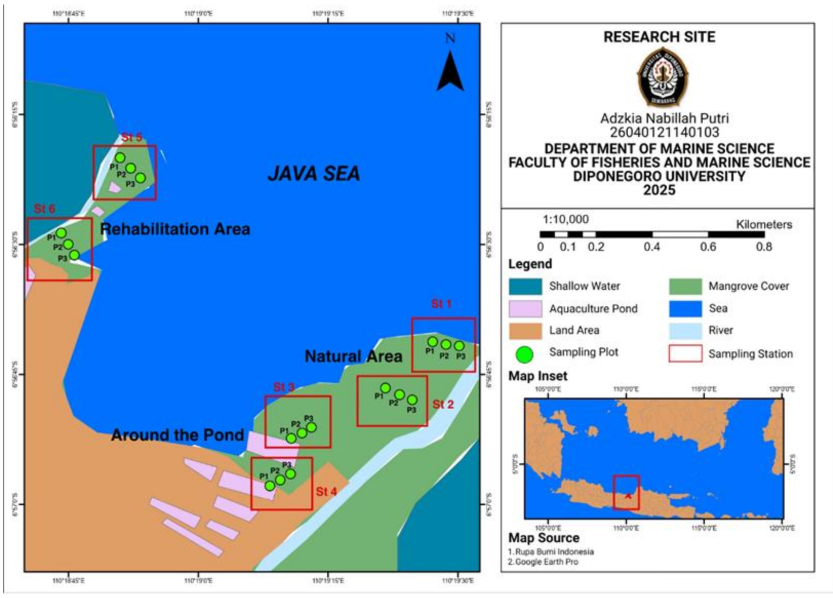

Figure 1. Research Location Map

2.2.2 Data Collection Methods

The measurement of tree trunk diameter was conducted using the Diameter at Breast Height (DBH) method, wherein each individual mangrove tree within the observation plot is measured using a tape measure at a height of 1.3 meters from the ground surface, and trees with a diameter < 5 cm are collected and counted (Aye *et al.*, 2022). Meanwhile, environmental parameter measurements were conducted in situ using portable instruments, namely a refractometer for salinity, a thermometer for temperature, and a pH meter for measuring pH, with each being repeated three times. The testing of nitrate and phosphate levels was carried out by taking a 100 ml water sample into a plastic bottle wrapped in black plastic. The water samples were then tested using a spectrophotometer with nitrate and phosphate reagents at the Fisheries Resource Management Laboratory, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Central java, Indonesia.

2.2.3 Analisis of Mangrove Density

The vegetation data that has been collected is analyzed to determine the density of mangroves with reference to Muller-Dombois and Ellenberg (1974), as follows:

$$Tree\ Density = \frac{\sum Individual\ trees\ counted}{Area\ of\ the\ sampling\ plot}$$

2.2.4 Calculation of Mangrove Biomass

The biomass calculation is carried out using allometric equations that include the computation of Above Ground Biomass and Below Ground Biomass (Komiyama *et al.*, 2005). The allometric equation for determining the biomass value of mangrove trees is presented in Table 1.

Table 1. Allometric Equations for Mangrove Species.

Number	Allometric Equation	Sources
1	$AGB = 0{,}251 \times \rho \times D^{2{,}46}$	Komiyama *et al.* (2005)
2	$BGB = 0{,}199 \times \rho^{0{,}899} \times D^{2{,}22}$	Komiyama *et al.* (2005)

Where is: AGB = Above Ground Biomass (kg/m2); BGB = Below Ground Biomass (kg/m2); ρ = Wood density (gr/cm2); D = Diameter of Tree Trunk (cm)

The wood density of each species has different values. The wood density values of the two species are presented in Table 2.

Table 2. The Wood Density of Mangrove Species

Number	Species	ρ (g/cm)	Sources
1	*Rhizophora mucronata*	0.79	Ardhana *et al.* (2018)
2	*Avicennia marina*	0.65	Lukman *et al.* (2022)

2.2.5 Carbon Stock Calculation of Mangrove Stands

After the biomass values are determined, the calculation of blue carbon stock is then carried out by converting AGB and BGB. The carbon conversion factors used are 46% for aboveground carbon (AGC) and 39% for belowground carbon (BGC) (Howard *et al*., 2014). The calculation of tree biomass carbon stock can be seen in Table 3.

Table 3. Calculation of Carbon Stock in Mangrove Stands

Number	Equation	Sources
1	$AGC = B \times 0{,}46$	Howard *et al*. (2014)
2	$BGC = B \times 0{,}39$	Howard *et al.* (2014)

Where is: AGC = Above Ground Carbon (ton/ha); BGC = Below Ground Carbon (ton/ha); B = Biomass (ton/ha).

3. Results

3.1 Research Environment Conditions

The environmental conditions of the aquatic ecosystem in mangrove environments are significantly influenced by various physical and chemical parameters. In this study, the environmental qualities observed include temperature, salinity, pH, nitrate, and phosphate. The average values of each water quality parameter can be seen in Table 4.

Table 4. Environmental Parameters

Areas	**Temperature (ºC)**	**Salinity (ppt)**	**pH**	**Nitrate (mg/L)**	**Phosphate (mg/L)**
Natural	28.70 ± 0.75	19.60 ± 0.84	7.46 ± 0.15	2.55 ± 0.07	0.86 ± 0.08
Around the Pond	28 ± 0.20	24.67 ± 0.63	7.42 ± 0.18	2.15 ± 1.06	2.42 ± 0.82
Rehabilitation	27.44 ± 0.11	10.67 ± 5.34	7.49 ± 0.17	1.3 ± 0	0.48 ± 0.08

Table 4 shows that the average values of temperature, water pH, and salinity in the three areas indicate relatively close ranges, although the rehabilitation area has lower salinity compared to the natural area and around the pond. The concentrations of nutrients in the form of nitrates and phosphates in the three areas also vary. The nitrate concentration in the natural area and around the pond is above 2 mg/L, while in the rehabilitation area, the concentration is much lower, at only 1.3 ± 0 mg/L. Meanwhile, the phosphate concentration in the area around the pond is 2.42 ± 0.82 mg/L, which is significantly higher compared to the natural and rehabilitation areas, both of which have phosphate concentrations of less than 1 mg/L.

3.2 Diameter Breast Height

Based on the field data collection results, two species of mangroves were identified, namely *Avicennia marina* and *Rhizophora mucronata*, with varying diameters at breast height (DBH). This data can be seen in Table 5.

Table 5. Average Diameter of Tree Trunks in the Research Area

Areas	**Species**	**Number of Mangroves Found**	**DBH (cm)**	**Average DBH ± Standard Deviation (cm)**
Natural	*A. marina*	158	5.10 - 26.27	10.82 ± 3.68
Around the Pond	*A. marina*	134	5.10 - 27.55	9.52 ± 4.35
	R. mucronata	62	5.73 - 13.22	9.36 ± 2.08
Rehabilitation	*A. marina*	75	7.01 - 23.57	15.38 ± 4.31
	R. mucronata	15	6.37 - 12.42	8.94 ± 1.87

Table 5 shows that the largest number of mangroves was found in the area around the ponds with a total number of 196 individuals, followed by the natural mangrove area and the rehabilitation area was the smallest. The number of individuals found does not always correlate with the average DBH value of the mangroves. The rehabilitation area has the highest average DBH value, followed by the natural mangrove area, and then the area around the ponds. Overall, the average DBH value of *Avicennia marina* found at the research site is relatively larger, ranging from 9.52 ± 4.35 to 15.38 ± 4.31 cm, while *Rhizophora mucronata* has a DBH ranging from 8.94 ± 1.87 to 9.36 ± 2.08 cm.

3.3 Mangrove Density

The density value of mangroves in a research area is greatly influenced by the number of mangrove individuals found. Based on the observations of mangrove vegetation at the research site, the three areas have varying density values. This data can be seen in Table 6.

Table 6. Mangrove Density in the Research Area

Area	Mangrove Density (ind/ha)	Status
Natural	2,633	Good/Very Dense
Around the Pond	3,267	Good/Very Dense
Rehabilitation	1,500	Good/Very Dense

Table 6 shows that the three research areas fall into the category of good/very dense density. The highest total density value is found in the area around the fishponds, followed by the natural area, and the rehabilitation area has the lowest density value.

3.4 Biomass Value of Mangrove Stands

The biomass value in mangrove stands is influenced by the size of the DBH of mangrove trees and the wood density of each species. The results of the data analysis show variations in the biomass value of mangrove stands in each research area. Figure 2 shows that the rehabilitated mangrove area has the highest average total biomass value, which is 290.47 ± 23.19 tons/ha, with AGB and BGB of 204.53 ± 16.93 tons/ha and 85.94 ± 6.26 tons/ha, respectively. This is followed by the area around the pond. The natural mangrove area was the lowest.

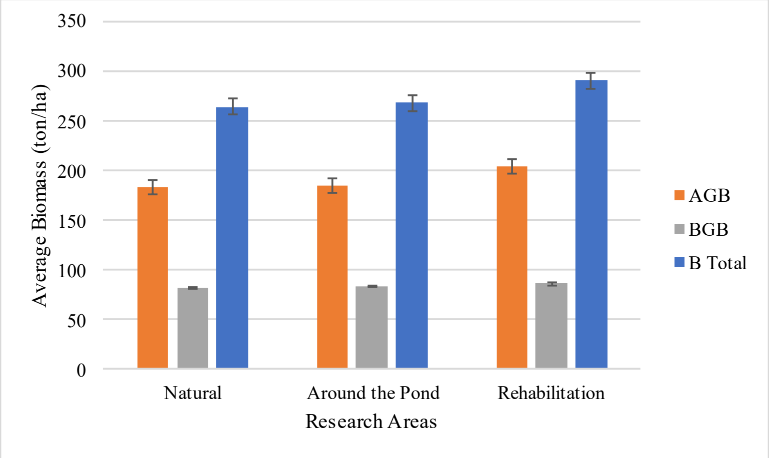

Figure 2. Average Biomass of Mangrove Stands in the Research Area

3.5 Carbon Stock Value of Mangrove Stands

The carbon stock value of mangrove stands in a research area is influenced by the amount of biomass. Data analysis results show variations in the carbon stock value of mangrove stands in each research area. Figure 3 shows that the highest average total carbon stock value is found in the rehabilitation area, which is 127.60 ± 10.23 tons/ha, with AGC and BGC values of 94.09 ± 7.79 tons/ha and 33.52 ± 2.44 tons/ha respectively. This is followed by the area around the ponds. The lowest total carbon stock value is found in the natural area. , which is 115.85 ± 25.30 tons/ha, with AGC and BGC values of 84.07 ± 19.61 tons/ha and 31.79 ± 5.69 tons/ha respectively.

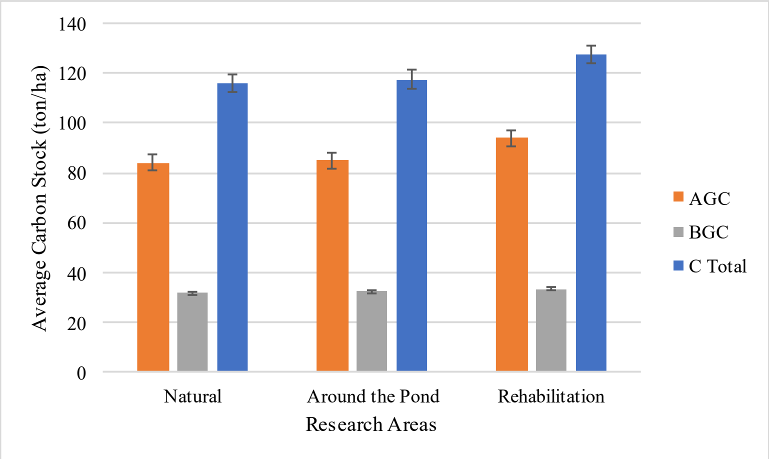

Figure 3. Average Carbon Stock of Mangrove Stands in the Research Area

4. Discussion

4.1 Research Environment Conditions

The research location is in the mangrove area located in Mangunharjo Village, Semarang City, Central Java, Indonesia. The area of Mangunharjo Village is 482.37 ha, with the mangrove area reaching 60.3 ha (Saputra *et al.*, 2025). The research was conducted in three different areas, namely natural mangrove area, around the pond, and rehabilitation. Observations at the research location showed that two types of mangrove were found, namely *Avicennia marina* and *Rhizophora mucronata*. When visually assessed, the substrate types in the three research areas consisted of muddy substrate, where muddy substrate is suitable for both types of mangroves. This is supported by the statement of Rosyid *et al.* (2020), that muddy substrate is very good for the stand of *Rhizophora mucronata* and *Avicennia marina.*

The results of environmental parameter measurements indicate that each area has varying environmental characteristics. The environmental parameters measured at the research locations include temperature, salinity, pH, nitrate, and phosphate concentrations presented in Table 4. The temperature at the research site ranges from 27.44 ± 0.11 °C to 28 ± 0.20 °C. This temperature range is still categorized as suitable for mangrove growth. This is supported by Indrazoa et al. (2024), who state that mangroves can grow and photosynthesize well at temperatures ranging from 25 – 35 °C. The pH values across all research areas range from 7.49 ± 0.17 to 7.42 ± 0.18. These values still comply with the quality standards of pH that are good for mangrove growth. This aligns with the statement of Tufiha *et al.* (2019), that the optimal pH for mangrove growth ranges from 6.5 – 8.5. The salinity at the research location ranges from 10.67 ± 5.34 to 24.67 ± 0.63 ppt. The values are still consistent with the quality standards and are classified as good for mangrove growth. This is in line with Badu *et al.* (2022), which states that the salinity levels suitable for mangrove growth range from 10 – 30 ppt.

The concentration of nutrients in the form of nitrate and phosphate also shows varying values. The highest nitrate concentration is found in the natural area, which is 2.55 ± 0.07 mg/L. The area around the pond also has a fairly high nitrate concentration, which is 2.15 ± 1.06 mg/L. The rehabilitation area has the lowest nitrate concentration of 1.3 ± 0 mg/L. The high nitrate concentration in the mangrove area around the pond and the natural area occurs because both areas are still close to aquaculture activities, so the waste input from the pond will increase the nitrate concentration in the research area. The high nitrate concentration in both areas is also influenced by the high density value, where a high density is suspected to produce larger mangrove litter. This is supported by research conducted by Ridwan *et al.* (2018), which explains that the levels of nitrate content can be influenced by mangrove litter as well as human activities such as household activities and aquaculture. The concentration of phosphate in the three research areas ranged from 0.48 ± 0.08 to 2.42 ± 0.82 mg/L. These phosphate concentrations are considered high because they are influenced by human activities that produce waste such as waste from aquaculture. This is in line with the statement made by Prihatin *et al.* (2018), which states that high phosphate concentrations generally occur in environments close to land and are influenced by human activities.

4.2 Mangrove Density

Based on the research results, the average total density in the three study areas varies considerably but still falls within the good category. The average total density in the three study areas ranges from 1,500 to 3,267 ind/ha, where these values are categorized as good density according to Government Regulation No. 21 of 2021. The density values classified as good indicate a correspondence between a species and its environment. This is in line with the statement by Sunarni *et al.* (2019), which posits that good density values reflect an adjustment pattern of a species to its environment; mangrove species with high density exhibit significant adaptation patterns.

The high density values in most research areas occur due to favorable environmental conditions suitable for mangrove growth. One of the factors supporting the survival of mangroves is the availability of nutrients. This is in accordance with the statement by Musa *et al.* (2023), that the availability of nitrates and phosphates as nutrients is an important element influencing the composition, structure, and productivity of mangroves. Nitrate is a crucial primary nutrient that plays a significant role in the growth processes of plants, including mangroves. This aligns with the assertion by Yahra *et al*. (2020), that nitrate is a primary nutrient that greatly influences mangrove density, as nitrate is a nutrient that determines the stability of mangrove vegetation growth. High concentrations of nitrate are suspected to enhance soil fertility and support the growth processes of mangrove seedlings, leading to an increased number of successful seedlings and higher mangrove density. However, an increase in nitrate does not always correlate with a rise in stem diameter. This phenomenon occurs because stem diameter growth is more influenced by other factors such as stand density and light intensity. This is supported by Uthbah *et al*. (2017), who stated that the lower the stand density, the higher the intensity of light that enters, and vice versa. Stands that receive little sunlight will experience slow growth, resulting in smaller stem diameters.

4.3 Biomass of Mangrove Stands

Based on the research conducted at the study site, the three areas exhibit different average values of mangrove stand biomass. The highest total average biomass value was found in the rehabilitated mangrove area. The high average value of total biomass in the rehabilitated mangrove area is due to the larger diameter of the tree trunks in that area. This aligns with the statement by Jones *et al.* (2020), which indicates that trunk diameter is a primary factor influencing tree biomass. This occurs because trunk diameter is an important variable in allometric models for estimating mangrove biomass. The large biomass value is also influenced by the composition of mangrove species present in the research area. Phillips *et al.* (2019), in their study, stated that different tree species will affect forest biomass through varying wood density values. This demonstrates that wood density is one of the factors influencing the biomass of mangrove stands. *Rhizophora mucronata* is one of the mangrove species that possesses a high wood density compared to other species. This is supported by Quadros *et al.* (2021), who state that the majority of the Rhizophoraceae species have a high wood density. The presence of *Rhizophora mucronata* in the rehabilitated mangrove areas and around the ponds results in a higher biomass value in these areas compared to natural mangrove areas that are solely dominated by *Avicennia marina*.

The low biomass values in natural mangrove areas occur because the diameter of tree trunks in these areas tends to be smaller. Although natural areas have a higher density compared to other areas, the biomass values in this area are classified as low due to the dominance of trees with relatively small trunk diameters. The small trunk diameter in natural mangrove areas is believed to result from slow individual growth due to higher competition for nutrients. This aligns with the statement by Samsi *et al*. (2018), that high mangrove density will lead to increased competition among individual trees for available food nutrients, thereby hindering mangrove growth and resulting in smaller tree trunk diameters.

4.4 Carbon Stock of Mangrove Stands

The data processing results indicate that the carbon storage values in the three research areas show significant variations and are directly proportional to the biomass values that have been analyzed previously. The high total carbon stock value in the rehabilitated mangrove area is due to the large amount of biomass in that area. This aligns with the statement by Hidayati *et al.* (2023) that biomass and carbon content in mangrove forests have a positive correlation. Therefore, any factors leading to an increase or decrease in biomass will subsequently affect the carbon stock value.

The high carbon stock values found in the rehabilitated mangrove areas indicate that the rehabilitation efforts undertaken in Mangunharjo, Semarang, have had a positive impact on ecosystem recovery. The elevated carbon stock levels reflect the success of mangrove vegetation in adapting and thriving in a given location, thus enabling it to optimally serve its functions as a carbon absorber and storage. Therefore, the mangrove rehabilitation program in Mangunharjo can be considered successful in enhancing environmental quality and supporting climate change mitigation efforts.

Overall, the average carbon stock stored in the form of biomass in the Mangrove Mangunharjo area, Semarang, Central Java, Indonesia is 120.36 tons/ha. This value is greater when compared to the study conducted by Hickey *et al*. (2018), which took place in a subtropical region, specifically Mangrove Bay, Northwestern Australia. The results of that study indicated that the carbon stock value in Mangrove Bay is 45 tons/ha. The carbon stock value in the Mangrove Mangunharjo area is lower compared to the research by Amanda *et al.* (2021), conducted at the estuary of Batang Apar River, Pariaman, West Sumatra, Indonesia, which showed that the average carbon stock value of mangrove stands in that area is 313.52 tons/ha.

5. Conclusions

Based on the research results, there are differences in biomass values and carbon stocks in each area, namely the natural mangrove area, the area around the pond, and the rehabilitation area in the Mangrove Mangunharjo region, Semarang. The rehabilitated mangrove area has the highest average biomass and carbon stock values, with average biomass and carbon stock values in the rehabilitated mangrove area of 290.47 ± 23.19 tons/ha and 127.60 ± 10.23 tons/ha, respectively. The mangrove area around the pond also shows relatively high biomass and carbon stock values, with average biomass and carbon stock values of 268.39 ± 66.16 tons/ha and 117.63 ± 28.96 tons/ha, respectively. Meanwhile, the natural mangrove area has the lowest average values, with average biomass and carbon stock values in the natural area of 264.25 ± 57.23 tons/ha and 115.85 ± 25.30 tons/ha, respectively. The average carbon stock value in Mangunharjo Subdistrict is greater when compared to the carbon stock value in Mangrove Bay, Australia, which is only 45 tons/ha, but is smaller when compared to the carbon stock value at the estuary of the Batang Apar River, Pariaman, West Sumatra, Indonesia, which has a carbon stock value of 313.52 tons/ha.

Ethics approval

No permits were required.

Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Author contributions

ANP is doing research ideas, data curation, data collecting, data analysis, methodology, project administration, visualization, and writing the original draft. NS is doing supervision, validation, review, and editing. EY is doing supervision validation, review, and editing.

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Declaration of competing Interest

None

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