EREM 81/4
Journal of Environmental Research, Engineering and Management
Vol. 81 / No. 4 / 2025
pp. 93–103
10.5755/j01.erem.81.3.40210

Received 2025/01 | Accepted after revisions 2025/07

https://doi.org/10.5755/j01.erem.81.3.40210

The Blue Carbon Value in Mangrove Ecosystems Under Different Growth Conditions

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Each mangrove ecosystem had different carbon absorption capacities depending on the mangrove stand itself. The aim of this study was to compare the blue carbon value of mangrove ecosystems under different growing conditions. The research was conducted in Sangkaragung Village, Jembrana Regency, Bali. The measurement technique used to assess the blue carbon value of mangroves was conducted at the surface without harvesting (non-destructive sampling), following the method of carbon stock estimation for mangrove ecosystems. The research results showed that the mangrove species in the study location included *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, *Ceriops decandra*, *Sonneratia alba*, *Bruguiera gymnorrhiza*, and *Xylocarpus granatum*. The highest biomass carbon storage value was found in the natural mangrove ecosystem in the pond, amounting to 17.53 C/ha. The highest organic matter value at a depth of 0–15 cm was found in the planted mangrove in the pond, with a value of 17.01%, at a depth of 15–30 cm in the natural mangrove in the pond, with a value of 14.82%, and at a depth of 30–50 cm, the planted mangrove in the pond showed the highest value at 28.32%. The highest organic carbon storage was found in the planted mangrove in the pond at a depth of 0–15 cm, with 205.05 C/ha, at a sediment depth of 15–30 cm in the natural mangrove in the pond, with 240.12 C/ha, and at a sediment depth of 30–50 cm, the natural mangrove in the pond also had the highest carbon absorption, with 332.12 C/ha. The total tree biomass carbon storage was 31.95 tonnes C/ha, and the sediment carbon storage was 598.19 tonnes C/ha, resulting in a total carbon storage of 630.14 tons C/ha.

Keywords: blue carbon, mangrove, different growth condition, Bali.

Introduction

During the 20th century, the Earth's temperature increased by 0.74 ± 0.32°C (Aldrian et al., 2011; Estrada et al., 2013). The rise in greenhouse gas (GHG) concentrations is the main driver of this sharp temperature increase. Human activities such as the use of motor vehicles, ships, airplanes, factories, office buildings, and industries require fossil fuels, which emit carbon. The increased concentration of GHGs in the atmosphere leads to an increase in the amount of energy in the atmosphere. According to the Law of Conservation of Energy, energy is not lost but rather changes form. In other words, the increase in GHGs causes a change in the composition of energy in the atmosphere in various forms, including the heating of the Earth's surface.

Current climate change is a priority issue that needs to be addressed through mitigation efforts. One necessary action is contributing to the reduction of carbon emissions released into the atmosphere. Earth's climate system is a complex interaction between the atmosphere, land surface, snow and ice, oceans, and other bodies of water (such as rivers, reservoirs, wetlands, etc.), as well as living organisms. The climate conditions in Indonesia are considered unique due to several factors, including its location in the tropics and its archipelagic structure. Its position between two oceans (the Pacific and the Indian Oceans) also influences the uniqueness of Indonesia's climate.

Mangroves are coastal plants that thrive in tropical climates with muddy substrates and are resistant to salinity (Rumondang et al., 2023). As a tropical country, Indonesia has the largest mangrove ecosystem in the world, covering 29,000–31,894 km^2 (21–23% of the global total) (FAO, 2023) Mangroves offer numerous and valuable benefits to the environment. These benefits include coastal protection, serving as a habitat for biodiversity, absorbing waste and pollutants, providing food sources, carbon storage, income and employment opportunities, and recreational and educational spaces. However, mangroves are currently facing various challenges, both locally and globally, such as pollution, deforestation, and rising sea surface temperatures (Giri et al., 2011; La Sara, 2014).

One of the benefits of mangroves is their role as carbon storage areas. Mangroves contribute to reducing emissions generated by various fossil fuel consumption activities. Several studies highlight the impact of different sectors on carbon emissions: the average carbon footprint of households is 138.04 kg CO_2eq/month (Wiratama et al., 2016), emissions from the leather tanning industry is 1692.17 kg CO_2eq per group (Nugraha et al., 2020), educational activities generate a carbon footprint of 6951.59 kg CO_2 per month (Kusuma et al., 2018), and emissions from the aviation sector reach 8171,040 tonnes CO_2eq (Wahyu, 2015). These conditions emphasize the need for carbon absorption area inventories, with mangroves being capable of fulfilling this role.

Bali is one of the provinces in Indonesia that has a distribution of mangrove ecosystems. The mangroves in Bali are divided into three main zones: Zone A, which covers the regencies of Buleleng and Jembrana; Zone B, which includes the city of Denpasar and the regency of Badung; and Zone C, which is part of the regency of Klungkung. As of 2021, the total area of mangrove forests on the island of Bali is 2488.7 hectares, with the following density: 662.5 ha in Badung, 470.3 ha in Buleleng, 539.9 ha in Jembrana, 225.5 ha in Klungkung, and 590.5 ha in Denpasar (Husnayaen et al., 2023). The density condition must be supported by its carbon sequestration capacity. Each ecosystem has a different carbon absorption capability, depending on the mangrove species present. In previous years, blue carbon measurements were conducted in the Denpasar and Jembrana regions. The mangrove ecosystem in Denpasar has a carbon absorption capacity ranging from 17.047 kg/m^2 to 3031.989 kg/m^2 (Astawa et al., 2015), while in Jembrana, the above-ground biomass is 187.21 tonnes/ha, the below-ground biomass is 125.43 tonnes/ha, the above-ground carbon storage is 86.11 tonnes/ha, the below-ground carbon storage is 57.69 tonnes/ha, and the sediment organic carbon is 359.24 tonnes/ha (Suryono et al., 2018).

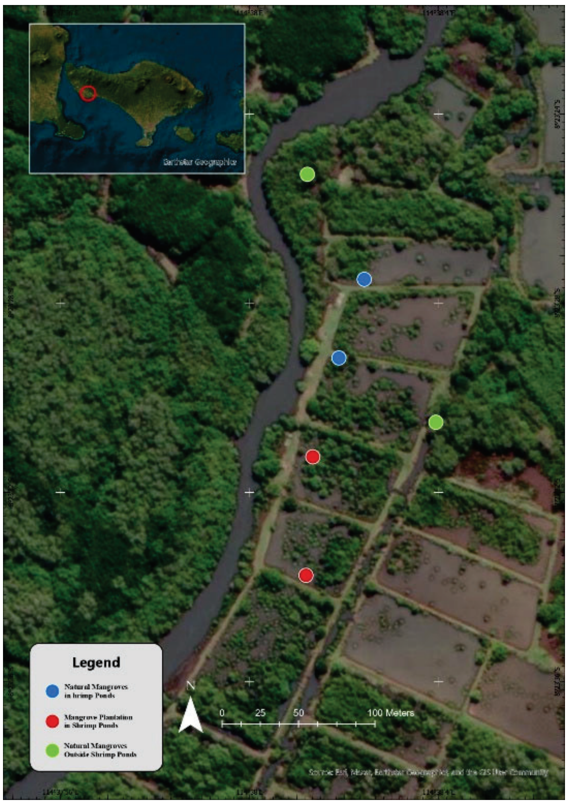
A comparison of blue carbon values in mangrove ecosystems under different growth conditions will be carried out in Jembrana Regency. This is necessary because there has been no research comparing the blue carbon content in planted mangroves, naturally growing mangroves, and mangroves that have grown naturally in newly affected areas. Meanwhile, mapping the blue carbon values will provide an overview of the distribution of areas with potential carbon sequestration, as well as the possibility of discovering new regions that could become mangrove habitats due to environmental changes.

Methods

Location and research sampling method

The research was conducted in Sangkaragung Village, Jembrana Regency, Bali Province, Indonesia. The measurement technique employed to assess the blue carbon value of mangroves was conducted on the surface without harvesting (non-destructive sampling), with measurements following the Mangrove Ecosystem Carbon Stock (Lestari and Rahadian, 2017).

Fig. 1. *Map of research sample distribution*



The determination of research sites was carried out using the purposive sampling method, considering the main mangrove vegetation zones and their accessibility. The research plots used were 10 m x 10 m in size and two plots were taken each at different growing conditions (*Fig. 1*), in accordance the SNI 7724:2019 (Asadi et al., 2024; BSN, 2019). Measurement of mangrove health referred to the mangrove community monitoring guidelines (Eka Dharmawan and Pramudji, 2017). In assessing mangrove health, the following parameters are evaluated: mangrove species, Mangrove health index (MHI), canopy cover, average tree height (m), seedling density (1000 individuals/ha), tree density (individuals/ha), sapling density (individuals/ha), and average stem diameter (cm). Mangrove biomass measurements referred to SNI 7724:2019 (BSN, 2019) on the Measurement and Calculation of Carbon Stocks (Field Measurements for Forest Carbon Stock Estimation). Biomass estimation measurements are carried out through two activities: measuring above-ground biomass (stem) and collecting organic sediment samples from the mangrove ecosystem.

Data analysis method

The data analysis of above-ground carbon (stem) and organic sediment carbon was conducted using Microsoft Excel 2019. The results of the analysis were formally presented in the form of tables and graphs, displaying their standard deviations. Subsequently, a descriptive explanation was provided to interpret the research findings.

1 Mangrove health calculation

Refers to the mangrove community monitoring guidelines (Eka Dharmawan and Pramudji, 2017)

2 Calculation of tree biomass carbon stock

The calculation of carbon mass is performed using the following equation:

$$Cag = B\ x\ \%\ C.organic \quad (1)$$

where C_{ag} – carbon mass/carbon content of biomass (kg or tonnes); B – biomass (kg or tonnes); % $C_{.organic}$ – carbon content percentage of 0.47, or using the % C result obtained from laboratory analysis.

3 Calculation of mangrove organic sediment carbon

The analysis of organic sediment carbon was be tested at the Animal Science Laboratory, Udayana University. The measured organic sediment content included organic matter, organic carbon (C), and bulk density.

a Organic matter in sediment was the result of natural processes where material from living organisms, such as plants and animals, underwent decomposition and was returned to the sediment. The calculation of organic matter was as follows:

$$Organic\ Matter\ (\%) = \frac{(Initial\ sediment\ weight - Residual\ sediment\ weight)}{Initial\ sediment\ weight}\ x\ 100\% \quad (2)$$

b The percentage of C-organic was a determining factor in the quality of mineral sediment. The higher the total organic carbon content, the better the quality of the mineral sediment. The determination of organic carbon content was carried out using the following formula:

$$C - Organic\ (\%) = \%\ Organic\ Matter\ x\ 0.58 \quad (3)$$

where % Organic – Laboratory result percentage; 0.58 – Vanbemmelen factor.

c Bulk density, also known as the weight or mass of sediment per unit volume, was a measure of the weight per unit volume of sediment, including its pores. Bulk density could vary spatially and temporally due to differences in organic matter content, sediment texture, sediment structure, fauna presence, and sediment depth. The calculation of bulk density was as follows:

$$Soil\ bulk\ density\ (g\ cm^{-3}) = \frac{oven-dry\ mass\ (g)}{Sampel\ Volume\ (cm^3)}\ x\ 100\% \quad (4)$$

d The carbon content in sediment was calculated using the equation from SNI 7724:2011

$$Cs\ \left(ton\frac{C}{ha}\right) = BD\ x\ SDI\ (soil\ depth\ interval)\ x\ \%\ C \quad (5)$$

where Cs – carbon sediment; BD – soil bulk density (g/cm^3); SDI – sample depth interval (cm); %C – percentage of carbon organic in sediment.

Results and Discussion

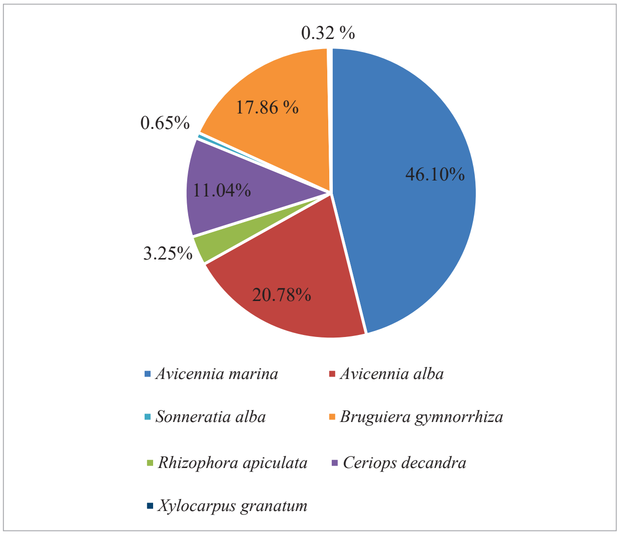
The measurement of the blue carbon value in mangrove ecosystems was conducted under three growth conditions, namely: mangrove plantations within shrimp ponds, natural mangroves within shrimp ponds, and natural mangroves outside shrimp ponds. The blue carbon value of the mangrove ecosystem was assessed based on mangrove health, the carbon storage value of tree biomass, and the carbon storage value of organic sediments. The biomass measurement process included determining sample plots, measuring above-ground biomass (trunk), and collecting organic sediment samples from mangrove areas. The stages of these measurements are illustrated in *Fig. 2*.

Fig. 2. *a) and b) Determination of sample plots, c) and d) Measurement of above-ground biomass (trunk), e) and f) Collection of organic sediment samples from mangroves*

State of the mangrove ecosystem

Based on the results of the conducted research, it is known that there are 7 mangrove species distributed across 3 different growth conditions. The percentage of mangrove species can be seen in *Fig. 3*, while *Table 1* shows the composition of mangrove species in mangrove plantations within shrimp ponds, natural mangroves within shrimp ponds, and natural mangroves outside shrimp ponds.

Fig. 3. *Percentage of mangrove species*



The percentage of mangrove species at the research site is as follows: 46.10% of *Avicennia marina*, 20.78% of *Avicennia alba*, 3.25% of *Rhizophora apiculata*, 11.04% of *Ceriops decandra*, 0.65% of *Sonneratia alba*, 17.86% of *Bruguiera gymnorrhiza*, and 0.32% of *Xylocarpus granatum*. From these results, it is evident that *Avicennia marina* is the most dominant species (46.10%), while *Xylocarpus granatum* is the least abundant (0.32%). This condition is similar to the study by Suryono et al. (Suryono et al., 2018), which found that the dominant species at the research site were *Rhizophora* sp. and *Avicennia sp*. The composition in this study differs from the research conducted by Gultom et al. (2021), which identified six mangrove species in both natural mangrove communities and rehabilitated mangrove communities. This indicates that different growth conditions can influence the types of mangrove species that thrive in an area.

Based on the data in *Table 1*, it is known that there are 5 mangrove species in the mangrove plantations within shrimp ponds. These species are *Avicennia marina* with 94 individuals, *Avicennia alba* with 8 individuals, *Rhizophora apiculata* with 7 individuals, *Ceriops decandra* with 3 individuals, and *Bruguiera gymnorrhiza* with 47 individuals. In the natural mangroves within shrimp ponds, there are also 5 species. The number of individuals for each species is as follows: *Avicennia marina* with 48 individuals, *Avicennia alba* with 54 individuals, *Rhizophora apiculata* with 3 individuals, *Sonneratia alba* with 1 individual, and *Bruguiera gymnorrhiza* with 3 individuals. For the natural mangroves outside shrimp ponds, there are 5 species, namely *Avicennia alba* with 2 individuals, *Ceriops decandra* with 31 individuals, *Sonneratia alba* with 1 individual, *Bruguiera gymnorrhiza* with 5 individuals, and *Xylocarpus granatum* with 1 individual.

Table 1. *Distribution of mangrove species*

No.	Mangrove species	Growth condition		
		Mangrove plantation in shrimp ponds	Natural mangroves in shrimp ponds	Natural mangroves outside shrimp ponds
1	*Avicennia marina*	+	+	–
2	*Avicennia alba*	+	+	+
3	*Rhizophora apiculata*	+	+	–
4	*Ceriops decandra*	+	-	+
5	*Sonneratia alba*	–	+	+
6	*Bruguiera gymnorrhiza*	+	+	+
7	*Xylocarpus granatum*	–	–	+
	Total Spesies	5	5	5

Table 2. *Condition of mangrove ecosystem health*

	Growth condition		
	Mangrove plantation in shrimp ponds	Natural mangroves in shrimp ponds	Natural mangroves outside shrimp ponds
Mangroves health index (MHI)	28.59–42.30	45.51–49.61	42.49–43.54
Canopy cover (%)	7.02–17.62	66.04–68.03	60.49–62.94
Tree height (m)	8.10–9.66	13.18–13.51	12.87–12.93
Seedling density (1000 ind/ha)	64–95	0	0
Tree density (ind/100m^2)	0–14	17–19	18–20
Sapling density (ind/100m^2)	11–73	13–30	16–21
Trunk diameter (cm)	2.83–3.62	4.47–5.55	5.50–6.11

The health condition of the mangrove ecosystem can be seen in *Table 2*. Mangrove health is assessed using the Mangrove Health Index (MHI), canopy cover, average tree height (m), seedling density (1000 individuals/ha), tree density (individuals/ha), sapling density (individuals/ha), and average trunk diameter (cm).

Mangrove health is assessed using the Mangrove health index (MHI). The MHI results are then analyzed based on three different categories (34): if MHI < 33.33%, the health condition is considered low; if MHI is between 33.34% and 66.67%, the health condition is considered moderate; and if MHI > 66.67%, the health condition is considered good. The MHI condition for mangrove plantations within shrimp ponds ranges from 28.59 to 42.30, for natural mangroves within shrimp ponds it ranges from 45.51 to 49.61, and for natural mangroves outside shrimp ponds it ranges from 42.49 to 43.54. This shows that in each growth condition – whether mangrove plantations in shrimp ponds, natural mangroves in shrimp ponds, or natural mangroves outside shrimp ponds – the health condition of the mangroves is moderate. Looking at the three growth conditions, natural mangroves in shrimp ponds exhibit a better percentage compared to the other growth conditions.

Canopy cover refers to the uppermost layer of the mangrove ecosystem formed by leaves, which covers the layers beneath it. The method used to determine canopy cover is hemispherical photography, utilizing an Oppo A96 smartphone with a photo resolution of 3873024 megapixels. According to the mangrove forest damage standards from the Ministry of Environment and Forestry (KemenLH) No. 201 of 2004, canopy cover is categorized as follows: if the cover is < 50%, it is classified as damaged/ sparse; if it is between 50% and 75%, it is classified as good-moderate; and if it is ≥ 75%, it is classified as good-dense. In the research area, the canopy cover in mangrove plantations within shrimp ponds ranged from 7.02% to 17.62%, which falls under the damaged/sparse category. However, in reality, the mangroves in this area are still small and are in a growth phase that will continue. The canopy cover in natural mangroves within shrimp ponds ranges from 66.04% to 68.03%, while natural mangroves outside shrimp ponds have a canopy cover between 60.49% and 62.94%, both of which are categorized as good-moderate. When compared with the canopy cover in other regions, it is known that in Gili Petagan, Padak Guar Village, Sambelia District, East Lombok Regency, the canopy cover is 71%, which falls under the good (moderate) category (Puna et al., 2023). In the TNBB (Bali Barat National Park) area, the cover is 60.27%, which is also in the good (moderate) category (Damanik et al., 2023). In Gilimanuk Bay, TNBB, the canopy cover is 83.84%, which is classified as good (dense) (Ma'ruf et al., 2022).

Tree height (m) in the growth conditions of mangrove plantations within shrimp ponds ranges from 8.10 to 9.66 m, while for natural mangroves within shrimp ponds, it ranges from 13.18 to 13.51 m, and for natural mangroves outside shrimp ponds, it ranges from 12.87 to 12.93 m. The mangrove conditions in shrimp ponds are similar to the height of mangrove seedlings in Benoa Bay, which is 11.06 ± 2.02 m (Dewi et al., 2021). The seedling density (1000 ind/ha) in mangrove plantations within shrimp ponds is between 64 and 95 ind/ha, while for natural mangroves within shrimp ponds and outside shrimp ponds, the density is 0 ind/ha. This condition is vastly different from Benoa Bay, where seedling density is 1811 ± 521 individuals/ha, taking into account the proportion of each zone area (Dewi et al., 2021).

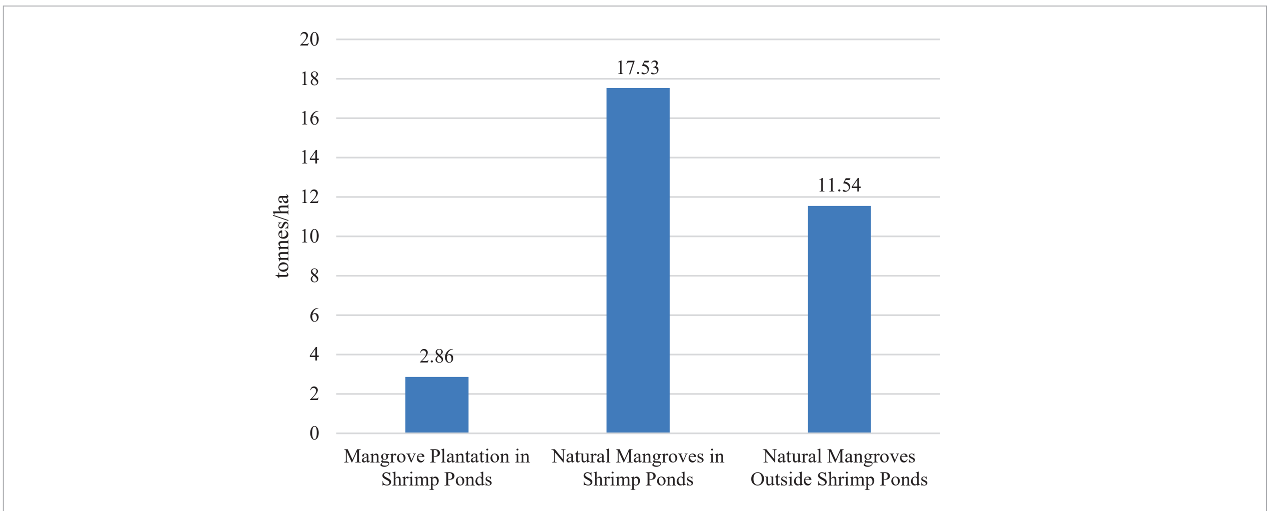
The tree density (ind/100m^2) in mangrove plantations within shrimp ponds is between 0 and 14 ind/100m^2, while for natural mangroves in shrimp ponds, it is 17–19 ind/100m^2, and for natural mangroves outside shrimp ponds, it is 18–20 ind/100m^2. Other studies also reported tree densities in different areas: in Gilimanuk Bay, the density is 2390.32 ind/ha (Ma'ruf et al., 2022); in Benoa Bay, it is 2851 ± 524 individuals/ha (Dewi et al., 2021); and in Gili Petagan, it is 3120 ind/ha (Puna et al., 2023). The sapling density (ind/100m^2) in mangrove plantations within shrimp ponds ranges from 11 to 73 ind/100m^2, while for natural mangroves within shrimp ponds, it ranges from 13 to 30 ind/100m^2, and for natural mangroves outside shrimp ponds, it is between 16 and 21 ind/100m^2. This is significantly different from the average mangrove sapling density in Benoa Bay, which is 390 ± 185 individuals/ha (Dewi et al., 2021), and in Gili Petagan, where sapling density ranges from 200 to 3600 ind/ha (Puna et al., 2023). Trunk diameter (cm) in mangrove plantations within shrimp ponds is between 2.83 and 3.62 cm, for natural mangroves in shrimp ponds, it ranges from 4.47 to 5.55 cm, and for natural mangroves outside shrimp ponds, it is between 5.50 and 6.11 cm. The average trunk diameter of mangrove stands in Benoa Bay is 11.15 ± 2.16 cm (Dewi et al., 2021), in Gili Petagan, it ranges from 4.7 to 9.56 cm (35), and in Benoa Bay, the average trunk diameter is 10.85 ± 2.06 cm (Andiani et al., 2021).

Organic carbon storage value in tree biomass

The biomass storage value of the trees is measured based on the trunk diameter of the mangroves found in the research plots. The results of biomass measurements using the allometric method can be seen in *Fig. 3.*

Based on *Fig. 4*, the carbon storage values for mangrove plantations within shrimp ponds are 2.87 C/ha, for natural mangroves within shrimp ponds are 17.53 C/ha, and for natural mangroves outside shrimp ponds are 11.55 C/ha. The carbon storage value of natural mangroves within shrimp ponds is the highest compared to the others. This indicates that the environmental conditions within the shrimp ponds provide the most favorable nutrients, which support healthy mangrove ecosystem growth. When compared to other studies, the biomass carbon in the mangroves of Tugurejo – Semarang is 301.58 tonnes C/ha (Irsadi et al., 2017), in the Batang Apar River Mouth Mangrove Forest in North Sumatra, it is 666.97 tonnes C/ha (Yossie et al., 2021), in east of the mouth of the Amazon River, Brazil mean ecosystem carbon stocks of the salt marshes were 257 Mg C/ha while those of mangroves ranged from 361 to 746 Mg C/ha (Kauffman et al., 2018), and in the Pandansari – Brebes Mangrove Ecotourism Area, it ranges from 203.97 to 330.19 tonnes/ha (Ahmed et al., 2023). Tree biomass increases as the plants grow, which also leads to the cambium layer producing new cells that increase the trunk diameter (Imiliyana et al., 2011).

Fig. 4. *Carbon storage value of tree biomass based on different growth conditions*



Organic carbon storage value in mangrove sediments

The organic carbon storage value in the sediments in this study refers to the carbon stored within sediments at depths of 0–15 cm, 15–30 cm, and 30–50 cm. Subsamples were differentiated into three categories to observe the variations in organic content. Each plot underwent two sampling events to represent the sediment conditions. The organic matter content and the organic carbon storage in the sediments across different growth conditions can be seen in *Fig. 5* and *Fig. 6*.

Fig. 5. *Organic matter content in sediments based on different growth conditions*

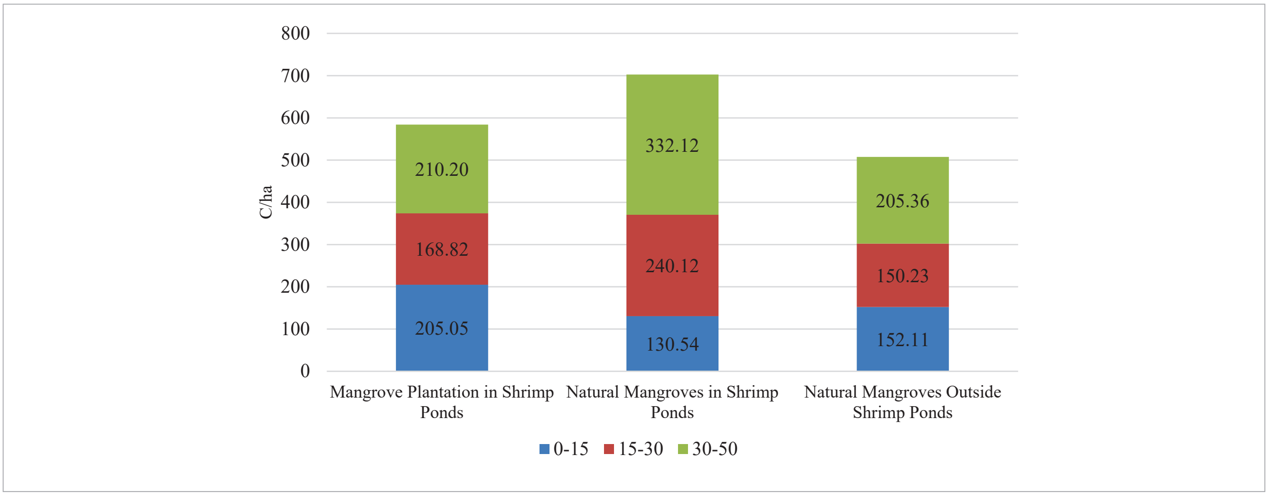
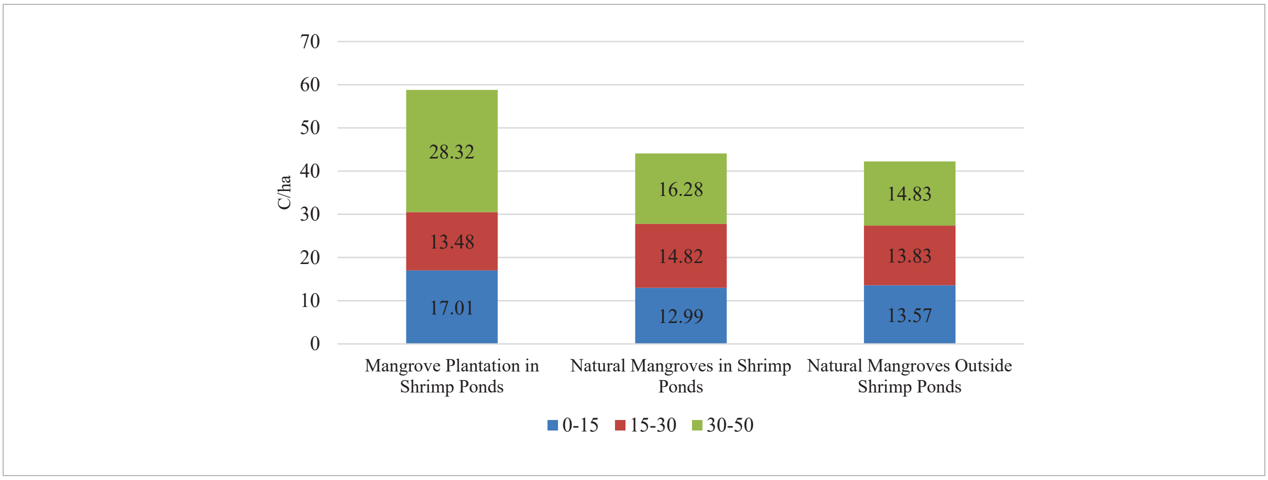


Fig. 6. *Organic carbon storage in sediments based on different growth conditions*



The highest organic matter content at a depth of 0–15 cm was found in the mangrove plantations within shrimp ponds, with a value of 17.01%, followed by natural mangroves outside shrimp ponds at 13.57%, and the lowest in natural mangroves within shrimp ponds at 12.99%. At a depth of 15–30 cm, the highest percentage was observed in natural mangroves within shrimp ponds at 14.82%, followed by natural mangroves outside shrimp ponds at 13.83%, and lastly, mangrove plantations within shrimp ponds at 13.48%. At a depth of 30–50 cm, mangrove plantations within shrimp ponds had the highest percentage at 28.32%, followed by natural mangroves within shrimp ponds at 16.28%, and natural mangroves outside shrimp ponds at 14.83%.

The organic carbon storage value for mangrove plantations within shrimp ponds at a sediment depth of 0–15 cm is 205.05 C/ha, which is the highest when compared to other growth conditions. This is followed by natural mangroves within shrimp ponds with a value of 130.54 C/ha, and natural mangroves outside shrimp ponds with 152.11 C/ha. At a sediment depth of 15–30 cm, natural mangroves within shrimp ponds exhibit the highest carbon sequestration at 240.12 C/ha, followed by mangrove plantations within shrimp ponds at 168.82 C/ha, and natural mangroves outside shrimp ponds at 150.23 C/ha. For the deepest sediment layer (30–50 cm), natural mangroves within shrimp ponds again show the highest carbon storage at 332.12 C/ha, followed by mangrove plantations within shrimp ponds at 210.20 C/ha, and natural mangroves outside shrimp ponds at 205.36 C/ha.

Total carbon storage value

The total carbon storage value referred to in this study is the sum of the average carbon storage from tree biomass and sediment carbon across different growth conditions. Based on the calculations, the total carbon storage obtained is 630.14 tonnes C/ha. This value is derived from 31.95 tonnes C/ha of tree biomass carbon and 598.19 tonnes C/ha of sediment carbon. The data for the summation of tree biomass carbon and sediment carbon can be seen in *Table 3*.

Table 3. *Total carbon storage value*

Growth Condition	Carbon Storage (tonnes C/ha)	
	Biomass Carbon Storage	Sediment Carbon Storage
Mangrove Plantation in Shrimp Ponds	2.87	194.69
Natural Mangroves in Shrimp Ponds	17.53	234.26
Natural Mangroves Outside Shrimp Ponds	11.55	169.24
	31.95	**598.19**

Based on *Table 3*, it is evident that each mangrove region exhibits varying carbon storage values. Previous research by Suryono et al. (2018), reported that the biomass carbon content in the Perancak Mangrove Forest was 398.75 tonnes C/ha. Other studies conducted in different locations revealed diverse levels of carbon storage, such as in the Gilimanuk Bay Mangrove Forest, which stored 193.91 tonnes C/ha (Wulandari et al., 2024), and in the Pandansari Ecotourism Mangrove Area in Brebes Regency, which had a carbon stock of 1078.31 tonnes C/ha (Ahmed et al., 2023). Older mangrove stands (17 and 35 years old) were found to store twice the total carbon (aboveground and soil stocks; ~115 tonnes C/ha) and sequester carbon in soil at double the rate (~3 tonnes C/ha/year) compared to the youngest stand (13 years old) (Carnell et al., 2022). According Chowdhury et al. (2023) natural mangrove populations possess a higher carbon storage capacity compared to mixed-species plantations. Overall, biomass carbon content increases as mangrove trees mature. Each mangrove ecosystem demonstrates distinct total carbon storage values due to various influencing factors, including mangrove species composition, environmental conditions, management and conservation practices, human disturbances, climate variability, and ecosystem structure.

Conclusions

The highest biomass carbon storage value in tree biomass was found in natural mangroves within ponds, which was 17.53 C/100 m^2. The highest organic material value at a depth of 0–15 cm was found in planted mangroves within ponds (17.01%), at a depth of 15–30 cm the highest value was found in natural mangroves within ponds (14.82%), and at a depth of 30–50 cm the highest value was found in planted mangroves within ponds (28.32%). The organic carbon storage value at a depth of 0–15 cm was 205.05 C/100 m^2 in planted mangroves within ponds, at a depth of 15–30 cm it was 240.12 C/100 m^2 in natural mangroves within ponds, and at a depth of 30–50 cm it was 332.12 C/100 m^2 in natural mangroves within ponds. The total carbon storage value was 630.14 C/100 m^2. A good follow-up study would be to compare different geographic conditions, species diversity, and perhaps create a long-term carbon sequestration model.

Acknowledgements

Acknowledgments are extended to Universitas Mahasaraswati Denpasar for their financial support provided through the Internal Grant Program, and to Mangrove Nusantara for their assistance in the implementation of this research activity.

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