**Jurnal Presipitasi**
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 21, No 1, 2024, 165-173
Article available at *homepage presipitasi*

*Regional Case Study*

# Analysis of the Application of Mangrove Rehabilitation Structures on Mangrove Growth and Calculation of Carbon Stocks in the Coastal Area of Demak, Indonesia

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## Abstract

Mangroves participate in controlling climate change by acting as the lungs of the world through the absorption and storage of blue carbon. The high-standing water on the land that must be rehabilitated is one of the obstacles encountered, so a special strategy is needed, namely, implementing a mangrove rehabilitation media structure using the *demplot mangrove* method. This study aimed to analyze mangrove growth based on the application of mangrove rehabilitation media structures and to calculate potential carbon stocks based on the value of tree biomass from mangrove rehabilitation monitoring. In this study, tree height and diameter were measured and linked to the water quality and frequency of inundation. Mangrove carbon reserves were also calculated based on biomass values. Good growth in the height and diameter of mangroves occurred in Avicennia lanata stands with an inundation frequency of 6 h/day. The largest projection of potential carbon stocks from the results of monitoring mangrove rehabilitation was also stored in Avicennia lanata mangrove stands at 0.3467 kg/tree (60 months), 0.6287 kg/tree (120 months), and 0.9107 kg/tree (180 months).

**Keywords**: Blue carbon; Demak; mangrove; rehabilitation; demplot mangrove

## 1. Introduction

Climate change is a pressing environmental issue in Indonesia and the world. The marine continent of Indonesia is particularly vulnerable to the effects of climate change (Zikra et al., 2015). Coastal regions in Indonesia are susceptible to climate change, which leads to environmental degradation and vulnerability. The North Coast of Java is particularly threatened by erosion due to rising sea levels caused by climate change. Among the most pressing issues faced by coastal areas is the rise in sea level (Bott et al., 2021 & Andari et al., 2023). This can also cause changes in sea currents in coastal areas, resulting in damage to mangrove ecosystems (Sugianto et al., 2018 & Buchori et al., 2021). Demak Regency is experiencing a gradual increase in air temperature, with an average of 0.02°C/year. It is projected that this trend will continue, resulting in an average increase of 0.037°C/year or a total increase of 1.11°C by 2050. Rising temperatures are a significant concern for Demak waters, located in Central Java, which is among the areas most threatened by erosion due to rising sea levels caused by climate change. On average, the sea level in the area rises by 7.9 mm/year (Sugianto et al., 2020).

Mangrove ecosystems play vital roles in climate change. They help reduce the impact of natural disasters such as erosion and increase the resilience of coastal communities. Mangroves act as the lungs of the world by absorbing and storing blue carbon, thus participating in the control of climate change.

Unfortunately, the mangrove ecosystem on the coast of Central Java is 12,226 ha, of which 96.9% are damaged. In the coastal area of Demak, 58.55 hectares of mangrove forests have been degraded (Ward et al., 2016). In addition, mangrove forests have unique characteristics compared to other forest formations. The uniqueness of the forest can be seen from the habitat where it lives, as well as the diversity of flora, such as Avicennia, Rhizophora, Bruguiera, and other plants that can survive in seawater salinity, and fauna, such as crabs, fish, mollusks, and others. Mangrove forests also have economic, ecological, and social functions (Azuelo et al., 2010 & Oktavia et al., 2021).

Rehabilitation and restoration of mangrove ecosystems are ongoing in various parts of Indonesia, including the coastal areas of Demak (Damastuti et al., 2022). One of the obstacles facing land rehabilitation is high-standing water. This has prevented mangroves from growing optimally because there is no process in place to remove standing water during low tides (Handayani et al., 2021). This method is generally used for mangrove rehabilitation, but research on its effectiveness is lacking.

Conventional methods for rehabilitating and restoring mangrove ecosystems have not yielded desired results. Therefore, it is essential to develop appropriate eco-friendly strategies and technologies. A successful rehabilitation program should involve careful planning, monitoring, and evaluation activities (Ntibona et al., 2022). The purpose of this activity is to support global efforts to achieve the Sustainable Development Goals (SDGs). These goals are aimed at ending poverty, reducing inequality, and protecting the environment by 2030. Achieving these goals requires collaboration and synergy between different sectors such as the government, academia, and society. A key factor that can help achieve these goals is the application of science and technology. Therefore, this study aimed to analyze the growth of mangroves using the structure of mangrove rehabilitation media *(demplot mangrove)* and project the potential for carbon stocks based on the monitoring results of mangrove rehabilitation. This research is part of an urgent action to combat climate change and its impacts while protecting the environment in coastal areas.

## 2. Methods

Tambakbulusan Village, located in the Demak Regency, is a coastal village in the Central Java Province. The village has a total mangrove area of 200 ha, which makes it a potential site for mangrove conservation. However, some areas of the mangrove ecosystem in Tambakbulusan Village have suffered damage due to erosion and robbing, mangrove land conversion, rehabilitation failure, and lack of monitoring and supervision.

This research was conducted in the coastal area of Demak, Central Java, Indonesia, for six months (September 2022-February 2023) with six observation stations. Mangrove growth was determined by measuring the height and diameter of the mangrove trunk. Water quality measurements (pH, DO, salinity, and temperature) were carried out directly, while analysis of sediment organic matter content was carried out in the laboratory using the loss-on-ignition method. The inundation frequency was obtained from land height data relative to the sea level at the time of measurement, which was then corrected with tidal data.

**Table 1.** Mangrove types for each station

| Station | Mangrove Type |
|---|---|
| S1 | *Rhizophora mucronata* |
| S2 | *Avicennia lanata* |
| S3 | *Avicennia lanata* |
| S4 | *Avicennia lanata* |
| S5 | *Rhizophora mucronata* |
| S6 | *Rhizophora mucronata* |

To determine the carbon stocks in the mangrove ecosystem around the study area, which has an area of 53,919.27 m2, carbon calculations were performed at seven locations along the coast. These locations are representative of the area, with each station having a 10 × 10 m2 transect. The transect was repeated three times, and the distance was adjusted to the condition of the mangroves in the field. To obtain aboveground mangrove biomass and carbon stored, data on measurements of diameter or DBH of mangroves and specific gravity of wood were analyzed using special allometric equations based on species. The Allometric equations are presented in the following table (Ong et al., 2004).

**Table 2.** Allometric equation for biomass calculation

| Species Name | Upper biomass (kg) |
|---|---|
| *Rhizophora apiculata* | $0.235\ DBH^{2.42}$ |
| *Rhizophora mucronata* | $0.1466\ DBH^{2.3136}$ |
| *Avicennia lanata* | $0.251\ DBH^{2.46}$ |
| *Xilocarpus granatum* | $0.0823\ DBH^{2.59}$ |
| *Bruguiera gymnorrhiza* | $0.186\ DBH^{2.31}$ |
| *Excoecaria agalloch* | $0.251\rho DBH^{2.46}$ |
| | ρ: 0.450 |

Calculation of carbon stocks in mangroves uses a formula that refers to the National Standardization Agency (2011) following equation (1)

$$Cb = B\ x\ \%C\ Organic \quad \text{.......} \quad (1)$$

With:
Cb : Carbon Stocks
B : Biomass
%C Organic : Carbon percentage: 0.47

## 3. Result and Discussion

### 3.1. Rehabilitation of Mangrove Water Quality

Water quality is also a factor in the growth of mangrove ecosystems and affects the health of mangrove plants. Although mangroves are known for their ability to adapt to changes in salinity, they are still sensitive to changes in water quality, such as temperature, degree of acidity (pH), and Dissolved Oxygen (DO). Water quality data were compared with water quality standard values for mangroves (marine biota) based on Appendix VIII PP. 22 of 2021, concerning the Implementation of Environmental Protection and Management.

**Table 3.** Water quality data for each station (Measurements September 2022-January 2023)

| Parameter | Unit | Quality standards | Results | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | S4 | S5 | S6 |
| Salinity | ‰ | up to 34 | 13.90 | 16.98 | 16.55 | 14.55 | 12.82 | 11.90 |
| pH | - | 7-8.5 | 7.28 | 7.15 | 7.11 | 7.37 | 7.26 | 7.31 |
| DO | mg/L | >5 | 16.43 | 13.25 | 11.15 | 11.00 | 10.95 | 11.05 |
| Temperature | °C | 28-32 | 30.25 | 30.90 | 3.,20 | 30.77 | 31.95 | 31.05 |

### 3.2. Rehabilitation Mangrove Sediment Organic Material Content

Nutrient content is an important factor in mangrove growth. Sufficient nutrients, particularly organic matter, promote plant growth.

**Table 4.** Sediment organic matter content

| Station | Mangrove Type | Organic Material (%) | High growth every month (cm) | Diameter growth every month (cm) |
|---|---|---|---|---|
| S1 | *Rhizophora mucronata* | 15.48 | 7.6 | 0.01 |
| S2 | *Avicennia lanata* | 10.08 | 8.2 | 0.01 |
| S3 | *Avicennia lanata* | 10.08 | 9.3 | 0.0,3 |
| S4 | *Avicennia lanata* | 10.38 | 9.8 | 0.04 |
| S5 | *Rhizophora mucronata* | 9.60 | 5.2 | 0.015 |
| S6 | *Rhizophora mucronata* | 8.13 | 6.1 | 0.005 |

### 3.3. Rehabilitation Mangrove Flooding Frequency

Mangrove growth is influenced by various factors, including inundation frequency. In this study, the frequency of land inundation was determined by collecting sea-level height data at each station and correcting it with tidal data obtained at the same time as data collection.

**Table 5.** Frequency of inundation at each station

| Station | Mangrove Type | Inundation Frequency (hours/day) |
|---|---|---|
| S1 | *Rhizophora mucronata* | 4 |
| S2 | *Avicennia lanata* | 6 |
| S3 | *Avicennia lanata* | 6 |
| S4 | *Avicennia lanata* | 6 |
| S5 | *Rhizophora mucronata* | 4 |
| S6 | *Rhizophora mucronata* | 4 |

### 3.4. Rehabilitation Mangrove Vegetation Monitoring

As part of regular monitoring activities, we measured the height and diameter growth of mangrove trees that were planted in November 2021. The purpose of these monitoring activities is to track the development of mangrove vegetation and collect information on the amount of carbon that mangroves can potentially sequester.

**Table 6.** Rehabilitation mangrove height measurement results

| Station | Mangrove Type | Yield (cm) | | | | | | Monthly Average Growth (cm) |
|---|---|---|---|---|---|---|---|---|
| | | Sept 2022 | Oct 2022 | Nov 2022 | Dec 2022 | Jan 2023 | Feb 2023 | |
| S1 | *Rhizophora mucronata* | 118 | 125 | 133 | 140 | 151 | 156 | 7.6 |
| S2 | *Avicennia lanata* | 215 | 222.5 | 230 | 240 | 248.5 | 256 | 8.2 |
| S3 | *Avicennia lanata* | 211 | 223 | 232 | 240 | 248.5 | 257.5 | 9.3 |
| S4 | *Avicennia lanata* | 201.5 | 210 | 220 | 229 | 239.5 | 250.5 | 9.8 |
| S5 | *Rhizophora mucronata* | 92.5 | 96.5 | 101 | 108.5 | 115 | 118.5 | 5.2 |
| S6 | *Rhizophora mucronata* | 86 | 99.5 | 101.5 | 107 | 114.5 | 116.5 | 6.1 |

**Table 7.** Rehabilitation mangrove diameter measurement results

| Station | Mangrove Type | Diameter(cm) Sept 2022 | Nov 2022 | Jan 2023 | Average growth (cm) |
|---|---|---|---|---|---|
| S1 | *Rhizophora mucronata* | 0.79 | 0.79 | 0.81 | 0.01 |
| S2 | *Avicennia lanata* | 1.30 | 1.31 | 1.32 | 0.01 |
| S3 | *Avicennia lanata* | 1.27 | 1.28 | 1.33 | 0.03 |
| S4 | *Avicennia lanata* | 1.24 | 1.27 | 1.32 | 0.04 |
| S5 | *Rhizophora mucronata* | 0.60 | 0.63 | 0.63 | 0.015 |
| S6 | *Rhizophora mucronata* | 0.66 | 0.66 | 0.67 | 0.005 |

### 3.5. Rehabilitation Mangrove Carbon Stock Potential and Projection

The potential carbon stocks of rehabilitated mangroves were calculated by monitoring mangrove vegetation using the allometric equation for *Rhizophora mucronata* and *Avicennia lanata*. This involves the use of diameter data to obtain the values of biomass and carbon stocks in units of kg/tree.

**Table 8.** Calculation of rehabilitation mangrove carbon stocks

| Station | Mangrove Type | Biomass (kg/tree) | | | Carbon (kg/tree) | | |
|---|---|---|---|---|---|---|---|
| | | Sept 2022 | Nov 2022 | Jan 2023 | Sept 2022 | Nov 2022 | Jan 2023 |
| **S1** | *Rhizophora mucronata* | 0.085 | 0.085 | 0.087 | 0.040 | 0.040 | 0.041 |
| **S2** | *Avicennia lanata* | 0.268 | 0.268 | 0.273 | 0.126 | 0.126 | 0.128 |
| **S3** | *Avicennia lanata* | 0.253 | 0.253 | 0.283 | 0.119 | 0.119 | 0.133 |
| **S4** | *Avicennia lanata* | 0.239 | 0.253 | 0.278 | 0.112 | 0.119 | 0.131 |
| **S5** | *Rhizophora mucronata* | 0.045 | 0.050 | 0.050 | 0.021 | 0.024 | 0.024 |
| **S6** | *Rhizophora mucronata* | 0.056 | 0.056 | 0.064 | 0.026 | 0.026 | 0.030 |

The projected potential of mangrove reserves was done for five years (60 months), ten years (120 months), and 15 years (180 months).

**Table 9.** Projection of potential rehabilitation mangrove carbon stocks

| Station | Mangrove Type | Carbon Projection Equation | Carbon Stock (kg/tree) x=60 months | x=120 months | x=180 months |
|---|---|---|---|---|---|
| **S1** | *Rhizophora mucronata* | y=0.0003x+0.0368 | 0.0548 | 0.0728 | 0.0908 |
| **S2** | *Avicennia lanata* | y=0.0006x+0.1196 | 0.1556 | 0.1916 | 0.2276 |
| **S3** | *Avicennia lanata* | y=0.0036x+0.0808 | 0.2968 | 0.5128 | 0.7288 |
| **S4** | *Avicennia lanata* | y=0.0047x+0.0647 | 0.3467 | 0.6287 | 0.9107 |

| Station | Mangrove Type | Carbon Projection Equation | Carbon Stock (kg/tree) | | |
|---|---|---|---|---|---|
| | | | x=60 months | x=120 months | x=180 months |
| **S5** | *Rhizophora mucronata* | y=0.0006x+0.0152 | 0.0512 | 0.0872 | 0.1232 |
| **S6** | *Rhizophora mucronata* | y=0.001x+0.0161 | 0.0761 | 0.1361 | 0.1961 |

### 3.6. Mangrove Growth Analysis Rehabilitation

Mangrove rehabilitation and restoration aims to prevent further degradation. The basic principles for rehabilitation consist of prioritizing ecological rehabilitation, conducting rehabilitation properly, assisting, following rules when doing physical rehabilitation, and living in harmony with the ecosystem.

Water quality measurements from all stations were compared with the seawater quality standards for mangroves (marine biota), as stated in Appendix VIII PP No. 22 of 2021, which pertains to the implementation of environmental protection and management. All the results met the quality standard values. The salinity levels suitable for mangrove growth in the seawater to brackish water zone range from 10 to 30 ppt, whereas the suitable salinity levels for mangrove growth in the brackish water to fresh water zone range from 0 to 10 ppt (Ahmed et al., 2022). This varying salinity is caused by a mix of seawater during high tides and freshwater from rivers, particularly during the rainy season (Dittmann et al., 2022). Previous studies have shown that mangroves flourish in the soil at pH levels between 6 and 7. The slightly acidic pH of the soil results from the decomposition of mangrove litter by soil microorganisms, which produces organic acids that lower the soil pH (Cabañas-Mendoza et al., 2020). The optimal pH level for plants is neutral, which means that it should be between 6.6 7.5. When the pH of the soil is neutral, it becomes easier for plants to absorb the essential nutrients. The quality of water can be determined by observing certain chemical parameters, such as the amount of dissolved oxygen (DO). The higher the amount of DO in the water, the better the quality. During high tide, the DO value tends to increase, which results in a decrease in temperature, whereas during low tide, the DO value tends to decrease, leading to an increase in temperature (Dewiyanti et al., 2021).

The water temperature in the area fluctuates between 30-31°C. Mangroves require a temperature range of 28-32°C for ideal photosynthesis, which is crucial for their diameter growth. The diameter growth of mangroves occurs when the photosynthetic products meet the requirements of respiration, leaf replacement, root growth, and height (Osland et al., 2020). In addition to temperature, the nutrient content of mangroves also influences their growth rate. Organic matter is essential for providing energy and materials to bacteria, plants, and animals. It also contains vitamins and substances that can either accelerate or slow the growth rate (Constance et al., 2022).

Mangrove growth is influenced by several factors, including the frequency of land inundation (Dewiyanti et al., 2021). Different types of mangrove plants grow in different areas depending on the frequency of seawater recession caused by tides. For instance, *Avicennia lanata* at Stations 2-4 were inundated for 6 h per day, which was the longest frequency of land inundation, while Rhizophora mucronate at Stations 1 and 5-6 were only inundated for 4 h per day, the lowest frequency of inundation. *Avicennia lanata* exhibited higher growth rates than *Rhizophora mucronata*. Therefore, the frequency of inundation has a significant impact on mangrove growth (Constance et al., 2022). After monitoring the growth of mangroves in a rehabilitation area for six months, it was discovered that the height and diameter of mangroves were not significantly affected by water quality and organic matter content. The environment at each station was typically suitable for mangrove growth. All mangroves planted in November 2021 thrive because of site protection from waves, currents, and garbage. The slow growth of mangroves at stations 5 and 6 was influenced by competition for nutrient absorption between the two mangrove types. Initially, only *Rhizophora mucronata* was planted at these stations; however, over time, *Avicennia lanata* began to grow naturally, resulting in competition for nutrient absorption. The development of mangroves at each station can differ based on the environmental carrying capacity and adaptation patterns. Therefore, homogeneous plantations (of only one type) tended to show better growth.

### 3.7. Projected Potential Blue Carbon Stocks for Rehabilitation Mangroves

Global warming is an important issue in many countries. Global warming is characterized by an increase in the Earth's surface temperature (Ahima, 2020). The rise in temperature on Earth's surface is directly linked to the increasing concentration of greenhouse gases in the atmosphere, such as $CO_2$. One of the primary contributors to high levels of $CO_2$ emissions is forest degradation, which leads to climate change. In response to this growing issue of global warming, mangroves play a crucial role in reducing the increase in greenhouse gases (Abbass et al., 2022).

Diameter data from monitoring mangrove vegetation were used to estimate the potential carbon stocks of rehabilitated mangroves. This was achieved by applying allometric equations to Rhizophora mucronata and Avicennia lanata. These equations help to obtain the biomass and carbon stocks of mangroves in terms of kg per tree. The processed data revealed that *Avicennia lanata* stands had the highest biomass value, indicating that they have the greatest potential for storing carbon stocks (Malik et al., 2022). Tree biomass has a strong impact on carbon stocks in mangroves. A higher tree biomass leads to a greater carbon stock (Putra et al., 2019).

## 4. Conclusions

A significant factor that greatly influences the height and diameter of mangroves is the frequency of inundation. Good growth in height and diameter of mangroves occurred in *Avicennia lanata* stands with an inundation frequency of 6 h/day, a height growth of 9.8 cm per month, and a diameter growth of 0.04/month. The largest projection of potential carbon stocks from the results of monitoring mangrove rehabilitation was stored in *Avicennia lanata* stands at 0.3467 kg/tree (60 months), 0.6287 kg/tree (120 months), and 0.9107 kg/tree (180 months).

## Acknowledgment

We extend our gratitude to the Oceanography Department Universitas Diponegoro, Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, SDGs Center Universitas Diponegoro, LPPM Universitas Diponegoro, and the Ministry of Education and Culture Republic of Indonesia for funding our research (grant number 354-50/UN7.6.1/PP/2022).

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