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Analysis of Canopy Cover and Estimation of Carbon Storage Potential in Mangrove Vegetation on Rakit Island, Indramayu Regency

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ABSTRACT

The health of mangrove vegetation on both the mainland and small islands is crucial for maintaining the balance of coastal and marine ecosystems. The mangrove forest on Rakit Island, also known as Biawak Island, plays an important role in carbon sequestration by converting carbon into organic biomass. Variations in mangrove growth conditions influence vegetation dynamics and canopy cover. This study aimed to analyze canopy cover and to estimate stored carbon in mangrove stands on Rakit Island, Indramayu Regency. A survey method with purposive sampling was employed for data collection. Mangrove vegetation data were obtained using the plot sampling method, while canopy cover was measured through hemispherical photography.
The results show that the mangrove community structure on Rakit Island consists of three species: *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, and *Sonneratia alba*. Mangrove density ranged from 33.33 to 833.33 individuals per hectare. The canopy cover percentages were 77.74 ± 8.30% at Station 1 (dense/good), 48.25 ± 28.55% at Station 2 (sparse/degraded), and 72.57 ± 17.15% at Station 3 (moderate/good). The estimated carbon storage potential of mangrove stands on Rakit Island was 41.25 tons per hectare, with the highest contribution from *Rhizophora mucronata* at 40.02 tons per hectare. Overall, the findings suggest that the carbon sequestration capacity of the Rakit Island mangrove ecosystem remains relatively low.

INTRODUCTION

Indonesia, as the world's largest archipelagic country, possesses the most extensive mangrove forests, covering approximately 3,489,140.68 hectares **(Rachmawan, 2019)**. The country accounts for 23% of the world's mangroves, with an estimated coverage of 3.31 million hectares in 2019, where 80.74% were in good condition and 19.26% were classified as critical **(Gustami *et al.*, 2023)**. Rakit Island, also known as Biawak Island, in Indramayu Regency, spans approximately 120 hectares, of which 80 hectares consist of mangrove forests, while the remainder comprises beaches **(Purba & Harahap, 2013)**. Rakit Island exhibits a well-preserved mangrove ecosystem in terms of both physical structure and ecological function. Its coastal ecosystem consists of mangroves, seagrass beds, and coral reefs.

Mangroves belong to the division Magnoliophyta and class Magnoliopsida, forming communities that interact with other flora and fauna to establish dense forest ecosystems in the intertidal zones of tropical to subtropical coastlines **(Kusmana *et al.*, 2003)**. Mangrove ecosystems offer numerous ecological, physical, and economic benefits **(Prihadi *et al.*, 2018)**. The mangrove canopy, formed by overlapping branches and leaves, plays a crucial role in photosynthesis. The density of the canopy influences light penetration, with denser canopies restricting sunlight access for seedlings and saplings **(Purnama *et al.*, 2020)**. Hemispherical photography is one method used to estimate canopy width and cover. This technique, which utilizes a camera to capture canopy coverage, offers advantages in terms of time efficiency and flexibility under various environmental conditions **(Baksir *et al.*, 2018)**.

One of the critical ecological functions of mangrove ecosystems is carbon sequestration, which mitigates global warming by absorbing atmospheric carbon dioxide **(Senoaji & Hidayat, 2016)**. Mangrove ecosystems sequester carbon through photosynthesis and store it as biomass **(Komiyama *et al.*, 2008)**. According to **Sutaryo (2009)**, mangrove biomass results from photosynthesis, which absorbs atmospheric carbon and converts it into organic carbon stored in tree roots, trunks, leaves, and other parts **(Hairiah & Rahayu, 2007)**. Mangrove forests are known to sequester carbon at a rate five times faster than terrestrial forests **(Ray *et al.*, 2011)**. Given these considerations, this study aimed to assess canopy cover and to estimate stored carbon in mangrove stands on Rakit Island using hemispherical photography and biomass analysis.

MATERIALS AND METHODS

Location

This research was conducted on Rakit Island, Indramayu Regency, West Java. Data were collected from three observation stations with the following coordinates:

- **Station 1**: 5°56'06.0"S, 108°22'41.7"E (southern part of Rakit Island)
- **Station 2**: 5°55'44.0"S, 108°23'10.8"E (northern part of Rakit Island)
- **Station 3**: 5°56'08.7"S, 108°22'49.4"E (southern part of Rakit Island)

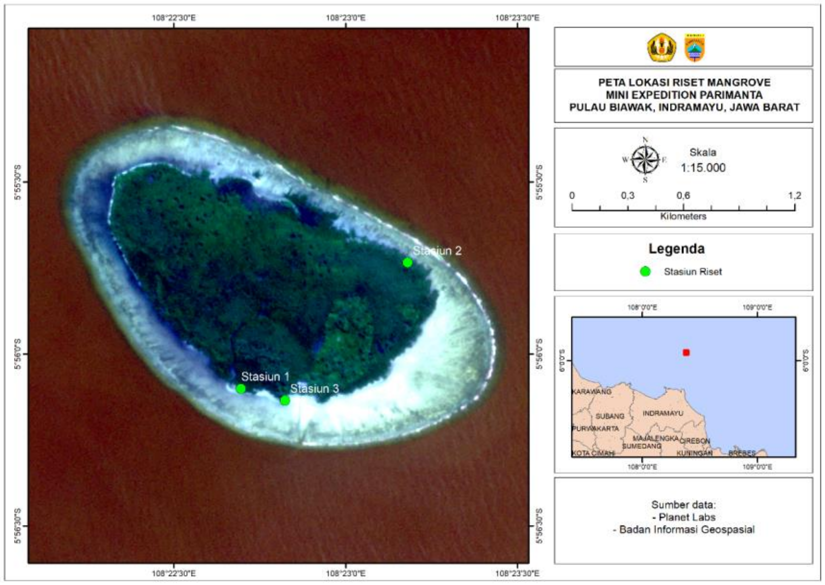

Fig. 1. Area of interest (AOI) map of Rakit Island with 3 transect location site (Green circles)

Equipment and materials

The equipment used in this study was categorized into two groups: tools for collecting mangrove vegetation data and others for measuring environmental water quality and substrate conditions. The details are as follows:

1. Equipment for collecting mangrove vegetation data included a Global Positioning System (GPS), compass, measuring tape, nylon rope, survey sheets, tailor's tape measure, smartphone camera, and the *Mangrove Guidebook of Indonesia* **(Kitamura *et al.*, 1997)**.

2. Equipment for measuring environmental water quality and substrate conditions included a refractometer for salinity, thermometer for temperature, pH meter for acidity, dissolved oxygen (DO) meter, shovel for substrate sampling, ziplock plastic bags for storing substrate samples, and a sieve shaker for filtering coarse particles into fine fractions.

Data collection

A survey method was employed to collect data on mangrove vegetation and environmental conditions. Vegetation data were obtained using the Transect Line Plot (TLP) method. Transects were placed perpendicular to the shoreline, with plots measuring 10 × 10m for trees (diameter >10cm), 5 × 5m for saplings (diameter 2– 10cm), and 1 × 1m for seedlings (diameter < 2cm) **(SNI, 2011)**. Tree diameter at breast height (DBH) was recorded to estimate biomass **(Surahmat *et al.*, 2023)**. Water quality parameters, including salinity, temperature, pH, and dissolved oxygen (DO), were measured *in situ* at each station.

In addition to field observations, satellite imagery analysis was also conducted. Level-2A Sentinel-2 imagery was acquired and processed using Quantum GIS (QGIS). The imagery was obtained from the open-access platform developed by the European Space Agency (ESA), *Copernicus Data Space Ecosystem* (https://browser.dataspace.copernicus.eu). Images from July 14, 2024, were selected due to their low cloud cover and temporal relevance. The dataset consisted of B04 (red), B08 (near-infrared/NIR), and natural color rasters.

The analysis involved applying the Normalized Difference Vegetation Index (NDVI) algorithm, extracting pixel values, and validating results with field photographs. NDVI measures reflectance of NIR light and absorption of red light to detect healthy green vegetation **(Gupta *et al.*, 2021)**. According to **Rouse *et al.* (1974)**, NDVI values range between –1 and +1, with higher values indicating dense, healthy vegetation. This algorithm also captures non-mangrove vegetation present on the island. The process was carried out by applying the NDVI equation to Band 08 and Band 04 imagery in QGIS's raster calculator, followed by converting raster pixels to points, selecting points around the station areas, and transferring the values from the attribute table to an Excel sheet for analysis. The supporting photos then worked as verification of the pixel value. The equation of NDVI using the Sentinel-2 satellite imagery can be seen below:

$$\text{NDVI} = \frac{\rho\text{NIR} - \rho\text{Red}}{\rho\text{NIR} + \rho\text{Red}}$$

NDVI Equation

(Matthias & Martin, 2004)

Hemispherical photography data collection

Mangrove canopy cover was assessed using the hemispherical photography method, which requires a fisheye lens camera with a 180° field of view or a smartphone camera. This study followed the methodology outlined by **Dharmawan and Pramudji (2017)**, in which each plot is divided into quadrants based on mangrove forest conditions. A single photo was taken per quadrant according to predefined criteria, with each image captured twice for consistency.

Photographs were taken using the front camera of a smartphone with a 4-megapixel resolution. A key limitation of hemispherical photography is that images should not be captured under direct sunlight, as excessive brightness can cause radiation dispersion and reduce canopy visibility.

Each 10 × 10m plot was subdivided into multiple subplots, with the number of photographs determined by canopy density. In areas with sparse or irregular canopy cover, or where logging was evident, nine photos were taken per plot. In moderately dense forests with some canopy gaps or signs of logging, five photos were taken per plot. In dense, intact forests with tall trees, four photos per plot were considered sufficient.

Analysis of mangrove community structure and canopy cover

The analysis of the mangrove community structure was conducted using the Important Value Index (IVI), which was determined by calculating the Relative Density (KR), Relative Frequency (FR), and Relative Dominance (DR). According to **SNI (2011)**, the IVI is calculated using the following equations:

- Relative Density (KR): $\left(\frac{ni}{A}\right) \times 100$ where *ni* represents the number of individuals of a species and *A* is the total area sampled.
- Relative Frequency (FR): $\left(\frac{pi}{\Sigma p}\right) \times 100$ where *pi* is the number of plots where the species is found, and $\sum p$ is the total number of plots.
- Relative Dominance (DR): $\left(\frac{Ci}{\Sigma C}\right) \times 100$ where *Ci* represents the basal area of a species and $\sum C$ is the total basal area in the study plots.

The canopy cover analysis was conducted using hemispherical photography. This method involves separating sky pixels (assumed to be white) and vegetation pixels (assumed to be black) to determine the percentage of mangrove canopy cover using binary image analysis **(Chianucci *et al*. 2014)**. The photographs were analyzed using ImageJ and Microsoft Excel, applying the formula:

$$Mangrove\ canopy\ cover\ percentage = \left(\frac{P255}{\Sigma P}\right) \times 100$$

Based on Minister of Environment Decree No. 201 of 2004 on Mangrove Damage Criteria and Guidelines, the average mangrove canopy cover is categorized into three groups:

- Dense (>75%) with a density of ≥1500 individuals/ha
- Moderate (50-75%) with a density of 1000-1500 individuals/ha
- Sparse (<50%) with a density of <1000 individuals/ha

Analysis of biomass and carbon storage in mangroves

Mangrove biomass was determined by measuring the Diameter at Breast Height (DBH) of trees, which was then applied to species-specific allometric equations. The allometric equations for different mangrove species are presented in Table (1).

Table 1. Allometric equations for mangrove stands

Species	Allometric Equation	Source
Rhizophora mucronata	W = 0.1466*$DBH^{2.3136}$	Komiyama *et al*., 2008
Bruguiera gymnorrhiza	W = 0.186*$DBH^{2.31}$	Komiyama *et al*., 2008
Sonneratia alba	W = 0.825*$DBH^{0.89}$	Komiyama *et al*., 2008

Note: W = Biomass (kg); DBH = Diameter at Breast Height (cm).

To estimate carbon storage, the biomass of mangrove stands was first calculated. According to the **IPCC (2006)**, carbon constitutes approximately 47% of organic biomass. The total carbon storage (Cn) was estimated using the following equation **(Azzahra *et al*., 2020)**:

$$Cn\left(\frac{ton}{ha}\right) = Biomass\left(\frac{ton}{ha}\right) \times 0.47$$

RESULTS

1. Mangrove community and important value index (IVI)

Based on calculations of density, frequency, and dominance of mangrove species at each observation station, the Important Value Index (IVI) was determined to reflect the mangrove community structure on Rakit Island, Indramayu Regency (Table 2). The species with the highest IVI at Station I was *Rhizophora mucronata*, with an IVI of 300%. The highest IVI values at Stations II and III were also recorded for *Rhizophora mucronata*, with IVIs of 259.62% and 254.28%, respectively. These stations share similar substrate characteristics with Station I, consisting of sandy-mud with high salinity, an optimal condition for *Rhizophora mucronata* expansion.

Table 2. Mangrove vegetation community structure on Rakit Island, Indramayu Regency

Station	Species	K (ind/ha)	KR (%)	FR (%)	DR (%)	IVI
I	*Rhizophora mucronata*	566,67	100	100	100	300
II	*Rhizophora mucronata*	400	92,31	75	92,31	259,62
	Bruguiera gymnorrhiza	33,33	7,69	25	7,69	40,38
III	*Rhizophora mucronata*	833,33	96,15	66,67	91,46	254,28
	Sonneratia alba	33,33	3,85	33,33	8,54	45,72

Fig. (2) shows the island area with NDVI algorithm applied. Based on the results, the overall NDVI value ranges from -0.64255 to 0.812065. The value includes negative numbers because the masked area includes the island's shallow part that is covered with water. The pixels from the station's areas range from +0.030 to +0.6755. Specifically, Station 1 samples have a range between +0.13613446 to +0.67554134, Station 2 between +0.34419751 to 0.65648049, and Station 3 between +0.03026907 to +0.56438237. According to **Rizki *et al*. (2017)**, NDVI values of mangroves range between +0.1 and +0.7. For the shallow areas, water has negative NDVI values while sands, rocks, and snow range between -0.1 and 0.1 **(Ya'Acob *et al*., 2014)**.

Fig. 2. NDVI map of Rakit Island with geotagging photo at each sampling station

2. Water quality

At Station 1, the average temperature was 27.6°C (Table 3), the lowest among the measured stations. Salinity was 26 ppt (Table 3), also the lowest value recorded. The pH was 7.30, representing the most acidic condition among the three stations. The substrate consisted of sandy mud, which supports the growth of *Rhizophora mucronata*. This species dominated the area due to its strong stilt roots, which stabilize the substrate and help prevent erosion.

At Station 2, the temperature was 28.8°C (Table 3), within the optimal range for mangrove photosynthesis. Salinity was 28 ppt (Table 3), a level suitable for *Rhizophora mucronata* and *Bruguiera gymnorrhiza*, both of which were found in this location. The pH was 7.60, indicating a more alkaline environment than Station 1 but slightly lower than Station 3. The substrate was sandy mud, providing a stable habitat for *Rhizophora mucronata*, which dominated this station. *Bruguiera gymnorrhiza* was also present, adapting to the substrate through specialized knee roots that facilitate respiration in less stable conditions **(Muzaki & Kurniasih, 2012)**.

At Station 3, the highest temperature was recorded at 29.1°C (Table 3), approaching the upper limit of the optimal range for mangrove photosynthesis. This suggests greater solar radiation or tidal activity contributing to heat distribution. Salinity was 28 ppt (Table 3), an ideal condition for both *Sonneratia alba* and *Rhizophora mucronata*, which were present at this site. The pH was 7.72, indicating a slightly alkaline environment. The substrate was sandy mud, suitable for *Sonneratia alba*, a pioneer species in intertidal zones that stabilizes the substrate and protects the shoreline from erosion **(Baderan, 2017)**. The presence of *Rhizophora mucronata* further demonstrates its ecological adaptability across different substrate types.

Table 3. Water quality parameters at Rakit Island

Station	Temperature (°C)	Salinity (ppt)	pH	Substrate
1	27.6	26	7.30	Sandy Mud
2	28.8	28	7.60	Muddy Sand
3	29.1	28	7.72	Muddy Sand

3. Canopy cover and mangrove density

The results of mangrove canopy cover calculations indicate that canopy conditions at the three stations ranged from 48.25 ± 28.55% to 77.74 ± 8.30% (Table 4). Conversely, good canopy cover was observed at Stations 1 and 3, where canopy cover exceeded 50 and 75%, respectively. However, canopy cover was dense at Stations 1 and 3, contrasting with the mangrove density, which was classified as degraded. This observation aligns with the calculation results, where canopy cover at Stations 1 and 3 was classified as good, whereas density values indicated degradation.

Table 4. Mangrove canopy cover and density criteria based on Minister of Environment Decree No. 201 of 2004

Station	Canopy Cover (%)	Standard Deviation	Cover Classification	Density (Ind/Ha)	Density Classification
1	77.74	8.30	Very Dense (Good)	566.67	Sparse (Degraded)
2	48.25	28.55	Sparse (Degraded)	433.33	Sparse (Degraded)
3	72.57	17.15	Moderate (Good)	866.66	Sparse (Degraded)

4. Carbon storage potential in mangrove vegetation

Mangrove ecosystems are highly effective in reducing atmospheric carbon dioxide (CO_2) concentrations by absorbing CO_2 through photosynthesis and storing carbon in biomass **(Windardi, 2014)**. Most mangrove biomass consists of stored carbon, making mangrove forests an important carbon sink. One way to assess carbon storage potential is through biomass estimation **(Twilley *et al*. 1992)**.

Table 5. Carbon storage potential of mangrove vegetation on Rakit Island, Indramayu Regency

Species	Biomass Potential (ton/ha)	Carbon Potential (ton/ha)
Rhizophora mucronata	85.15	40.02
Bruguiera gymnorrhiza	2.09	0.98
Sonneratia alba	0.54	0.25
Total Potential	**87.78**	**41.25**

The biomass and estimated carbon storage values for each mangrove species varied, as different species have unique biomass coefficients **(Komiyama *et al*., 2008)**. The study results indicate that *Rhizophora mucronata* has the highest carbon storage potential at 40.02 tons/ha, significantly higher than *Bruguiera gymnorrhiza* and *Sonneratia alba*. The higher carbon content in *Rhizophora mucronata* is due to its greater biomass value of 85.15 tons/ha (Table 5). This aligns with **Windardi (2014)**, who stateD that mangrove biomass significantly influences carbon storage potential, with higher biomass values leading to greater carbon conversion.

DISCUSSION

1. Mangrove community and important value index (IVI)

Substrate characteristics play a crucial role in limiting mangrove ecosystem growth. The high IVI value of *Rhizophora mucronata* at Station 1 is attributed to its well-adapted root system in sandy–muddy substrates. This finding aligns with **(Surahmat *et al.*, 2023)**, who noted that *Rhizophora mucronata* dominates sandy–mud substrates because its stilt roots anchor deeply into the soil, providing structural support and enhancing tree stability. Similarly, **(Rachmawati *et al.*, 2014)** reported that soil properties, including mineralogical and physical characteristics, significantly influence vegetation zonation and distribution.

The NDVI map (Fig. 2) produced pixel values that reflect vegetation condition. Based on **(Mangewa *et al.*, 2022)**, NDVI values can be categorized as very good (> 0.6–>0.9), good (> 0.4–0.6), poor (> 0.2–0.4), and very poor (≤ 0.2). However, vegetation condition cannot be determined solely from satellite imagery analysis, as accuracy may be affected by haze, clouds, sun glint, and mixed pixels **(Kay *et al.*, 2009; Hultberg, 2018)**. Therefore, field validation should be conducted in future research to improve accuracy.

Water quality

Three parameters were measured: temperature (°C), salinity (ppt), and pH.

- **Temperature:** Station 1 recorded the lowest temperature at 27.6°C (Table 3), slightly below the optimal range for mangrove photosynthesis (28–32°C) reported by **Gilman *et al.* (2008)**. This may have been influenced by rainfall prior to data collection, which lowered both water and air temperatures. In contrast, temperatures at stations 2 (28.8°C) and 3 (29.1°C) were within the optimal range.
- **Salinity:** Salinity values were relatively stable, ranging from 26 to 28 ppt. Station 1 recorded the lowest salinity (26 ppt), while stations 2 and 3 both measured 28 ppt. These values are considered ideal for mangrove growth **(Aksornkoae, 1993)**.
- **pH:** Values ranged from 7.30 to 7.72, all within the optimal range for mangrove ecosystems as defined by the Minister of Environment Decree No. 51 of 2004. Station 3 recorded the highest pH (7.72), indicating favorable conditions for mangrove metabolism and associated organisms. The lowest value, 7.30 at Station 1, was still within the optimal range **(Surahmat *et al.*, 2023)**. Station 2 (7.60) reflected chemically stable water conditions, minimizing physiological stress on vegetation.

Canopy cover and mangrove density

According to the Minister of Environment Decree No. 201 of 2004, the lowest canopy cover was recorded at Station 2, classifying it as sparse or degraded (< 50%). This value was derived from hemispherical photography analysis. High standard deviation values were influenced by station-specific conditions, particularly the sparse distribution of mangroves in the initial plots. In addition, measurement errors were more likely due to sun flare in the hemispherical images, which obstructed canopy detection **(Dharmawan, 2020)**. These results are consistent with field observations, where mangrove distribution was relatively uniform but density varied.

Carbon storage potential in mangrove vegetation

The total biomass potential of the mangrove ecosystem on Rakit Island was 108.66 tons/ha, indicating a moderate biomass level. According to **Dharmawan *et al.* (2008)**, biomass potential in mangroves is influenced by soil fertility and tree density. The estimated carbon storage potential was 41.25 tons/ha. Given this moderate sequestration capability, mangrove conservation efforts on Rakit Island should be strengthened to maximize ecological benefits and mitigate climate change impacts.

Mangrove ecosystems vary widely in their carbon sequestration capacity. **Kusmana (1996)** reported biomass ranges of 62.9–398.8 tons/ha, litterfall production of 5.8–25.8 tons/ha/year, and an annual volume increment of 9 m^3/ha/year in 20-year-old mangrove stands. Well-preserved Southeast Asian mangroves typically store 250–275 tons/ha of biomass, while degraded ecosystems may fall below 7.9 tons/ha **(Daniel *et al.*, 2011)**.

CONCLUSION

The study of mangrove canopy cover on Rakit Island, Indramayu Regency, revealed variations in ecosystem conditions across the three observation stations. Using the hemispherical photography method, canopy cover ranged from 48.25 to 77.74%. Stations 1 and 3 exhibited good to very dense canopy cover, while Station 2 showed sparse or degraded cover. The dominance of *Rhizophora mucronata* across all stations is attributed to its root adaptations to sandy–mud and muddy–sand substrates. Water quality parameters, including temperature, salinity, and pH, indicated optimal conditions for mangrove growth. These findings highlight the potential for preserving the mangrove ecosystem on Rakit Island, despite signs of degradation at certain stations. The mangrove ecosystem on Rakit Island was estimated to store 41.25 tons/ha of carbon, with the highest contribution from *Rhizophora mucronata* (40.02 tons/ha). This species' significant carbon storage capacity is linked to its high biomass value of 85.15 tons/ha compared with *Bruguiera gymnorrhiza* and *Sonneratia alba*. Although the mangrove ecosystem functions as a carbon sink, its sequestration potential remains relatively low compared with Southeast Asian mangrove biomass standards, which typically range from 250 to 275 tons/ha. Environmental factors such as soil fertility and tree density play crucial roles in determining both biomass potential and stored carbon levels.

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