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Research Paper

THE ECOLOGICAL MANGROVE HEALTH THROUGH BIOASSESSMENT APPROACHES FOR COASTAL RESILIENCE IN KULON PROGO YOGYAKARTA

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ARTICLE HIGLIGHTS

- This research is the first integrated bioassessment of mangroves in Kulon Progo combining vegetation and carbon.
- Reveals dominance of *R. mucronata* with low species diversity, indicating ecosystem degradation.
- Demonstrates high carbon storage in large-diameter species (*Avicennia, Sonneratia*).
- Fills research gap on site-specific carbon stock estimation in southern Java mangroves.
- Conservation strategy requires species diversification and eco-hydrology-based restoration can provide policy-relevant conservation strategies aligned with Indonesia's FOLU Net Sink 2030.

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ABSTRACT

Bioassessment of the mangrove ecosystem in the riparian estuary of Kulon Progo can be used as a scientific basis to support coastal conservation. This study focused on ecological conditions of the riparian estuary. The study was conducted using a descriptive-quantitative approach through the collection of biological indicator data in the form of mangrove vegetation data and physical-chemical environmental parameters. This study showed that changes in mangrove land cover reached a peak of 98.7 ha in 2016 and stabilized at around 95.8 ha in 2024. This study also showed the discovery of 16 species from 5 families with the dominance of *Rhizophora mucronata*, low to moderate diversity index values (H' = 1.28 – 1.71), and low uniformity (E), especially in Serang River. Estimates of biomass and carbon stocks showed that *R. mucronata* contributed the most overall, but large-diameter species such as *Avicennia marina* and *Sonneratia alba* had higher carbon reserves per tree (700 – 900 Mg C/ha). Analysis of physical-chemical parameters showed that conditions are still suitable for supporting mangrove growth, although they are strongly influenced by freshwater flow. According to MHI, the bioassessment results were in the moderate category, meaning that the mangroves still functioned as carbon sinks and coastal protection, but were vulnerable due to low diversity and anthropogenic pressure. This study emphasized the importance of conservation strategies based on species diversification, restoration of former pond areas using an eco-hydrology approach, regulation of ecotourism carrying capacity, and periodic bioassessment monitoring to strengthen the stability of mangrove ecosystems. These findings are relevant to Indonesia's FOLU Net Sink 2030 target and REDD+ program, while also providing a scientific basis for sustainable mangrove management in Kulon Progo.

Keywords: bioassessment, conservation, ecological health, mangrove, riparian estuary

INTRODUCTION

Mangroves are critical ecosystems, bridging land, freshwater, and sea. They host tremendous diversity, protect and provide for coastal communities around the world (Giesen *et al.* 2007; Montgomery *et al.* 2022; Twilley, 2019). Mangrove ecosystems in riparian estuarine zones are the most productive and ecologically significant habitats in tropical coastal regions (Arifanti *et al.* 2025). They provide critical ecosystem services and coastal protection, carbon sequestration, nursery grounds for fisheries, and support for local livelihoods(Blanton *et al.* 2024; Mucharomah, 2015; Prasetya *et al.* 2018).

Approximately 76% of all mangrove forests in Southeast Asia are located in Indonesia. This ecosystem comprises 15 plant families, 18 genera, and 41 true mangrove species, along with 116 associated species, covering a total area of about 35,337 km² (Arifanti *et al.* 2021; Prasetya *et al.* 2018). Mangrove vegetation, as the main component of the ecosystem in the riparian area of the river estuary in Kulon Progo Regency, has several functions, including as a spawning ground, nursery ground, feeding ground, and carbon sink. Unfortunately, not all people are aware of the importance of this ecosystem (Eddy *et al.* 2022; Hanca *et al.* 2023; Yani *et al.* 2024).

In Indonesia, and specifically in Kulon Progo Regency, these ecosystems are under increasing threat from pollution, land conversion and climate change (Firaswan *et al.* 2017; Syam *et al.* 2025). A specific issue in Kulon Progo is the increasing pressure on mangrove ecosystems from coastal abrasion, land-use change, aquaculture expansion, tourism development, and upstream pollution. These threats have caused fragmentation and ecological stress in riparian mangrove habitats, thereby strengthening the need for an integrated bioassessment to evaluate ecosystem health and resilience.

The urgency for effective bioassessment and conservation strategies is underscored by the rapid degradation of mangrove cover and the socio-economic vulnerabilities of coastal communities dependent on these resources. Scientific bioassessment, integrating both ecological and socio-economic dimensions, is essential as a foundation for targeted and adaptive conservation interventions in Kulon Progo and analogous tropical estuarine zones (Needham 2008; Rahayu & Nugroho 2020; Rivaldi *et al.* 2025).

Mangroves ecosystems have enormous ecological potential (Herawati *et al.* 2019; Setyawan *et al.* 2005; Syam *et al.* 2025). They play a crucial role in protecting and stabilizing coastal zones, enriching nearshore waters, and providing valuable forest products that sustain coastal fisheries. They rank among the most productive ecosystems globally, generating organic carbon far beyond their own metabolic needs and thus making a substantial contribution to the global carbon cycle. Moreover, bioactive compounds derived from mangroves and their associated organisms have demonstrated antimicrobial properties against pathogens affecting humans, animals, and plants.

These ecosystems also hold potential for further development as sources of commercially valuable products, fishery resources, and ecotourism destinations. Their distinct ecological characteristics make them exceptional natural laboratories for studying biodiversity and ecosystem processes. In areas where mangrove degradation occurs, revegetation efforts must be accompanied by continuous monitoring and comprehensive evaluation to enhance understanding of ecological recovery. Such insights are essential for formulating effective strategies to rehabilitate degraded mangrove habitats worldwide and to ensure the long-term sustainability of these vital ecosystems.

Mangrove ecotourism has become an important land-use context in the southern coast of Kulon Progo, particularly in the Bogowonto and Serang estuaries, where mangrove forests are developed as nature-based tourism sites. Although this activity can support local income and raise conservation awareness, it also creates pressure through visitor disturbance, infrastructure development, and associated habitat modification. Therefore, evaluating mangrove ecological health in this area is essential to understand how conservation and ecotourism can be balanced sustainably.

Since numerous factors interact in determining the health of mangrove ecosystems, a comprehensive evaluation of all factors that are interrelated at the ecosystem level is necessary for the selection of appropriate indices that can reflect the current health status of mangrove ecosystems. The appropriate strategy must be used in selecting effective indicator for the mangrove ecosystem health status (Ibrahim *et al.* 2019). Based on these issues, activities need to be carried out to determine the condition and quality of mangrove ecosystems in several river estuaries in Kulon Progo Regency.

To address the challenges of conservation and sustainable coastal management, a scientific approach based on bioassessment is needed, namely the assessment of ecosystem conditions through biological indicators such as mangrove vegetation.

MATERIALS AND METHODS

Research Location

A comprehensive study of mangrove ecosystem in riparian estuary was conducted from March to August 2025. The study was conducted in the estuarine and mangrove ecosystem located at the river mouth of the Bogowonto River, Serang River and Progo River. Kulon Progo Regency, Special Region of Yogyakarta, Indonesia and directly facing the Indian Ocean along the southern coast of Java (Fig. 1).

Reseacrch stations and sampling points were selected using purposive sampling to ensure that the samples represented the actual conditions of mangrove vegetation at each site. Each research station covered an area of 500 m² and was used as the sampling unit.

Observation and Data Sampling

Observations were conducted utilizing remote sensing. In observing vegetation cover or density in an area Vegetation Indices (VIs) was applied using radiometric measurement on photosynthesis activity of vegetation. Vegetation cover varies in each region. The cover of vegetation affects the condition and balance of ecosystems. The density of vegetation cover can be used as a parameter in assessing ecosystem dynamics or agricultural parameters. Vegetation has good reflectance to near-infrared (NIR) light.

The Normalized Difference Vegetation Index (NDVI) is categorized as a parameter with a high degree of accuracy for mapping mangroves in an area. The concept of NDVI is quite simple, which is to look at the optimal NIR light reflected by chlorophyll and the absorption of red light by green plants.

Landsat imagery and remote sensing techniques provide valuable insights into the extent and dynamics of mangrove deforestation in Kulon Progo. These tools support effective monitoring and inform management strategies, including community-based approaches and stronger enforcement of regulations, which are essential for reducing deforestation and promoting mangrove conservation.

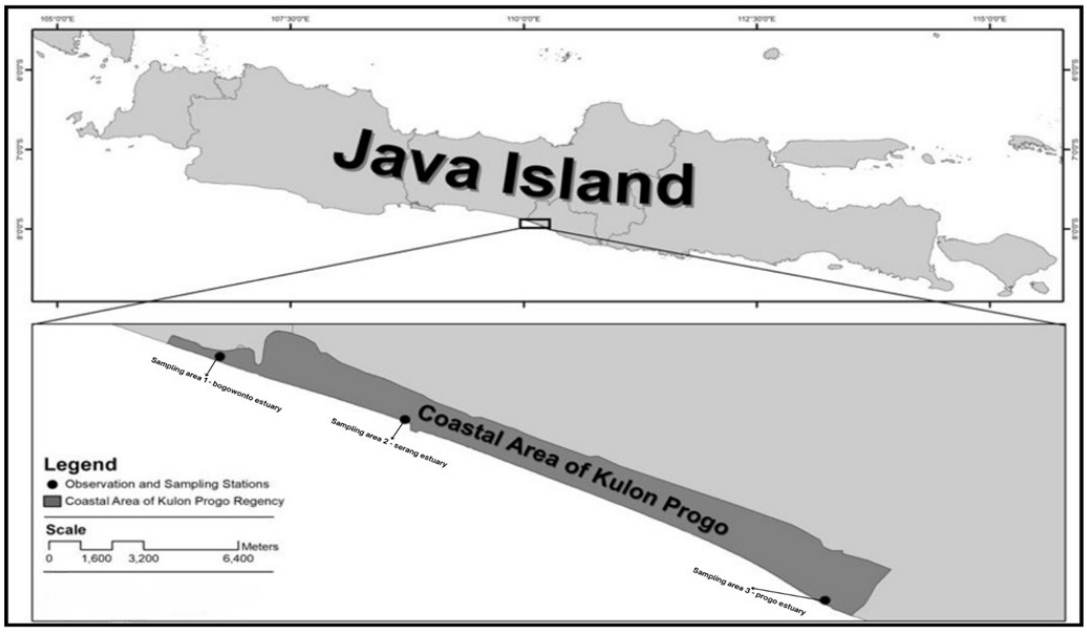


Figure 1 Map of the research location

Data Analysis

The biotic integrity index for mangrove ecosystems was determined based on diversity and dominance, but it differed across vegetation classes. Combining various data types through satellite remote sensing, geographic information systems (GIS) using NDVI, and modeling could provide an effective method for evaluating the condition of mangrove ecosystems.The value of community structure was obtained from calculating the abundance of mangrove vegetations, calculating diversity, uniformity and dominance indices.

$$\text{Density} = \frac{\text{Number of individuals of speciesi}}{\text{Total Number of observation plots}} \quad (1)$$

The Shannon-Wiener species diversity index was calculated by:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (2)$$

where:

H' = Shannon–Wiener Biodiversity Index
Pi = Total individual in each species
S = Summary of all individuals

Range score categories:

H' < 1 = Low diversity index
1 < H' < 3 = Moderate diversity index
H' > 3 = High diversity index

The similarity index assesses degree of similarity in the total of individuals from various species within a group. Higher the homogeneity index, the more unstable the ecosystem's balance.

$$E = \frac{h'}{\text{Ln } S} \quad (3)$$

where:

H' = Diversity index
S = Species total
E = Similarity index

Range score categories:

E < 0.4 = Low similarity, Stresses community
E 0.4 – 0.6 = Moderate similarity, Fragile community
E > 0.6 = High Similarity, Stable community

The dominance index (C) measures how much one group of biota dominates another. A large enough dominance will result in a labile or depressed community.

$$C = \sum \left(\frac{n_i}{N}\right)^2 \quad (4)$$

where:

C = Dominance index
Ni = Number of i-th individuals
N = Total number of individuals

Range score categories:

0 < C < 0.5 = Low Dominance
0.5 < C ≤ 0.75 = Moderate Dominance
0.75 < C ≤ 1 = High Dominance

RESULTS AND DISCUSSION

Community Structure of Mangrove Ecosystem

Mangrove ecosystems are communities with unique vegetation because they can adapt to various environmental conditions spread across the intertidal zone with three types, namely major mangroves, minor mangroves, and associated mangroves. Major mangroves adapt to high salinity conditions, while minor mangroves adapt to low salinity (Nurrofik *et al.* 2021; Pramudji 2017). Major mangrove vegetation forms large, pure stands and usually dominates an area, while minor mangroves do not usually dominate but are present in the ecosystem.

Vegetation analysis was conducted to determine the composition of vegetation types at the research sites. Table 1 presents the vegetation composition at each research site.

In mangrove ecosystems, species composition (the number and distribution of mangrove species) is a key indicator, as healthy ecosystems are generally characterized by diverse, balanced communities that are suited to their habitat conditions (Table 2).



Figure 2 Several types of mangroves found at the research site
Notes: (1) *Avicennia marina*; (2) *A. alba*; (3) *A. officinalis*; (4) *Rhizopora mucronata*; (5,6) *Acanthus ilifocious*; (7) *Brugueira gymnorrhiza*.

Table 1 Mangrove species composition in the riparian area of the South Coast River

Species	Research Station		
	Bogowonto	Serang	Progo
Rhizopora mucronata L.	+	+	+
Rhizopora apiculata	+	+	+
Rhizopora stylosa	-	-	+
Avicennia marina	+	-	+
Avicennia alba	+	+	-
Sonneratia alba	+	-	+
Sonneratia caseolaris	+	-	+
Sonneratia ovata	-	-	+
Bruguiera gymnorrhiza	-	-	+
Nypa fruticans	+	+	-
Aegiceras corniculatum (L.)	+	-	-
Acanthus ilicifolius	+	+	-
Hibiscus tiliaceus L. (*Malvaceae*)	+	-	-
Pandanus tectorius	+	+	-
Cerbera manghas	-	-	+
Terminalia catappa	+	+	-

Table 2 Diversity (H'), similarity (S), evenness (E), and richness (R) indices of mangrove vegetation types

Data collection station	H'	S	E	R
Bogowonto River Estuary	1.71	0.7	0.61	2.78
Serang River Estuary	1.55	1.7	0.26	0.19
Progo River Estuary	1.28	0.61	0.46	1.48

Estimation of Biomass and Carbon Stock Potential

Calculations of carbon stocks in mangrove ecosystems in river estuary riparian areas are still in progress, as they require a considerable amount of time and await the results of soil content analysis. To determine this potential, the estimation of aboveground biomass (AGB) and belowground biomass (BGB) were calculated.

Analysis using allometric equations shows significant variation between mangrove species. *Rhizophora mucronata* is the dominant species with the highest total biomass due to its large number of individuals. However, the carbon stock value per tree is relatively smaller than other species. Conversely, *Avicennia marina* and *Sonneratia alba*, although fewer in number, have larger trunk diameters (DBH) of 35 – 42 cm, contributing up to 700 – 900 Mg C/ha. Donato *et al.* (2011) showed

that the average global mangrove ecosystem can store up to 1,023 Mg C/ha, while Alongi (2002) emphasized that Southeast Asia is the largest center of blue carbon storage in the world. This difference confirms that the research location at the river mouth still has a low level of diversity and tends to be degraded.

Each research location showed differences influenced by species composition and DBH variation. Locations with *Avicennia marina* and *Sonneratia alba* had higher carbon stock values despite having fewer trees. This confirms the importance of species diversification in determining the carbon storage capacity of mangrove ecosystems. Meanwhile, species with large diameters such as *Avicennia* and *Sonneratia* play an important role in maintaining the balance of ecosystem functions. Therefore, the presence of other species with large DBH needs to be maintained because it can increase total carbon storage while strengthening ecosystem resilience.

Bioassessment Integration Results

To determine the bioassessment results in mangrove ecosystems in river estuary riparian areas, two different approaches were used. The first approach evaluated vegetation condition using the Normalized Difference Vegetation Index (NDVI) derived from satellite imagery, while the second approach assessed vegetation structure and composition using the Importance Value Index (IVI), Shannon-Wiener Diversity Index (H'), Evenness Index (E) and Species Richness Index (R). Based on NDVI values, the Mangrove Health Index (MHI) was determined as follows (Table 3).

Figure 3 presents the results of the mangrove health analysis at the research site based on satellite imagery.

Table 3 Determination of mangrove quality based on satellite imagery

Class	Range of NDVI	Interpretation of mangrove health
1	≤ 0.2	Non-vegetation/Very poor (damaged, open, or waterlogged areas)
2	0.2 – 0.4	Stressed/Slightly damaged (sparse mangroves, environmental stress, low regeneration)
3	0.4 – 0.6	Moderate (mangroves are dense, conditions are moderate)
4	> 0.6	Healthy/Good (dense mangroves, thick canopy, high productivity)

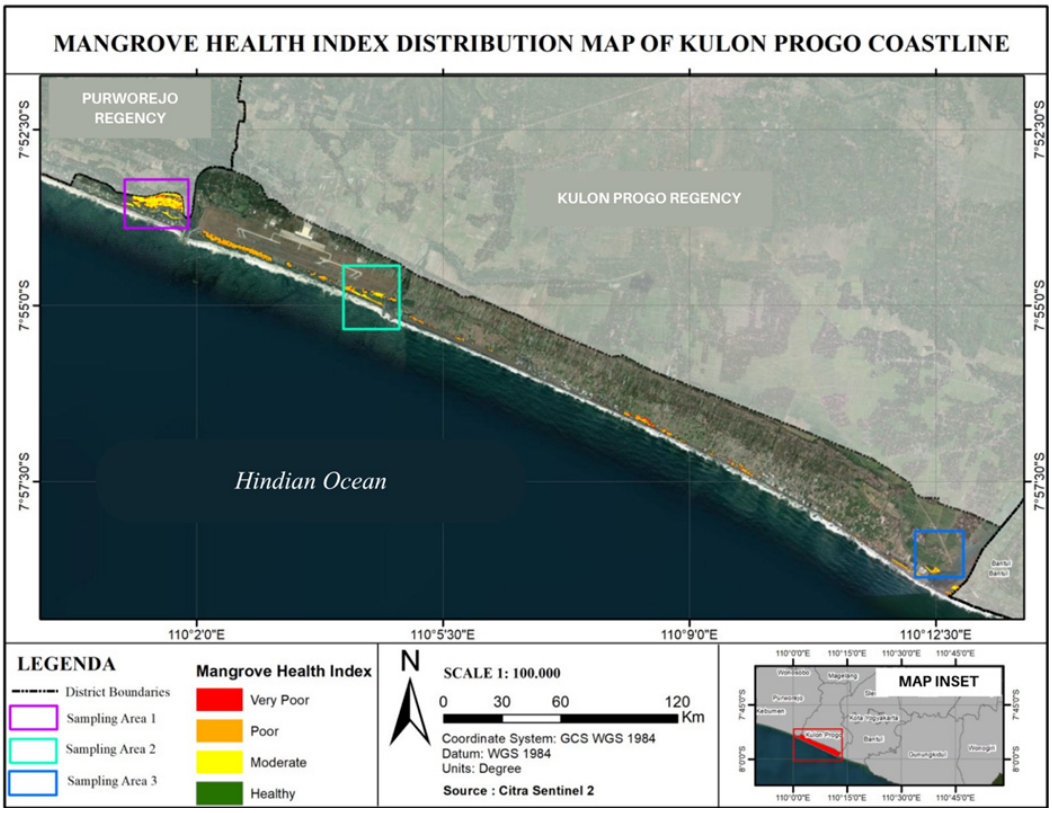


Figure 3 Map of Mangrove health in Kulon Progo Coastal Area

Based on the data obtained, mangrove ecosystems on the coast of Kulon Progo Regency can be found at every research station at each river mouth. These mangrove ecosystems consist of true mangroves and associated mangroves that live side by side. Bioassessment of the mangrove ecosystem at the river mouth on the coast of Kulon Progo Regency was determined based on the Importance Value Index (IVI), Shannon-Wiener Diversity Index (H'), Evenness Index (E), and Species Richness Index (R). The bioassessment was conducted to determine the stability and health of the mangrove ecosystem.

Vegetation analysis revealed that the mangrove ecosystem at the river mouth in Kulon Progo Regency was dominated by *Rhizophora mucronata*. At the Bogowonto estuary, this species dominated more than 90% of individuals, with a very high Importance Value Index (IVI) value. Similar conditions were observed at the Serang and Progo estuaries, although *Rhizophora apiculata* was also found at both locations, and *Rhizophora stylosa* was also found at Progo. However, the contribution of these two additional species was still low, so the dominance of *R. mucronata* remained strong.

The Shannon-Wiener Diversity Index (H') values at the three locations were classified as low to moderate (1.28 – 1.71), with relatively low Evenness (E), especially at the Serang estuary (E = 0.26). This indicates an imbalance in the distribution between species, with only one or two species dominating the community. According to Pratiwi *et al.* (2023), *R. mucronata* is the species with the highest density in the Kulon Progo mangrove and plays a major role in ecological functions, particularly carbon sequestration. When compared to research conducted by Rombe *et al.* (2022) which mentioned six types of mangroves (including *Avicennia alba*, *Avicennia marina*, *Sonneratia alba*, and *Nypa fruticans*), this research location showed a lower level of diversity. This may indicate a more degraded ecosystem condition or the limited success of mangrove rehabilitation at the river mouth compared to other areas in Kulon Progo.

The dominance of *R. mucronata* resulted in low diversity values, but it still contributed to the ecological function of mangroves. This species is known to have prop roots that are effective in retaining sediment and reducing abrasion, as well as a high capacity for carbon sequestration. The results of research by Pratiwi *et al.* (2023) indicated that *R. mucronata* in Kulon Progo is capable of storing up to 45.87 tonnes/ha of carbon in stem biomass alone, making it a key element in climate change mitigation in coastal areas. However, low species diversity also indicates the vulnerability of the ecosystem to disturbance. Monospecific ecosystems tend to be less stable against environmental changes such as seawater intrusion, pollution, or anthropogenic disturbances. In this context, the bioassessment shows that the ecosystem is still functional but not yet ecologically stable.

Overall, the bioassessment results showed that the mangrove ecosystem in Kulon Progo is currently in the moderate category, meaning that the ecosystem is still functioning but is beginning to show signs of declining carrying capacity. The dominance of certain species indicates vegetation homogenization that is vulnerable to environmental change. With multiple pressures from anthropogenic activities, the mangrove ecosystem in Kulon Progo is at a critical point, without conservation and restoration-based management interventions, its ecological functions are likely to experience further degradation in the medium term.

Based on the results of the bioassessment, the mangrove ecosystem on the southern coast of Kulon Progo Regency requires comprehensive management efforts, supported by government policies and managed using a scientific data-based conservation approach that involves community participation. Conservation strategies that can be implemented in this area need serious support from the government and encourage the community to actively participate in conservation activities. Science-based policies and management would lay the groundwork for a sustainable framework for mangrove management and consequently enhance blue carbon governance at the national level (Arifanti *et al.* 2025).

Indirectly, the results of this study also support Indonesia's FOLU Net Sink 2030 target and REDD+ commitment. Increasing species diversification in mangrove rehabilitation programs can strengthen the contribution of coastal ecosystems to climate change mitigation and expand economic benefits, including mangrove ecotourism in Kulon Progo. Regarding the results of the analysis of land use and change in the southern coastal area during 2014–2024, if anthropogenic pressure continues without conservation intervention, it is very likely that there will be a further decline in mangrove

area. However, if rehabilitation efforts (replanting, coastal stabilization) and land use regulation are carried out, some areas may experience improved coverage. According to Kurniawan *et al.* (2020), mangrove development is greatly influenced by location access, local policies, and community participation.

As a global comparison, the Mahakam Delta in Kalimantan experienced mangrove conversion to ponds of ~21,000 ha in 11 years. At the national level, conversion to ponds, agriculture, or infrastructure expansion is the main cause of mangrove loss. However, the State of the World's Mangroves 2024 report noted that although conversion is still ongoing, the rate of loss has slowed in many areas (Akram *et al.* 2023; Sahputra *et al.* 2022). Therefore, if there are consistent conservation interventions in Kulon Progo, such as zoning, restoration of former pond areas, and community empowerment, mangrove cover after 2016 could remain stagnant or even show a slight increase in certain locations.

Referring to these results, conservation efforts need to be carried out by establishing strategies with the following objectives.

1. Maintain the sustainability of ecological functions related to coastal protection and blue carbon storage.
2. Increase ecosystem stability through species diversification.
3. Integrate conservation with the local economy (ecotourism, environmental services).
4. Support national policies: Indonesia FOLU Net Sink 2030 and the 2020–2024 National Mangrove Action Plan.

The conservation action plan strategies to achieve these objectives are as follows.

a. Rehabilitation and Species Diversification, whereby mangrove rehabilitation does not only focus on *Rhizophora mucronata*, but also the introduction of *Avicennia* and *Sonneratia*, which have been proven to contribute significantly to carbon stocks. Mixed planting techniques can be used to increase ecosystem resilience to environmental change.

b. Restoration of Affected Areas, determining priority areas in former ponds and degraded land is a crucial first step. An eco-hydrology approach can also be applied to improve water circulation before planting.

c. Mangrove Ecotourism Management, including determining tourism carrying capacity based on bioassessment results so as not to damage the ecosystem. Development of education-based ecotourism (mangrove tracking, bird watching, blue carbon education tourism). Every mangrove management activity must involve community participation in planting and monitoring.

d. Bioassessment-Based Monitoring, conducted regularly by calculating ecological indices (H', E, R) every 2-3 years. Use of satellite imagery (Landsat, Sentinel) to detect changes in land cover. Integration of vegetation + carbon data for REDD+ / MRV (Measurement, Reporting, Verification) reports.

e. Strengthening Regulations & Institutions, including law enforcement against illegal logging, enforcing riparian mangrove protection zones along river estuaries, and forming multi-stakeholder collaborations between local governments, communities, universities, and NGOs.

CONCLUSION

A mangrove bioassessment on the southern coast of Kulon Progo, Yogyakarta confirmed that although carbon stocks are significant, species diversity is still low, making the ecosystem vulnerable. Conservation strategies based on species diversification, restoration of pond areas, and integration with educational ecotourism are the best ways to improve ecosystem stability and the contribution of mangroves to climate change mitigation.

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