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DYNAMICS OF HEALTH, BLUE CARBON, AND ECONOMIC POTENTIAL OF MANGROVES IN MUARA GEMBONG: SENTINEL-2 AND GOOGLE EARTH ENGINE ANALYSIS FOR FOOD SECURITY AND FOLU NET SINK 2030

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Abstract

Mangroves are vital coastal ecosystems that act as blue carbon sinks, natural barriers against erosion, and economic resources for local communities. However, anthropogenic pressures have caused degradation, including in Muara Gembong, West Java. This study analyzes mangrove health and blue carbon stock dynamics between 2020 and 2025 using Sentinel-2 imagery processed in Google Earth Engine (GEE). Mangrove health was classified using NDVI into three categories: unhealthy, healthy, and very healthy. Aboveground biomass (AGB) was estimated from NDVI-derived models and converted to carbon using a 0.47 factor. Results reveal a decline in healthy mangroves from 87.11 ha to 57.33 ha, while very healthy stands increased from 1,036.15 ha to 1,050.81 ha. Carbon stock decreased by 412 tons, from 11,115 t C (2020) to 10,703 t C (2025). Degradation mainly occurred in transitional zones critical for regeneration. This study highlights the importance of adaptive and integrative mangrove management linking ecological restoration, blue carbon monitoring, and community-based economic initiatives to support Indonesia's FoLU Net Sink 2030 target.

Keywords: *mangrove, NDVI, blue carbon, coastal economy, Muara Gembong* p-ISSN: 2303-2332; e-ISSN: 2597-8020 DOI : doi.org/10.21009/jgg.151.04

INTRODUCTION

Mangrove forests are very important coastal ecosystems because they function in coastal protection, provide habitat for aquatic biota, and store significant blue carbon (Donato et al., 2011; Murdiyarso et al., 2015). Indonesia has the largest mangrove area in the world, but has experienced degradation of up to 40% in recent decades due to land conversion to ponds, logging, and abrasion (Friess et al., 2019).

In addition to ecological functions, mangroves also provide economic benefits for coastal communities. Mangrove derivative products such as syrup, natural dye batik, snacks, and fishery products from mangrove areas contribute to the local economy (Rahman et al., 2025). Furthermore, mangroves support food security through the provision of important habitats for fish, crabs, and shrimp which are the main sources of protein for coastal communities (Alongi, 2014).

Muara Gembong, West Java, is a coastal area that has experienced quite high degradation. The loss of mangrove vegetation has an impact on coastal ecology and reduces climate change mitigation capacity. Therefore, monitoring the health conditions of mangroves and the dynamics of blue carbon stocks is very important as a basis for rehabilitation planning and adaptive management.

The use of Sentinel-2 imagery with the support of Google Earth Engine (GEE) offers opportunities for accurate and efficient monitoring of mangrove ecosystems (Otero et al., 2020). This study aims to analyze changes in mangrove health in Muara Gembong for the 2020–2025 period, calculate the dynamics of blue carbon stocks, and provide a basis for the development of adaptive management models to support *FoLU Net Sink 2030* and strengthen the local economy.

Mangrove forests are coastal ecosystems that are important in coastal protection, provide habitat for aquatic biota, and absorb blue carbon (Donato et al., 2011; Murdiyarso et al., 2015). Indonesia has the largest mangrove area in the world, but has been degraded by up to 40% due to land conversion, logging, and abrasion (Friess et al., 2019).

Theoretically, mangrove ecosystems follow the theory of ecological zoning (Tomlinson, 1986; Kathiresan & Bingham, 2001), where vegetation types are divided based on salinity, tides, and sedimentary conditions. Transition zones that function for natural regeneration tend to be most susceptible to anthropogenic stresses.

In addition, the blue carbon theory emphasizes that mangrove damage causes

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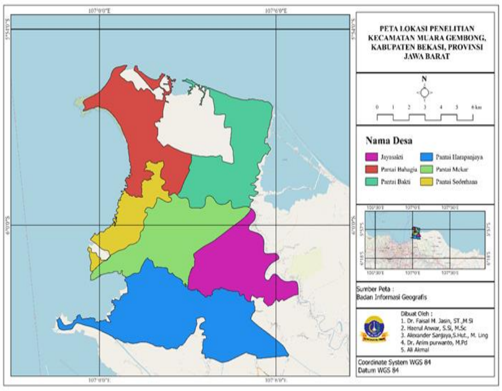
large amounts of carbon release (Nellemann et al., 2009; Murdiyarso et al., 2015). Therefore, monitoring the health of mangroves with remote sensing technology, such as NDVI (Tucker, 1979; Pettorelli et al., 2005), became very important.

Mangroves also have productive economic value (silvofishery, ecotourism, derivative products such as batik and mangrove syrup) and have the potential to be a source of food security for coastal communities (FAO, 2007). This study aims to: (i) analyze the dynamics of mangrove health and blue carbon stocks for the period 2020–2025, and (ii) provide a basis for adaptive management based *on the Faisal M. Jasin Integrate Maggrove Management Model* (FMJ-IM³) to support *FoLU Net Sink 2030.*

This situation demands the birth of a new approach to mangrove management, which emphasizes not only conservation, but also ecosystem rehabilitation, external pressure control, and multi-stakeholder engagement**.** From these needs, FMJ-IM³ was developed**,** an integrative, adaptive, and collaborative model.

METHODS

The research was carried out in the coastal areas of Muara Gembong, especially Pantai Bahagia Village and Simple Beach Village with the method of collecting mangrove vegetation data by *purposive sampling* in 15 observation plots. The research data consists of primary data and secondary data. Primary data includes the type and density of mangrove vegetation. Biophysical data were carried out by direct observation *(insitu)* and spatial analysis based on satellite imagery. Secondary data were obtained from related agencies and previous research. The research was conducted for one month in July 2025 using Sentinel-2 images in 2020 and 2025 processed through Google Earth Engine (GEE). The location of the research is presented in Figure 1.



Pictures of Research Locations

1. Determination of Mangrove HealthThe health of vegetation is analyzed by Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

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with NIR = band 8 (842 nm) and RED = band 4 (665 nm). NDVI values are used to classify mangroves into: unhealthy (NDVI < 0.32), healthy (0.33–0.42), and very healthy (>0.43) (Tucker, 1979; Pettorelli et al., 2005).

2. Biomass and Carbon Estimation Above-surface biomass (AGB) was calculated using the NDVI–AGB regression equation from previous research (Kauffman & Donato, 2012), then converted to carbon stocks using a factor of 0.47 (Hairiah et al., 2011).

3. Spatial AnalysisThe spatial distribution of mangrove health and carbon stocks is compared between 2020 and 2025. Validation was carried out with literature related to tropical mangrove vegetation and secondary data on local conditions (Murdiyarso et al., 2015; Kathiresan & Bingham, 2001).

RESULTS AND DISCUSSION

Results

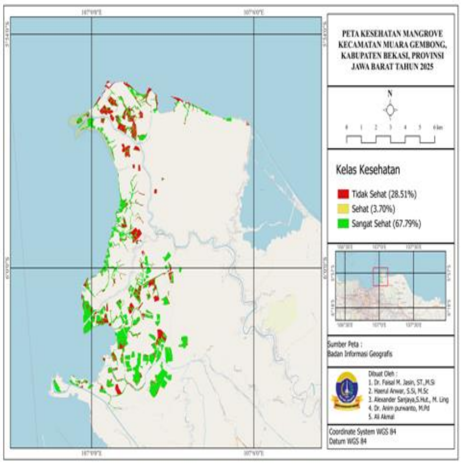

Table 1. Changes in Mangrove Health in Muara Gembong (2020–2025) Class	2020	Year Percentage 2020	2025	Percentage Year 2025	Addition/ Reduction	Δ %
Unhealthy	426.86 ha	27,54	441.99 ha	28,51324218	15.13 ha	0,975874
Healthy	87.11 ha	5,62	57.33 ha	3,698250311	-29.78 ha	-1,92115
Very Healthy	1036.15 ha	66,84	1050.81 ha	67,78850751	14.65 ha	0,945278

Table 2. Changes in Mangrove Carbon Stocks (2020–2025)

Year	Total Carbon (ton C)	Unit
Karbon 2020	11115,11448	tC/Year
Karbon 2025	10703,1999	tC/Year

Discussion

The results showed a significant decline in healthy mangroves (moderate NDVI), which is an important transition zone for regeneration (Alongi, 2015). The loss of 412 tonnes of C has implications for emissions of around 1,510 t CO_2-eq.

According to the blue carbon theory (Nellemann et al., 2009), the loss of mangrove carbon stocks contributes to the acceleration of climate change. Meanwhile the theory of socio-ecological resilience (Holling, 1973; Folke, 2006) explained that a healthy ecosystem increases the resilience of coastal communities, both from environmental and food aspects.

Economically, mangroves provide food resources (fish, crabs, shellfish) as well as high-value derivative products (FAO, 2007). Thus, maintaining the health of mangroves not only saves the ecosystem, but also supports the local economy and food security.

An adaptive management framework (Armitage et al., 2009) forms the basis of the FMJ-IM³ model, which integrates conservation, rehabilitation, external stress control, and community engagement. This approach enables sustainable management and supports the *FoLU Net Sink 2030 target*.

CONCLUSION

Mangroves in Muara Gembong experience a decline in health and carbon stocks between 2020–2025, especially in transition zones. The loss of 412 tons of C signals the need for urgent protection and rehabilitation efforts. In addition, ecosystem degradation also has an impact on the decline in economic value and food security of coastal communities. The use of Sentinel-2 and GEE has proven to be effective for spatial monitoring. The FMJ-IM³ model can be an integrative approach in adaptive mangrove management in Indonesia, supporting *FoLU Net Sink 2030*, while strengthening food security and local economies.

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