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Spatial Analysis of Mangrove Density and Carbon Stock Potential Estimation in Ambon Bay, Maluku

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ABSTRACT

Mangrove ecosystems function as blue carbon stores. Mangroves are capable of accumulating carbon in above-ground biomass, below-ground biomass, and sediments over long periods of time, making them one of the priority ecosystems in global climate change mitigation efforts. Ambon Bay is a coastal area in Maluku that possesses biophysical conditions conducive to mangrove growth; however, comprehensive spatial information regarding the distribution, density, and carbon stock potential of its mangroves remains very limited. This study aims to analyze the density and estimate the carbon stock potential of mangroves in Ambon Bay. Mangrove density analysis was conducted spatially using Sentinel-2A satellite imagery through the Normalized Difference Vegetation Index (NDVI) approach, with density classifications of low (NDVI ≤ 0.32), moderate (0.32–0.42), and high (0.43–1.00). Carbon stock estimation was calculated based on above-ground and below-ground biomass measurements using species-specific allometric equations with a diameter at breast height approach. Biomass was subsequently converted into carbon stock using a carbon fraction factor of 47% in accordance with the standards set by the National Standardization Agency of Indonesia. The results showed that the mangrove ecosystem in Ambon Bay has a total area of 29.62 hectares and estimated carbon stock potential of 904.51 tons/ha. Mangrove distribution is concentrated in the coastal areas of the inner bay, with varying density patterns across locations. The Nania and Passo areas are dominated by high-density mangroves, reflecting dense canopy cover and large stand biomass, whereas the Waiheru area tends to exhibit low density due to higher anthropogenic pressure. Field surveys identified 8 mangrove species from 4 families, including Avicennia officinalis, Rhizophora apiculata, Rhizophora mucronata, Sonneratia alba, and Xylocarpus moluccensis, indicating a vegetation zonation structure that remains relatively intact. The high carbon stock values found confirm the role of Ambon Bay's mangrove ecosystem as a significant blue carbon sink and store in the context of climate change mitigation. The spatial information generated is expected to serve as a scientific basis for the formulation of sustainable management, conservation, and mangrove rehabilitation policies, particularly through prioritizing rehabilitation in the Waiheru area and protecting high-density areas in Nania and Passo.

INTRODUCTION

The mangrove ecosystem is an ecosystem that grows in the intertidal zone along tropical and subtropical coastlines. Ecologically, mangroves serve as natural habitats for various types of aquatic biota, ranging from fish, shrimp, and crabs to various benthic organisms. Mangroves also function as spawning grounds, nursery grounds, and feeding grounds for various aquatic organisms (Agusrinal *et al.* 2015). In addition to supporting coastal

biodiversity, mangroves serve a physical function as natural protectors of coastlines against the threats of abrasion and waves, and as effective natural biofilters in absorbing, settling, and retaining various pollutants that can contaminate the environment (Bai'un *et al.* 2021). Mangrove ecosystems have the capacity to store more carbon than other forest types (Fitria and Dwiyanoto 2021). Mangroves are capable of absorbing carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis and storing it over long periods in above-ground biomass, below-ground biomass, and organic-rich sediments. Therefore, the existence of mangroves is of great importance in supporting climate change mitigation efforts through the reduction of greenhouse gas concentrations in the atmosphere (Husain *et al.* 2025). Their considerable carbon storage potential also positions mangroves as one of the priority ecosystems in various conservation and environmental rehabilitation programs based on the blue carbon ecosystem concept.

Despite their high ecological functions and strategic value, numerous studies have shown that the condition of mangrove ecosystems in Indonesia continues to decline in both quality and quantity. Mangrove degradation occurs due to the high pressure of anthropogenic activities, such as land conversion for residential areas, aquaculture ponds, industrial zones, and coastal infrastructure. Furthermore, uncontrolled exploitation of natural resources and the lack of sustainable management have further accelerated the destruction of mangrove ecosystems. These conditions have a direct impact on the reduction of mangrove vegetation cover, the decline of biodiversity, and the weakening of the ecological functions of coastal ecosystems (Saidah *et al.* 2024). The reduction in mangrove area and density also diminishes the capacity of these ecosystems to absorb and store carbon, which may increase the risk of carbon release into the atmosphere (Sondak 2015).

Ambon Bay is one of the coastal areas in Indonesia that possesses biophysical conditions conducive to the growth and development of mangrove ecosystems. The characteristics of its relatively sheltered coastal environment, supported by calm water conditions and the availability of suitable substrates, make this area a potentially significant mangrove habitat (Suyadi 2012). The presence of mangroves in Ambon Bay plays an important role in maintaining the balance of coastal ecosystems, supporting aquatic productivity, and providing economic benefits for surrounding communities. Nevertheless, the increase in human activities in the coastal zone — such as infrastructure development, land use change, and pressures from coastal resource utilization has the potential to cause degradation of the mangrove ecosystem in the region. If not managed wisely, these conditions may lead to a sustained decline in coastal environmental quality and a continuous weakening of mangrove ecological functions.

To date, detailed and comprehensive spatial information regarding the distribution, density levels, and carbon stock potential of mangroves in Ambon Bay remains relatively limited. This lack of data and information constitutes a significant constraint in formulating scientifically grounded and sustainable mangrove management, conservation, and rehabilitation policies. Spatial data on mangrove conditions are essential for supporting informed decision-making in integrated coastal zone management. Therefore, this research was conducted to analyze the spatial distribution patterns of mangroves, identify vegetation density levels, and estimate the carbon stock potential stored within the mangrove ecosystem of Ambon Bay. The findings of this study are expected to serve as a scientific information source and a basis for consideration in future efforts toward the sustainable management, conservation, and rehabilitation of mangrove ecosystems.

The novelty of this study lies in the integration of spatial analysis of mangrove density with the estimation of carbon stock potential at the scale of Ambon Bay, an approach that has not been widely examined to date. This study mapped mangrove density using Sentinel-2A satellite imagery, combined with carbon biomass density data obtained from field surveys, to generate integrated spatial information on mangrove carbon stock. This approach enables the provision of more efficient, standardized, and applicable data as a basis for blue carbon-based mangrove management in the Ambon Bay area, Maluku.

METHOD

Research Time and Location

The research was conducted from 22 to 25 June 2026 in Ambon Bay, Maluku (Figure 1). The satellite image processing and data analysis stages were carried out at the Marine Remote Sensing Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Science, Pattimura University.

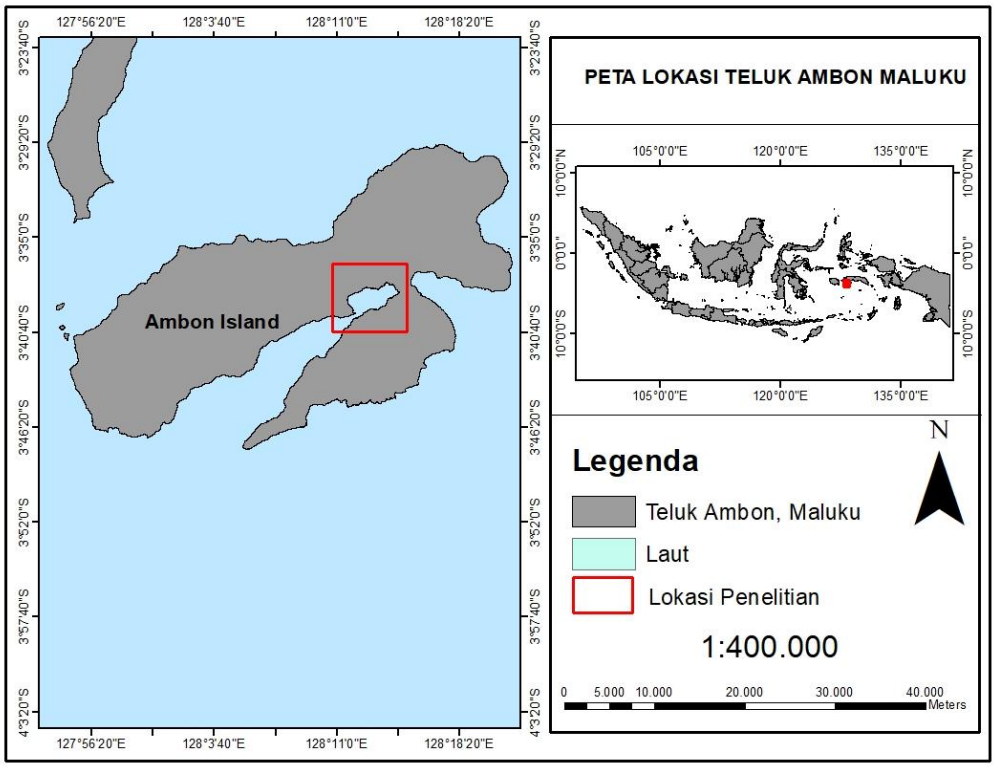


Figure 1. Research Location Map

Tools and Materials

The tools used in this study included a laptop with ArcGIS 10.8, Microsoft Word, and Microsoft Excel installed, a Global Positioning System (GPS), a roll meter, and a sediment core. The materials used in this study consisted of Sentinel-2A data obtained from https://dataspace.copernicus.eu/, mangrove distribution data obtained from https://www.globalmangrovewatch.org/, hillshade data obtained from https://www.lapakgis.com/, and Indonesia shapefile data obtained from https://tanahair.indonesia.go.id/.

Data Processing

Data processing began with image cropping and restoration, which serves to delimit the area to be processed in accordance with the research location (Tino et al. 2022). Geometric correction was also performed to improve geometric accuracy using Ground Control Point (GCP) tie points and to rectify the position of objects so that their coordinate locations correspond to their actual positions on the earth's surface. This was followed by radiometric correction, which functions to enhance the visual quality of the imagery by correcting pixel values that do not correspond to the actual reflectance or spectral emission values of the objects.

Assessment of mangrove vegetation density was carried out using the Normalized Difference Vegetation Index (NDVI), a vegetation index that has been widely validated in numerous coastal ecosystem studies (Amal *et al.* 2023). NDVI is a derived index based on a combination of ratio operations and the subtraction of spectral values from two image bands,

namely the Red band and the Near-Infrared (NIR) band. Although relatively simple in its computation, NDVI possesses a dynamic value range and high sensitivity to changes in vegetation cover conditions, making it highly effective for spatially detecting and mapping vegetation density and health (Fadhillah *et al.* 2018).

The use of the Red and NIR bands in NDVI calculation is based on the principle that both bands exhibit contrasting spectral responses to the presence of chlorophyll and vegetation biomass. Healthy and dense vegetation absorbs energy in the red band for photosynthesis while reflecting high energy in the NIR band, resulting in higher NDVI values. Conversely, sparse vegetation or non-vegetated surfaces produce low or even negative NDVI values. Operationally, NDVI is formulated as follows:

$$NDVI = (NIR - Red) / (NIR + Red) \quad \text{..... (1)}$$

Where:

NDVI : Normalized Difference Vegetation Index
NIR : Near-infrared radiation channel of the pixel
Red : Red light radiation channel of the pixel

NDVI values have a theoretical range of −1 to +1. Values approaching +1 indicate very dense and healthy vegetation cover, while values approaching 0 indicate very sparse vegetation cover or non-vegetated surfaces such as bare soil and water bodies. Negative values generally indicate water surfaces or other non-vegetated objects. The classification of mangrove density levels based on NDVI threshold values refers to the criteria developed by Amal *et al*. 2023 (Table 1).

Table 1. Mangrove density levels based on NDVI

Mangrove Density Category	NDVI Value
Low Density Mangrove	-1 ≤ NDVI ≤ 0,32
Moderate Density Mangrove	0,32 ≤ NDVI ≤ 0,42
High Density Mangrove	0,43 ≤ NDVI ≤ 1,00

Source: Amal *et al.* 2023

Spatial mangrove distribution data used as the baseline were obtained in vector shapefile format from the Global Mangrove Watch platform (https://www.globalmangrovewatch.org/). The shapefile data were integrated into ArcGIS software for further spatial analysis and processing alongside the mangrove density classification results. Estimation of blue carbon stock potential was calculated based on mangrove biomass density values. Mangrove biomass measurement was conducted on two main components, namely Above-Ground Biomass (AGB) and Below-Ground Biomass (BGB). Both were measured using the Diameter at Breast Height (DBH) approach as recommended by Komiyama *et al.* (2005) and *Bengen et al.* (2022). For trees taller than 2 m, diameter was measured at a height of 130 cm from the ground surface, whereas for trees shorter than 2 m, diameter was measured at a height of 50 cm and recorded as Trunk Diameter (TD). Only individuals with a stem diameter greater than 5 cm (D > 5 cm) were recorded, in accordance with the classification used by Rahman *et al.* (2024). Biomass values were calculated using allometric equations selected specifically for each species based on the highest correlation coefficient (r). Biomass values were subsequently converted into carbon stock using a carbon fraction factor of 47%, applicable to the genera Bruguiera, Rhizophora, and Sonneratia as reported by Rahman *et al.* (2023), whereby the stand carbon stock (kg C/stand) is obtained by multiplying biomass by a factor of 0.47. Bachmid *et al.* (2018) and the National Standardization Agency of Indonesia (BSN) (2011) state that the concentration of organic carbon contained in mangrove vegetation biomass amounts to 47% of its total biomass value. Accordingly, the carbon stock stored per unit area of mangrove can be calculated by multiplying the biomass value by the conversion factor of 0.47. The equation used is as follows:

$$C = B \times 0.47 \quad \text{..... (2)}$$

Where:
C : Total carbon stock (tons)
B : Biomass

The conversion factor of 0.47 is based on the assumption that carbon constitutes approximately 47% of the total dry organic matter of plant biomass, a value that has been widely recognized in the scientific literature on mangrove ecosystems (Bachmid *et al.* 2018; National Standardization Agency of Indonesia (BSN) 2011). The mangrove distribution data and carbon stock values were then overlaid with the mangrove density classification results to produce a mangrove distribution and density map (Tino and Rahman 2026).

RESULT AND DISCUSSION

Spatial analysis of mangrove density in the Ambon Bay area indicates that mangrove ecosystems are concentrated along the coastal zone of the inner bay, particularly in the Waiheru, Nania, and Passo areas, which ecologically constitute intertidal zones with biophysical conditions conducive to mangrove vegetation growth. The total mangrove area identified in Ambon Bay reaches 29.62 hectares, with an estimated carbon stock of 904.51 tons/ha (Figure 2). Mangroves function as blue carbon stores as well as natural buffers for the coastal ecosystem of Ambon Bay. The pattern of mangrove distribution concentrated along the inner coastal zone of the bay is consistent with the ecological characteristics of mangroves, which generally develop optimally in relatively sheltered waters with limited exposure to large waves, the availability of nutrient-rich muddy substrates, and stable tidal influences (Suyadi 2012).

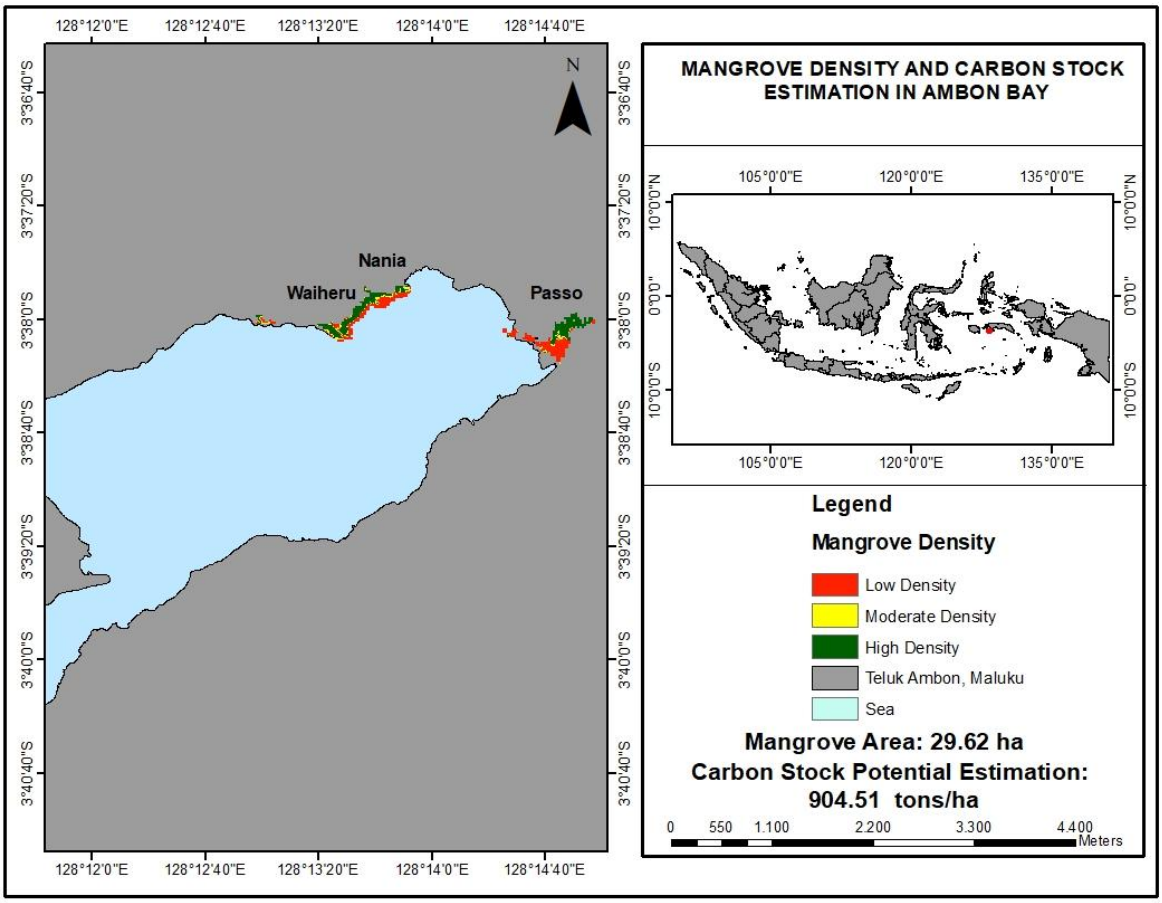


Figure 2. Mangrove Density and Carbon Stock Estimation Map

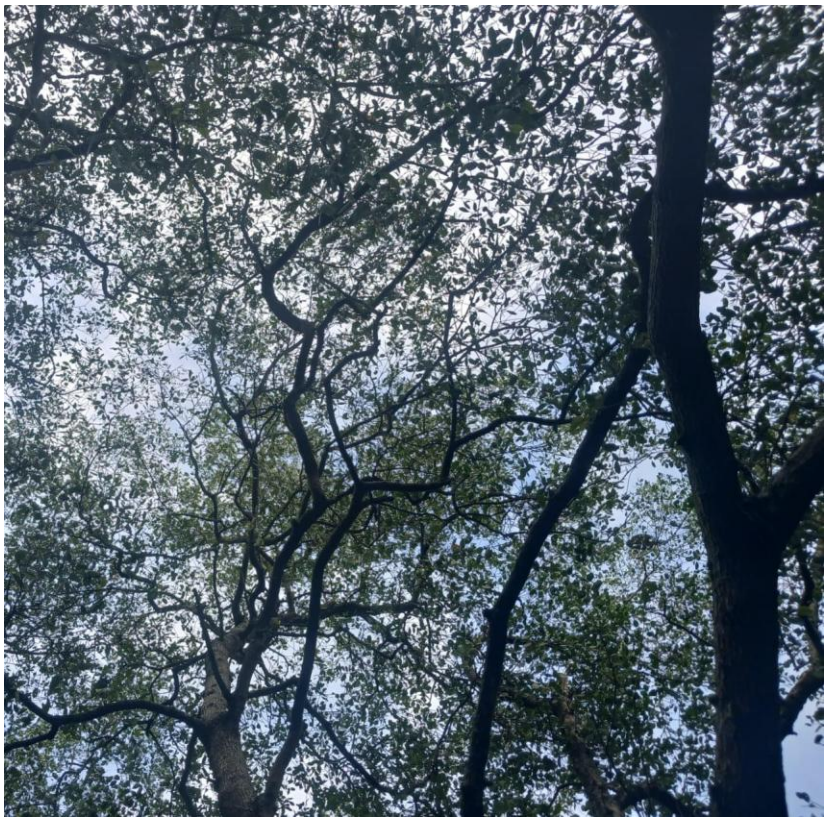


Figure 3. High Density Mangrove

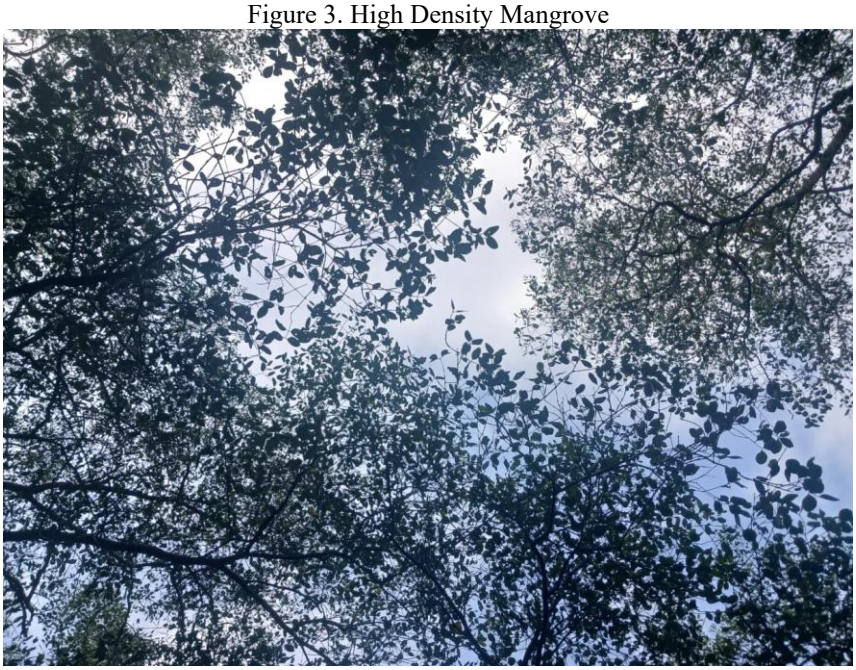


Figure 4. Moderate Density Mangrove

The mangrove density levels in the Ambon Bay area exhibit variation in vegetation density distributed along the coastline, with three main classes: low-density mangrove (indicated in red), moderate-density (yellow), and high-density (green) (Amal *et al.* 2023). Based on the results of spatial classification, the high-density class is predominantly found in the Nania and Passo areas, reflecting dense canopy cover and well-developed vegetation. This high-density class indicates optimal ecological functions, including greater carbon storage capacity (Figure 3). The moderate-density class is characterized as a transitional zone between the high- and low-density classes, reflecting vegetation conditions that are either in a recovery

stage or facing moderate environmental pressures (Figure 4). The low-density class is more prevalent in the Waiheru area and along the outer margins of mangrove distribution in Nania, indicating the presence of anthropogenic disturbances such as land use conversion, coastal infrastructure development, and substrate conditions that are less conducive to optimal vegetation growth (Figure 5). The overall spatial pattern indicates that the Waiheru area is under greater degradation pressure compared to Nania and Passo, and therefore requires more intensive management attention and intervention (Saidah *et al.* 2024).



Figure 5. Low Density Mangrove

Based on the results of field surveys, the mangrove community found in the Ambon Bay area consists of 8 species belonging to 5 families (Table 2). The diversity of species composition reflects that the mangrove ecosystems across the three locations still maintain a relatively diverse vegetation structure, despite being situated in areas facing considerable coastal development pressure. Avicennia officinalis generally dominates the outermost zone directly facing the bay waters, owing to its high salinity tolerance and ability to grow on muddy substrates through a pneumatophore root system. Species of the genus Rhizophora grow in the middle zone on more stable substrates, utilizing their characteristic prop root systems to obtain oxygen and provide mechanical stability to the substrate. Meanwhile, Sonneratia alba is commonly found in transitional zones that are periodically influenced by tidal dynamics, with high adaptive capacity through its cone-shaped pneumatophore system.

Table 2. Mangrove species found in Ambon Bay

No	Family	Species
1	Primulaceae	Aegiceras corniculatum
2	Acanthaceae	Avicennia officinalis
3	Rhizophoraceae	Bruguiera cylindrica
4	Rhizophoraceae	Rhizophora apiculata
5	Rhizophoraceae	Rhizophora mucronata
6	Rhizophoraceae	Rhizophora stylosa
7	Lythraceae	Sonneratia alba
8	Meliaceae	Xylocarpus moluccensis

The spatial information generated from this study, encompassing mangrove density distribution and carbon stock estimation in Waiheru, Nania, and Passo, holds significant

strategic value as a scientific foundation for the formulation of integrated mangrove ecosystem management, conservation, and rehabilitation policies. The Waiheru area, which exhibits a dominance of low-density mangrove, needs to be prioritized as a mangrove rehabilitation site through replanting programs and the reduction of anthropogenic pressures, given its critical position in supporting the continuity of mangrove distribution across Ambon Bay as a whole. Conversely, the Nania and Passo areas, which still maintain high-density canopy cover, must be protected from potential land use conversion and excessive exploitation in order to preserve their established ecological functions and carbon storage capacity (Agusrinal *et al.* 2015). A spatially data-driven management approach, such as that produced in this study, is expected to support the achievement of greenhouse gas emission reduction targets through blue carbon mechanisms, while simultaneously maintaining the coastal protection functions of Ambon Bay against the continuously increasing threat of ecosystem degradation (Fitria and Dwiyanoto 2021).

CONCLUSION

The distribution of mangroves is concentrated in the Waiheru, Nania, and Passo areas, with a total mangrove area reaching 29.62 hectares. Mangrove density levels vary from low, medium, to high categories, with the Nania and Passo areas dominated by mangroves of high density, while the Waiheru area tends to exhibit low density due to pressure from anthropogenic activities. Carbon stock estimation indicates that the mangrove ecosystem of Ambon Bay possesses high carbon storage potential, amounting to 904.51 tons/ha. The findings of this study confirm that the mangrove ecosystem of Ambon Bay plays an important role as a blue carbon sink, a protector of coastal areas, and a supporter of coastal ecosystem sustainability.

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