HAYATI
Journal of Biosciences

Vol. 31 No. 3, May 2024 589-595
DOI:10.4308/hjb.31.3.589-595
ISSN: 1978-3019
EISSN: 2086-4094

Mangroves in Alas Purwo National Park, Indonesia: Diversity and Its Potential Carbon Services

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ARTICLE INFO

Article history:
Received November 20, 2022
Received in revised form May 8, 2023
Accepted September 15, 2023

KEYWORDS:
Alas Purwo,
Carbon Services,
Diversity,
Mangroves

ABSTRACT

Mangroves are important ecosystems that help prevent global warming by storing carbon. A study in Alas Purwo National Park aimed to identify the species diversity and estimate the market value of total carbon from each mangrove species. The study used field sampling and diversity indexes. The study found that the study area has high diversity, with Shannon-Weiner, Margalef, and Pielou's Indexes of H' = 2.276, J = 0.949, and R = 1.453, respectively. *Rhizophora apiculata* was the dominant species with Above-Ground Carbon (AGC) and Below-Ground Carbon (BGC) stocks of about 34.73 Mg C Ha^{-1} and an economic value of $1,605, the highest among other species. The results of this study can help improve our understanding of the role of mangrove characteristics for both ecology and the economy.

1. Introduction

Global warming is one of our most pressing environmental issues (Purnamasari *et al.* 2021). As greenhouse gas emissions continue to rise, so does climate change risk (Bindu *et al.* 2020), which can have devastating consequences for people and ecosystems worldwide (Heshmati 2016). Mangrove forests are one of the most effective natural ways to mitigate climate change (Brown 1997). These unique ecosystems, which thrive in intertidal zones around the world, can store four times more carbon than other tropical forests despite covering only a fraction of the area (Donato *et al.* 2011; Giri *et al.* 2011; Estrada *et al.* 2015; Sidik *et al.* 2019).

There has been growing interest in using mangroves to help offset carbon emissions. However, most studies have focused on modeling the amount of carbon that mangroves can store (Pham *et al.* 2019; Tran *et al.* 2022; Rijal *et al.* 2023), without considering the economic value of this carbon. This is a critical omission, as carbon monetization is essential to support forest carbon initiatives. By putting a price on carbon, a market for mangrove conservation and restoration can be created, which will help to protect these vital ecosystems and mitigate climate change (Muzanni *et al.* 2022).

Previous studies have estimated the market value of mangrove carbon in Brazil and Malaysia (Estrada *et al.* 2015; Hong *et al.* 2017), but there has been less research on this topic in Indonesia, especially in undisturbed mangrove forests inside national parks. This is because most studies have focused on mangroves outside conservation areas (Easteria *et al.* 2022; Maulidia *et al.* 2022), which are more likely to be converted to other land uses. A study by (Fauzi *et al.* 2019) found that 22.64 % of mangroves in Southeast Asia have been converted to agriculture or other land uses, which suggests that mangroves in Indonesia are also at risk of conversion. This is a concerning trend, as mangroves are important in mitigating climate change and providing other ecosystem services (Latiff and Faridah-Hanum 2014). More research is needed on the market value of mangrove carbon in Indonesia to address this issue, particularly in undisturbed mangrove forests inside national parks. This research could help raise awareness of mangroves' economic value and encourage conservation efforts.

The lack of a market value for carbon services could undermine efforts to Reduce Deforestation and forest Degradation (REDD). This study aimed to

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(1) understand the diversity of mangrove species, (2) calculate the carbon stocks of each species, and (3) estimate the economic value of mangrove forests. The study was conducted in Alas Purwo National Park, Banyuwangi, East Java.

2. Materials and Methods

2.1. Study Site

Alas Purwo National Park is in the eastern part of Java Island, Indonesia (Figure 1). It is bordered by the Bali Strait and the Indian Ocean to the east and south and by the land of Banyuwangi Regency to the north and west. The park covers an area of approximately 43 hectares and is divided into six resorts: Grajagan, Rowobendo, Kucur, Sembulungan, Pancur, and Tanjung Pasir. Mangrove vegetation is most abundant in the Grajagan resort, along the Segara Anak River. There are at least 26 species of mangroves in the park, with the most common being *Rhizophora apiculata, Rhizophora mucronata, Bruguiera gymnorhyza, Avicennia marina, Xylocarpus granatum, Sonneratia alba*, and *Sonneratia caseolaris*. Two of 26 are rare species, *Ceriops decandra* and *Scyphiphora hydrophyllacea*. Mangroves in Alas Purwo thrive in muddy substrates with slightly polluted organic and inorganic waste.

2.2. Field Survey

In a field survey conducted following (Dharmawan *et al.* 2020), data were collected from square plots measuring 10 × 10 meters. This included coordinate tagging, species identification, and mangrove measurements such as Girth at Breast Height (GBH), height, and number of trees. The survey logbook was assisted by MonMang, an application developed by the Indonesian Institute of Sciences (LIPI) (Dharmawan and Sastrosuwondo 2014) for collecting mangrove field data.

2.3. Mangrove Measurements

2.3.1. Diversity

This study applied three diversity indexes: Shannon-Weiner Index, Margalef's Index, and Pielou's Index (Magurran 2004). These indexes

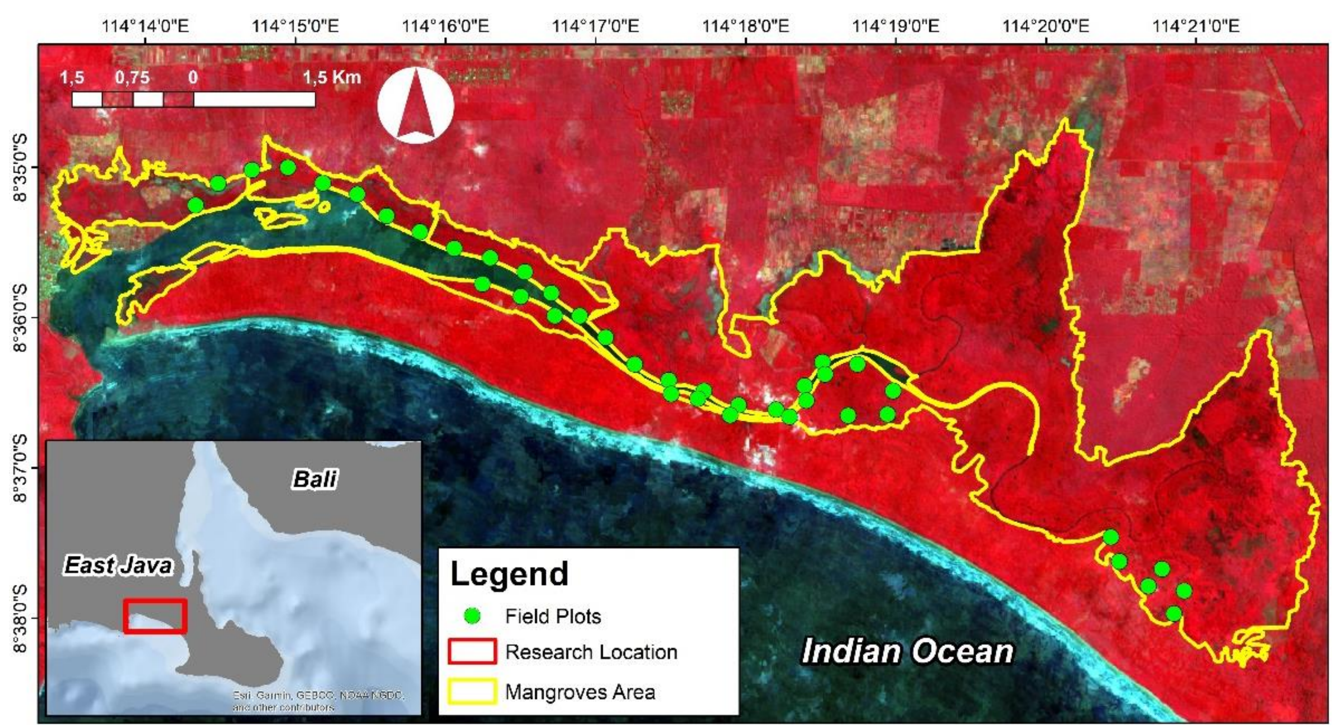

Figure 1. The study area (yellow line) overlaid above Sentinel-2B imagery with false color composite (Near Infrared-Red-Green wavelengths). Sampling plots are indicated with green dots, while the red tone on the imagery indicates the existence of vegetation

measure the diversity, richness, and evenness of mangrove species. The formulas are as follows:

Shannon-Weiner Index

$$H' = -\sum\left[\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right)\right] \quad \text{Eq. 1}$$

Where:
H' = Shannon-Weiner index
N = total individuals of the population sampled
ln = the natural algorithm
ni = total number of individuals belonging to i species

Margalef's Index

$$R = \left(\frac{s - 1}{Ln\,(N)}\right) \quad \text{Eq. 2}$$

Where:
R = Margalef's index
ln (N) = natural algorithm of the total number of individuals
S = total number of species

Pielou's Evenness Index

$$J = \left(\frac{H'}{Ln\,(s)}\right) \quad \text{Eq. 3}$$

Where:
J = Pielou's Evenness index
H' = Shannon-Weiner index
ln (S) = natural algorithm of the total number of species

2.3.2. Biomass and Carbon Calculations

The Komiyama equation (Komiyama *et al.* 2005) was used to estimate each species' below- and above-ground biomass. This equation was developed specifically for mangroves in Southeast Asia, which is relevant to the study area. The equation is as follows:

$$AGB\ (Kg) = 0.251\ \rho\ (DBH)^{2.46} \quad \text{Eq. 4}$$

$$BGB\ (Kg) = 0.199\ \rho^{0.899}\ DBH^{2.22} \quad \text{Eq. 5}$$

Where:
AGB = Above Ground Biomass
BGB = Below Ground Biomass
ρ = wood density corresponding to the mangrove species, based on the (World Agroforestry 2016) (in gr/cm^3)
DBH = diameter at breast height (in cm)

To calculate the biomass of mangroves, the Girth of Breast Height (GBH) needs to be converted into the Diameter at Breast Height (DBH) by dividing the GBH by 3.14. The biomass value is multiplied by 47% to yield the carbon value. This is because about 47% of biomass is carbon; the following equation was used to calculate the carbon value in hectare unit, known as Mg C Ha^{-1} or Megagram Carbon per Hectare (Badan Standar Nasional 2011):

$$= \frac{\text{Total carbon in Kilogram}}{1{,}000} \times \frac{10{,}000}{\text{plot size in meter}} \quad \text{Eq. 6}$$

2.3.3. Benefits of Carbon Stock

The monetary value of carbon stocks in this research was calculated using a modified formula from (Muzanni *et al.* 2022). The formula is:

$$= \text{Total carbon / ha} * 3.67 * \text{US\\$ 12.59/ton } CO_{2e} \quad \text{Eq. 7}$$

The constant value of 3.67 is the ratio of molecular weights between carbon dioxide (CO_2) equivalent and carbon, as explained by (Kauffman and Donato 2012). US$ 12.59 is the average price of carbon stocks in the global market, as proposed by (Ullman *et al.* 2013).

3. Results

3.1. Mangrove Forests Characteristics

The study area had a high level of species diversity, with an index value of H' = 2.276. This means that there was a wide variety of mangrove species present and that the distribution of these species was relatively even (J = 0.949). The overall index value based on species richness (R) was 1.453, which is also quite high. This is considering that 15 species were identified in 40 sampling plots. The mangrove species that thrived in the muddy substrate were identified as follows: *Aegiceras corniculatum, Avicennia alba, Avicennia lanata, Avicennia marina, Avicennia officinalis, Bruguiera cylindrica, Bruguiera gymnorrhiza, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora apiculata, Rhizophora mucronata, Sonneratia alba, Xylocarpus molluccensis*, and *Xylocarpus granatum*. The height of tree species varied from 4.89 m up to 10.76 m.

Rhizophora apiculata was the dominant species, with 266 stands out of the 973 identified stands (Table 1). Despite its relatively low average Diameter at Breast Height (DBH) of 9.851 cm, *Rhizophora*

Table 1. Mangrove species and their characteristics*

Species name	Number of Individual Stands	Average diameter at breast height (DBH) (cm)	Average height (m)
Aegiceras corniculatum (Ac)	6	5.042	4.89
Avicennia alba (Aa)	78	11.183	6.35
Avicennia lanata (Al)	2	11.943	6.80
Avicennia marina (Am)	25	11.694	7.59
Avicennia officinalis (Ao)	101	10.462	7.25
Bruguiera cylindrica (Bc)	8	7.444	8.45
Bruguiera gymnorrhiza (Bg)	135	9.351	10.76
Ceriops tagal (Ct)	60	6.874	4.20
Excoecaria agallocha (Ea)	28	15.639	7.72
Lumnitzera racemosa (Lr)	48	7.152	7.10
Rhizophora apiculata (Ra)	266	9.851	8.05
Rhizophora mucronata (Rm)	54	14.526	10.55
Sonneratia alba (Sa)	77	11.378	8.12
Xylocarpus molluccensis (Xm)	73	16.076	9.46
Xylocarpus granatum (Xg)	12	35.642	9.55
Total	973		

*All mangrove species thrived in the muddy substrates

apiculata could outcompete other species and dominate the study area.

3.2. Carbon Stocks from Mangrove Species and its Economic Valuation

Rhizophora apiculata, the most dominant species, had the highest value of Above-Ground Carbon (AGC) and Below-Ground Carbon (BGC), totaling 34.73 Mg C ha^{-1}. This translates to a carbon valuation of $1,605 (Figure 2). *Bruguiera gymnorrhiza*, the second most dominant species, did not directly reach second place regarding carbon valuation. *Xylocarpus molluccensis* achieved the second-highest AGC and BGC, with a total of 27.15 Mg C ha^{-1}, equivalent to $1,255 in Figure 2. Although *Xylocarpus* sp. was not the dominant species in this study and had a smaller wood density of 0.6721–0.7325 g/cm^3 compared to *Bruguiera* sp.'s 0.8683–0.8700 g/cm^3, the species of *Xylocarpus* sp. had a larger average Diameter at Breast Height (DBH) than *Bruguiera* sp. (Table 1). Therefore, this species had a greater contribution to the value of carbon and economic valuation. The potential carbon service of the mangrove in the study area yields the highest total value compared to another prior study conducted in Indonesia despite this study's research area was not the broadest and the carbon rate was not the highest.

4. Discussion

Rhizophora sp. was the dominant species in the study area, with over 300 individual stands established on 15 of 40 plots. This suggests that *Rhizophora* sp. has a high level of distribution, which can be influenced by habitat characteristics, tides, coastal physiography, waves, and currents (Alwidakdo *et al.* 2014; Makaruku and Aliman 2019). These findings are consistent with previous studies (Cerón-Souza *et al.* 2010), showing that *Rhizophora* sp. is common in tropical coastal ecosystems.

The presence of *Rhizophora* sp. is appropriate, given its carbon stocks and economic valuation. However, the number of stands may not always correlate with high carbon stocks and economic valuation. Mangroves with a high density might not guarantee a high carbon value. Instead, species with a large Diameter of Breast Height (DBH) can increase carbon value (Heriyanto *et al.* 2020). This study proves that *Bruguiera* sp. is one of the dominant species, with about 126 stands. Still, due to their differences in DBH, its carbon value is lesser than *Xylocarpus* sp., which is not dominant (85 stands only). The DBH range of *Bruguiera* sp. is about 7–9 cm; meanwhile, the *Xylocarpus* sp. ranges from 16 to 35 cm. The carbon values calculations for both

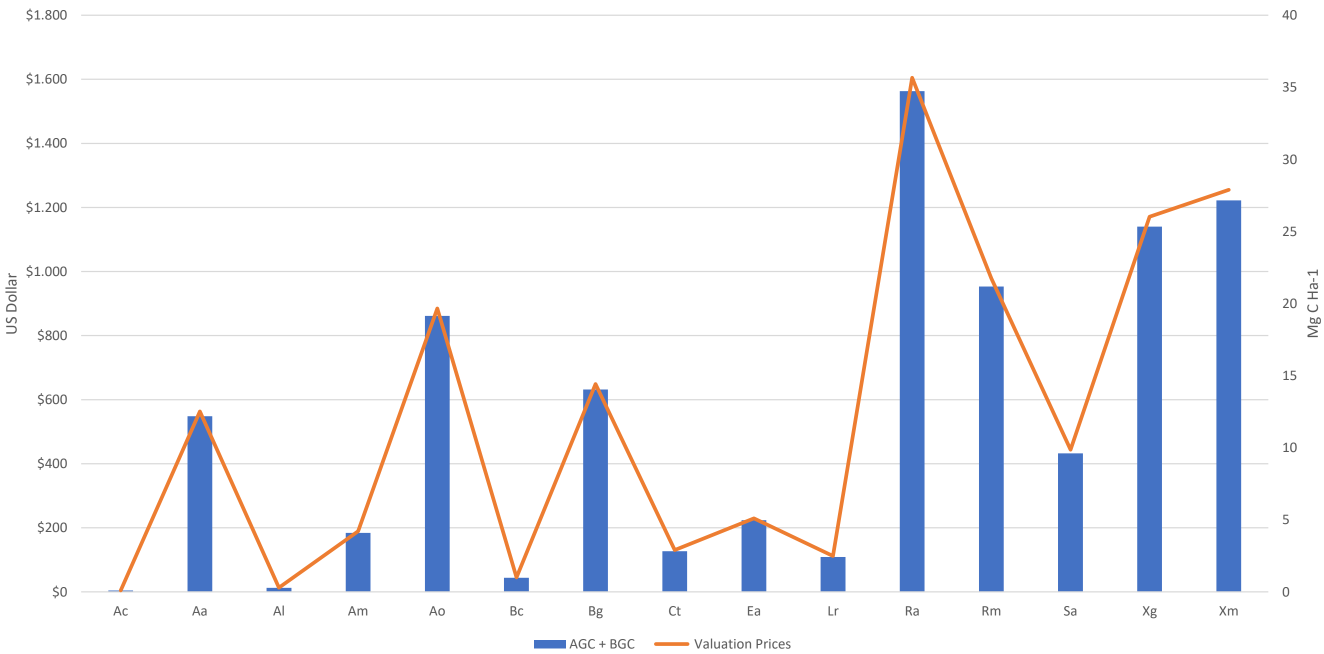

Figure 2. Mangrove species Above-Ground Carbon (AGC) and Below-Ground Carbon (BGC) stocks and their economic valuation

species were lower than 20 Mg C Ha^{-1} and more than 40 Mg C Ha^{-1}, respectively. Therefore, it is important to consider both the number of stands and the DBH of mangrove trees when assessing their carbon stocks and economic valuation. Furthermore, (Prakoso *et al.* 2017) also mentioned that the age of trees is also matter to produce more biomass through photosynthesis, which leads to amounts of carbon storage. In addition, tree height is not considered a biomass variable estimator (Ketterings *et al.* 2001; Soares and Schaeffer-Novelli 2005; Jachowski *et al.* 2013).

Mangroves in the study area were sampled in a varied environment, depicted in Figure 1, from the estuarine area to the river zone. In the estuary, mangrove was affected by salt water from the ocean; meanwhile, in the river zone, brackish water and freshwater dominantly contributed to the growth of the mangroves. These diverse environments allow for the diversity and fertility of mangroves in the study area (Alwidakdo *et al.* 2014). Mangrove diversity can be caused by some factors (Islets *et al.* 2011), including (1) mangrove species that cannot successfully grow. Some mangrove species are more tolerant of certain environmental conditions than others. For example, some species are more tolerant of salty water, while others are more tolerant of flooding. If a particular mangrove species cannot successfully grow in an area, it will not be represented in the mangrove community. (2) Only certain mangroves are planted on small islands within a certain period. Mangroves can be planted to restore degraded mangrove areas or to create new mangrove forests. However, not all mangrove species are suitable for planting in all areas. The species that are planted will depend on the area's environmental conditions and the planting project's goals.

The study site had a high diversity index (more than 1), indicating that the mangrove community has many species and that these species are relatively evenly distributed (Magurran 1988). This is likely because many individuals and groups of each species were present in the study area (Nurudin *et al.* 2013). The value of diversity can be used to assess the richness and evenness of a high mangrove community in the study area. Several factors can cause differences in the diversity index (Nahlunnisa *et al.* 2016), including (1) the observation area. (2) The larger the observation area, the more likely a wider variety of mangrove species will be present. (3) The condition of habitat characteristics. The environmental conditions of an area can affect the types of mangrove species that can successfully grow in that area. For example, an area with high salinity will not suit all mangrove species. The value of species richness depends on the number of mangrove species in an observation area. A high species richness indicates a wide variety of mangrove species in the area.

About 40 % of carbon stock in the study area was contributed from *Rhizophora* sp. followed by *Xylocarpus* sp. and *Avicennia* sp. with 29% and 19%, respectively. These findings also align with the previous study by (Heriyanto *et al.* 2008). Mangroves are classified as blue carbon ecosystems with a contribution value of around 14% of the total coastal sequestration (Alongi 2012).

Carbon payment is more dependent on the rate of carbon sequestration rather than the size of carbon stock or species diversity (Alongi 2011). The carbon rate used in this study is relatively high by (Catarina *et al.* 2020), who previously stated that the estimated prices are about 3-13 USD. However, this value is very low compared to tropical forests, which vary between 30-51 USD (Warren-Thomas *et al.* 2018), and even within coastal ecosystems (Murray *et al.* 2011). The carbon price value may vary widely across regions based on local land use options, logistical aspects, and the level of land use (Bayraktarov *et al.* 2015). The most important thing is that, to maintain the existence of mangroves, the estimated carbon prices need to compensate for the annual profits from aquaculture or other potential mangrove land conversion.

In conclusion, several factors contribute equally to mangrove carbon stocks, such as the number of stands, species, and Diameter at Breast Height (DBH). However, in some cases, a high number of stands with small DBH may not produce significant carbon storage. The study area has a variety of mangrove species with high carbon prices, reflecting its well-managed national park status as an area for mangrove conservation. Future work could consider building a map that exhibits mangrove carbon spatially and depicts the total value resulting from mangrove carbon.

Acknowledgements

This research was funded by Hibah Penelitian Strategis (Strategic Research Grant) of LPPM Universitas Brawijaya in 2022 with the contract number 1665.23 NN.0l NBl2022.

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