Species Diversity, Biomass, and Carbon Stock Assessments of Mangrove Forest in Labuhan, Indonesia

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Abstract. Mangroves provide numerous ecosystem services, including fisheries production, nutrient cycling, soil formation and carbon storage. However, the forests and their habitat have degraded rapidly due to anthropogenic threats. Consequently, the loss of carbon (C) stored in these ecosystem is inevitable. The purpose of this study was to evaluate the species diversity of mangrove forest of Labuhan, Lamongan regency, Indonesia and evaluate its above-ground and below-ground-root biomass and C. Twenty-four plots with a size of 10x10 m were carried out using the quadrat sampling technique to identify, record and measure the DBH of the trees. The Shannon – Wiener’s diversity index (H’=1.51) was moderate, having a total of nine true mangrove forests dominated by *Rhizophora mucronata* and *Rhizophora apiculata* with an importance value index of 100.40% and 80.46% respectively. The total C stored in above-ground and below-ground-root was 74.70 ± 15.58 Mg C ha⁻¹, which is equivalent to total CO₂ sequestration of 274.15 ± 57.18 Mg CO₂ ha⁻¹. This study suggests that the Labuhan mangrove forest has a potential to store and sequester a substantial amount of atmospheric C; therefore, it is needed to protect and sustainably manage this important forest.

1. Introduction

Burning of fossil fuels and deforestation are the main sources of greenhouse gases that lead to higher carbon dioxide (CO₂) concentration in the atmosphere. In particular, deforestation and changes in tropical land use account for up to 1.6 ± 1 GtC per year, which is one third of total anthropogenic CO₂ emissions [1]. This has induced many studies of the capacity of forests and wetland ecosystems in sequestrating carbon. Most of the available studies are related to terrestrial forest ecosystem, and there are not enough studies on carbon sequestration potential of mangrove forests. These forests have a high capacity to reduce greenhouse effect via carbon (C) sequestration and storage, and have been reported to sequester up to three times more C per equivalent area than terrestrial forests [2]. However, these forests are vulnerable to climate change impacts, particularly sea level rise, and threatened by rapidly expanding aquaculture and infrastructure development [3].

Globally, up to 35% of mangrove areas has been lost since 1980, and mangrove areas are estimated to disappear as high as 2–8% per year [4]. In Indonesia, mangrove cover has decreased by 40% in the past three decades mainly due to the development of aquaculture, which was the impact of rapid expansion of pond aquaculture between 1997 and 2005 [5]. In order to mitigate the degraded mangrove ecosystem, mangrove restoration and rehabilitation programs have been initiated in many regions in which tourism benefits and shoreline stabilization are added as mangrove conservation goals. Recently, carbon sequestration has also been included as the objective of mangrove restoration for mitigating climate change, in which it is aimed to maintain forest C store through carbon credits.
financial intensive [6]. This importance has promoted to address mangrove forest in climate change mitigation strategies, and induces the study of mangrove forest capacity in sequestrating atmospheric CO$_2$.

Furthermore, the total area of mangrove forest in Indonesia is estimated at about 3.2 million hectares, approximately 20% of the world’s mangrove forest area. Indonesia also has the richest mangrove diversity in the world by far, in which 45 of 70 true mangrove species have been found in this archipelago [7]. The province of East Java contains 50% of the mangrove forest area in Java Island, 18,253 ha of 34,491 ha, in which some of the forest are naturally regenerated [8]. In Labuhan, Lamongan, East Java, the mangrove forest covers are at least 90 hectares, which is mostly dominated by natural mangrove [9]. Therefore, the aim of this study is to estimate above-ground and below-ground-root biomass and its C-stocks, as well as assessing species diversity of mangrove forest of Labuhan, Lamongan, East Java, Indonesia.

2. Materials and Methods

2.1. Study Area

This study was conducted in the mangrove forest of Labuhan Village, which is located at the northern west of Lamongan Regency, East Java. The area has a precipitation average of 1465 mm, with a temperature average of 27.4 °C, and it has humid tropical savanna climate [9]. The area has diurnal tidal regime, 0.9 m at neap tide and 2.1 m at spring tide [10]. The mangrove forests of the area consist of not only primary forest, but also secondary forest and artificially regenerated forest (mangrove plantation). The forests are fringe mangrove forests that have on average a 50 m wide strip along the coast. On the landward side, the forests are separated by a large pond levee, followed by extensive shrimp ponds. The field study was conducted in March and April 2017 during the rainy season. We conducted survey at 6 stations with 4 sampling plots in each station, totalling 24 sampling plots. Station selection was primarily based on random selection along the mangrove forest of Labuhan Village. The latitude of the stations was between 6°52'23.047"S and 6°52'51.928"S, while the longitude was between 112°12'46.518"E and 112°14'0.189"E. A map of the research stations is presented in Figure 1.

![Map of the study sites in Labuhan Village, Lamongan Regency, East Java, Indonesia.](image-url)
2.2. Data Collection
Twenty-four plots of size 10 x 10m were laid out to determine the species structure and species composition of the study area. The sampling is a non-destructive quadrat technique with a distance of each plot between 5 and 10 m depending on the forest’s characteristics. In each plot, the mature mangroves with diameter of at least 5 cm were identified according to Giesen et al. [11], and measured the trunk diameter breast height (DBH). DBH of Bruguiera and Rhizophora species were determined by measuring the trunk diameter at 30 cm above the buttress and above the highest prop root respectively, whereas the DBH of the rest were measured at 130 cm above ground [12]. Physical and chemical characteristics that were also measured in the research stations were pH, temperature, salinity, phosphate, and nitrate.

2.3. Data Analysis
The structural importance of each species in the community was determined using the importance value index (IVI), which is measured by the sum of relative density (RD), relative frequency (RF), and relative dominance (RDom), where:

\[
RD = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100
\]

\[
RF = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100
\]

\[
RDom = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}} \times 100
\]

Shannon’s diversity index was used to characterize the species diversity in the mangrove habitat, where: \(H’\) is the diversity index, \(P_i\) is the proportion of individuals belonging to the \(i^{th}\) species, and \(\ln\) is the natural logarithm [12],[13].

\[
H' = - \sum P_i \ln P_i
\]

We estimated standing above-ground biomass (AGB) and below-ground-root biomass (BGB) from three DBH data by using general and species-specific allometric equations. For Avicennia marina, the species-specific allometric equations were 0.308 x \(D^{2.11}\) (diameter at the DBH, cm) and 1.28 x \(D^{1.17}\) for the standing above-ground biomass (AGB) and below-ground root biomass (BGB) respectively [14]. For other mangrove species, the general allometric equations for Indo-West Pacific were used for AGB and BGB estimation, which were 0.251 x \(\rho\) (wood density of the species, g cm\(^{-3}\)) x \(D^{2.46}\) and 0.199 x \(\rho^{0.899} \times D^{2.22}\) respectively [15]. The biomasses of AGB and BGB were multiplied by 0.47 and 0.39 to determine above-ground carbon (AGC) and below-ground carbon (BGC) respectively [16].

3. Results and discussions
3.1. Surface Sediment Characteristics
The variations of grain size in surface sediments of the mangrove forest areas are shown in Figure 2. The distribution patterns of grain size were dominated by silk, except in station 1 where sand was a major contributor to the sediment. In the sediments of the research stations, silk was accounting for 33-69%, while clay and sand were accounting for 6-29% and 8-60% respectively. On average, the proportion of silk was quite high (57±12%), while the proportion of sand and clay particles content were almost similar, but sand relatively had a high standard deviation (22±19% 21±8% respectively). The dominance of silk is common in sediment of mangrove forests and wetland. In Zhangjiang estuary, Cina, silk constituted 61-72% of mangrove forest sediment [17], while in some primary mangrove forests of Sunderbans, India, silk was accounting for 36-62% of the forest sediments [18]. Furthermore, mangrove forests have a significant ecosystem service as sediment traps and play an important role for
sinking suspended matter. The complex aerial root structures of mangrove trees catch sediments and function as land builders [19].

![Diagram of sediment size composition](image)

**Figure 2.** The distribution of grain size in surface sediments in the mangrove forest of Labuhan Village.

### 3.2. Species Diversity

A total of 236 sample trees representing nine true mangrove species, namely: B. gymnorrhiza, B. parviflora, C. decandra, L. litoria, L. racemose, R. apiculata, R. mucronata, X. moluccensis and X. rumphii, belonging to three families were recorded at the mangrove stand of Labuhan Village (Table 1). Strict or true mangroves species are found exclusively in the mangrove habitat and do not extend into terrestrial plant community and are morphologically, physiologically and reproductively adapted to saline, waterlogged and anaerobic condition [4]. Meanwhile, the DBH of the mangroves varied between 5.1 cm and 34.1 cm, with the average ranging from 9.1 cm to 19.9 cm in each plot. Mangrove of the genus Rhizophora was found to be dominating the mangrove forest with an IVI of 100.40% and 80.46% for R. mucronata and R. apiculata respectively, which 83 and 49 individuals of these species occurred in 20 and 17 plots respectively (Table 1 and 2). The concept of ‘important value index (IVI)’ has been developed to measure the dominance and ecological success of a species with a single value [9],[20]. The index was determined based on the total contribution of a species to the community by means of its relative abundance, relative dominance and relative frequency in a study plot or area [12].

R. mucronata and R. apiculata were also among mangrove species with the highest density in the research areas (345.83 ind. ha⁻¹ and 204.17 ind. ha⁻¹ respectively). Rhizophora is generally the most notable genus in tropical, coastal mangrove ecosystems [21]. The mangrove of Labuhan Village is located along the coastline that is suitable for Rhizophora species, for which their habitat is in intertidal zones that are inundated daily by the ocean. They adapt to this harsh environment using pneumatophores to respire oxygen even while their lower roots are submerged, and molecular pump mechanism to remove salt from the xylem stream [22]-[24].

The Shannon–Wiener’s diversity index ($H'$) of mangrove community of Labuhan Village was 1.51, which was higher than that of the mangrove forest in Palawan, the Philippines ($H'$= 0.99). This was due to the fact that Labuhan Village possessed a higher number of mangrove species. In contrast to tropical lowland rainforest, the mangroves have very low diversity as few plants have their special adaptations, which are attributed to their unique stands formation and harsh coastal habitat [8]. Furthermore, some species were only represented by one individual mangrove stand (Table 2); therefore, management actions need to be implemented to ensure the long-term persistence of the mangrove biodiversity.

**Table 1.** Species composition and DBH of the mangrove forest of Labuhan Village, Lamongan Regency, East Java, Indonesia.

| Plot | No. of trees | Species | DBH (cm) |
|------|--------------|---------|----------|
|      |              |         | Mean     |
|      |              |         | Min.     |
|      |              |         | Max.     |
|      |              |         | SD       |
|   | No. | Species                  | Density (Ind ha⁻¹) | RF (%) | Rdom (%) | RD (%) | IVI (%) | H' |
|---|-----|-------------------------|--------------------|--------|----------|--------|---------|-----|
| 1 | 13  | Ra, Rm, Bp              | 11.2               | 6.7    | 16.6     | 3.4    | 983.33  |
| 2 | 34  | Ra, Rm, Bg              | 9.4                | 5.1    | 23.6     | 3.5    |         |
| 3 | 12  | Ra, Rm, Bg              | 10.1               | 5.1    | 14.3     | 3.1    | 345.83  |
| 4 | 12  | Ra, Rm, Bg              | 10.5               | 6.4    | 15.6     | 3.1    |         |
| 5 | 7   | Ra, Bg                  | 19.9               | 9.6    | 28.7     | 6.5    |         |
| 6 | 4   | Rm, Ra                  | 17.6               | 13.1   | 16.9     | 4.4    |         |
| 7 | 12  | Rm                      | 18                 | 15     | 27.1     | 3.3    |         |
| 8 | 3   | Li, Cd, Rm              | 15.1               | 12.7   | 18.8     | 3.3    |         |
| 9 | 12  | Ra, Rm, Bg, Bp          | 13.2               | 8.3    | 22.9     | 5.2    |         |
| 10| 10  | Ra, Rm, Bg              | 11.2               | 5.7    | 15.6     | 2.5    | 204.17  |
| 11| 11  | Ra, Lr, Rm, Bp          | 18.8               | 7.0    | 15.9     | 3.5    | 64.51   |
| 12| 10  | Ra, Rm, Bp, Lr          | 14.1               | 8.6    | 22.6     | 4.3    |         |
| 13| 14  | Bg, Lr, Rm              | 12.4               | 6.7    | 22.9     | 5.5    |         |
| 14| 12  | Ra, Rm, Lr, Bg          | 13.6               | 8.9    | 34.1     | 7.3    |         |
| 15| 11  | Bg, Lr                  | 11                 | 5.7    | 26.1     | 5.9    |         |
| 16| 5   | Bg, Lr                  | 10.7               | 8.3    | 11.8     | 1.5    |         |
| 17| 9   | Rm, Ra                  | 18.2               | 8.6    | 28.7     | 7.3    |         |
| 18| 7   | Ra                      | 14.5               | 12.4   | 15.9     | 1.3    |         |
| 19| 10  | Ra, Rm, Bg              | 11.2               | 5.7    | 13.1     | 2.6    |         |
| 20| 4   | Ra, Rm                  | 17.6               | 13.1   | 16.9     | 4.4    |         |
| 21| 5   | Cm, Rm, Xr, Cd          | 14.6               | 5.7    | 22.9     | 6.9    |         |
| 22| 6   | Ra, Rm, Cd              | 10                 | 8.0    | 15.9     | 3      |         |
| 23| 7   | Ra, Rm, Bp              | 14.3               | 11.1   | 19.7     | 3      |         |
| 24| 6   | Rm, Bg                  | 10.5               | 8.0    | 12.7     | 1.6    |         |

Note: Bg = Bruguiera gymnorrhiza, Bp = Bruguiera parviflora, Cd = Ceriops decandra, Ll = Lumnitzera litoria, Lr = Lumnitzera racemosa, Ra = Rhizophora apiculata, Rm = Rhizophora mucronata, Xm = Xylocarpus moluccensis, Xr = Xylocarpus rumphii.

Table 2 Analysis of importance value index (IVI) of the mangrove forest of Labuhan Village, Lamongan Regency, East Java, Indonesia.

3.3. Biomass and C-stocks of Mangrove.
The mean of DBH, AGB, AGC, BGB, and BGC of mangrove stands in Labuhan Village is presented in Table 3. The average biomass of mangrove stands in Labuhan Village was 168.05 ± 35.34 Mg B ha⁻¹.
which was slightly higher than that of in the previous study in the same area (163.96 ± 35.34 Mg B ha⁻¹) [9]. However, the former study encompassed only three plots in one research station while our study covered broader areas, 24 plots in six stations (Figure 1). The mangrove stands biomass was equivalent to 74.70 ± 15.58 Mg C ha⁻¹ which can be assumed that the mangrove stands of Labuhan Village sequestered 274.15 ± 57.18 Mg CO₂ ha⁻¹.

The average of above-ground carbon (AGC) of mangrove stands in this study was 53.89 ± 10.65 Mg C ha⁻¹ (Table 3), which was higher than that of North Sulawesi, Indonesia and Okinawa, Japan (30.8 and 40.25 Mg C ha⁻¹ respectively) [25],[5]. Meanwhile, even though R. mucronata had highest number of mangrove (83 trees), in total R. apiculata had significantly higher biomass and carbon (63.69 ± 11.32 Mg B ha⁻¹ and 28.67 ± 3.84 Mg C ha⁻¹ respectively) (Tukey’s multiple comparisons test p < 0.05). It was due to the facts that R. apiculata had bigger DBH than R. mucronata, and the wood density of R. apiculata was also higher than that of R. mucronata [15]. The mangrove forest of Labuhan Village not only harbour some mangrove species, but also most importantly provide for carbon sequestration. Therefore, local communities and authorities should preserve this mangrove habitat.

Table 3. The mean of DBH, AGB, AGC, BGB, and BGC of mangrove stands in Labuhan Village.

| Species            | DBH (Mg B ha⁻¹) | AGB (Mg C ha⁻¹) | AGC (Mg C ha⁻¹) | BGB (Mg B ha⁻¹) | BGC (Mg C ha⁻¹) |
|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| R. apiculata       | 15.70 ± 4.93    | 45.53 ± 5.66    | 21.39 ± 2.66    | 18.16 ± 5.66    | 7.08 ± 1.18     |
| R. mucronata       | 12.41 ± 4.75    | 29.97 ± 5.24    | 14.09 ± 2.46    | 17.74 ± 1.95    | 6.92 ± 0.76     |
| B. gymnorrhiza     | 9.80 ± 2.51     | 15.15 ± 3.27    | 5.90 ± 1.27     | 7.06 ± 1.48     | 2.75 ± 0.57     |
| B. parviflora      | 11.05 ± 5.20    | 5.33 ± 1.35     | 2.50 ± 0.63     | 2.25 ± 0.56     | 0.87 ± 0.22     |
| C. Decandra        | 15.28 ± 5.52    | 1.87 ± 0.51     | 0.88 ± 0.24     | 1.02 ± 0.26     | 0.39 ± 0.10     |
| L. litoria         | 12.74 ± 0.00    | 0.40 ± 0.16     | 0.18 ± 0.07     | 0.18 ± 0.07     | 0.07 ± 0.03     |
| L. racemosa        | 16.58 ± 7.75    | 14.91 ± 5.76    | 7.01 ± 2.71     | 5.76 ± 2.20     | 2.24 ± 0.86     |
| X. moluccensis     | 22.93 ± 0.00    | 1.33 ± 0.54     | 0.62 ± 0.25     | 1.11 ± 0.45     | 0.43 ± 1.17     |
| X. rumphii         | 9.55 ± 0.00     | 0.19 ± 0.08     | 0.09 ± 0.03     | 0.09 ± 0.03     | 0.03 ± 0.01     |
| **Total**          | **-**           | **114.68 ± 22.68** | **53.89 ± 10.65** | **53.37 ± 12.66** | **20.81 ± 4.93** |

4. Conclusion
This study was the first comprehensive mangrove forest inventory in Labuhan Village. We employed random sampling design across mangrove forest of Labuhan Village as the basic of mangrove identification and DBH measurement. Mangrove allometry was used to solve the biomass and C stocks of mangrove stands. The mangrove forest of Labuhan Village harboured nine species of true mangroves in which R. mucronata and R. apiculata dominated the forest communities with an IVI of 100.40% and 80.46% respectively. R. apiculata also had the highest contribution to the mangrove trees’ biomass and C stocks (63.69 ± 11.32 Mg B ha⁻¹ and 28.67 ± 3.84 Mg C ha⁻¹ respectively). Meanwhile, the average biomass and C of mangrove stands in Labuhan Village were 168.05 ± 35.34 Mg B ha⁻¹ and 74.70 ± 15.58 Mg C ha⁻¹ respectively, which was equivalent to 274.15 ± 57.18 Mg CO₂ ha⁻¹ sequestered and stored in the biomass. A follow-up study on the soil C stocks of the mangrove ecosystem is recommended to quantify the total ecosystem C stocks of the mangrove forest.

5. References
[1] Mitra A, Banerjee K and Sett S 2012 Spatial Variation in Organic Carbon Density of Mangrove Soil in Indian Sundarbans Natl. Acad. Sci. Lett. 35 147–154
[2] Donato D, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M and Kanninen M 2011 Mangroves among the most carbon-rich forests in the tropics Nat. Geosci. 4 293–297
[3] Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J and Duke N 2011 Status and distribution of mangrove forests of the world using earth observation satellite data Glob. Ecol. Biogeogr. 20 154–159

[4] Polidoro BA et al. 2010 The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern PLOS ONE 5 e10095

[5] Murdiyarso D, Donato D, Kauffman JB, Kurnianto S, Stidham M and Kanninen M 2010 Carbon storage in mangrove and peatland ecosystems: a preliminary account from plots in Indonesia (Bogor: CIFOR)

[6] Wylie L, Sutton-Grier AE and Moore A 2016 Keys to successful blue carbon projects: Lessons learned from global case studies Mar. Policy 65 76–84

[7] Aslan A, Rahman AF, Warren MW and Robeson SM 2016 Mapping spatial distribution and biomass of coastal wetland vegetation in Indonesian Papua by combining active and passive remotely sensed data Remote Sens. Environ. 183 65–81

[8] Suhardjono S 2013 Hutan Mangrove Cagar Alam Pulau Sempu, Jawa Timur J. Biol. Indones. 9 121–130 [in Bahasa Indonesia]

[9] Asadi MA, Guntur G, Ricky AB, Novianti P and Andik I 2017 Mangrove ecosystem C-stocks of Lamongan, Indonesia and its correlation with forest age Res. J. Chem. Environ. 21(8) 1–9

[10] Hoekstra P 1989 Hydrodynamics and depositional processes of the Solo and Porong Deltas, East Java, Indonesia, in: van der Linden WJM et al (Eds.), Coastal Lowlands: Geology and Geotechnology (Dordrecht: Springer Netherlands) pp 161–173

[11] Giesen W, Wulffraat S, Zieren M, Scholten L 2006 Mangrove Guidebook For Southeast Asia (Bangkok: FAO and Wetlands International)

[12] Abino AC, Castillo JAA and Lee YJ 2014 Species diversity, biomass and carbon stock assessments of a natural mangrove forest in Palawan, Philippines Pak. J. Bot. 46 1955–1962

[13] Nguyen H, Lamb D, Herbohn J and Firn J 2014 Designing Mixed Species Tree Plantations for the Tropics: Balancing Ecological Attributes of Species with Landholder Preferences in the Philippines PLOS ONE 9 e95267

[14] Comley BWT and McGuinness KA 2005 Above- and below-ground biomass, and allometry, of four common northern Australian mangroves Aust. J. Bot. 53 431–436

[15] Komiyama A, Ong JE and Pongparn S 2008 Allometry, biomass, and productivity of mangrove forests: A review Mangrove Ecol. – Appl. For. Costal Zone Manag. 89 128–137

[16] Kauffman JB and Donato D 2012 Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests (Bogor: CIFOR)

[17] Xue B, Yan C, Lu H and Bai Y 2009 Mangrove-Derived Organic Carbon in Sediment from Zhangjiang Estuary (China) Mangrove Wetland J. Coast. Res. 949–956

[18] Hossain MD and Nuruddin A 2016 Soil and Mangrove: A Review J. Environ. Sci. Technol. 9 198–207

[19] Kathiresan K 2003 How do mangrove forests induce sedimentation? Rev. Biol. Trop. 51 355–360

[20] Mishra R 1968 Ecology Workbook (New Delhi: Oxford and IBH Co.)

[21] Cerón-Souza I, Rivera-Ocasio E, Medina E, Jiménez JA, McMillan WO and Bermingham E 2010 Hybridization and introgression in New World red mangroves, Rhizophora (Rhizophoraceae) Am. J. Bot. 97 945–957

[22] Naskar S and Palit PK 2015 Anatomical and physiological adaptations of mangroves Wetl. Ecol. Manag. 23 357–370

[23] Reef R and Lovelock CE 2015 Regulation of water balance in mangroves Ann. Bot. 115 385–395

[24] Spalding MD 2001 Mangroves* A2 - Steele, John H., in: Encyclopedia of Ocean Sciences (Second Edition) (Oxford: Academic Press) pp 496–504

[25] Khan MNI, Suwa R and Hagihara A 2009 Biomass and aboveground net primary production in a subtropical mangrove stand of Kandelia obovata (S., L.) Yong at Manko Wetland, Okinawa, Japan Wetl. Ecol. Manag. 17 585–599
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