The potential contribution of the lagoon ecosystem as mangrove carbon sinks in Java

H F Pratiwi* and E Haryono

*Corresponding e-mail: hanifahfitriasani@gmail.com

Abstract. The concentration of CO$_2$ in the atmosphere continues to increase due to the increased release of CO$_2$ in the atmosphere effect of anthropogenic activity. Mangrove ecosystems have an important role in carbon sequestration and reduce the concentration of CO$_2$ emissions in the atmosphere. Mangrove on the southern coast of Java partially growth in river mouth lagoon ecosystem, thus it has the potential for more vast mangrove restoration as carbon sink. Therefore, the purpose of this study is to assess the potential mangrove as carbon sink by the lagoon ecosystem on the Java island. One of the locations selected as an assessment sample, that is the Bogowonto Lagoon in Kulonprogo district by set up 12 plots in the planted mangrove. Allometric equation are described for assess the aboveground carbon stored in the stem and calculate the diameter at breast height (DBH) in each plot. Soil sampels were taken in each plot for assess organic carbon soil content were determined using Walkley-Black method, thus the belowground carbon sink was calculated. There was total potential mangrove carbon sink in Java which is 11,758,729.65 tons of CO$_2$ and it can reduce carbon emissions by 4.4% in Java Island.

1. Introduction

The lagoon is shallow water that is still part of the coast and is separated from the ocean by a barrier. These barriers can be formed by coral reefs, barrier islands, spit-shaped sand dunes, or even coral-shaped. Lagoon waters can increase tidal mixtures with varying salinity from the requirements of bargaining competition for hypersalin [1,2]. Tides affect soil conditions in the lagoon ecosystem to become unstable. The instability of soil substrate can be overcome by mangroves, such as Rhizophora which has a root that extends sideways to provide support to the stem [2,3].

The lagoon ecosystem has conditions that support the growth of mangroves, such as mud, tidal influences, and salinity fluctuations [2]. One of the mangrove ecosystems in Indonesia is in Java, with a percentage of 2.35%, but the growth of the mangrove is affected by development activities. Development activities such as reclamation of coastal areas [4], especially on the north coast of Java, are a major threat to the preservation of mangrove forests. The south coast of Java has unique geomorphology at the river mouth with the formation of sand dunes. Sand dune causes the formation of a protected lagoon from sea waves so that it allows the growth of mangroves [5].

On the south coast of East Java, mangroves are found in Grajakhan Bay - Segara Anak National Park, Alas Purwo, Sempu Island, and Pacitan Bay. The south coast of Central Java, mangroves are found at the mouth of the Bogowonto River, Segara Anakan (Cilacap). On the south coast of West Java, it is found in the Pelabuhan Ratu and the Ujung Kulon National Park. While on the north coast of Java, almost along the coast can be overgrown with mangroves [5].
Mangroves are considered to have an ecological function of mangroves that is to have an intense carbon process and has the potential to influence the global carbon cycle. Mangrove ecosystems have an important role in reducing the concentration of CO$_2$ emissions in the atmosphere due to increased human activity, thus it is important to assess the potential of carbon that can be stored by mangroves [6]. Carbon is assimilated and stored both above and below the surface is stored biomass (stems, branches, leaves, and roots) [7] and stored in the soil, with up to 90% carbon stock stored as soil organic matter [6]. Based on the potential of mangroves and the distribution of mangroves on the island of Java, the potential contribution of mangroves can be calculated as carbon sinks that grow in the lagoon ecosystem and can assess its contribution to reducing CO$_2$ emissions in the atmosphere.

2. Materials and Methods

2.1. Study area

The study was conducted on the south coast of Java Island (Figure 1) especially for assessment carbon sinks in Bogowonto Lagoon, Jangkaran Village, Kulonprogo Regency during the rainy season and the mangrove ecosystem was more affected by tides (December 2018-January 2019). Mangrove area that grows along the left and right sides of the lagoon of the Bogowonto River is 7.34 hectares. Mangroves that grow in Bogowonto Lagoon can be categorized as riverine mangroves with the dominant material characteristics of silt and clay. Mangrove that can be grown includes *Avicennia marina* and *Rhizophora mucronata* which are cultivated, and a small portion of *Sonneratia caseolaris*.

2.2. Data collection and analysis

Data collection was carried out at 12 sample points shown in Figure 2. Measurement of mangrove composition is based on identification of mangrove species and the diameter of the main tree trunk at breast height (DBH). Measurement of total carbon conducted with non-destructive aboveground biomass, roots, and measurement of soil organic matter content with disturbed and undisturbed soil samples [8]. Measurement of aboveground and roots biomass is done by measuring the diameter of the trunk at breast height (DBH) in a measuring plot measuring 5x5 m. The sludge substrate in the form of disturbed soil is taken with a composite sampling method, which is taking samples based on depth profiles and put together into one sample at the time of testing [9]. Furthermore, the measured carbon sinks value is multiplied by the area of the lagoon found on the island of Java.

![Figure 1. distribution of lagoons on the south coast of Java, there are 1. Handoyan, 2. Talanca, 3. Cipager, 4. Cisiih, 5. Ciletuh, 6. Citepus, 7. Cimandiri, 8. Cikaso, 9. Cibuni, 10. Ciujung, 11. Cipandak, 12. Cikandang, 13. Cipabeluh, 14. Ciawi, 15. Cibako, 16. Cijulang, 17. Segara Anakan, 18. Ij o (Logending), 19. Cincinguling/Kr. Bolong, 20. Lukulo, 21. Wawar, 22. Cakrayasan (Jali), 23. Bogowonto, 24. Serang, 25. Progo, 26. Opak, 27. Teleng, 28. Grindulu, 29. Kitri, 30. Kalisongo, 31. Clungup, 32. Mujur, 33. Puger, 34. Gonggo, 35. Baru, 36. Segoro Anakan (TNAP)](image-url)
Figure 2. Sample point distribution in Bogowonto Lagoon

Calculation of aboveground ($W_{\text{top}}$) and roots ($W_{\text{root}}$) biomass is done by calculating using the allometric equation according to the mangroves species found and can be seen in Table 1. where a and b are constants in allometric equations [10].

\[
W_{\text{top}} = a \cdot (DBH)^b
\]

\[
W_{\text{root}} = 0.199 \cdot p^{0.899} \cdot (DBH)^{2.22}
\]

**Table 1. Allometric Equations in Each Mangrove Type**

| Mangrove species         | Allometric equation          | Wood density (gr/cm$^3$) |
|--------------------------|-------------------------------|--------------------------|
| Avicennia marina         | $Y = 0.1848(DBH)^{2.3524}$ [11] | 0.7316                   |
| Rizkopora mucronata      | $Y = 0.1466(DBH)^{2.3136}$ [12] | 0.8483                   |
| Sonneratia caseolaris    | $Y = 0.258(DBH)^{2.287}$ [13]  | 0.62                     |

Conversion of biomass content assuming carbon content in plants that is equal to 50% [14]. The below-ground carbon content is determined by the value of carbon content using the Walkley-Black method and bulk density which is done by laboratory tests of the oven method. So the total soil carbon can be calculated by summing the area segment, bulk density value, c-organic percentage, and soil thickness. The total value of carbon content is obtained by summing the total above-ground biomass, roots and carbon content in the soil. Total carbon storage converted into CO$_2$ absorption as carbon sinks. Equation carbon konversion to CO$_2$.

\[
\text{CO}_2 = C_{\text{total}} \cdot \frac{\text{Mr CO}_2}{\text{Ar C}}
\]

3. Results

3.1. Mangrove Characteristics
Mangroves that are dominantly growing are the result of rehabilitation and are planted lengthwise from side to side of the lagoon. Mangroves that are widely planted for rehabilitation are *Avicennia marina*.
and *Rhizophora mucronata* so that the two are the most common among the others. While there are several types of mangroves that grow as a result of introducing such as *Sonneratia caseolaris* (figure 3), and mangroves that grow naturally, such as *Acanthus ilicifolius*, *Acrostichum aureum* (sea spikes), and *Nypa fruticans*. Mangrove species that grow naturally are still found but in quite a small amount.

The characteristics of mangrove ecosystems along the Bogowonto Lagoon are riverine mangrove types, which are growing mangroves affected by tides and river sedimentation processes. Riverine type mangrove characteristics in Bogowonto Lagoon can be identified based on cross-sections, as shown in figure 4. Based on the cross-sectional identification results, mangrove distribution in Bogowonto Lagoon tends not to form certain zoning, but grows in groups of one type and alternates in different types, and there are locations with mixed cultivation. In general, observations of the distribution of mangrove species in the field can be seen in figure 5, the mangrove distribution map.

![Mangroves in Bogowonto Lagoon](image1)

Figure 3. Mangroves are found in the Bogowonto Lagoon

The characteristics of mangroves that grow elongated cause the distribution of species and age tend to be random and varied. Based on field observations, mangroves along the lagoon were non-dense. The distance between mangrove trees has a variation of 0.5-1 meters. Mangroves that have a low density or a distance between trees ± 1 meter are spread on mangroves that grow close to an estuary such as *Avicennia marina*. In contrast to mangroves that have a higher density or which have a spacing of about 0.5 meters, there are mangroves that grow further from the river mouth, as in *Rhizophora mucronata*. 
3.2. Estimated carbon storage

3.2.1. Aboveground biomass
Surface biomass is calculated using allometric equations so that the biomass value of each tree is obtained. Based on the results of measurements and calculations in the field, aboveground biomass in 12 measuring plots has a variation in the amount of yield that is between 96-600 kg. Carbon storage alongside close to the coast (plots 1-5) has 209.7 tons while carbon storage alongside close to the mainland (plots 6-12) has 228.9 tons. The total amount of carbon stored aboveground of the mangrove is 438.602 tons C and is equivalent to CO₂ absorption of 60.08 tons C/ha.
3.2.2. Belowground carbon storage
The belowground of mangrove can store 2-3 times the carbon compared to the carbon stored aboveground [6]. The total root biomass from the allometric calculation is 373.24 tons with a total root carbon of 49.29 tons/ha. The carbon stored in the root has lower content than the carbon on the surface due to the proportion of photosynthetic storage in the root is less than the stem. Based on the calculation, the total carbon storage value in the soil is 1,123.96 tons C with a carbon sinks of 153.17 tons C/ha.

3.2.3. Total Carbon Storage
The results of the analysis of carbon stored aboveground and belowground level in mangroves along the side near the coast and near the mainland can be seen in Figure 6. The total carbon content in the mangrove ecosystem that grows along the Bogowonto Lagoon is 1,935.802 tons C with a total carbon of 265.59 tons C/ha. The amount of total carbon content is equivalent to the absorption of 7,079.95 tons CO₂ or carbon absorption of 967.28 tons of CO₂/ha.

![Figure 6. Carbon stored aboveground and belowground level in mangroves](image)

Lagoons on the Java Island has a total area that has the potential to plant mangroves is 12,156.49 hectares. Based on this area, the carbon potential absorbed along the south coast of Java is 3,228,618 tons C and equivalent to the absorption of 11,758,729.65 tons CO₂.

4. Discussions
Information on mangrove carbon storage has an important role for the benefit of mangrove conservation. Mangrove ecosystem is one of the ecosystems that are productive in the coastal environment. In recent years, research has been carried out to calculate the mangrove carbon deposits in Indonesia, one of them in Java. The vast potential to absorb and store carbon causes the mangrove ecosystem to play a role in the carbon cycle. Increasing the concentration of carbon dioxide in the atmosphere causes carbon storage in the atmosphere to change [15]. This is a result of the acceleration of carbon emissions into the atmosphere triggered by anthropogenic processes [16]. One of the accelerations of additional carbon dioxide emissions in the atmosphere is caused by the burning of fossil fuels and changes in land use [17].

CO₂ emissions in the atmosphere in 2018 in Java reached 270.4 million tons CO₂ or 270,400,000 tons CO₂[18]. This is not proportional to the amount of CO₂ reduction in the atmosphere. Data from the Ministry of Forestry in 2014 [19] states that carbon storage on the island of Java for primary and secondary mangrove forests is 572.62 tons C / ha. Carbon stores in one of the lagoon ecosystems in Java, namely the bogowonto lagoon amounting to 265.59 tons C / ha or half of the amount of carbon storage of mangrove forests on the island of Java. It means that twice the carbon sink of the Bogowonto
lagoon is the same as the amount of carbon stored on the island of Java. So if there are 36 lagoons, the amount of potential carbon storage in the lagoon ecosystem on the island of Java is 9,561.24 tons C/ha. Mangroves on the southern coast of the island of Java have the potential to absorb carbon at 11,758,729.65 tons CO₂. Thus, the amount of carbon uptake can contribute to 4.4% reduction in CO₂ in the atmosphere.

5. Conclusion
The total carbon stored in the Bogowonto Lagoon mangrove ecosystem is 1.935,80 tons with a density of 263,80 tons C/ha. Thus, the carbon potential absorbed along the south coast of Java is 3,228,618 tons C and equivalent to the absorption of 11,758,729.65 tons of CO₂. Thus, the amount of carbon uptake can contribute to 4.4% reduction in CO₂ in the atmosphere of Java.

Acknowledgement
This paper is an undergraduate thesis at the Department of Environmental Geography, UGM. The authors wish to thank the LPPM UGM for the financial support under the scheme of Rekognisi Tugas Akhir (RTA) Tahun 2019. We would like to also give our thanks to the managers of Wanatirta Mangroves, Pasirkadilangu, and Jembatan Api-api for their permission and assistance during this research.

References
[1] Kjerfve B 1994 Coastal lagoon processes Elsevier Oceanography Series 60 1–8
[2] Milthapala S 2013 Lagoons and Estuaries Coastal Ecosystems Series Coastal Ecosystems Series 4
[3] Kathiresan K and Bingham B L 2001 Biology of Mangroves and Mangrove Ecosystems Advances in Marine Biology 40
[4] Nusantara R W, Sudarmadji, Sugandawaty T and Haryono E 2014 Soil Emissions of CO₂ Due to Land Use Change of Peat Swamp Forest at West Kalimantan. Jurnal Manusia Dan Lingkungan 21 3 268–276
[5] Setyawatan A D, Winarno K and Purnama P C 2003 Eksistem Mangrove di Java: 1. Kondisi Terkini. Biodiversitas 4 2 130–142
[6] Hidayah Z and Andriyani L 2019 Carbon Stock Analysis of Mangrove Ecosystems in Paliat Island Sumenep East Java IOP Conference Series: Earth and Environmental Science p 276
[7] Donato D C, Kauffman J B, Murdiyarso D, Kurnianto S, Stidham M and Kanninen M 2011 Mangroves Among the Most Carbon-Rich Forests in the Tropics. Nature Geoscience 4(5) 293–297
[8] Fourqurean J W, Johnson B, Kauffman J B, Kennedy H, Lovelock C E, Megonigal J P, … Simard M 2017 Coastal blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors in Mangroves, Tidal Salt Marshes, and Seagrasses (J. Howard, S. Hoyt, K. Isensee, E. Pidgeon, & M. Telszewski, Eds.), UNESCO Arlington, Virginia, USA: Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature
[9] Sutaryo D 2009 Penghitungan Biomassa: Sebuah Pengantar untuk Studi Karbon dan Perdagangan Karbon (Bogor: Wetlands International Indonesia Programme)
[10] Komiyama A, Poungparn S and Kato S 2005 Common Allometric Equations for Estimating the Tree Weight of Mangroves Journal of Tropical Ecology 21(4) 471–477
[11] Dharmawan I W S and Siregar C A 2008 Karbon Tanah dan Pendugaan Karbon Tegakan Avicennia marina (Forsk.) Vierh. di Ciasem, Purwakarta Penelitian Hutan Dan Konservasi Alam 5 4 317–328
[12] Dharmawan I W S 2010 Pendugaan Biomassa Karbon di Atas Tanah Pada Tegakan Rhizophora mucronata di Ciasem, Purwakarta Jurnal Ilmu Pertanian Indonesia 15 1 50–56
[13] Kusmana C, Hidayat T, Tiryana T, Rusdiana O and Istomo 2018 Allometric models for above-
and below-ground biomass of Sonneratia spp Global Ecology and Conservation 15
[14] Brown S 1997 Estimating Biomass and Biomass Change of Tropical Forests: a Primer 134 FAO-Food and Agriculture Organization of the United Nations 134 3–6
[15] IPCC 2007 Climate Change 2007: The Physical Science Basis (S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, … Z. Chen, Eds.), IPCC 2007 (Cambridge, United Kingdom and New York, USA: Cambridge University Press)
[16] Arjasakusuma S, Pribadi U A and Seta G A 2018 Accuracy and Spatial Pattern Assessment of Forest Cover change Datasets in Central Kalimantan Indonesian Journal of Geography 50 2 222–227
[17] Sukarna R M and Syahid Y 2016 FCD Application of Landsat for Monitoring Mangrove in Central Kalimantan Indonesian Journal of Geography 47 2 160–170
[18] Zacky A, Supriyadi A R A, Kusumawanto A, Wicaksono A, Maetzri D and Nugroho W A 2014 Pedoman Teknis Perhitungan Baseline Emisi Gas Rumah Kaca Sektor Berbasis Energi (Jakarta)
[19] Rochmayanto Y, Wibowo A, Lugina M, Butarbutar T, Mulyadin R and Wicaksono D 2014 Cadangan Karbon Pada Berbagai Tipe Hutan Dan Jenis Tanaman Di Indonesia (2) (Yogyakarta)