The potential of delta ecosystem in North Coast of Java in reducing CO\textsubscript{2} emissions

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Abstract. Global warming causes more carbon dioxide (CO\textsubscript{2}) emissions. The mangrove forest is one of the world's largest carbon sinks, as it is capable of storing and absorbing CO\textsubscript{2} more than other forests. This research aims to determine carbon storage and CO\textsubscript{2} sequestration at various zones of mangrove forests on the Wulan Delta, i.e. pond, river, and coastal zone, also determine the potential of delta ecosystem in North Coast of Java in reducing CO\textsubscript{2} emissions with Wulan Delta as the sample. Systematic and non-destructive sampling method was used by measuring the Diameter at Height Breast (DBH) of mangrove trees with a diameter of >5 cm inside plot areas of 10 m x 10 m each, and the measurement result was then calculated based on an allometric equation. The mangrove forest of Wulan Delta has the above-ground of carbon density 245.578 ton C/ha, root carbon density of 100.778 ton C/ha, and soil carbon density of 42,991.169 ton C/ha. It sums up to the total carbon storage of 9,171,845.27 ton C and CO\textsubscript{2} sequestration of 33,660,672.12 ton CO\textsubscript{2} with an annual sequestration value of 1,530,030.55 tons CO\textsubscript{2}/year. The CO\textsubscript{2} sequestration results are then compared with the delta in North Coast of Java with extrapolation method. The results obtained that Delta in North Coast of Java can absorb CO\textsubscript{2} national emissions in 2018 by 3.416x10\textsuperscript{6} CO\textsubscript{2}/year.

1. Introduction
Global warming occurs as the carbon dioxide (CO\textsubscript{2}) gas emission increases to the atmosphere. It is triggered by human activities in the forms of industrial growth, land-use change, and excessive use of fossil fuels and causes the rising atmospheric temperature of 1.5\textdegree{}C to 5.8\textdegree{}C during the 21st century [1]. The CO\textsubscript{2} gas is considered as a benchmark of temperature rise, as it has 50% contribution to global warming; thus, it contributes the most compared to other gas emissions. However, CO\textsubscript{2} has the smallest Global Warming Potential (GWP) value. The large contribution is due to high CO\textsubscript{2} concentration so that other greenhouse gases are not the main source of global warming. Besides, non-methane compounds such as CH\textsubscript{4} and CO will turn into CO\textsubscript{2} in a certain period [2].

There are five of the world's largest carbon storage sites, which ordered from the largest to smallest are the ocean, geological formation, soil, atmosphere, and vegetation [3]. The carbon can transfer from one place to another, following the carbon cycle. Carbon transfer can make carbon loss or stored. One of the carbon stores is in vegetation. It is broadly spreaded, one of which on the coastal areas. Coastal vegetation are generally dominated by mangrove. Mangrove has the benefits as a coastal wave breaker...
in high tide period, as well as a CO$_2$ absorber. Mangrove forest is a coastal ecosystem with high productivity, i.e. 5,000 gigatons C m$^2$ year$^{-1}$ [4]. These benefits could be a good help in controlling global warming impacts.

Mangrove ecosystems in Indonesia are degraded due to land conversion. The area of mangrove forests in Indonesia were shrunk into 2.5 million hectares in 2006 [5]. There are more than 50% of damages happen in Indonesia’s mangrove potential, especially on the northern coast of Java Island, which 96.95% of the area is covered by mangrove ecosystem that has damage levels of moderate, severe or potentially damage. Regional development emphasizes on economic aspect rather than environmental aspect. It is showed by massive physical infrastructure development that disturbs mangrove forest existence due to uncontrolled illegal logging, e.g coastal cities (settlements), agricultural land, and tourism destinations. When the converted land use is not suitable for its initial purpose and is exceeding the carrying capacity, it will certainly cause degradation of the former mangrove ecosystem [6].

The 13$^{th}$ Conference of the Parties (COP) in Bali, Indonesia has discussed climate change and decided that mangrove forest is one of the contributing factors in reducing the climate change impacts due to its function in absorbing carbon dioxide gas through photosynthesis. The mangrove ecosystem began to be seen as a carbon sink potential ever since. Mangrove ecosystem only covers 0.4% of the world's forest area but globally could absorb carbon for more than 4 gigatons of C year$^{-1}$ to 112 gigatons of C year$^{-1}$.

Delta is an important ecosystem for the growth of mangrove vegetation. Mangrove in Wulan Delta, Demak Regency grows naturally. The majority of mangrove species is Rhizophora spp., in the forms of trees, bushes, seedlings or saplings [7]. However, there are certain parts of mangrove forests in the area that have been damaged. The damage is mainly caused by land conversion to fish ponds and salt ponds by the local community. This condition might reduce the role and function of mangrove forests as the biggest carbon storage in coastal areas. This condition also occurs in some deltas on the North Coast of Java, such as Bengawan Solo Delta, Bodri Delta, Pemali Delta, Comal Delta, Cimanuk Delta, Citarum Delta and Cipunegara Delta (Figure 1).

Mangrove vegetation cannot grow on steep and wavy coastal areas which are strongly influenced by tidal currents. Such conditions will not allow the deposition of mud substrate to support the mangrove growth [8]. A large river mouth continues to form a delta and a mud deposition site, which will be the growing medium and place to store nutrients for mangrove forests. The trapped mud or sediment in
mangrove vegetation will be carried by river flow straight to the sea to form a delta, including the Wulan Delta. The mud or sediment will be brought back to shore by the tides, which will be captured and deposited on the bottom of mangrove vegetation afterward. The purpose of this study was to determine the amount of carbon storage of mangrove vegetation in Wulan Delta, determine the CO\textsubscript{2} sequestration of mangrove in Wulan Delta, and determine potential of the CO\textsubscript{2} sequestration from the CO\textsubscript{2} sequestration of various deltas on the North Coast of Java.

2. Data and Methodology

2.1. Data Collection

This research used the systematic sampling method, in which the samples were determined based on certain patterns. Systematic sampling is a way of observing a population by only using a portion of the population unit concerned with the determination of units carried out in accordance with a predetermined pattern [9]. Measuring plots in square forms were made with the size of 10 m x 10 m, on the areas which mangrove poles dominated [10]. Five substrate samples in the disturbed and undisturbed conditions were taken from each plot area. Data measurements were done by a non-destructive method. The carbon storage calculation was based on the allometric equation [11].

Diameter measurements were done in each land use zone of mangrove forest, i.e. river zone, pond zone, and coastal zone. It is important to know the amount of carbon stock according to the composition of mangrove vegetation in those land use zones. The collected data were the number of mangrove trees, mangrove species, and Diameter at Height Breast (DBH) of mangrove. The samples of this research were taken in 48 measuring plots, thus each zone has 16 measuring plots settled. The sample distribution is showed by Figure 2.

![Figure 2. Map of Mangrove Zones at Wulan Delta](image)

The measurement of carbon deposits is carried out either on stands or on mud substrates, the measured variable is DBH. Measurement of carbon on the substrate were carried out with disturbed-substrate samples by making soil profiles 0 - 5 cm, while undisturbed-substrate samples were carried out using ring samples. Measurement of the thickness of the mud is done by sticking wood that is perpendicular to the ground surface to the bottom of the mud. Measurement of organic carbon in the
mud substrate is carried out in the laboratory. This data is used to calculate the carbon storage in the mud substrate.

2.2. Data Processing and Analysis
The total amount of carbon was preceded by calculating aboveground biomass and root biomass using the following allometric equation [11]:

\[
W_{\text{top}} = 0.251 \times \rho \times D^{2.46}
\]

\[
W_r = 0.199 \times \rho^{0.189} \times D^{2.2}
\]

where, 
\(W_{\text{top}}\) = soil surface biomass (kg) \\
\(W_r\) = root biomass (kg) \\
\(\rho\) = wood density (gr/cm\(^3\)) \\
D = DBH (1.3 m); or 30 cm above the root limit with a minimum diameter of 5 cm.

The wood density values were based on the obtained data from World Agroforestry. The calculation result units in kilograms were converted into tons by multiplying with a constant number of 0.5, which is based on the assumption of the 50% carbon portion in the biomass. The calculation of carbon in the substrate was based on the following equation:

\[
\text{Soil Carbon} = A \times B \times C \times D
\]

where, 
A = area of each zone (m\(^2\)) \\
B = bulk density (ton/m\(^3\)) \\
C = C-organic (%) \\
D = mud thickness (m)

The total carbon was the accumulation of carbon at aboveground, total carbon at root, and total soil carbon at each zone. The data was presented in tables and was analysed by quantitative descriptive method.

The data carbon storage and CO\(_2\) sequestration that has been calculated, then calculated area of delta in the North Coast of Java by digitization using Citra Sentinel 2A in December 2018. Delta that has been measured in area then was measured with buffer distance of 20 meters from the coastline and river boundaries, assuming that mangrove vegetation appears 20 meters from the coastline and river boundaries, such as vegetation in the Wuulan Delta. The potential for CO\(_2\) sequestration in delta on the North Coast of Java is obtained by the extrapolation method.

\[
A \times B = C \times D
\]

where, 
A = Area of Wuulan Delta (ha) \\
B = The Value of CO\(_2\) Sequestration Wuulan Delta (tons CO\(_2\) year\(^{-1}\)) \\
C = Area of X Delta (ha) \\
D = The Value of CO\(_2\) Sequestration X Delta (tons CO\(_2\) year\(^{-1}\))

3. Result and Discussion
3.1. Condition of Mangrove Forest on Wuulan Delta
The mangrove forest on Wuulan Delta is administratively located in 2 villages, which are Berahan Wetan and Berahan Kulon. According to the local people, mangrove forest has existed even since Wuulan Delta has not yet developed. Wuulan Delta was initially covering the area of Berahan Wetan, thus the mangrove
forest had not reached the current area. It was, according to the local people, naturally developed and has not yet experienced land conversion. However, Wulan Delta developed rapidly following the Wulan canal construction in 1892 [12]. The dredging activity in Wulan River canal caused rising carried sediment, followed by rising deposited sediment on the estuary, thus accelerating the delta development. The Wulan Delta development which enlarged the delta size was considered by the surrounding community as the most potential pond areas. In low tide periods when the land was not inundated, the local people would compete to put up pegs to support the ponds (Ruswanto and Karsono, 1990 as quoted in Reference [13]). The mangrove forest area used to get wider as the Wulan Delta developed, but it starts to get narrower due to ponds expansion.

The current condition of the mangrove forest zones is showed by Figure 1. There were eight mangrove species found in the measuring plots: Rhizopora apiculata, Rhizopora stylosa, Rhizophora mucronata, Sonneratia alba, Avicennia marina, Avicennia alba, Xylocarpus sp., and Lumnitzera sp. Each zone was dominated by Rhizopora spp. and Avicennia spp. which were spreaded in scattered patterns. The scattered-pattern distribution was caused by the high rate of mangrove conversion into ponds, logging of mangrove forests, sedimentation, and environmental pollution (Walsh, 1974; Lewis, 1990; Nybakken, 1993; Primavera, 1993; as quoted in [14]).

3.2. Total of Carbon Storage on Wulan Delta

Carbon deposits above ground level was calculated based on allometric equations involving the wood density of each mangrove species, as stated in www.db.worldagroforestry.org/wd. Table 1 shows the density and total carbon in each mangrove forest zone. The pond zone had the largest above-ground carbon storage and carbon density, with the values of 26,111.23 tons and 88.801 tons C/ha respectively; while the river zone had the lowest carbon storage and carbon density, with the values of 3,059.341 tons C and 74.822 tons C/ha respectively. The carbon storage and density above the soil surface is directly proportional to the zone area. Total carbon aboveground level in mangrove forest was measured as much as 42,896.392 tons C.

| Zone       | Total Aboveground Carbon (tons) | Density of Aboveground Carbon (tons/ha) | Total Carbon of Root (tons) | Density of Root Carbon (tons/ha) | Soil Carbon (ton) | Density of Soil Carbon (ton/ha) |
|------------|--------------------------------|----------------------------------------|----------------------------|---------------------------------|------------------|---------------------------------|
| Pond       | 26,111.231                     | 88.801                                 | 10,391.702                 | 35.341                          | 6,780,998,381    | 23,061.377                      |
| River      | 3,059.341                      | 74.822                                 | 1,320.443                  | 32.294                          | 325,304.019      | 7,955.915                       |
| Coastal    | 13,725.819                     | 81.955                                 | 5,550.858                  | 33.143                          | 2,005,383.471    | 11,973.878                      |
| Total      | 42,896.392                     | 245.578                               | 17,263.003                 | 100.778                         | 9,111,685.870    | 42,991.169                      |

The density and total carbon were not only influenced by the mangrove zone area, but also by the plant diameter. The diameter was considered as one of the major determinants of biomass following the plant height, wood density, and soil fertility (Kusmana et al, 1992 as quoted in [15]). The dry parts of plant include the trees, litter, deadwood, and root ratio; it is based on the assumption that a 30 cm section from aboveground level has 50% carbon stock [16]. Thus, technically in the mathematical equation, the carbon storage is resulted by multiplying 50% of plant biomass.

The carbon density in a biomass is directly proportional to the age of vegetation. As the plant ages, so does the biomass within, which influences the carbon storage. The diameter of the vegetation will also increase because it grows through continuous cell division process that slows down at a certain age [17]. The larger the diameter of the tree, the biomass will certainly increase.

Carbon is not only stored in stems, but also in the roots. Carbon density of roots on each mangrove forest zone tended to have insignificant numbers, but the highest carbon density was found at the pond zone, with the value of 35.341 tons C/ha; whilst the lowest was found at river zone with the value of
32.294 tons C/ha. The root carbon tended to be lower than the aboveground carbon. It could be caused by the limited condition of root diameter that influenced the carbon storage. The highest amount of biomass is contained by located in the stems, as the photosynthesis products are mostly stored on the stems.

The carbon density of roots affects the mangrove density of each zone. The lower the zone density, the lower the carbon density of roots. The carbon in mangrove roots will be even higher if the plant is older. A mangrove vegetation will grow and develop a complex root system according to the nutrient and water requirements of each vegetation. The process involved are deposition of organic matters and catching of sediment particles. A high value of root carbon will increase soil organic matters [17].

*Rhizopora spp.* in the study area had a dense root system with an anchor-shape. The 1-3 years old *Rhizopora mucronata* tends to strengthen its root growth rather than its stem to build protection from extreme environment condition such as high tide periods and massive mud deposition. A strong root is also needed to support the mature *Rhizopora mucronata* which can reach the wood density of 1,020 kg/m³ [18] [19]. A dense root system of mangrove plant would increase the amount of biomass in the root, and thus increase the carbon storage.

Apart from the vegetation itself, carbon can also be stored in the soil (substrate) as well. The measurement of soil carbon was done on both disturbed-substrate and undisturbed-substrate conditions. The disturbed-soil samples were used to determine the soil organic carbon, whilst the undisturbed-soil samples were used to determine the bulk density to convert C values in tons of carbon per hectare unit.

The C-organic of soil contributes to the total carbon storage [20]. C-organic also affects the total carbon storage in sludge substrate. The higher C-organic, the greater the ability of substrate to store carbon. The determination of soil carbon which involved C-organic factor also used bulk density measurement from of undisturbed-soil samples.

The results showed that the C-organic in soil or mud substrate contained higher carbon than mangrove plants did. The highest soil carbon density was found at the pond zone, with the amount of 23,061.377 tons C/ha; whilst the lowest was found at the river zone, with the amount of 7,955.915 tons C/ha. It shows that the thicker the mud, the more the carbon to be stored. The large amount of carbon would affect the soil carbon density value per hectare. It is influenced by the decomposed mangrove leaves that was found on the substrate—which contained high organic matters—thus increased the mud thickness.

The difference in mud thickness at each zone would affect the total soil carbon. It is because the rates of organic matter decomposition varies with soil depth [19]. The pond zone had thickest mud, with the value of 0.65 m. The decomposition rate is getting higher along with the growth of Wulan Delta. The further away from the beach, the higher the rate of decomposition.

The mud substrate of mangrove came from deposited sediments that previously transported by the Wulan River flow and was formed around the mangrove roots after they trapped it as the flow passes through them. The settled sediment on the mangrove roots will not be channeled back into the river. The mud thickness will continue to grow over time [19]. Strong and dense mangrove roots cause more organic matters and sediments trapped on the roots to form stable mangrove substrate [21].

C-organic in mangrove mud substrate will increase along with the age of the plant [22]. As the mangrove age increases, the biomass production will be higher. The old mangrove plants would fall some of its parts gradually, followed by the decomposing process that produces plant biomass which will be stored as soil organic matter.

Bulk density is a ratio of dry soil weight and the soil volume in the ring. Bulk density values in the entire measuring plot had an average of 0.90 tons/m³. Measuring plots that were predominantly located in the pond zone had low bulk density, with had the average value of 0.85 tons/m³. It had muddy soil texture, which would shrink and break in dry conditions. Whilst, the coastal zone had sandy soil texture and higher bulk density value, with the average of 0.93 tons/m³.

3.3. Total Carbon and CO₂ Sequestration in Wulan Delta
The total carbon was calculated by summing the amount of carbon deposit above the soil, at the root, and within the soil. The total carbon in mangrove forest of Wulan Delta at each zone is shown in Table 2.

Table 2. Total Carbon Storage and Carbon Dioxide Sequestration

| Zones       | Aboveground Carbon (tons) | Root Carbon (tons) | Soil Carbon (tons) | Total Carbon (tons) | CO2 Sequestration (tons) |
|-------------|---------------------------|-------------------|-------------------|---------------------|--------------------------|
| Pond        | 26,111.23                 | 10,391.70         | 6,780,998.38      | 6,817,501.31        | 25,020,229.82            |
| River       | 3,059.34                  | 1,320.44          | 325,304.02        | 329,683.80          | 1,209,939.56             |
| Coastal     | 13,725.82                 | 5,550.86          | 2,005,383.47      | 2,024,660.15        | 7,430,502.74             |
| Total       | 42,896.39                 | 17,263.00         | 9,111,685.87      | 9,171,845.27        | 33,660,672.12            |

The highest total carbon was found at the pond zone, with the value of 6,817,501.31 tons C; whilst the lowest was found at the river zone with the value of 329,683.80 tons C. The varying carbon value was due to the biomass contained in the soil surface and roots, mangrove species and thus wood density, bulk density, and the the area of each zone as the main factor.

This research resulted that the largest amount of carbon was contained in the soil. That being said, soil carbon had the highest value among the other carbon sources. Mangrove forest has the second highest carbon storage among the wetland ecosystems, following the peatland ecosystem. The complex root system in mangrove forest blocks the sea tides. The carbon cycle in mangrove forest runs slower due to anaerobic conditions resulted by inundated condition on muddy soil that slows down the decomposition process by organisms. This causes a lot of carbon accumulate in the soil [23].

The measured carbon dioxide sequestration of mangrove forests in Wulan Delta was 33,660,672.12 tons of CO2. The value was obtained by multiplying the total carbon storage and a constant number of 3.67, which shows the ratio of Relative Molecular Mass (MR) of CO2 and Relative Atomic Mass (AR) of C. Total of CO2 sequestration in Wulan Delta annually is 1,530,030.55 tons CO2 year⁻¹. This value is obtained from mangrove sequestration during its life divided by 22 years of mangrove age.

3.4. Potential of Emissions Sequestration in Deltas on the North Coast of Java

Basically, deltas on the North Coast of Java can be estimated for their CO2 absorption potential to determine the role of deltas in absorbing emissions on the island of Java or emissions at the national level. Calculation of CO2 sequestration all deltas using extrapolation method. The estimated potential values can be seen in Table 3.

Table 3. Estimation of CO2 sequestration in deltas at North Coast of Java

| No | Name of Delta | Regency     | Area (ha) | Estimation of sequestration (tons CO2) | Estimation of sequestration (tons CO2 year⁻¹) | National Emissions 2017 (tons CO2) | Percentage of sequestration (%) |
|----|---------------|-------------|-----------|---------------------------------------|---------------------------------------------|----------------------------------|---------------------------------|
| 1. | Wulan         | Demak       | 1,484.35  | 33,660,672.12                         | 1,530,030.55                                | 1.15x10⁻¹⁵                       | 1.32x10⁻⁷                      |
| 2. | Bodri         | Kendal      | 6,303.34  | 142,941,126.42                        | 6,497,323.92                                | 5.62x10⁻⁹                       | 1.63x10⁻⁷                      |
| 3. | Cimanuk       | Indramayu   | 1,826.86  | 41,427,786.89                         | 1,883,081.22                                | 3.39x10⁻⁷                       | 1.42x10⁻⁶                      |
| 4. | Cipunegara    | Pamanukan   | 3,803.93  | 86,261,892.75                         | 3,720,955.12                                | 2.06x10⁻⁷                       |                                |
| 5. | Citarum       | Bekasi      | 15,896.77 | 360,491,772.65                        | 16,385,989.66                               |                                |                                |
| 6. | Comal         | Pekalongan  | 2,304.86  | 52,267,414.52                         | 2,375,791.57                                |                                |                                |
| 7. | Pangkah (Bengawan Solo) | Gresik | 5,046.89  | 114,448,552.91                        | 5,202,206.95                                | 4.51x10⁻⁷                       |                                |
| 8. | Femali        | Brebes      | 1,590.37  | 36,064,892.46                         | 1,639,313.29                                | 1.42x10⁻⁷                       |                                |
| Total|              |             | 38,257.37 | 867,564,110.72                       | 39,434,732.28                               | 1.15x10⁻¹⁵                     | 3.42x10⁻⁷                     |
Information about the area and CO$_2$ sequestration in the delta is in Table 3. Disclaimer that the estimated value of CO$_2$ sequestration potential is obtained if all deltas are considered to have similar characteristics such as the Wulan Delta. The characteristics of Wulan Delta are that it has a large area of mangrove, ponds that are utilized by local people, and deltas that are still actively developing.

National emissions in 2017 amounted to 1.15x10$^{15}$ tons CO$_2$ [24]. The total sequestration of CO$_2$ in the delta on the North Coast of Java was 39,434,732.28 tons CO$_2$ year$^{-1}$. The value of sequestration could absorb national emissions of 3.42x10$^{-6}$%. Citarum Delta located in Bekasi Regency is the largest contributor of emissions absorbers in the Delta on the North Coast of Java, amounting to 1.42x10$^{-6}$%. Citarum Delta is the highest contributor due to the delta area of 15,896.77 ha, the most extensive compared to other deltas on the North Coast of Java. The percentage absorption pattern is also known based on the area of the delta, that the wider the delta, the greater the potential for absorption of national emissions.

4. Conclusion

The estimated value of carbon storage in mangrove forest of Wulan Delta consists of (a) above-ground carbon storage of 42,896.339 tons C with carbon density of 245.578 tons C ha$^{-1}$, (b) root carbon storage of 17,263.003 tons C with carbon root density of 100,778 tons C ha$^{-1}$, (c) soil carbon storage of 9,111,685.870 tons C with soil carbon density of 42,991.169 tons C ha$^{-1}$. The total carbon storage in the mangrove forest of Wulan Delta is 9,171,845.27 tons C. Meanwhile, the value of CO$_2$ sequestration in mangrove forest of Wulan Delta is 33,660,672.12 tons CO$_2$ with total of CO$_2$ sequestration in Wulan Delta annually is 1,530,030.55 tons CO$_2$ year$^{-1}$. Estimation of sequestration in deltas at North Coast of Java 39,434,732.28 tons CO$_2$ year$^{-1}$. This value can absorb national emissions in 2017 by 3.42x10$^{-6}$%.

References

[1] Inter governmental Panel on Climate Change, “Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report,” 2007.

[2] W. E. Cahyono, “Pengaruh Pemanasan Global terhadap Lingkungan Bumi,” Lembaga Penerbangan dan Antariksa Nasional, vol. 8, pp. 28–31, 2006.

[3] B. A. Schumacher, Method for The Determination of Total Organic Carbon (TOC) in Soils and Sediments. Las Vegas: United States Environmental Protection Agency, 2002.

[4] Supriharyono, Pelestarian dan Pengelolaan Sumber Daya Alam di Wilayah Pesisir Tropis. Jakarta: PT Gramedia Pustaka Umum, 2000.

[5] C. Saparinto, Pendayagunaan Ekosistem Mangrove. Semarang: Dahara Prize, 2007.

[6] Y. R. Noor, M. Khazali, and I. N. N. Suryadiputra, Panduan Pengenalan Mangrove di Indonesia. Bogor: Wetland International - Indonesia Programme, 2012.

[7] H. Sulistiwati, “Biodiversitas Mangrove di Cagar Alam Pulau Sempi,” SainsTek, vol. 8, no. 1, pp. 59–64, 2009.

[8] A. Nontji, Laut Nusantara. Jakarta: Djambatan, 2007.

[9] I. Jaya, Samsuri, T. Lastini, and E. S. Purnama, Teknik Inventarisasi Sediaan Ramin di Hutan Rawa Gambut. Bogor: ITTO Cities Project bekerjasama dengan Pusta Penelitian dan Pengembangan Hutan Konservasi Alam BPPK Kementerian Kehutanan, 2010.

[10] Standar Nasional Indonesia (SNI), Pengukuran dan penghitungan cadangan karbon –Pengukuran lapangan untuk penaksiran cadangan karbon hutan (ground based forest carbon accounting). Jakarta: Badan Standarasi Nasional, 2011.

[11] A. Komiyama, S. Poungparn, and S. Kato, “Common allometric equations for estimating the tree weight of mangroves.” J. Trop. Ecol., vol. 21, no. 4, pp. 471–477, 2005.

[12] E. Bird and O. S. Ongkosongo, Environmental Changes of the Coasts of Indonesia. Tokyo: United Nations University, 1980.

[13] B. Septiangga, “Analisis Morfodinamika Wilayah Kепesiran Muara Delta Wulan dan Sekitarnya Tahun 1995-2015,” Universitas Gadjah Mada, 2017.
[14] A. D. Setyawan, K. Winarno, Indrowuryatno, Wiryanto, and A. Susilowati, “Tumbuhan Mangrove di Pesisir Jawa Tengah: 3. Diagram Profil Vegetasi,” *Biodiversitas*, vol. 9, no. 4, pp. 315–321, 2008.

[15] N. Aqila and E. Haryono, “Kuantifikasi Kandungan Karbon pada Hutan Rehabilitasi Mangrove Pasar Banggi, Rembang, Jawa Tengah,” *J. Bumi Indones.*, pp. 1–10, 2017.

[16] D. C. Donato, J. B. Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham, and M. Kanninen, “Mangrove Adalah Salah Satu Hutan Terkaya Karbon di Kawasan Tropis,” *CIFOR*, no. 12, Australia, pp. 1–12, 2012.

[17] P. D. Srikandi, “Estimasi Simpanan Karbon pada Tegakan dan Substrat Mangrove di Hutan Rehabilitasi Mangrove Dusun Pandansari Desa Kaliwlingi Kabupaten Brebes,” Universitas Gadjah Mada, 2014.

[18] I. Yusidarta, “Estimasi Penyerapan dan Penyimpanan Karbon pada Tegakan Rhizophora mucronata Hasil Rehabilitasi Mangrove di Kampus Marine Station Teluk Awur Jepara,” Universitas Gadjah Mada, 2011.

[19] I. A. D. Widyantari, “Potensi Simpanan Karbon di Kawasan Rehabilitasi Mangrove Taman Hutan Raya Ngrurah Rai Bali,” Universitas Gadjah Mada, 2013.

[20] D. Sutaryo, *Perhitungan Biomassa: Sebuah Pengantar untuk Studi Karbon dan Perdagangan Karbon*. Bogor: Wetland International - Indonesia Programme, 2009.

[21] H. Purnobasuki, Y. L. Agustin, and M. Muryono, “Estimasi Stok Karbon pada Tegakan Pohon Rhizophora stylosa Pantai Talang Iring Pamekasan Madura,” *Biol. Fak. Mat. dan Ilmu Pengetah. Alam*, 2012.

[22] D. M. Alongi, “Carbon Sequestration in Mangrove Forest,” *Carbon Manag.*, vol. 3, pp. 313–322, 2012.

[23] S. Manuri, C. A. S. Putra, and A. D. Saputra, *Teknik Pendugaan Cadangan Karbon Hutan*. Palembang: Merang REDD Pilot Project German International Cooperation-GIZ, 2011.

[24] Direktorat Jenderal Pengendalian Iklim Kementerian Lingkungan Hidup dan Kehutanan, *Statistik Direktorat Jenderal Pengendalian Perubahan Iklim Tahun 2018*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan, 2019.