JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(5), 263–271
https://doi.org/10.12911/22998993/135945
ISSN 2299-8993, License CC-BY 4.0

Received: 2021.02.26
Accepted: 2021.04.14
Published: 2021.05.01

# Using Allometric Equations to Estimate Mangrove Biomass and Carbon Stock in Demta Bay, Papua Province, Indonesia

Ervina Indrayani[1,2], John Dominggus Kalor[1,2], Maklon Warpur[1,2], Baigo Hamuna[1,2*]

[1] Department of Marine Science and Fisheries, Faculty of Mathematics and Natural Sciences, Cenderawasih University, Kamp Wolker Street, Jayapura City 99315, Papua Province, Indonesia

[2] Center for Marine and Fisheries Resources Studies, Cenderawasih University, Kamp Wolker Street, Jayapura City 99315, Papua Province, Indonesia

* Corresponding author's e-mail: bhamuna@yahoo.com.sg

**ABSTRACT**

The mangrove ecological services as carbon sinks and storage are very useful in the efforts to mitigate global warming and climate change. In this study, the above and below-ground biomass, carbon stock, as well as carbon sequestration by the mangroves in Demta Bay, Papua Province, Indonesia were estimated. Allometric equations were used to determine the mangrove biomass in 36 observation plots. The biomass value was used to determine carbon stock and estimate carbon sequestration. Nine mangrove species were found in Demta Bay, with the contribution of mangrove species to biomass (AGB and BGB) in the following order: *Rhizophora apiculata* > *Rhizophora mucronata* > *Bruguiera gymnorhiza* > *Bruguiera cylindrica* > *Heritiera Littoralis* > *Xylocarpus molucensis* > *Rhizophora stylosa* > *Avicennia marina* > *Sonneratia caseolaris*. The average mangrove biomass was estimated at 174.20 ± 68.14 t/ha (AGB = 117.62 ± 45.68 t/ha and BGB = 56.58 ± 22.49 t/ha). The carbon stocks in mangroves at the Ambora site were higher than the Tarfia and Yougapsa sites, averaging 123.57 ± 30.49 t C/ha, 81.64 ± 25.29 t C/ha, and 56.09 ± 39.03 t C/ha, respectively. The average carbon stock in the mangrove ecosystem of Demta Bay is estimated at 87.10 ± 34.07 t C/ha or equivalent to 319.37 ± 124.92 t $CO_2$ e/ha. The results of this study indicate that the mangrove ecosystem in Demta Bay stores quite high carbon stocks, so it is necessary to maintain it with sustainable management. Therefore, climate change mitigation is not only done by reducing the carbon emission levels but also needs to be balanced by maintaining the mangrove ecosystem services as carbon sinks and sequestration.

**Keywords:** mangrove species; allometric equations; above-ground biomass; below-ground biomass; carbon stock; carbon sequestration

## INTRODUCTION

Some of the most important mangrove ecological services for humans and other living creatures are absorption and storage of carbon which is very useful in mitigating global warming and climate change. The carbon stored in the mangrove ecosystems began to show significant economic value after the emergence of carbon markets [Jaikishun et al., 2017]. Mangroves are one of the important „blue carbon" parameters in reducing the effects of greenhouse gases as a mitigation of climate change, because they can reduce $CO_2$ through the mechanism of carbon sequestration from the atmosphere [Komiyama et al., 2008; Kauffman and Donato, 2012]. The role of mangroves as an absorber and storage of carbon is emphasized as an effort for mangroves to utilize carbon for photosynthesis and store it in biomass stocks, both above and below the soil surface [Kauffman and Donato, 2012; Alongi, 2012]. Meanwhile, the fall of organic material such as litter and dead mangrove stems on the substrate contributes to storing organic carbon in the soil [Bouillon et al., 2008]. Mangroves trap and convert carbon dioxide into organic compounds in their biomass through the primary production process [Bouillon et al., 2008]. Therefore, mangroves are considered to have the potential to absorb and store carbon that is very significant in the global carbon cycle [Estrada and Soares, 2017; Kauffman et al., 2020].

Geographically, the potential of carbon stocks and the level of carbon sequestration by mangroves varies greatly due to large variations in local factors [Estrada and Soares, 2017; Kusumaningtyas et al., 2019]. The ability of mangroves to absorb and store carbon is very high and greater than that of tropical forests [Donato et al., 2011; Kauffman and Donato, 2012; Murdiyarso et al., 2015]. Globally, the estimates of mean carbon storage in mangrove ecosystems approximate 885 tons C/ha [Kauffman and Bhomia, 2017] to 1.023 tons C/ha [Donato et al., 2011]. The mangrove ecosystems in Indonesia have great potential to absorb carbon from the atmosphere and store it as biomass. This can be seen from the total area of mangroves in Indonesia, which reaches 22.4% of the total area of mangroves in the world [Giri et al., 2011]. Various methods have been developed to estimate and quantify the mangrove biomass. One method that can be used involves the use of allometric equations [Komiyama et al., 2005]. Biomass estimation is done by measuring the diameter at breast height (DBH) which is then used as an input to the allometric equation. Allometric equations have been widely used to estimate mangrove biomass in several studies, especially for estimating the above- and below-ground biomass. [Abino et al., 2014; Eusop et al., 2018; Kusumaningtyas et al., 2019; Harishma et al., 2020].

Given the importance of the ecological function of mangroves as carbon sinks in nature, the study of estimated biomass, carbon stocks, and carbon sequestration are needed to determine the ability of mangroves in Demta Bay as one of the important environmental components in climate change mitigation. Besides, the data on biomass, carbon stocks, and carbon sequestration in mangrove ecosystems are important to support the management of conservation of mangrove ecosystems. Therefore, this study aimed to estimate and evaluate the potential of above- and below-ground biomass, carbon stocks, and carbon sequestration in the mangrove ecosystems in Demta Bay, Papua Province, Indonesia.

## MATERIALS AND METHODS

### Study Site

Demta Bay is located in the Demta District, which is one of the districts located in the northern coastal area of Jayapura Regency, Papua Province, Indonesia (Figure 1). The coastal area of Demta Bay is quite rich in natural resources, such as mangroves, coral reefs, seagrass beds and fishery resources [Kalor et al., 2019]. The mangrove ecosystem in Demta Bay is unique because it is directly connected to the Pacific Ocean in the north and the tropical forests of Papua Island in the south. The morphological, ecological, and biological conditions in Demta Bay form the main ecosystem zone in the coastal area consisting of coral reef ecosystems, seagrass ecosystems, and mangrove ecosystems. The existence of the mangrove ecosystem provides enormous benefits for the survival of local Papuan communities, who live around the mangrove ecosystem and work as small-scale fishermen [Rumahorbo et al., 2019; Rumahorbo et al., 2020]. Many mangrove ecosystems in the Demta District are found in Ambora, Yougapsa and Tarfia Villages, where as many as nine types of mangroves have been identified in the three villages [Kalor et al., 2019].

### Data collection

Non-destructive methods through quadratic sampling techniques used in this study were conducted in June 2020 at three study sites in Demta Bay, namely in the villages of Ambora, Yougapsa, and Tarfia (Figure 1). Data collection was carried out by stretching a 50 m transect from the edge of the water perpendicular to the mangrove forest (4 transects at each study site). A 10 m × 10 m plot was installed along the transect at 10 m intervals (a total of 3 plots in each transect). Thus, there were 12 observation plots at each station (a total of 36 plots in all stations). All mangrove trees in the observation plots were identified at the species level, counted in number, and measured DBH (at a height of 1.3 m) for estimating above- and below-ground biomass. Referring to Abino et al. (2014), an inventory of mangrove species is only for trees with a minimum DBH of 5 cm and it was used to calculate the mangrove biomass. The identification of mangrove species in the observation plot refers to Noor et al. [1999]. A global positioning system (GPS, Garmin 78s) was used to mark the coordinates of each data collection location.

### Data analysis

The mangrove carbon stock estimates were determined from the mangrove biomass. The

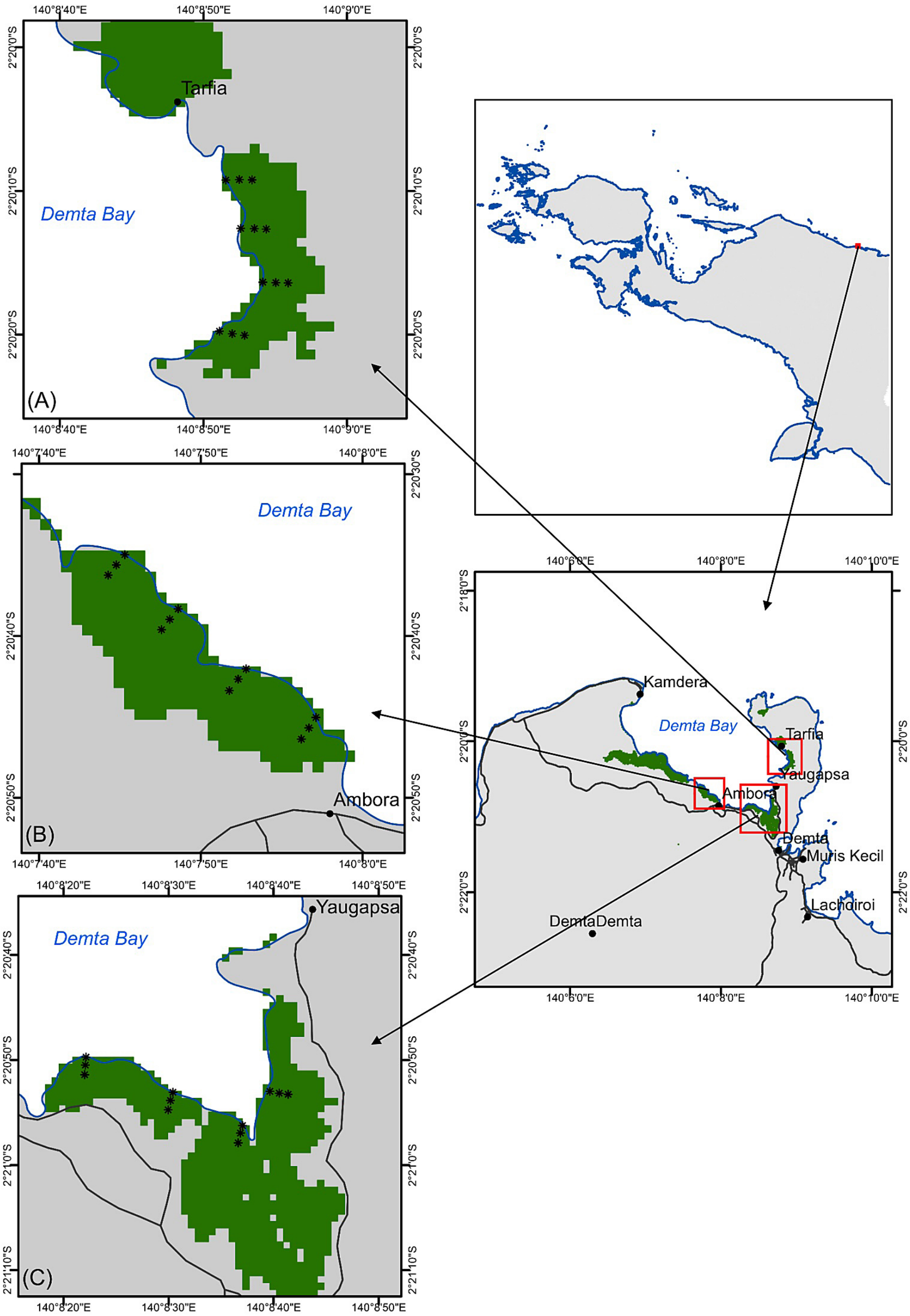


**Figure 1**. Study area showing the plots points for mangrove data collection in Demta Bay, Jayapura Regency, Indonesia

mangrove biomass was obtained with a non-destructive method based on the data from the measurement of DBH. The data was then converted into the above- and below-ground biomass using allometric equations according to mangrove species. In turn, several other mangrove species use a general allometric equation for mangrove species in Southeast Asia developed by Komiyama et al. [2005]. The allometric equations used to determine the above-ground biomass (AGB) were as follows:

*Avicennia marina* [Dharmawan and Siregar, 2008]:

$AGB = 0.1848\ D^{2.3524}$

*Rhizophora apiculata* [Vinh et al., 2019]:

$AGB = 0.38363\ D^{2.2348}$

*Rhizophora mucronata* [Fromard et al., 1998]:

$AGB = 0.128\ D^{2.60}$

*Rhizophora stylosa* [Clough and Scott, 1989]:

$AGB = 0.105\ D^{2.68}$

*Sonneratia caseolaris* [Hanh et al., 2016]:

$AGB = 0.04975\ D^{1.94748}$

Common equations [Komiyama et al., 2005]:

$AGB = 0.251\ \rho\ D^{2.46}$

While the allometric equations used to determine the below-ground biomass (BGB) were as follows:

*A. marina* [Komiyama et al., 2008]:

$BGB = 1.28\ D^{1.17}$

*R. stylosa* [Gevana and Im, 2016]:

$BGB = 0.134\ D^{2.40}$

*S. caseolaris* [Hanh et al., 2016]:

$BGB = 0.01420\ D^{2.12146}$

Common equations [Komiyama et al., 2005]:

$BGB = 0.199\ \rho^{0.899}\ D^{2.22}$

where: D is tree DBH in cm and $\rho$ is wood density in $g \cdot cm^{-3}$. The wood density values of various mangrove species are presented in Table 1.

The values of the above- and below-ground mangrove biomass were summed to obtain the total biomass for all observation plots. Then, the biomass value was averaged to obtain the mean total of mangrove biomass (t/ha). The carbon content (C) in organic matter is usually 50%, so the carbon stock can be calculated by multiplying the total weight of the biomass by the percentage of carbon content (0.5) [IPCC, 2006].

**Table 1**. Mean value of wood density for mangrove species [World Agroforestry Center, 2017]

| Mangrove species | Wood density (g/cm$^3$) |
|---|---|
| *Avicennia marina* | 0.732 |
| *Bruguiera cylindrica* | 0.810 |
| *Bruguiera gymnorhiza* | 0.741 |
| *Heritiera Littoralis* | 0.885 |
| *Rhizophora apiculata* | 0.881 |
| *Rhizophora mucronata* | 0.848 |
| *Rhizophora stylosa* | 0.940 |
| *Sonneratia caseolaris* | 0.534 |
| *Xylocarpus molucensis* | 0.654 |

## RESULTS AND DISCUSSION

### The characteristics of the mangrove ecosystem in Demta Bay

There are nine species of true mangroves found in Demta Bay (Table 2). Only five mangrove species were found in all study sites, namely *B. cylindrical*, *B. gymnorhiza*, *R. apiculate*, *R. mucronata*, and *X. molucensis*. The mangrove species *A. marina*, *H. Littoralis*, and *R. stylosa* were only found at one site, whereas *S. caseolaris* was found at two sites. A total of 902 individual mangroves were found in all observation plots. The species composition of *B. gymnorhiza*, *R. apiculata*, *R. mucronata*, and *B. cylindrical* was higher at 27.94%, 25.17%, 21.84%, and 18.29%, respectively. Meanwhile, the species composition of *R. stylosa*, *A. marina*, *X. molucensis*, *S. caseolaris*, and *H. littoralis* was very low at 2.00%, 1.55%, 1.44%, 1.22%, and 0.55%, respectively (Figure 2). The number of true mangrove species found in this study was higher than the results of the study at the same location reported by Kalor et al. [2019], where *H. Littoralis* was not found, but one species of mangrove association *Derris trifolia* was reported in his study. Major mangroves or true mangroves can form pure stands and release saltwater, so that they can grow in standing water,

**Table 2.** Species diversity and characteristics of the mangrove ecosystem in Demta Bay

| Mangrove species | Ambora | Yougapsa | Tarfia | DBH range (cm) | DBH Mean (cm) |
|---|---|---|---|---|---|
| *A. marina* | – | – | + | 5.73 – 9.23 | 7.09 ± 1.11 |
| *B. cylindrica* | + | + | + | 5.09 – 17.82 | 8.00 ± 2.06 |
| *B. gymnorhiza* | + | + | + | 5.09 – 13.36 | 7.63 ± 1.42 |
| *H. Littoralis* | – | + | – | 11.14 – 24.50 | 19.03 ± 5.01 |
| *R. apiculata* | + | + | + | 5.09 – 16.55 | 10.14 ± 2.70 |
| *R. mucronata* | + | + | + | 5.09 – 15.91 | 9.05 ± 2.88 |
| *R. stylosa* | + | – | – | 5.73 – 8.27 | 6.51 ± 0.69 |
| *S. caseolaris* | + | – | + | 8.27 – 20.36 | 13.86 ± 4.62 |
| *X. molucensis* | + | + | + | 5.09 – 20.36 | 8.76 ± 5.22 |
| Diversity index | 1.62 | 1.45 | 1.54 | | |
| Tree density (tree/ha) | 2991.67 | 1750.00 | 2808.33 | | |

**Note:** (+) = was found; (–) = not found.

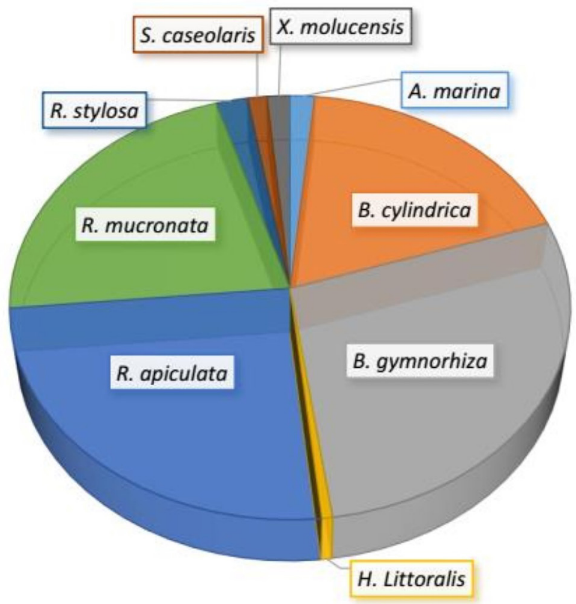


**Figure 2**. Composition of mangrove species in the study area

minor mangroves grow on the edge of mangrove habitats and do not form pure stands, while associated mangroves tend to only grow in terrestrial habitats [Tomlinson, 1986].

The diameter of mangrove trees (DBH) in Demta Bay ranged from 5.09 to 24.50 cm with an average of 8.75 ± 2.78 cm (Table 2). The composition of DBH mangrove was dominated by DBH 5 to 10 cm as much as 74.50%. Meanwhile, the DBH composition of 10.01 to 15 cm, 15.0 to 20 cm, and 20.01 to 25 cm is 23.17%, 1.44%, and 0.89%, respectively. The mangrove species diversity index (Shannon-Wiener diversity index) ranges from 1.54 to 1.62 which are classified as medium diversity categories [Magguran, 1991] (Table 2). The mangrove vegetation density level in Demta Bay ranges from 1750.00 to 2991.67 trees/ha (Table 2). Mangrove vegetation with a density of >1500 trees/ha is classified as very dense, >1000 to <1500 trees/ha are classified as dense, and <1000 trees/ha are classified as rare [Kementerian Negara Lingkungan Hidup, 2004]. On the basis of these criteria, the mangrove density level of Demta Bay is classified as very dense. The level of mangrove density can be maintained by issuing binding regulations for the community so that mangrove destruction is not carried out.

## Above- and Below-ground Biomass

The mangrove biomass in Demta Bay ranged from 112.17 ± 29.14 to 247.14 ± 61.28 t/ha, with an average of 174.20 ± 68.14 t/ha (Table 3). AGB contributed higher mangrove biomass than BGB averaging 117.62 ± 45.68 t/ha (67.52%) and 56.58 ± 22.49 t/ha (32.48%), respectively. The contributions of AGB and BGB to the mangrove biomass obtained in this study were similar to the contributions of AGB and BGB in Kerala, southwest India coast of 68.49% and 31.51%, respectively [Harishma et al., 2020].

Different mangrove species make different contributions to the mangrove biomass. The contribution of mangrove species to mangrove biomass (AGB and BGB) was in the following order: *R. apiculata* > *R. mucronata* > *B. gymnorhiza* > *B. cylindrical* > *H. Littoralis* > *X. molucensis* > *R. stylosa* > *A. marina* > *S. caseolaris*. The mangrove species *R. apiculata*, *R. mucronata*, *B. gymnorhiza*, and *B. cylindrical* contributed significantly to AGB and BGB (Figure 3). The contribution of the four mangrove species to mangrove biomass are 141.18 t/ha, 78.47 t/ha, 61.46 t/ha, and 52.27 t/ha for AGB, and 63.07 t/ha, 42.61 t/ha, 30.39 t/ha, and 24.96 t/ha for BGB. Several research results show a different sequence for the contribution of each mangrove species to its biomass. In the mangrove ecosystem in Kerala, the southwest coast of India, *A. marina* and *R. mucronata* contributed to the mangrove biomass around 81.09 t/ha and 53.50 t/ha, while *R. apiculata* only 0.85 t/ha [Harishma et al., 2020]. Likewise, the mangrove species *R. mucronata* and *B. cylindrical* in the mangrove ecosystem in Alas Purwo National Park, Indonesia have a very high contribution of 217.22 t/ha and 115.66 t/ha respectively [Heriyanto and Subiandono, 2012]. The order of

**Table 3**. Average (± SD) of above- and below-ground mangrove biomass in each study site

| Sites | AGB (t/ha) | BGB (t/ha) | Total biomass (t/ha) |
|---|---|---|---|
| Ambora | 166.90 ± 42.09 | 80.24 ± 18.99 | 247.14 ± 61.28 |
| Yougapsa | 76.69 ± 56.28 | 35.48 ± 21.81 | 112.17 ± 29.14 |
| Tarfia | 109.28 ± 36.18 | 54.01 ± 14.59 | 163.29 ± 39.09 |
| Average | 117.62 ± 45.68 | 56.58 ± 22.49 | 174.20 ± 68.14 |

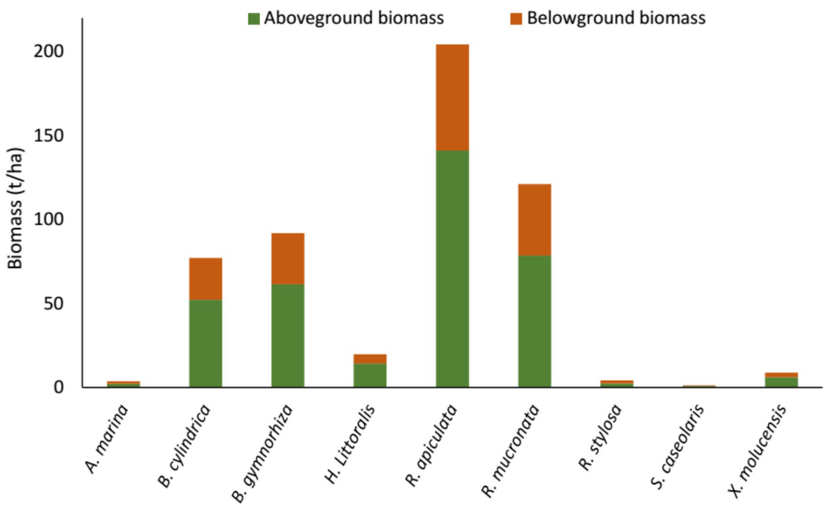


**Figure 3**. Comparison of above- and below-ground biomass on different mangrove species in Demta Bay

the contribution of mangrove species in Pulau Cawan Village, Riau Province, Indonesia is relatively similar to the results of this study, where *R. apiculata*, *R. mucronata*, and *B. gymnorhiza* had the highest contribution of 2317.48 t/ha, 1142.53 t/ha, and 680.19 t/ha, respectively [Syafruddin et al., 2018]. The difference in the contribution of each mangrove species to biomass in different areas can be related to the peculiarities of the mangrove vegetation structure in each region.

Generally, the mangrove biomass is different for each mangrove species, which is strongly influenced by tree diameter, tree height, mangrove density, soil fertility, and sequestration ability [Kusmana et al., 1992]. Sintayehu et al. [2020] added that species richness, diversity index, and functional diversity can have a significant effect on the storage of aboveground carbon, so that it also directly affects the biomass. Besides, the presence of species dominance also affects the carbon storage above the soil surface.

## Potential Carbon Stock

The average carbon stock in the mangrove ecosystem in Demta Bay is estimated to be 87.10 ± 34.07 t C/ha (Table 4). These carbon stocks come from the above and below ground carbon stocks averaging 58.81 ± 22.84 t C/ha and 28.29 ± 11.24 t C/ha, respectively. The average above and below ground carbon stock at the Ambora site is higher than the Tarfia and Yougapsa sites estimated at 166.90 ± 42.09 t C/ha and 80.24 ± 18.99 t C/ha, 109.28 ± 36.18 t C/ha, and 54.01 ± 14.59 t C/ha, and 76.69 ± 56.28 t C/ha and 35.48 ± 21.81 t C/ha, respectively. The high carbon stock at the Ambora site can be attributed to the higher density of mangrove trees compared to the other two sites. Besides, although the DBH range at the Ambora site is smaller (5.09 to 16.55 cm), the average is higher (9.41 ± 2.76 cm) than the Yougapsa site (DBH range 5.09 to 24.50 cm, average DBH 8.18 ± 2.79 cm) and Tarfia site (DBH 5.09 to 20.36 cm range, average DBH 8.44 ± 2.65 cm). The differences in environmental settings and conditions can affect the local variations in carbon stock, including the influence of hydrodynamic processes, landform, and vegetation conditions of the mangrove ecosystem (canopy cover and mangrove density) [Hinrichs et al., 2009; Li et al., 2015]. Therefore, disturbed mangrove ecosystems (for example: a large number of mangrove cutting activities) and small tree DBH will result in very low carbon stocks [Kusumaningtyas et al. 2019].

**Table 4**. Carbon stock estimates and sequestration ($CO_2$ equivalent) calculated from mangrove biomass

| Sites | Carbon stock (t C/ha) | $CO_2$ equivalent (t $CO_2$e/ha) |
|---|---|---|
| Ambora | 123.57 ± 30.49 | 453.09 |
| Yougapsa | 56.09 ± 39.03 | 205.66 |
| Tarfia | 81.64 ± 25.29 | 299.35 |
| Average | 87.10 ± 34.07 | 319.37 ± 124.92 |

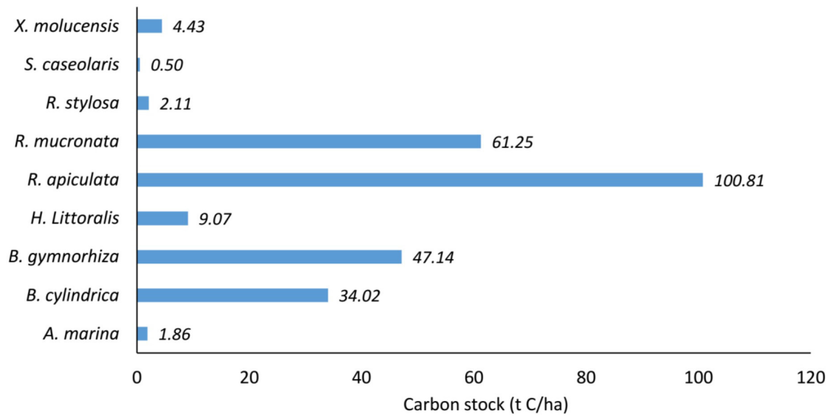


**Figure 4**. Mangrove species contribution to carbon stock in Demta Bay

The results of the analysis of the average carbon stock for each mangrove species in Demta Bay based on biomass according to the area was in the following order: *R. apiculata* > *R. mucronata* > *B. gymnorhiza* > *B. cylindrical* > *H. Littoralis* > *X. molucensis* > *R. stylosa* > *A. marina* > *S. caseolaris* (Figure 4). The contribution of mangrove species *R. apiculata*, *R. mucronata*, *B. gymnorhiza*, and *B. cylindrical* at the Ambora site was very high was 57.43 t C/ha, 39.06 t C/ha, 12.88 t C/ha, and 10.57 t C/ha, respectively. Likewise, at the Tarfia site, the four mangrove species also contributed highly, i.e. 28.70 t C/ha, 13.38 t C/ha, 12.50 t C/ha, and 21.75 t C/ha, respectively. In turn, at the Yougapsa site, *B. gymnorhiza*, *R. apiculata*, *H. Littoralis*, and *R. mucronata* contributed significantly at 14.82 t C/ha, 14.67 t C/ha, 9.07 t C/ha, and 8.81 t C/ha, respectively. The highest carbon stock in mangrove species *R. apiculata* was found in Pulau Cawan Village, Riau [Syafruddin et al., 2018], and in Kubu Raya, West Kalimantan [Heriyanto and Subiandono, 2016], but the lowest was in Saukori Bay, Manokwari [Hendri et al., 2020]. The mangrove species *R. mucronata* has the highest carbon stock in the Alas Purwo National Park [Heriyanto and Subiandono, 2012] and in Kema, North Sulawesi [Kepel et al., 2017], while *A. marina* is the highest in Kerala, the southwest coast of India [Harishma et al., 2020]. Generally, it is not much different from the variations in biomass content, where the differences in carbon stocks in the same mangrove species in various mangrove ecosystems can be caused by the differences in density or number of individuals, structural stands, and tree diameters [Kusmana et al., 1992; Kusumaningtyas et al., 2019].

The carbon stock assessment can provide an overview of $CO_2$ uptake in the air. The mangroves in Demta Bay have a high potential in reducing global warming because of their ability to absorb $CO_2$. In this study, the estimated carbon sequestration ($CO_2$ equivalent) was only calculated from the mangrove biomass with an average of 319.37 t $CO_2$ e/ha, where the highest carbon uptake at the Ambora location was 453.09 t $CO_2$ e/ha and the lowest was at the Yougapsa site, reaching 205.66 t $CO_2$ e/ha (Table 4). This carbon sequestration value is interpreted as an indicative value to highlight the importance of mangrove conservation and the estimation of mangrove ecosystems in the world [Donato et al., 2011; Kauffman et al., 2014]. Climate change and anthropogenic disturbances can impact not only the loss of biodiversity and coastal protection but also the loss of function of mangrove ecosystem services as carbon sequestration and storage [Nellemann et al., 2009]. Mangrove ecosystems need to be conserved as a strategy for climate change mitigation [Pendleton et al., 2012; Murdiyarso et al., 2015]. Thus, it is imperative to emphasize and implement the importance of Reduced Emissions from Deforestation and Degradation (REDD+) as a key and relatively low-cost option for mitigating climate change.

## CONCLUSIONS

A total of nine mangrove species are found in Demta Bay and contribute to biomass and carbon stock in the mangrove ecosystem. The contribution of mangrove species to biomass and carbon stock was in the following order: *R. apiculata* > *R. mucronata* > *B. gymnorhiza* > *B. cylindrical* > *H. littoralis* > *X. molucensis* > *R. stylosa* > *A. marina*

> *S. caseolaris*. Mangroves in Demta Bay store a fairly high carbon stock, estimated at 87.10 ± 34.07 t C/ha, where the aboveground carbon and belowground carbon contribute 67.52% and 32.48%, respectively. Among the three research sites in Demta Bay, the mangrove ecosystem at the Ambora site was found to store higher carbon because it has a higher mangrove density and an average of DBH than the other two sites. The results of this study have provided an overview of the important contribution of the mangrove ecosystem in Demta Bay to climate change mitigation. Therefore, the climate change mitigation efforts are not only carried out by reducing the level of carbon emissions but also need to be balanced by maintaining the mangrove ecosystem services as carbon storage and sink.

### Acknowledgements

The authors would like to thank the Institute for Research and Community Service, Cenderawasih University for funding this research (Doctoral Development Research in 2020, Grant No. 084/UN20.2.1/PG/2020). Thanks to the Government of Ambora, Yougapsa, and Tarfia villages for permitting data collection, also to Natan Baransano and students of the Department of Marine Science and Fisheries of Cenderawasih University for their assistance during fieldwork.

## REFERENCES

1. Abino A.C., Castillo J.A.A., Lee Y.J. 2014. Assessment of species diversity, biomass and carbon sequestration potential of a natural mangrove stand in Samar, the Philippines. Forest Sci. Technol. 10(1), 2–8.
2. Alongi D.M. 2012. Carbon sequestration in mangrove forests. Carbon Manag. 3(3), 313–322.
3. Bouillon S., Borges A.V., Castañeda-Moya E., Diele K., Dittmar T., Duke N.C., et al. 2008. Mangrove production and carbon sinks: A revision of global budget estimates. Global Biogeochemi Cycles 22, GB2013.
4. Clough B.F., Scott K. 1989. Allometric relationships for estimating above-ground biomass in six mangrove species. For. Ecol. Manag. 27, 117–127.
5. Dharmawan I.W.S., Siregar, C.A. 2008. Soil carbon and carbon estimation of *Avicennia marina* (Forsk.) Vierh. stand at Ciasem, Purwakarta. Jurnal Penelitian Hutan dan Konservasi Alam 5(4), 317–328 (in Indonesian).
6. Donato D.C., Kauffman J.B., Murdiyarso D., Kurnianto S., Stidham M., Kanninen M. 2011. Mangroves among the most carbon-rich forests in the tropics. Nat. Geosci. 4(5), 293–297.
7. Estrada G.C.D., Soares M.L.G. 2017. Global patterns of aboveground carbon stock and sequestration in mangroves. An Acad Bras Ciênc 89(2), 973–989.
8. Eusop M.E.M., Ismail M.H., Kasim M.R.M. 2018. Estimating aboveground biomass and carbon stocks of mangrove forests in Kuala Sepetang, Perak. The Malaysian Forester 81(2), 145–153.
9. Fromard F., Puig H., Mougin E., Marty G., Betoulle J.L., Cadamuro, L. 1998. Structure, above-ground biomass and dynamics of mangrove ecosystems: New data from French Guiana. Oecologia 115, 39–53.
10. Gevana D.T., Im S. 2016. Allometric models for *Rhizophora stylosa* griff. in dense monoculture plantation in the Philippines. The Malaysian Forester 79(1&2), 39–53.
11. Giri C., Ochieng E., Tieszen L.L., Zhu Z., Singh A., Loveland T., et al. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecol. Biogeography 20, 154–159.
12. Hanh N.T.H., Tinh P.H., Tuan M.S. 2016. Allometry and biomass accounting for mangroves *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler planted in coastal zone of Red River Delta, Vietnam. Int. J. Dev. Res. 6(5), 7804–7808.
13. Harishma K.M., Sandeep S., Sreekumar V.B. 2020. Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecological Processes 9, 31.
14. Hendri H., Hadiyan Y., Rumbruren Y.P., Moeljono S., Maturbongs R. 2020. Vegetation structure and potential of blue carbon based on hydromorphic degraded mangrove in the Northern Manokwari, West Papua. IOP Conf Series: Earth and Environmental Science 522, 012016.
15. Heriyanto N.M., Subiandono, E. 2012. Composition and structure, biomass, and potential of carbon content in mangrove forest at National Park Alas Purwo. Jurnal Penelitian Hutan dan Konservasi Alam 9(1), 23–32 (in Indonesian).
16. Heriyanto N.M., Subiandono E. 2016 Role of mangrove biomass in carbon sink, in Kubu Raya, West Kalimantan. Jurnal Analisis Kebijakan 13(1), 1–12 (in Indonesian).
17. Hinrichs S., Nordhaus I., Geist S.J. 2009. Status, diversity and distribution patterns of mangrove vegetation in the Segara Anakan lagoon, Java, Indonesia. Reg. Environ. Change 9, 275–289.
18. Intergovernmental Panel on Climate Change (IPCC). 2006. IPCC Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry and other land use. Hayama Japan: Institute

for Global Environmental Strategies. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19. Jaikishun S., Ansari A.A., Dasilva P., Hosen A. 2017. Carbon storage potential of mangrove forest in Guyana. Bonorowo Wetlands 7(1), 43–54.
20. Kalor J.D., Indrayani E., Akobiarek M.N.R. 2019. Fisheries resources of mangrove ecosystem in Demta Gulf, Jayapura, Papua, Indonesia. AACL Bioflux 12(1), 219–229.
21. Kauffman J.B., Adame M.F., Arifanti V.B., Schile-Beers L.M., Bernardino A.F., Bhomia R.K., et al. 2020. Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. Ecol. Monogr. 90(2), e01405.
22. Kauffman J.B., Bhomia R.K. 2017. Ecosystem carbon stocks of mangroves across broad environmental gradients in West-Central Africa: Global and regional comparisons. PLoS ONE 12(11), e0187749.
23. Kauffman J.B., Donato, D.C. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. CIFOR Working Paper No. 86. Bogor: Center for International Forestry Research (CIFOR).
24. Kauffman J.B., Heider C., Norfolk J., Payton F. 2014. Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. Ecol. Appl. 24, 518–527.
25. Kementerian Negara Lingkungan Hidup. 2004. Decree of the Minister of Environment of the Republic of Indonesia, number 201 of 2004 concerning standard criteria and guidelines for determining mangrove damage. Jakarta: Kementerian Lingkungan Hidup (in Indonesian).
26. Kepel T.L., Suryono D.D., Ati R.N.A., Salim H.L., Hutahaean, A.A. 2017. Important value and economic value estimation of carbon storage of mangrove vegetation in Kema, North Sulawesi. Jurnal Kelautan Nasional 12(1), 19–26 (in Indonesian).
27. Komiyama A., Ong J.E., Poungparn S. 2008. Allometry, biomass, and productivity of mangrove forests: A review. Aquat. Bot. 89(2), 128–137.
28. Komiyama A., Poungparn S., Kato, S. 2005. Common allometric equations for estimating the tree weight of mangroves. J. Trop. Ecol. 21, 471–477.
29. Kusmana C., Sabiham S., Abe K., Watanabe H. 1992. An estimation of above ground tree biomass of a mangrove forest in East Sumatera, Indonesia. Tropics 1(4), 143–257.
30. Kusumaningtyas M.A., Hutahaean A.A., Fischer H.W., Pérez-Mayo M., Ransby D., Jennerjahn T.C. 2019. Variability in the organic carbon stocks, sources, and accumulation rates of Indonesian mangrove ecosystems. Estuar. Coast. Shelf Sci. 218, 310–323.
31. Li N., Chen P., Qin C. 2015. Density, stronge and distribution of carbon in mangrove ecosystem in Guangdong's coastal areas. Asian Agric. Res. 7(2), 62–65.
32. Magurran A.E. 1991. Ecological diversity and its measurement (2nd ed.). London: Chapman and Hall.
33. Murdiyarso D., Purbopuspito J., Kauffman J.B., Warren M.W., Sasmito S.D., Donato D.C., et al. 2015. The potential of Indonesian mangrove forests for global climate change mitigation. Nature Clim. Change 5, 1089–1092.
34. Nellemann C., Corcoran E., Duarte C.M., Valdés L., De Young C., Fonseca L., et al. 2009. Blue carbon: a rapid response assessment. GRID-Arenda: United Nations Environment Programme.
35. Noor Y.R., Khazali M., Suryadiputra I.N.N. 1999. Guide to introduction of mangroves in Indonesia. Bogor: PHKA/Wetland International-Indonesia Programme (in Indonesian).
36. Pendleton L., Donato D.C., Murray B.C., Crooks S., Jenkins W.A., Sifleet S., et al. 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PLoS ONE 7(9), e43542.
37. Rumahorbo B.T., Keiluhu H.J., Hamuna B. 2019. The economic valuation of mangrove ecosystem in Youtefa bay, Jayapura, Indonesia. Ecological Question 30(1), 47–54.
38. Rumahorbo B.T., Hamuna B., Keiluhu H.J. 2020. An assessment of the coastal ecosystem services of Jayapura City, Papua Province, Indonesia. Environ. & Socio-Econ. Stud. 8(2), 45–53.
39. Sintayehu D.W., Belayneh A., Dechassa N. 2020. Aboveground carbon stock is related to land cover and woody species diversity in tropical ecosystems of Eastern Ethiopia. Ecological Processes 9, 37.
40. Syafruddin Y.S., Mahdi M., Yuerlita Y. 2018. Estimation of blue carbon stocks at tree level in Pulau Cawan and Bekawan Villages, Mandah District, Riau Province. Jurnal Spasial 2(5), 54–62 (in Indonesian).
41. Tomlinson P.B. 1986. The botany of mangroves. Cambridge: Cambridge University Press.
42. Vinh T.V., Marchand C., Linh T.V.K., Vinh D.D., Allenbach M. 2019. Allometric models to estimate above-ground biomass and carbon stocks in Rhizophora apiculate tropical managed mangrove forests (Southern Viet Nam). Forest Ecol. Manag. 434, 131–141.
43. World Agroforestry Center. 2017. Wood density. http://db.worldagroforestry.org//wd