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# Estimation of Carbon Stocks on Mangrove Forests at Pulau Kampai Using Destructive and Nondestructive Methods

**Anton Syahputra Siregar[1*], Zulkifli Nasution[2], Rahmawaty[3]**
*[1]Natural Resources and Environmental Management Study Program, Postgraduate School, Universitas Sumatera Utara, Indonesia*
*[2]Department of Regional Planning, Postgraduate Studies, Universitas Sumatera Utara*
*[3]Natural Resources and Environmental Management Study Program, Postgraduate School, Universitas Sumatera Utara*
*[3]Forestry Study Program, Faculty of Forestry, Universitas Sumatera Utara*
*Email: antonbravo41@gmail.com*

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***Abstract***

Mangrove forests are essential in maintaining the balance of coastal ecosystems and climate change mitigation. This study aimed to analyze carbon stocks in 2022 in natural mangrove forests at Pulau Kampai, Pangkalan Susu Sub District, Langkat District, North Sumatra Province, with an area of approximately 1,786.25 ha. Estimating carbon stocks in this study uses destructive and nondestructive methods using allometric equations from various aboveground and belowground studies. The sampling plots used a circle plot with a radius of 5.64 m. The sampling plot was determined by purposive sampling based on NDVI criteria (low, moderate, dense, high dense) with a sampling plot distance of 20 m from the edge of the coast or river. The destructive sample tree was taken from the dominant species which grew in the study area, namely Rhizophora apiculata, with a diameter of 7.1 cm with a total biomass yield of 91 kg consisting of aboveground biomass of 67.55 kg (74.23%) and belowground biomass was 23.45 kg (25.77 %). Meanwhile, the average C-organic content produced 56% aboveground and 56% belowground. The estimated carbon stocks using this study's conversion factor was 62.06 tons C/ha with a total carbon stock of 110,849.28 tons C. Meanwhile, the conversion factor using other studies was 48.20 tons C/ha with a complete carbon stock of 86,095.30 tons C.

**Keywords:** Destructive, Nondestructive, Carbon Stocks, C-organic, and NDVI

## INTRODUCTION

Carbon stocks are carbon reserves stored in 5 carbon pools: 1). Above ground biomass, 2). Below ground biomass, 3). Deadwood, 4). Litter, and 5). Soil carbon (IPCC, 2006). Since 2006, the IPCC (Intergovernmental Panel on Climate Change) has developed an emission calculation method that is currently recognized internationally. This method has been developed in the Good Practice Guidance 2000 and IPCC Guidelines for National Greenhouse Gas Inventories 2006 versions (Arifanti et al., 2014).

Hossain and Nuruddin (2016) stated that mangrove forests absorb $CO_2$ and produce $O_2$ at which relatively high rate compared to other forest types. In addition, mangroves have high adaptability when combined with anaerobic environments and conditions (Ghizella et al., 2020), so it was potentially affected by long-term carbon storage (Murdiyarso et al., 2015).

In the study of (Suprayogi et al., 2020), the estimation of nondestructive carbon stocks for the types Rhizophora apiculata and mucronata at intervals age of 2, 4, 6, 8, 10, and 12 years in Tanjung Rejo Village, Deli Serdang District, and Sei Meran Village and Karang Gading Village, Langkat District, North Sumatra on the type of river land was 34.4-51.1 MgC/ha higher than the carbon stocks in ponds of 33.6-42.4 MgC/ha.

Harefa et al. (2022) stated that one of the factors that affected carbon stocks is canopy cover and mangrove land area. In the study by (Harefa et al., 2022) was obtained that the value of mangrove carbon stocks in the pond ecosystem in Deli Serdang District, more than 58.87 tons C/ha, was dominated by the Rhizophora apiculata species with an average diameter of 7.9 cm.

Biomass and carbon stocks estimation by using the destructive method for 20 years old species of Rhizophora apiculata in Malaysia recorded that the total biomass (including belowground) was 117 tons C/ha (equivalent to 234 tons/ha) with a stem biomass ratio was 74%, root biomass was 15% and leaf and twig biomass were 10.6% (Eong et al., 1995).

Using Sentinel-2 and ALOS-2 PALSAR-2 imagery, remote sensing can accurately estimate mangrove biomass in Vietnam, where the average estimated aboveground biomass is 106.93 tons/ha with a coefficient of determination 0.805 and RMSE 28.13 tons/ha (Pham et al., 2020).

The area of mangroves in several watersheds in Langkat District has decreased over the last ten years. According to (Rahmawaty et al, 2022), The Lepan watershed has reduced by 31.51 ha (22.41%) in 10 years from 2009 to 2019, from 140.62 ha to 109.11 ha. Likewise, the mangrove area of the Besitang watershed has decreased by 1,677.74 ha (28.90%) from 2008 to 2018 and 5,804.40 ha to 4,126.66 ha due to land conversion to plantations, ponds, and bare land (Suharso et al., 2019).

Pulau Kampai is one of the outermost islands in the Langkat District, directly adjacent to the Malacca Strait. Pulau Kampai has a mangrove forest that functions as a barrier to abrasion, maintaining the balance of coastal ecosystems and climate change mitigation. It is hoped that this study can provide an overview and information about the carbon stocks of Pulau Kampai mangrove forests, so it can assist in making policies for the sustainable management of mangrove forests.

## RESEARCH METHODS

### Study location

This study was carried out in the natural forest of the mangrove ecosystem located at Pulau Kampai, Pangkalan Susu Sub-district, Langkat District, North Sumatra Province, with a wide mangrove area of approximately 1,786.25 ha (interpreted from Sentinel 2A imagery) (Figure 1). This study was conducted for six (6) months, from October 2022 to March 2023.

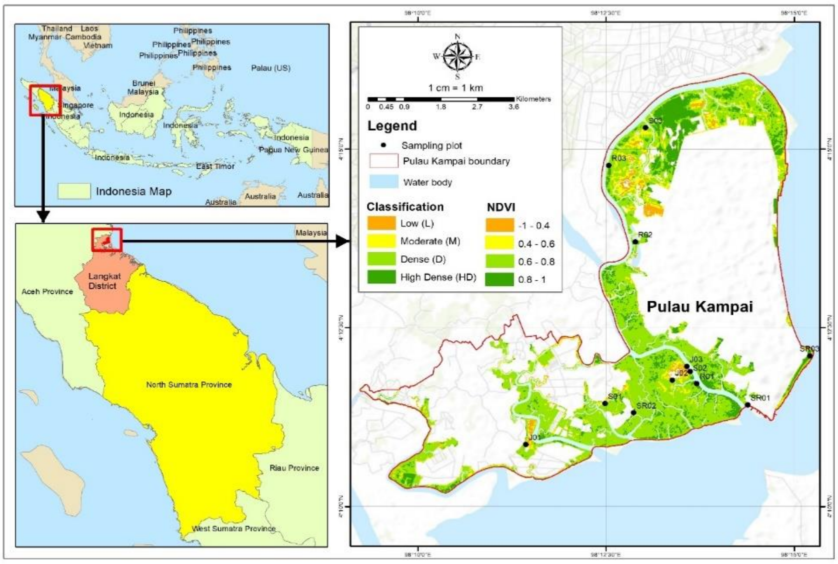


Figure 1. Map of study location in Pulau Kampai, Pangkalan Susu Sub-district, Langkat District, North Sumatra Province, Indonesia

**Destructive method**

Tree samples were taken based on the dominant mangrove species growing at the study site in the following ways:

1. Before cutting, the stem diameter will be measured.
2. Cut the tree and separate the roots, stems, branches, twigs, and leaves (flowers, fruit, seeds). Then, the tree's height was measured from the ground to the highest shoot.
3. Dry the parts of the tree in the shade for about 3 hours to remove water that sticks to the surface.
4. Weigh the root, stem, branch, twig, and leaf biomass.
5. Take samples from each part of the tree, each part of the tree weighed 500 gr, with composition as follows: (i) The stems are divided into ten parts, and each part is taken a sample 50 gr with a total of 500 gr, (ii) branches are taken 500 gr from young, medium and old branches, (iii) twigs are taken 500 gr from young, medium and old twigs, (iv) leaves are taken 500 gr from young, medium and old leaves, (v) the roots are taken 500 g consisting of 125 gr for stilt roots, 125 gr for aerial roots, 125 gr for tertiary roots and 125 gr for fibrous roots.
6. Carry out an analysis of organic carbon content at the Medan Palm Oil Research Center (PPKS) Laboratory with the loss on ignition method.

**Nondestructive method**

The materials and instruments in this study were Sentinel 2A imagery recording date from 01 January to 31 August 2022, ArcGIS 10.8.2 (ESRI Reference ID: 551727205147. Authorization Number: ESU991393923), Google Earth Engine (GEE) open source, measuring tool, phi band, rope, stick, compass Suunto KB-14/360R, GPS Garmin 64s, analytical weigh scale 150 kg and 1 kg, saw, hoe, machete, basket size 52 x 36 x 31 cm, plastic clip size 25 x 35 cm, plastic bag size 60 x 45 cm and paint.

Determination of sampling plots by purposive sampling is determined deliberately based on Normalized Difference Vegetation Index (NDVI) criteria and also considering the tides. The distance of the sampling plots from the coast or river is 20 m. Sampling plot measurements were divided into four strata, namely low (L), moderate (M), dense (D), and high dense (H.D.) (Figure 1). Each stratum represents three sampling plots with 12 sampling plots of carbon measurement in the field. The NDVI classification used in this study can be seen in Table 1.

Table 1. NDVI Classification

| NDVI in this study | | NDVI NASA | |
|---|---|---|---|
| NDVI | Classification | NDVI | Classification (1999) |
| (-1) - 0,4 | Low | < 0,1 | Nonvegetation |
| 0,4 - 0,6 | Moderate | 0,2 - 0,3 | Shrub and grassland |
| 0,6 - 0,8 | Dense | 0,6 - 0,8 | High-density tropical rainforest |
| 0,8 - 1,0 | High Dense | - | - |

Source: NASA, 1999

The low values of NDVI (< 0.1) correspond to barren rock, sand, or snow areas. The moderate values represent shrub and grassland (0.2 to 0.3), while the high values indicate temperate and tropical rainforests (0.6 to 0.8) (NASA, 1999). The coordination of sampling plots in this study can be seen in Table 2.

Table 2. Coordinates Of Sampling Plots

| Sampling Plot | Coordinates | |
|---|---|---|
| | Longitude | Latitude |
| L01 | 98° 11' 25.949" E | 4° 10' 52.131" N |
| L02 | 98° 13' 22.757" E | 4° 11' 46.104" N |
| L03 | 98° 13' 34.268" E | 4° 11' 57.655" N |
| M01 | 98° 12' 29.187" E | 4° 11' 26.511" N |
| M02 | 98° 13' 36.963" E | 4° 11' 53.324" N |
| M03 | 98° 13' 1.335" E | 4° 15' 18.061" N |
| D01 | 98° 13' 42.285" E | 4° 11' 43.285" N |
| D02 | 98° 12' 53.210" E | 4° 13' 42.255" N |
| D03 | 98° 12' 32.146" E | 4° 14' 46.383" N |
| HD01 | 98° 14' 22.965" E | 4° 11' 25.256" N |
| HD02 | 98° 12' 51.819" E | 4° 11' 18.750" N |
| HD03 | 98° 15' 12.367" E | 4° 12' 6.471" N |

The following methods carried out biomass measurement: (i) measuring the diameter at breast height (DBH) measured 1.3 m from the ground. Standing dead trees are measured as part of the tree inventory (not fallen wood) (SNI 7724, 2011), (ii ) tree height measured > 1.5 m and stem diameter ≥ 2 cm (SNI 7724, 2011), (iii) for species that have stilt roots (e.g., Rhizophora spp.) diameter at breast height is measured 30 cm from the top of the stilt roots (Komiyama et al., 2005), (iv) sampling plot measurements by using the method which is developed for mangrove forests (SNI 7724, 2011) (Figure 2). Measurement plots are created in a circular pattern, each with a radius of 5.64 m, The area of one measurement plot was 99.85 $m^2$, or the rough equivalent is 100 $m^2$.

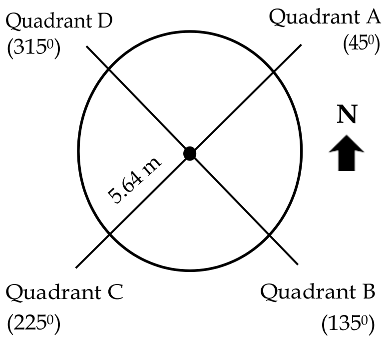


Figure 2. Schematic plot for measuring mangrove vegetation
Source: SNI 7724 (2011).

The level of dead trees is recorded as follows (Figure 3).

1. State 0: Healthy tree (correction factor = 1).
2. Status 1: Dead trees still have small branches, twigs, or partially dry branches but no leaves (correction factor = 0.975).
3. Status 2: The absence of smaller branches and twigs or partially dry branches (correction factor = 0.8).
4. Status 3: The dead tree has few or no branches; only the main stem remains (correction factor = 0.6).
5. Status 4: Stumps not reaching dbh due to

being cut down or broken naturally are also measured for the stump's diameter. (correction factor = 0.4).

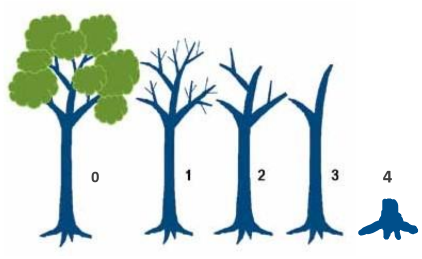


Figure 3. The level of dead trees
Source: IPCC (2003); Solichin (2009) in Kauffman and Donato, 2012; Hairiah et al., 2011. Redesigned by researchers.

**Data analysis**

The estimation of aboveground carbon stocks was determined by using the allometric equations of tree biomass aboveground (Table 3). To estimate the belowground tree biomass using the allometric equations of tree biomass belowground (Table 4). Furthermore, to convert biomass into carbon, it can be done by multiplying it with the conversion factor (C-organic). This study used a conversion factor that consists of (i) the results of carbon concentration from this study (destructive analysis) and (ii) the result from other studies, namely: 47% for aboveground (Kauffman et al., 2011) and 39% for belowground (Komiyama et al., 2008).

Table 3. Aboveground Biomass Allometric Equation

| Species | Allometric | Reference |
|---|---|---|
| General Equation | $B = 0{,}251\ \rho\ (D)^{2{,}46}$ | Komiyama et al., 2005 |
| Rhizophora apiculata | $B = 0{,}043D^{2{,}63}$ | Amira, 2008 |
| Avicennia marina | $B = 0{,}1848D^{2{,}3524}$ | Dharmawan & Siregar, 2008 |
| Xylocarpus granatum | $B = 0{,}1832D^{2{,}21}$ | Tarlan, 2008 |

Source: Kauffman dan Donato, 2012

Table 4. Belowground Biomass Allometric Equation

| Species | Allometric | Reference |
|---|---|---|
| General Equation | $B_{TB} = 0{,}199 \times \rho^{0{,}899} \times (D)^{2{,}22}$ | Komiyama et al. (2008) |
| Avicennia alba | $B_{TB} = 1{,}28 \times (D_{30})^{1{,}17}$ | Comley & McGuinness (2005) |
| Avicennia marina | $B_{TB} = 1{,}28 \times (D_{30})^{1{,}17}$ | Comley & McGuinness (2005) |
| Avicennia officinalis | $B_{TB} = 1{,}28 \times (D_{30})^{1{,}17}$ | Comley & McGuinness (2005) |
| Bruguiera sexangula | $B_{TB} = 0{,}0188 \times ((D_{30})^2 \times (D_{30})/((0{,}025 \times D_{30}) + 0{,}583)))^{0{,}909}$ | Tamai et al., (1986) |

## RESULTS AND DISCUSSION

**Biomass and carbon stocks destructive method**

The selection of mangrove species taken as sample trees must be based on the dominant species growing in the sampling plots, namely *Rhizophora apiculata*. The sample tree taken was in plot D01 with a stem diameter ($D_{30}$) of 7.1 cm and a tree height of 5.7 m, which was approximately 12 years old. Kadarsah & Choesin (2013) stated that the type of *Rhizophora* spp. twelve years old was characterized by a tree with a height of 5.17 m and a stem diameter of 5.15 cm. The estimation of tree biomass using the destructive method can be seen in Table 5.

Table 5. Biomass Tree

| Samples | Biomass (kg) | Percentage of Biomass to Total Weight (%) |
|---|---|---|
| Root | 23,45 | 25,77 |
| Stem | 37,60 | 41,32 |
| Branch | 12,95 | 14,23 |
| Twig | 5,50 | 6,04 |
| leaf | 11,50 | 12,64 |
| Total | 91,00 | 100,00 |

Source: Study Results, 2023.

Table 5 shows that the total biomass of mangrove trees aged approximately 12 years old is 91 kg, whereas aboveground biomass (stems, branches, twigs, leaves) is 67.55 kg (74.23%). Belowground biomass (roots) is 23.45 kg (25.77 %). The highest biomass is stems which is 37.60 kg (41.32%), and roots are 23.45 kg (25.77%), branches are 12.95 kg (14.23%), leaves are 11.50 kg (12.64 %), and twigs are 5.50 kg (6.04 %).

In this study, roots have a fairly high biomass of 25.77%, (Hilmi & Siregar, 2006) said that the weight of root biomass of Rhizophora spp. was 8 – 23% and Bruguiera spp. was 23 – 29%, caused by the type of mangrove forest, which has a low oxygen level (an aerobic), so that the root system forms a lateral root system (smaller) and stilt roots.

The comparison between the diameter (cm) and biomass (kg) of Rhizophora spp. in various countries' studies can be seen in Table 6.

Table 6. The comparison between diameter and biomass

| No | Location | Diameter (cm) | | | Reference |
|---|---|---|---|---|---|
| | | 5 | 15 | 25 | |
| 1 | Malaysia | 10 (kg) | 156 (kg) | 562 (kg) | Putz & Chan (1986) |
| 2 | Malaysia | 11 (kg) | 154 (kg) | 530 (kg) | Eong et al. (1985) |
| 3 | N.T. Australia | 11 (kg) | 160 (kg) | 562 (kg) | Comley & McGuinness (2005) |
| 4 | W.A. Australia | 11 (kg) | 154 (kg) | 528 (kg) | Clough et al. (1997) |
| 5 | Mexico | 12 (kg) | 187 (kg) | 672 (kg) | Day et al. (1987) |
| 6 | Srilanka | 14 (kg) | 138 (kg) | 397 (kg) | Amarasinghe & Balasubramaniam (1992) |
| 7 | Indonesia | | | 721,66 (kg) | Hilmi & Siregar (2006) |

Source: Secondary Data.

White (1981) explained that the organic carbon (C) of trees consisted of 60-65% C-organic stems, while the study of Hilmi & Siregar (2006) said that the C-organic stems of Rhizophora spp. with a diameter of 10-40 cm reached an average 57-61% and Bruguiera spp. with a diameter of 10-30 cm with C-organic ranges from 40-53%.

Rhizophora mucronata aged 12 years was planted in Kenya and produced a standing biomass of 106.7 ± 24.0 tons/ha with an accumulation rate of 8.9 tons/ha/year with a percent ratio between stem and root biomass of 42.0% and 30.4%. (Cairo et al., 2008). In this study, stem biomass was 41.32% and 25.77% root. The data analysis of carbon content (C-organic) from this study can be seen in Table 7.

Table 7. C-Organic Tree Analysis

| No. | Samples | C-organic (%) | |
|---|---|---|---|
| | | Above ground | Below ground |
| 1 | Root | | 56.18 |
| 2 | Stem | 56,84 | |
| 3 | Branch | 56.27 | |
| 4 | Twig | 55.63 | |
| 5 | Leaf | 54.06 | |
| Average C-organic (%) | | 55.70 | 56.18 |
| Average C-organic | | 0.56 | 0.56 |

Source: Study Results, 2023

In another study, the carbon content was 41-47.9% (IPCC, 1996). In Hilmi & Siregar (2006), the average carbon content of Rhizophora spp. and Bruguiera spp. ranged from 33.14-55.12%. The carbon content of Rhizophora apiculata was 40.48-55.12%, Rhizophora mucronata was 42.31-49.13%, and Bruguiera spp. of 33.14-38.60%. In this study, all carbon content was 54.06-56.84%, and the average aboveground and belowground carbon content was 56%.

Comparison of the amount of tree biomass and carbon stocks between the results of destructive and nondestructive methods (allometric equation) using the conversion factor in this study and other studies can be seen in Table 8 and Table 9.

Table 8. The Result of Biomass and Destructive Carbon Stocks

| Samples | C organic (%) | Biomass (kg) | Amount of Carbon (kg C) |
|---|---|---|---|
| Roots | 56.18 | 23.45 | 13.17 |
| Stems | 56.84 | 37.60 | 21.37 |
| Branches | 56.27 | 12.95 | 7.29 |
| Twigs | 55.63 | 5.50 | 3.06 |
| leaves | 54.06 | 11.50 | 6.22 |
| | | 91.00 | 51.11 |

Source: Study Results, 2023

Table 9. The result of Biomass and Nondestructive Carbon Stocks

| Allometric | C-organic | Tree Biomass (kg) | Amount of Tree Carbon (kg C) |
|---|---|---|---|
| Using the conversion factor of this study | Above (56 %) | 7.45 | 4.17 |
| | Below (56 %) | 13.34 | 7.47 |
| Amount | | 20.79 | 11.64 |
| Using the conversion factor of other studies | Above (47 %) | 7.45 | 3.50 |
| | Below (39 %) | 13.34 | 5.20 |
| Amount | | 20.79 | 8.71 |

Source: Study Results, 2023.

In the mixed allometric equation with the conversion factor in this study, the difference in biomass was 70.21 kg, and the amount of carbon was 39.47 kg C. Meanwhile, in the mixed allometric with the conversion factor of other studies, the difference in biomass was 70.21 kg, and the carbon amount was 42.4 kg C. Meanwhile, the comparison of allometric calculations using the conversion factor in this study is 11.64 kg C higher than the conversion factor of other studies, which is 8.71 kg C, and there is a difference of 2.93 kg C. There is a significant difference between the destructive and nondestructive methods (Figure 4).

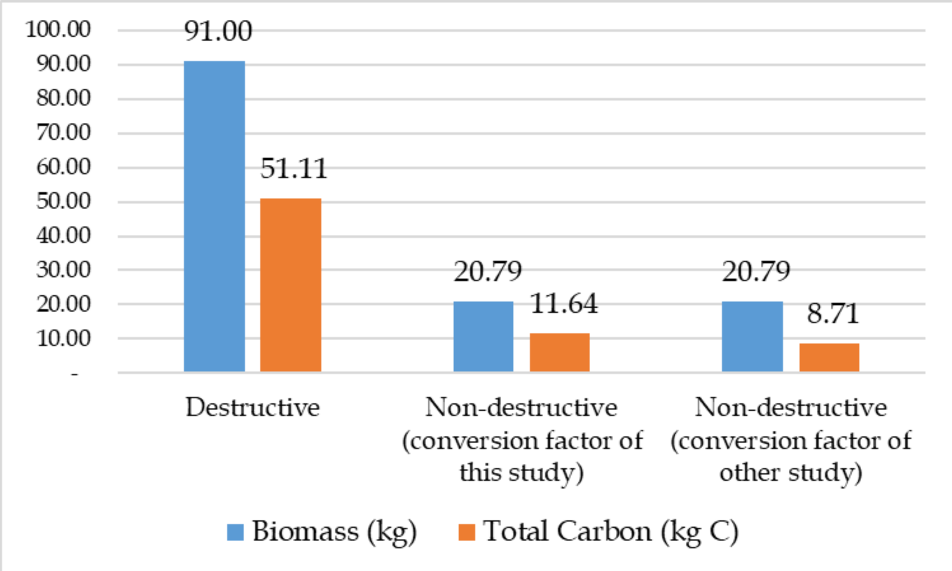


Figure 4. Comparison of Destructive and Nondestructive Methods

**Biomass and carbon stocks Pulau Kampai**

Based on the results of Sentinel 2A image analysis, the wide area of each mangrove cover can be seen in Table 10

Table 10. Mangrove cover

| Mangrove Cover | | | | |
|---|---|---|---|---|
| No. | NDVI Value | Class | Area (Ha) | Percentage (%) |
| 1 | (-1) - 0,4 | Low | 127.54 | 7.14 |
| 2 | 0,4 - 0,6 | Moderate | 295.42 | 16.54 |
| 3 | 0,6 - 0,8 | Dense | 1,156.63 | 64.75 |
| 4 | 0,8 - 1,0 | High Dense | 206.66 | 11.57 |
| Total | | | 1,786.25 | 100.00 |

Source: Study Results, 2023.

Table 10 showed that the highest mangrove cover was in the dense category, namely 1,156.63 ha (64.75%), followed by a moderate category 295.42 ha (16.54 %), a high dense category 206.66 ha (11.57 %), and low category 127.54 ha (7.14%). In general, the mangrove forests of Pulau Kampai were in good condition and fell into the dense category.

The total number of sample trees obtained from field measurements is 306 (Table 11).

Table 11. Mangrove species found in sampling plots

| No | Species | Trees | | Average Diameter (cm) |
|---|---|---|---|---|
| | | Amount | % | |
| 1 | Avicennia alba | 3 | 0,98 | 3,07 |
| 2 | Avicennia marina | 3 | 0,98 | 9,17 |
| 3 | Avicennia officinalis | 21 | 6,86 | 8,22 |
| 4 | Bruguiera cylindrica | 5 | 1,63 | 6,06 |
| 5 | Bruguiera sexangula | 14 | 4,58 | 6,52 |
| 6 | Lumnitzera racemosa | 33 | 10,78 | 3,95 |
| 7 | Rhizophora apiculata | 175 | 57,19 | 6,68 |
| 8 | Sonneratia alba | 44 | 14,38 | 10,28 |
| 9 | Xylocarpus granatum | 8 | 2,61 | 13,31 |
| | Total | 306 | 100 | |

Source: Study Results, 2023

Table 11 showed that nine mangrove species were included in the measurement plots, with the most dominant species being Rhizophora apiculata, with 175 trees (57.19%). Then followed by Sonneratia alba with 44 trees (14.38%), Lumnitzera racemosa with 33 trees (10.78%), Avicennia officinalis with 21 trees (6.86%), Bruguiera sexangula with 14 trees (4.58%), Xylocarpus granatum eight trees (2.61%), Bruguiera cylindrica five trees (1.63%), Avicennia marina three trees (0.98%), and Avicennia alba three trees (0.98%) (Figure 5).

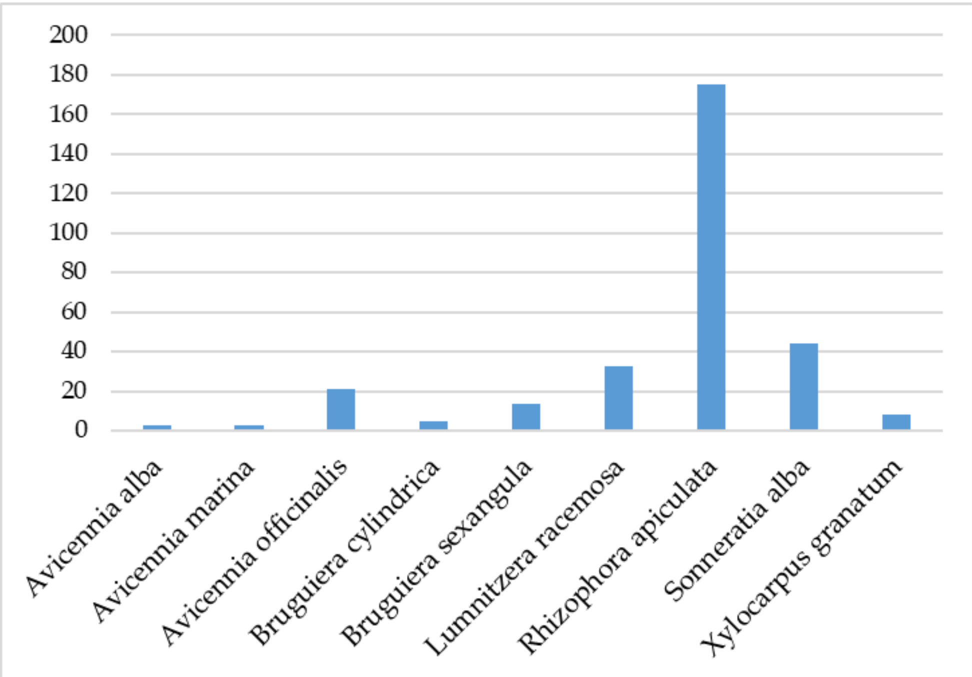


Figure 5. Mangrove Species Found in Sampling Plots

Mangrove trees with a diameter of 15 cm to 23 cm indicate that the mangrove tree is over 30 years old. Furthermore, other types of mangroves are 2.5 cm to 14 cm, indicating that the mangrove trees are between 4 and 30 years old (Kadarsah & Choesin, 2013).

The biomass and carbon stocks at

Pulau Kampai mangrove forests using the conversion factor of this study (above 56% and below 56%) can be seen in Table 12, showing that the highest average biomass and carbon stocks in the H.D. (High Dense) plots are 237.64 tons/ha and 133.08 tons C/ha with an average stem diameter 11.94 cm. Then, plot D (Dense), where the biomass is 141.92 tons/ha, and the carbon stocks are 79.47 tons C/ha with an average stem diameter of 9.23 cm. Meanwhile, plot M (Moderate), where the biomass is 48.08 tons/ha, and carbon stocks are 26.92 tons C/ha with an average stem diameter of 5.38 cm, the last plot L (Low), where the biomass is 15.63 tons/ha and carbon stocks of 8.75 tons C/ha with an average stem diameter is 3.90 cm.

The biomass and carbon stocks of the Pulau Kampai mangrove forest by using another conversion factor study (above 47% and below 39%) (Table 13), showed that the largest average biomass and carbon stocks in the H.D. plot are 237.64 tons/ha and 104.59 tons C/ha with an average stem diameter 11.94 cm. Then, followed by plot D where the biomass is 141.92 tons/ha, and the carbon stocks are 61.44 tons C/ha with an average stem diameter of 9.23 cm. Furthermore, plot M where the biomass is 48.08 tons/ha and carbon stocks are 20.25 tons C/ha with an average stem diameter of 5.38 cm, the last plot L, where the biomass is 15.63 tons/ha, and the carbon stocks are 6.52 tons C/ha with an average stem diameter 3.90 cm.

Hikmatyar et al. (2015) in his study stated that stem diameter, individual density, and diversity of tree species are parameters that affect the biomass and carbon content of an ecosystem. In line with this opinion, Maulana and Sandhi Imam (2009) stated that the potential high carbon content is more influenced by the diameter composition and specific gravity of wood than the density of land cover.

Figure 6 showed that the stem diameter has a strong relationship with total carbon stocks, indicated by high determination coefficients ($R^2$) 0.813 (using the conversion factor of this study) and 0.801 (using the conversion factor of other studies).

Table 12. Biomass and carbon stocks values by using the conversion factor of this study (above: 0.56 and below: 0.56)

| No | Sampling Plot | Number of Trees | Diameter Average (cm) | Biomass (Tons/Ha) | | | Carbon stocks (Tons C/Ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Above Ground | Below Ground | Total | Above Ground | Below Ground | Total |
| 1 | L01 | 21 | 4.34 | 6.16 | 12.69 | 18.85 | 3.45 | 7.10 | 10.56 |
| 2 | L02 | 26 | 3.74 | 5.84 | 8.44 | 14.28 | 3.27 | 4.73 | 8.00 |
| 3 | L03 | 29 | 3.62 | 4.15 | 9.60 | 13.75 | 2.32 | 5.38 | 7.70 |
| Average (L) | | 76 | 3.90 | 5.38 | 10.24 | 15.63 | 3.01 | 5.74 | 8.75 |
| 4 | M01 | 29 | 5.23 | 26.12 | 24.85 | 50.97 | 14.63 | 13.92 | 28.54 |
| 5 | M02 | 34 | 5.89 | 21.29 | 40.46 | 61.76 | 11.92 | 22.66 | 34.58 |
| 6 | M03 | 28 | 5.01 | 8.81 | 22.69 | 31.50 | 4.93 | 12.70 | 17.64 |
| Average (M) | | 91 | 5.38 | 18.74 | 29.33 | 48.08 | 10.49 | 16.43 | 26.92 |
| 7 | D01 | 27 | 9.58 | 64.89 | 87.03 | 151.91 | 36.34 | 48.74 | 85.07 |
| 8 | D02 | 25 | 9.47 | 94.94 | 55.55 | 150.50 | 53.17 | 31.11 | 84.28 |
| 9 | D03 | 23 | 8.64 | 68.50 | 54.85 | 123.35 | 38.36 | 30.72 | 69.07 |
| Average (D) | | 75 | 9.23 | 76.11 | 65.81 | 141.92 | 42.62 | 36.85 | 79.47 |
| 10 | HD01 | 15 | 13.57 | 96.14 | 87.47 | 183.61 | 53.84 | 48.98 | 102.82 |
| 11 | HD02 | 31 | 8.14 | 51.23 | 54.71 | 105.94 | 28.69 | 30.64 | 59.33 |
| 12 | HD03 | 18 | 14.10 | 299.03 | 124.35 | 423.38 | 167.46 | 69.64 | 237.09 |
| Average (H.D.) | | 64 | 11.94 | 148.80 | 88.84 | 237.64 | 83.33 | 49.75 | 133.08 |
| Total | | 306 | 30.44 | 249.03 | 194.23 | 443.26 | 139.46 | 108.77 | 248.23 |
| Average | | | 7.61 | 62.26 | 48.56 | 110.82 | 34.86 | 27.19 | 62.06 |

Source: Study Results, 2023

https://jurnal.unimed.ac.id/2012/index.php/tgeo/article/view/47945
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Table 13. Biomass and Carbon Stocks Values Using Other Studies' Conversion Factors (Above: 0.47 and below: 0.39)

| No. | Sampling Plot | Number of Trees | Diameter Average (cm) | Biomass (Tons/Ha) | | | Carbon Stocks (Tons C/Ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Above Ground | Below Ground | Total | Above Ground | Below Ground | Total |
| 1 | L01 | 21 | 4.34 | 6.16 | 12.69 | 18.85 | 2.90 | 4.95 | 7.84 |
| 2 | L02 | 26 | 3.74 | 5.84 | 8.44 | 14.28 | 2.74 | 3.29 | 6.04 |
| 3 | L03 | 29 | 3.62 | 4.15 | 9.60 | 13.75 | 1.95 | 3.74 | 5.69 |
| Average (L) | | 76 | 3.90 | 5.38 | 10.24 | 15.63 | 2.53 | 3.99 | 6.52 |
| 4 | M01 | 29 | 5.23 | 26.12 | 24.85 | 50.97 | 12.28 | 9.69 | 21.97 |
| 5 | M02 | 34 | 5.89 | 21.29 | 40.46 | 61.76 | 10.01 | 15.78 | 25.79 |
| 6 | M03 | 28 | 5.01 | 8.81 | 22.69 | 31.50 | 4.14 | 8.85 | 12.99 |
| Average (M) | | 91 | 5.38 | 18.74 | 29.33 | 48.08 | 8.81 | 11.44 | 20.25 |
| 7 | D01 | 27 | 9.58 | 64.89 | 87.03 | 151.91 | 30.50 | 33.94 | 64.44 |
| 8 | D02 | 25 | 9.47 | 94.94 | 55.55 | 150.50 | 44.62 | 21.67 | 66.29 |
| 9 | D03 | 23 | 8.64 | 68.50 | 54.85 | 123.35 | 32.19 | 21.39 | 53.58 |
| Average (D) | | 75 | 9.23 | 76.11 | 65.81 | 141.92 | 35.77 | 25.67 | 61.44 |
| 10 | HD01 | 15 | 13.57 | 96.14 | 87.47 | 183.61 | 45.19 | 34.11 | 79.30 |
| 11 | HD02 | 31 | 8.14 | 51.23 | 54.71 | 105.94 | 24.08 | 21.34 | 45.42 |
| 12 | HD03 | 18 | 14.10 | 299.03 | 124.35 | 423.38 | 140.54 | 48.50 | 189.04 |
| Average (H.D.) | | 64 | 11.94 | 148.80 | 88.84 | 237.64 | 69.94 | 34.65 | 104.59 |
| Total | | 306 | 30.44 | 249.03 | 194.23 | 443.26 | 117.05 | 75.75 | 192.80 |
| Average | | | 7.61 | 62.26 | 48.56 | 110.82 | 29.26 | 18.94 | 48.20 |

Source: Study Results, 2023

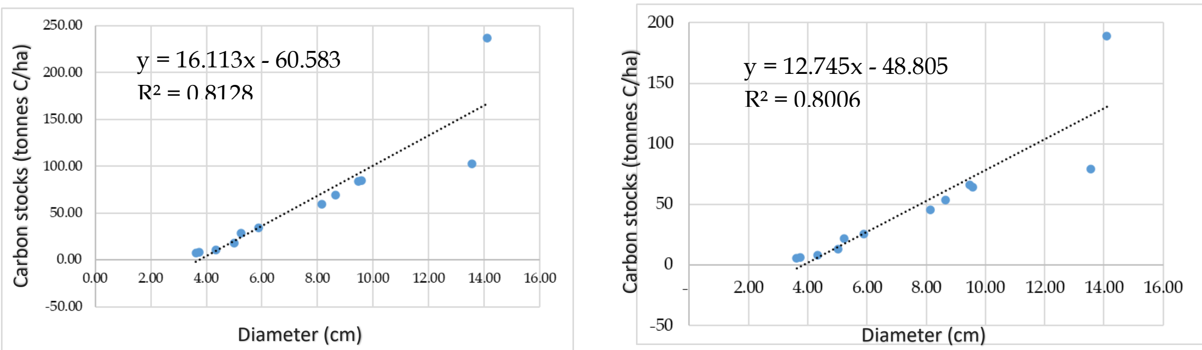


Figure 6. Relation Between Stem Diameter and Carbon Stocks Using the Conversion Factors of This Study (Left) and Other Studies (Right)

The total carbon stocks at Pulau Kampai mangrove forests in 2022, with an area of approximately 1,786.25 ha, showed that the largest carbon stocks in the allometric equation with the conversion factor of this study (above: 0.56 and below: 0.56) is 110,849.28 tons C. The lowest in the allometric equation with the conversion factor of other studies (above: 0.47 and below: 0.39) is 86,095.30 tons C (Table 14).

Table 14. The Total Carbon Stocks

| No | Allometric | Carbon stocks (Tons C/ha) | Mangrove forest area (Ha) | Total carbon stock (Tons C) |
|---|---|---|---|---|
| | | a | b | c = (a x b) |
| 1 | Using the conversion factor of this study (above: 0.56 and below: 0.56) | 62.06 | 1,786.25 | 110,849.28 |
| 2 | Using other studies, conversion factors (above: 0.47 and below: 0.39) | 48.20 | 1,786.25 | 86,095.30 |

Source: Study Results, 2023

## CONCLUSION

The mangrove forests of Pulau Kampai are included in the dense forest category with an average stem diameter of 3.62-14.10 cm. The number of mangrove species found in the sampling plots was nine mangrove species, namely, Avicennia alba, Avicennia marina, Avicennia officinalis, Bruguiera cylindrica, Bruguiera sexangula, Lumnitzera racemosa, Rhizophora apiculata, Sonneratia alba, and Xylocarpus granatum. From 306 sample trees, the most dominant species was Rhizophora apiculata, namely 175 trees (57.19%).

Stem diameter has a strong correlation with carbon stocks, where the greater the diameter of stems, the more carbon stocks will also be stored. Meanwhile, if the diameter of the stems is small, the carbon stocks will also be low. The measurement results of the destructive method of this study with the average biomass for a 12-year-old mangrove tree with a diameter of 7.1 cm and a tree height of 5.7 m was 91 kg with a total carbon 51.11 kg C. Meanwhile, all carbon content (C-organic) was 54.06-56.84%, and the average aboveground and belowground carbon content was 56%.

From the results of carbon stocks calculation using nondestructive methods and conversion factors in this study, it was obtained that carbon stocks were 62.06 tons C/ha, with the total of carbon stocks stored at 110,849.28 tons C. Meanwhile, conversion factors in other studies, carbon stocks were 48.20 tons C/ha with the total of carbon stocks stored 86,095.30 tons C.

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