Moisture Content and Absorption Levels of Carbon Dioxide in *Binuang Bini* (*Octomeles sumatrana* Miq) Trees For Climate Change Management

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Abstract

*Binuang bini* (*Octomeles sumatrana* Miq) is a fast-growing tree with numerous economic benefits, such as the provision of wood for carpentry purposes, building boards, water management, and absorption of carbon dioxide (CO₂). Therefore, this tree species has great potential and needs to be included in Reducing Emission from Deforestation and Forest Degradation (REDD⁺)’s mitigation program to tackle climate change. In its development, REDD⁺ has made it possible to carry out carbon trading in the world. Therefore, countries capable of performing protective functions and carry out reforestation, afforestation, and restoration, have the opportunity to be involved in world carbon trading. This study aims to determine the moisture content and carbon absorption rate of *Binuang bini* trees as a first step to regulate the allometric equation using destructive and laboratory analysis. The results show that the water content in the roots, leaves, as well as the base, middle, and tip of the stem were: 73.69%, 68.39%, 65.59%, 61.22%, and 66.26%, respectively. Furthermore, the sample test results indicate a very close relationship between carbon concentration and absorbance in the O. sumatrana tree with a simple linear regression equation: \[ Y = 0.002X + 0.0593 \quad R = 0.9896. \] Therefore, this regression equation can be used to calculate the carbon concentration sample for the O. sumatrana tree fraction. The carbon content in 3 tree samples with a breast height diameter of 9.24 cm, 10.08 cm, and 11.68 cm was 2.585 kg, 2.913 kg, and 4.654 kg. In addition, the carbon sequestration for each tree diameter per year is 1.581 kg year⁻¹, 1.782 kg year⁻¹ and 2.847 kg year⁻¹, respectively.

Keywords: carbon sequestration, biomass, moisture content, REDD+, climate change

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Introduction

A forest is a large land area dominated by a collection of trees, with different microclimate and vegetation characteristics from its outside of area. According to Duncanson et al. (2010) and Luo et al. (2019), forests are important for the ecosystem due to their production of wood, bamboo, rattan, palm, honey, medicines, essential oils, etc. Besides that, they also have indirect benefits, such as erosion prevention, aesthetic value or natural beauty to be used as a tourist attraction, absorption of carbon (CO₂) elements, and regulating water system (H₂O) (Estornell et al., 2011; Frazer et al., 2011; Singh et al., 2015; Garcia et al., 2018). Today, many forests in the world are damaged due to degradation and deforestation (Zhang et al., 2016). These damages lead to climate change, which is characterized by the emergence of global warming due to the effects of greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCS), perfluorocarbons (PFCS), and sulfur hexafluoride (SF₆) in the atmosphere.

One of the efforts to control climate change is through mitigation and adaptation (Huy et al., 2016). Mitigation activities are inseparable from the Reducing Emission from Deforestation and Forest Degradation (REDD⁺) program. This program is based on respecting individuals, communities, projects, and countries that can reduce greenhouse gas (GHG) emissions produced from forests (Littlefield et al., 2017; Chang et al., 2019). Furthermore, it can reduce GHG emissions at a low cost and within a short period, while reducing poverty and enabling sustainable development. REDD⁺ is one of the most obvious, cheapest, fastest, and mutually beneficial ways to reduce GHG emissions. It is real because approximately a fifth of GHG emissions come from deforestation and forest degradation. In addition, REDD⁺ is also cheap because most forest degradation is only marginally profitable, therefore, it becomes cheaper to reduce GHG emissions from forests than other mitigation instruments. It is fast because large reductions in GHG emissions can be achieved by carrying out policy reforms and other measures that are not dependent on technological innovation. Subsequently, it is mutually beneficial because it has the potential to generate large amounts of income and improve governance. Therefore, it can benefit the poor in developing countries and provide other environmental benefits besides climate (Nurtjahjavilasa et al., 2013).

Although REDD⁺ is conceptually and mutually beneficial to the economy, its implementation is quite complicated. The measurement, reporting, and verification (MRV) system is basic and there is a need of significant requirement for implementing the REDD⁺ program using
Data and information on carbon stocks in forest biomass and their spatial changes are needed to develop strategies for reducing GHG emissions due to deforestation and forest degradation to increase carbon stocks. Therefore, a comprehensive, credible, and verifiable National Carbon Accounting System is needed. One of the first steps in developing this system is carrying out studies on the inventory of tree biomass and volume allometric models to obtain references to allometric models suitable for specific conditions in Indonesia. In connection with this, a monograph of various allometric models for estimating tree biomass in various forest ecosystem types has been prepared in Indonesia (Mardiatmoko et al., 2020). However, the biomass and volume allometries of the O. sumatrana tree were not available in the monograph (Krisnawati et al., 2012). Therefore, this study seeks to determine the absorption rate of CO₂ and H₂O as well as the density value of O. sumatrana trees. The results from this research are expected to complement existing data and information on carbon stocks in forest biomass for addressing climate change (Quegan et al., 2019).

The O. sumatrana is a tree species from the Datiscaceae family and grows on mineral soils with an altitude of 0–600 m above sea level. The tree has a maximum height of 45 m with a trunk diameter of 30 cm or more and a fiber length of 1.536 m (Suhartati et al., 2012). In Indonesia, it has several regional names such as binuang, benuwang, binuang male (Sumatera), benuang bini, benuang bini (Kalimantan), winuang, wenuang, benua motutu (Sulawesi), palaka, senao, walada (Makassar), buwar, kijare, jare (Papua). According to Martawijaya et al. (2005), O. sumatrana trees are distributed in Aceh, West Sumatera, South Sumatera, Sulawesi, Maluku, North Maluku, and Papua. During the plywood industry development in Maluku and North Maluku from 1990-2000, O. sumatrana was exploited as a significant raw material source for ply mills in both regions. Furthermore, numerous studies have been conducted to determine the physical and mechanical properties of the tree and insect pests of binuang because these plants are fast-growing and possess various advantages for the timber industry and planted forest development. There are many aspects of O. sumatrana that have been studied as described above, however, due to the lack of biomass data, this tree species is an option in this study.

Methods

Research location A sampling of binuang bini (O. sumatrana) for this research was conducted in Wari Ino Village, Tobelo District, Halmahera Regency, North Maluku Province. Physical properties, water content, and specific
Data collection and analysis

The early stages of field observation for sample determination of *O. sumatrana* were examined through laboratory analysis using three sample trees with a diameter at breast height (d.b.h) of 9.24 cm, 10.08 cm, and 11.68 cm and consecutive branch-free rods of 3 m, 3.5 m, and 3.5 m, respectively obtained from the City of Tobelo. Their moisture content and biomass were determined by taking the root components, stems, twigs, leaves as samples with American Standard Testing Material (ASTM D143, 1994; Kailola et al., 2019) and measuring the wet weight. Furthermore, it was inserted into the oven-dry kiln at a temperature of 100 ± 3 °C until it was constant before obtaining the dry weight.

The formula for calculating biomass is shown in Equation [1] (Brown & Iverson, 1992).

\[
\text{Total biomass (total weight) = } W_v + W_b + W_l + W_t
\]

Note: \( W_v = \text{stem biomass with formula as shown in Equation [1]} \), \( W_b = \text{branch biomass with formula as shown in Equation [2]} \), \( W_l = \text{leaf biomass with formula as shown in Equation [3]} \), \( W_t = \text{root biomass with formula as shown in Equation [4]} \).

Determination of carbon content with the spectrophotometer

The carbon content is measured using the Walkley & Black methods (Walkley & Black, 1934) in the spectrophotometer with the stages of carbon analysis activities are as follows:

1. Moisture content measurements: This comprises weighing dry disc, placement of 1 g (BBSS) of plant organ sample powder into the disc, measuring the disc and wet weight of the powdered sample (BC + Bbss), importation of disc and plant organ powder (BC + Bbss) into the oven at temperatures of 103 ± 2 °C, and weighing and recording every decrease in weight until it is constant. It also consists of weighing and recording the disc and powder sample (BC + Bkss). Calculation of water weight was performed using the following formula as shown in Equation [6].

\[
\text{BA (g)} = (\text{BC + Bbss}) - (\text{BC + Bkss}) \quad [6]
\]

2. Analysis of carbon was conducted with a balance of air-dried organ powder samples of 0.025 g (qualified 40 mesh) and weighed in a clean and dry watch glass. Powder samples were also placed in a 50 ml volumetric flask, with an addition of 2.5 ml \( \text{K}_2\text{Cr}_2\text{O}_7 \) 1 N using a pipette, and vigorously shaken. Consecutively, concentration 5 ml of \( \text{H}_2\text{SO}_4 \) was added to the solution, which was whisked in a flat, rotated (extraction process), and cooled for 30 minutes. The obtained solution was added to 50ml of ion-free water to fit the size. The sample solution was left for 1 day after which a clear measurement of the absorption of the solution was carried out with a spectrophotometer at a wavelength of 561 nm. Furthermore, comparisons were made with standard 0 and 250 ppm C. For the standard containing 250 ppm C, 2.5 ml solution of 5,000 ppm C was added into the volumetric flask of 50 ml using a pipette. In addition, 2.5 ml solution of \( \text{K}_2\text{Cr}_2\text{O}_7 \) and 5 ml \( \text{H}_2\text{SO}_4 \) were used as the workmanship in the treatment of samples, with Blanko used as a standard at 0 ppm C.

Results and Discussion

The tree of *O. sumatrana* absorption rate of CO₂ and H₂O

Results based on the level of absorption of water (H2O), through the oven method and carbon dioxide (CO2) by the spectrophotometric method shows that the roots' moisture content was higher than the base, middle, tip, and leaves (Table 1). Furthermore, Figure 2 shows the diagram of moisture content.

These results are in line with the research carried out by (Silloy, 1983; Kailola, 2006) who stated that the base has greater moisture content than the stem's middle and tip. This is due to cell wall formation occurring at the base, middle, and end of the stem. The cell walls at the base are thicker than the middle and ends, therefore, it has an impact on bound water, which occupies more of the cell walls. This is in line with the photosynthetic process that occurs in leaves, therefore, the water absorption rate at the end of the stem is higher than the middle.

The specific gravity of *O. sumatrana* using the klin over method on the roots was higher than the stem and branches (Table 2). According to Nuraeni et al. (2016) and Apriani and Rahmayanri (2009), the *O. sumatrana* wood used as raw material for pulp has a specific gravity of 0.160.48, a
cellulose content of 49.1%, 23.2% of lignin, and a fiber length of 1.427 U. This shows that the specific gravity at the root is higher than the stem and branch, with the difference influenced by the constituent components of the cell wall, namely the accumulation of extractive substances at the base which causes the cell walls to be filled with these extractive substances (Khan et al., 2020). The results of carbon testing with a spectrophotometer are shown in Table 3.

Table 4 is a sample test that represents each section according to the code, absorbance, and concentration. The percentages of the test results and carbon content are shown in Table 5, with examples illustrated in Figure 3. The results indicate a close relationship between carbon concentration and O. sumatrana wood's absorbance, as shown in Table 5 and Figure 4. Therefore, based on laboratory analysis results on carbon concentration and absorbance, there is a very close relationship, as shown in Figure 5 with a simple regression equation: \( Y = 0.002X + 0.0593 \) with an \( R^2 \) value of 0.9896. This means that an increase in carbon concentration leads to a rise in the O. sumatrana tree's absorbance. Therefore, this regression equation can be used in calculating the carbon concentration sample for the O. sumatrana tree fraction.

The calculation result of carbon stock in the roots, stems, branches, and leaves of the first tree is 3.93%, 19.32%, 2.67%, and 15.29%, respectively. In the second tree, they are 8.01%, 20.67%, 2.35% and 15.52%, while in the third, they are 1.75%, 20.60%, 5.58% and 16.64%. The average calculation of the carbon content percentage is 4.56% (roots), 20.20% (stems), 3.53% (branches), and 15.815% (leaves) (Table 6). This shows that the highest percentage of carbon content is found in the stem, followed by the leaves, roots, and branches.

### Table 2 Specific gravity of O. sumatrana for a section of stem, branch, and root

| Section   | Specific gravity (g cm\(^{-3}\)) |
|-----------|----------------------------------|
| Stem      | 0.11                             |
| Branch    | 0.11                             |
| Root      | 0.32                             |

### Table 3 Average carbon content of O. sumatrana wood species

| Sample   | Absorbance | Weight (mg) | Carbon concentration (ppm) | Carbon content (%) | Weight carbon content (g) |
|----------|------------|-------------|----------------------------|--------------------|--------------------------|
| Leaf     | 0.2207     | 0.0255      | 80.6833                    | 15.81              | 0.0040                   |
| Branch   | 0.0953     | 0.0255      | 3.5325                     | 3.53               | 0.0009                   |
| Stem tip | 0.1217     | 0.0255      | 31.1833                    | 6.14               | 0.0015                   |
| Stem middle | 0.1243   | 0.0255      | 23.1833                    | 4.56               | 0.0012                   |
| Stem base | 0.1370     | 0.0255      | 38.8000                    | 7.64               | 0.0019                   |
| Root     | 0.1057     | 0.0255      | 23.1833                    | 4.56               | 0.0012                   |

### Table 4 The carbon content (%) and carbon content (g) of each section of O. sumatrana wood were based on the sample weight test (mg) in the laboratory using spectrophotometry

| Sample   | Absorbance | Concentration (ppm) | Weight (mg) | Carbon content (%) | Weight carbon content (g) |
|----------|------------|---------------------|-------------|--------------------|--------------------------|
| DB1      | 0.214      | 77.35               | 25.3        | 15.29              | 0.0039                   |
| DB2      | 0.217      | 78.85               | 25.4        | 15.52              | 0.0039                   |
| DB3      | 0.231      | 85.85               | 25.8        | 16.64              | 0.0043                   |
| PB1      | 0.123      | 31.85               | 25.9        | 6.15               | 0.0016                   |
| PB2      | 0.170      | 55.35               | 25.0        | 11.07              | 0.0028                   |
| PB3      | 0.118      | 29.35               | 25.8        | 5.69               | 0.0015                   |
| AB1      | 0.100      | 20.35               | 25.9        | 3.93               | 0.0010                   |
| AB3      | 0.077      | 8.85                | 25.3        | 1.75               | 0.0004                   |
| AB2      | 0.140      | 40.35               | 25.2        | 8.01               | 0.0020                   |
| UB1      | 0.124      | 32.35               | 25.1        | 6.44               | 0.0016                   |
| UB2      | 0.119      | 29.85               | 25.6        | 5.83               | 0.0015                   |
| UB3      | 0.122      | 31.35               | 25.5        | 6.15               | 0.0016                   |
| CB1      | 0.087      | 13.85               | 25.9        | 2.67               | 0.0007                   |
| CB2      | 0.083      | 11.85               | 25.2        | 2.35               | 0.0006                   |
| CB3      | 0.116      | 28.35               | 25.4        | 5.58               | 0.0014                   |
| TB1      | 0.128      | 34.35               | 25.5        | 6.73               | 0.0017                   |
| TB2      | 0.097      | 18.85               | 25.0        | 3.77               | 0.0009                   |
| TB3      | 0.148      | 44.35               | 25.3        | 8.76               | 0.0022                   |

Note: DB = bimuang leaf, PB = bimuang stem base, AB = bimuang root, UB = bimuang stem tip, CB = bimuang branch, TB = bimuang stem middle.
The calculation results in Table 7 above show that the first tree has a d.b.h of 9.24 cm with a height, biomass content, carbon storage, and absorption rates of 8.5 m, 3.718 kg, 1.386 kg, and 5.088 kg. The total carbon sequestration of the first tree is 9.487 kg, with an annual absorption rate of 1.581 kg year\(^{-1}\). The second tree has a d.b.h of 10.08 cm, with a height, biomass content, carbon storage, and absorption rates of 8 m, 4.103 kg, 1.581 kg, and 5.803 kg. The second tree's total carbon sequestration is 10.689 kg, with an annual carbon sequestration rate of 1.782 kg year\(^{-1}\). The third tree with a d.b.h of 11.68 cm, with a height, biomass content, carbon storage, and absorption rates of 6 m, 3.718 kg, 1.592 kg, and 5.843 kg. The total third carbon sequestration is 17.079 kg, with an annual carbon sequestration rate of 2.847 kg year\(^{-1}\).

The average carbon content in species *O. sumatrana* in the stem, branches, roots, and leaves was 1.52 kg (45%), 0.26 kg (8%), 0.85 kg (25%), and 0.76 kg (22%), respectively. Therefore, the carbon stock content of *O. sumatrana* when sorted from the largest to smallest are stems, leaves, roots, and branches. This is in line with the research on carbon stocks of conventional and low-impact logging logged-over forests in East Kalimantan, which stated that the largest proportion of stored carbon is 74% found in stem (Indrajaya, 2012). The definition of dry weight biomass of organic matter living above the ground, including stems, stumps, branches, bark, seeds, and wood materials, leaves per unit area expressed in years per hectare (Quegan et al., 2019).

According to Hairiah et al. (2001), the calculation results of carbon biomass using the spectophotometry with the allometric model \(\text{AGB} = (\pi/40)\rho_{\text{dbh}}h \exp (-2,699 + 0,976\ln \rho_{\text{dbh}}h)\) (Ketterings et al., 2001), and modified \(\text{AGB} = \exp (-2,699 + 0.976n \text{[dbh]})\) (Chave et al., 2014). Therefore, the allometric calculation results from (Hairiah et al., 2001) are compared with the calculation results from Table 7.

### Table 5 Carbon content of *O. sumatrana*

| Glucose concentration (ppm) | Carbon concentration | Absorbance standard |
|-----------------------------|----------------------|---------------------|
| 25                          | 10                   | 0.067               |
| 50                          | 20                   | 0.112               |
| 100                         | 40                   | 0.135               |
| 150                         | 60                   | 0.183               |
| 200                         | 80                   | 0.227               |
| 250                         | 100                  | 0.256               |
| 300                         | 120                  | 0.296               |

### Table 6 Calculation of carbon content for each tree, in the roots, stems, and leaves

| Tree  | Leaf | Branch | Stem middle | Stem tip | Stem base | Root | Total |
|-------|------|--------|-------------|----------|-----------|------|-------|
| 1     | 15.29| 2.67   | 6.73        | 6.44     | 6.15      | 3.93 | 37.29 |
| 2     | 15.52| 2.35   | 3.77        | 5.83     | 11.07     | 8.01 | 38.54 |
| 3     | 16.64| 5.58   | 8.76        | 6.15     | 5.69      | 1.75 | 42.82 |
| Total | 47.45| 10.61  | 19.27       | 18.42    | 22.91     | 13.68| 118.65|
| Average| 15.81| 3.53   | 6.42        | 6.14     | 7.63      | 4.56 | 39.55 |

### Table 7 Carbon content of each section of the *O. sumatrana* tree

| No | Section | Specific gravity | Weight (g) | Biomass | Carbon | Carbon absorption |
|----|---------|-----------------|------------|---------|--------|-------------------|
|    |         |                 |            | g kg    | g kg   | g kg              |
| 1  | Stem    | 0.11            | 33,800     | 3,718   | 3,718  | 1,386.44          |
| 2  | Branch  | 0.11            | 5,400      | 0.594   | 0.594  | 221.50            |
| 3  | Root    | 0.32            | 2,500      | 800     | 0.800  | 298.32            |
| 4  | Leaf    | 0.26            | 7,000      | 1,820   | 1.820  | 678.68            |
| Total |       |                 |            | 693.93  | 6.932  | 2,584.94          |
|      | Total without root |       |            | 5,112   | 5,112  | 1,906.26          |

| No | Section | Specific gravity | Weight (g) | Biomass | Carbon | Carbon absorption |
|----|---------|-----------------|------------|---------|--------|-------------------|
|    |         |                 |            | g kg    | g kg   | g kg              |
| 1  | Stem    | 0.11            | 37,300     | 103     | 103    | 1,581.29          |
| 2  | Branch  | 0.11            | 3,400      | 0.374   | 0.374  | 144.14            |
| 3  | Root    | 0.32            | 5,400      | 1,728   | 1.728  | 665.97            |
| 4  | Leaf    | 0.26            | 5,200      | 1,352   | 1.352  | 521.06            |
| Total |       |                 |            | 7,557   | 7,557  | 2,912.48          |
|      | Total without root |       |            | 6,205   | 6,205  | 2,391.41          |

| No | Section | Specific gravity | Weight (g) | Biomass | Carbon | Carbon absorption |
|----|---------|-----------------|------------|---------|--------|-------------------|
|    |         |                 |            | g kg    | g kg   | g kg              |
| 1  | Stem    | 0.11            | 33,800     | 3,718   | 3,718  | 1,592.05          |
| 2  | Branch  | 0.11            | 9,000      | 0.990   | 0.990  | 423.92            |
| 3  | Root    | 0.32            | 9,500      | 3,040   | 3,040  | 1,301.73          |
| 4  | Leaf    | 0.26            | 12,000     | 3,120   | 3,120  | 1,335.98          |
| Total |       |                 |            | 10,868  | 10,868 | 4,653.68          |
|      | Total without root |       |            | 7,748   | 7,748  | 3,317.69          |
al., 2001) are similar to the results in Table 8. This is because the biomass content of a tree is strongly influenced by its diameter and site index.

According to Hairiah and Rahayu (2007), the amount of C stored between lands tends to vary depending on the diversity and density of existing plants, soil types, and management methods. Chairul et al. (2016) stated that these variations are also influenced by the types of forest, vegetation, climate, rainfall, topography, and other biophysical conditions, including the applied silvicultural and forest management techniques. Stas et al. (2017) reported that forest structure, age, composition, density, and quality of the growing site affect the amount of biomass produced. The highest correlation was found when combining tree volume and basic area, with the $R^2$ value of the correlation coefficient obtained at 0.9714, which indicates a very strong correlation between volume and basic area. Chave et al. (2014) also state that the composition and structure of the forest stands affect carbon storage, with a slight difference in the calculation of carbon biomass from

Figure 3 The test results of the average carbon content of the O. sumatrana wood research sample using spectrophotometry.

Figure 4 Analysis of spectrophotometry.

Figure 5 Carbon concentration.

$y = 0.002X + 0.0593$

$R^2 = 0.9896$
the allometric equation of statement (Hairiah et al., 2001), which confirmed that the allometric equation is local. Therefore, it cannot be applied to all places. The difference is due to variations in habitat conditions such as stand density, agro-climatic conditions including rainfall, humidity, soil fertility, and intensity of irradiation that contribute to _O. sumatrana_ trees’ growth, according to opinion of Lugo and Brown (1986) and Ravanini et al. (2020) that biomass is related to the proportion of wood density, the cross-sectional area of the trunk, and total height.

**Conclusion**

The moisture content of _O. sumatrana_ starting from the stem base, middle, and tip, as well as the roots and leaves, were 65.59%, 61.22%, 66.26%, 73.69%, 68.39%, respectively. The carbon content in 3 tree samples with the diameter at breast height of 9.24 cm, 10.08 cm, and 11.68 cm was 2.585 kg, 2.912 kg, and 4.654 kg, respectively. Furthermore, each diameter per year’s carbon absorption was 1.581 kg year⁻¹, 1.782 kg year⁻¹, and 2.847 kg year⁻¹. Therefore, based on the results of the sample test, there is a very close relationship between carbon concentration and absorbance in the _O. sumatrana_ tree with a simple linear regression equation: \( Y = 0.002X + 0.0593 \) at an \( R^2 \) value of 0.9896.

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**Table 8 Calculation results of carbon biomass according to various allometric equations**

| No | Dbh (cm) | Height (m) | Specific gravity | Ketterings et al. (2001) | Modified Chave et al. (2014) | Hairiah et al. (2001) | Method of Spectrophotometry |
|----|---------|------------|------------------|------------------------|-----------------------------|------------------------|---------------------------|
| 1  | 9.24    | 8.5        | 0.11             | 2.760                  | 4.834                       | 6.267                  | 5.112                     |
| 2  | 10.08   | 8.0        | 0.11             | 3.414                  | 5.400                       | 7.019                  | 6.025                     |
| 3  | 11.68   | 6.0        | 0.11             | 4.891                  | 5.437                       | 7.068                  | 7.748                     |
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