Analysis of biomass and carbon potential on eucalyptus stand in industrial plantation forest, North Sumatra, Indonesia

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Abstract. Forests degradation causes forestry businesses to be economically less profitable than other agribusiness commodities, thus triggering the policies of governments that plan to convert natural forests to other uses, such as industrial forest plantations. The purpose of this study was to determine the potential of biomass and carbon stores in eucalyptus stands in industrial plantation forests, North Sumatra, Indonesia. This research was carried out in Industrial Plantation Forest of Toba Pulp Lestari Areas, Toba Samosir, North Sumatra, Indonesia. Analysis of carbon content was carried out at the Laboratory of Chemical Products of Forest, Faculty of Forestry, Bogor Agricultural University. Preparation of research permanent sample plots (PSP) was carried out using the nesting plot method. The research permanent sample plot (PSP) made was three plots. Analysis of biomass and carbon was done by the destructive method felling of sample trees and measuring their diameter, length, and wet weight. To find out the eucalyptus carbon content, we took the samples from each part of the plant and tested in a laboratory. The results showed that the average carbon content of Eucalyptus stands on the main stem was 34.66%, in the branch was 25.75%, and in the leaf was 22.46%, respectively. This research found that the selected allometric equations for estimating the carbon stock of eucalyptus stands was $W = -174.670 + 0.347D^2 + 8.180H$ and $C = -55.668 + 0.085D^2 + 2.947H$ ($W=\text{biomass}; \ C=\text{carbon}; \ D=\text{diameter at breast height}; \ H=\text{height}$). This research indicated that the carbon potential of eucalyptus stands was 71.05 tons/ha and 26.23 tons C/ha.

1. Introduction
Sustainable forests is a large part of the world's biodiversity and provides a variety of environmental services that are fundamental to the well-being of all life on this earth. Forests help to stabilize the soil, prevent erosion, and maintain a clean water supply. Forests also play a role in reducing greenhouse gases that trigger global climate change by capturing carbon in the atmosphere [1].

The process of forest harvesting will cause the death of the felled trees and logging damage to the surrounding small trees due to logging, skidding and skid trail construction by the tractor. Without implementing Reduced Impact Logging (RIL), the damage of residual stand caused by logging becomes very large [2]. Automatically, the emission level due to decomposition becomes greater [3].

If selective logging is applied, and the forest is allowed to recover for years, then there is still an opportunity for the forest to re-absorb CO2 released back to the earth's surface. However, if there is deforestation due to illegal logging, forest fires, encroachment or land conversion, then the absorption of carbon stocks becomes unbalanced again. As it is happening now, degradation and deforestation of forests are not balanced with the rate of natural forest regeneration. It causes a very high rate of deforestation, which was estimated at more than 1 million hectares per year [4] or by 0.7 million hectares...
Eucalyptus is one type of choices in the development of industrial plantations, as a supply of raw materials for the pulp and paper industry. Eucalyptus is a type of fast growing plant that can be harvested at the age of seven. The rapid growth of eucalyptus is an opportunity to increase carbon uptake more quickly.

The purpose of this study was to determine the carbon content in each part of IND Eucalyptus plant 65 age five years in Industrial Plantation Forest (HTI) PT. Toba Pulp Lestari, Sector Aek Nauli.

2. Materials and method
This research was carried out in Industrial Plantation Forest (HTI) PT. Toba Pulp Lestari, Tbk, Aek Nauli Sector, North Sumatra. The research was carried out in two phases of activity, the first stage was data collection in the field and the second stage was an analysis of carbon content conducted at the Laboratory of Chemical Products of Forestry, Faculty of Forestry, Bogor Agricultural University. The research was held from September 2017 to December 2017.

The measurement of important tree parameters was carried out in each permanent sample plot (PSP) with the pathway method. The plot form commonly used in measuring carbon content was a circle. The sample plot for the study was made as many as three plots because in the need for monitoring, three plots or plots needed were selected for each zone where the observation/measurement of tree diameter was carried out [6].

Each PSP was made with a diameter of 22.56 m with a distance between sample plots of 100 m. The placement of the plot location was done by Random Sampling. While the sampling intensity (IS) used for plantations with the five year age class in this study was 2%. The sampling intensity aims to determine the number of samples taken so that the data produced were normal [7].

2.1. Sample of tree selection
After activities on each plot were inventoried, the next stage was the selection and retrieval of sample trees carried out in the following ways: (1). Selection of sample trees in each plot with healthy criteria and having an average diameter size that is considered to represent the trees in the research sample plot; (2). The number of sample trees was calculated based on the sample plot area, spacing, population number per plot, and sampling intensity.

Sample tree felling was carried out in accordance with the logging system at PT. Toba Pulp Lestari, Aek Nauli Sector because the exact sampling was done at the time of logging. The parts of the tree fraction are the base, middle, and end of the stem. Stems were separated from other tree organs, without exfoliation. The leaves were pruned first using scissors to separate from the twigs after the tree had collapsed; (3). Weighing the wet weight. Weighing is done to determine the total wet weight (BBT). Weighing includes stems, twigs, and leaves; and (4). Sampling, samples are needed to determine the water content and carbon content through laboratory testing. Biomass allometric model of Eucalyptus is used to estimate carbon biomass or carbon mass [8].

3. Results and discussion
3.1. Wet weight of eucalyptus sample plant
Based on the results of the weight measurement of the compiler components of IND 65 age 5 five years old of Eucalyptus in fresh conditions including stems, twigs, and leaves, the average overall weight was 221.96 kg per stand of IND 65 years old Eucalyptus. The results of the measurement of the wet weight of plants, for example is the IND age 5 years old of Eucalyptus, are presented in table 1.

Based on table 1 shows that the wet weight of each IND Eucalyptus stand aged five years is different and has a high enough weight, especially in the wet weight of the stem. It happened because Eucalyptus IND 65 trees were logged in rainy season and tree trunks contained much water. Wet weight in the branches/twigs also experienced a fairly high weight because the first branch in the tree was in the tree diameter > 5 cm. Leaf wet weight in this study was in the range of 1-7 kg, leaves of IND 65 Eucalyptus did not have a high weight, this was due to the presence of disease in the Aek Nauli Sector HTI which attacked the leaves and caused many leaves to fall.
The highest wet weight was found in plot 3 of the third replication with a diameter of 16.94 cm, which is equal to 287.5 kg. Whereas the lowest wet weight was found in the 1st replication plot II with a diameter of 14.14 cm, which is equal to 146.5 kg. In the plant parts of the IND 65-year-old Eucalyptus stand, the highest wet weight was found on the stem, then the twigs and leaves.

Table 1. Wet weight of Eucalyptus age five years.

| Plot | Sample | Total height (m) | High branch free (m) | Diameter at breast height (cm) | Wet weight (kg) | Total of wet weight (kg) |
|------|--------|------------------|----------------------|--------------------------------|-----------------|-------------------------|
| 1    | 1      | 25.14            | 19.50                | 16.71                          | 248.4           | 20.1                    | 3.9                    | 272.4                 |
| 1    | 2      | 24.75            | 19.12                | 17.00                          | 245.1           | 17.2                    | 3.7                    | 266.0                 |
| 1    | 3      | 22.36            | 18.33                | 14.39                          | 156.8           | 6.4                     | 1.6                    | 164.8                 |
| 1    | 4      | 20.4             | 17.42                | 14.14                          | 137.0           | 8.1                     | 1.4                    | 146.5                 |
| 1    | 5      | 24.50            | 17.20                | 15.66                          | 198.2           | 21.4                    | 6.7                    | 226.3                 |
| 1    | 6      | 25.87            | 18.80                | 16.94                          | 25.0            | 26.0                    | 4.5                    | 287.5                 |
| 1    | 7      | 22.90            | 18.20                | 15.09                          | 193.0           | 14.5                    | 7.2                    | 214.7                 |
| 1    | 8      | 23.30            | 18.49                | 14.71                          | 183.3           | 12.3                    | 5.1                    | 200.7                 |
| 1    | 9      | 23.50            | 18.38                | 15.95                          | 201.6           | 10.8                    | 6.4                    | 218.8                 |
| Average |       | 23.63            | 18.38                | 15.62                          | 202.26          | 15.2                    | 4.5                    | 221.9                 |

3.2. Plant water content

Water in plant growth plays an important role in the need to transport nutrients from the roots to the leaves, and throughout the plant's body, water also functions to process the transpiration of plants. Moisture is a percentage of the amount of water contained in a plant. Water content is the weight of water expressed in percent of water to the dry weight of the furnace (BKT). The test sample used in this study was a dry sample test. The results of testing the water content in stands for IND 5-year-old Eucalyptus are presented in table 2.

Table 2. Water content (%) in each part of five-year Eucalyptus stands based on a sample plot.

| Plot | Sample | Water content (%) | Stem | Branch | Leaf |
|------|--------|-------------------|------|--------|------|
| 1    | 1      | 100.14            | 94.37|        | 114.68|
| 1    | 2      | 131.00            | 107.27|        | 170.98|
| 1    | 3      | 130.27            | 109.24|        | 181.30|
| 2    | 4      | 113.84            | 49.68|        | 136.02|
| 2    | 5      | 124.67            | 39.97|        | 214.06|
| 2    | 6      | 93.66             | 98.84|        | 177.82|
| 3    | 7      | 124.58            | 131.84|       | 150.02|
| 3    | 8      | 119.14            | 115.26|       | 114.85|
| 3    | 9      | 119.70            | 98.85|        | 140.72|
| Average |       | 117.44            | 93.92|        | 155.60|

Table 2 shows that leaves of Eucalyptus age 5 years were the highest part of the water content, which ranged between 114.68% - 214.06% while the smallest water content was found in the twigs which was between 39.97% - 131.84%. It is in accordance with [9] who stated that the largest water content in leaves was 90.61%. According to Amira [10], the leaves have high water content because they are photosynthetic units which generally have cell cavities filled with water and mineral nutrients. Based on table 3, the water content in the stem and leaves section exceeded 100%, it is due to the calculation of the water content in this study using water content based on a dry basis.
3.3. Volatile substances

Volatile substance levels indicate the content of volatile substances and are lost at 9500°C heating which is composed of aliphatic, terpene and phenolic compounds. The average levels of flying substances in the IND 5-year-old of Eucalyptus stands are presented in table 3.

| Plot | Sample | Volatile Substance (%) |
|------|--------|------------------------|
|      |        | Stem | Branch | Leaf |
| 1    | 1      | 65.87 | 76.80 | 75.37 |
|      | 2      | 65.69 | 75.01 | 74.58 |
|      | 3      | 65.79 | 71.75 | 70.80 |
| 2    | 4      | 65.60 | 72.35 | 72.78 |
|      | 5      | 66.68 | 72.13 | 69.08 |
|      | 6      | 64.18 | 73.63 | 72.51 |
| 3    | 7      | 61.08 | 74.59 | 75.81 |
|      | 8      | 62.42 | 72.44 | 73.93 |
|      | 9      | 63.71 | 70.01 | 73.48 |
| Average |       | 64.55 | 73.14 | 73.19 |

Based on table 3, the highest levels of volatile substances were found in the leaves that was equal to 73.19% while the smallest levels of flying substances were found in the plant part, namely the stem that was 64.55%. It is in accordance with [11] who conducted research on rubber stands where the lowest flying substance content was at 61.70% and the highest in the leaves was 74.99% and based on [12] resulted that there were differences of secondary metabolites from binahong plant. It is due to the fact that the leaves are composed of chlorophyll with high molecular weights, which increase the ash content in the carbonization process.

3.4. Ash content

The results of ash content in the Eucalyptus stands are presented in table 4. The ash content in principle is to determine the amount of ash left behind (minerals that cannot evaporate) by burning powders into ash. The ash is the inorganic substances left after water, and organic matter has been exhausted at high-temperature heating. Ash content is the number of metal oxides remaining in high heating, which consists of minerals bound strongly to charcoal such as calcium, potassium, and magnesium [13].

| Plot | Sample | Ash Content (%) |
|------|--------|----------------|
|      |        | Stem | Branch | Leaf |
| 1    | 1      | 1.78 | 1.75  | 3.77 |
|      | 2      | 1.04 | 1.51  | 5.72 |
|      | 3      | 0.35 | 0.61  | 5.41 |
| 2    | 4      | 0.46 | 0.66  | 5.38 |
|      | 5      | 0.53 | 0.82  | 4.38 |
|      | 6      | 0.76 | 0.86  | 3.66 |
| 3    | 7      | 0.74 | 0.90  | 3.81 |
|      | 8      | 0.81 | 1.08  | 4.16 |
|      | 9      | 0.48 | 1.29  | 3.21 |
| Average |       | 0.77 | 1.05  | 4.38 |

Table 4 shows that the average value of the largest ash content was found in the leaves of 4.38% while the average value of the smallest ash content was in the stem that was equal to 0.77%. The highest percentage of ash content was found in leaves because the leaves contain more inorganic material than
the other parts and are as part of photosynthesis and xylem transport water and minerals to the leaves.

3.5. Carbon content
Carbon is one of the organic ingredients that make up a plant substance. Carbon content measurements of Eucalyptus IND 65 plant samples obtained from laboratory analysis were a reduction of 100% of the levels of flying substances and ash content. The results of measurements of the carbon content of samples of Eucalyptus IND 65 plants showed that each part of E 65 Eucalyptus plants had different average percentage of carbon content as presented in table 5.

| Plot | Sample | Carbon content (%) | Stem | Branch | Leaf |
|------|--------|--------------------|------|--------|------|
| 1    | 1      | 32.36              | 21.45| 20.86  |
|      | 2      | 33.27              | 23.48| 19.70  |
|      | 3      | 33.86              | 27.64| 23.79  |
|      | 4      | 33.94              | 26.99| 21.84  |
|      | 5      | 32.79              | 27.05| 26.54  |
|      | 6      | 35.06              | 25.51| 23.83  |
|      | 7      | 38.14              | 24.51| 20.38  |
|      | 8      | 36.77              | 26.48| 21.91  |
|      | 9      | 35.81              | 28.70| 23.31  |
| Average | 34.66  | 25.75              | 22.46|

Based on table 6, it can be seen that the highest average carbon content in the plant part of the IND 65-year-old Eucalyptus stands was in the stem, which was 34.66%, while the lowest average carbon content was in the leaf section, which was equal to 22.46%. The results of this carbon content research are following [14] research on Agathis damara, Pinus merkusii [4] and Toona surenii [15]. The amount of carbon content depends on ash content and levels of flying substances where the higher the levels of flying substances and ash content, the lower the carbon content or inversely.

| Plot | Sample | Biomass (kg) | Total of biomass (kg) | Stem | Branch | Leaf |
|------|--------|--------------|-----------------------|------|--------|------|
| 1    | 1      | 124.11       | 136.27                | 10.34| 1.81   |
|      | 2      | 106.10       | 115.76                | 8.29 | 1.36   |
|      | 3      | 68.09        | 71.72                 | 3.05 | 0.56   |
|      | 4      | 64.06        | 70.07                 | 5.41 | 0.59   |
|      | 5      | 88.21        | 105.64                | 15.28| 2.13   |
|      | 6      | 132.70       | 147.40                | 13.07| 1.61   |
|      | 7      | 85.93        | 95.07                 | 6.25 | 2.87   |
|      | 8      | 83.64        | 91.73                 | 5.71 | 2.37   |
|      | 9      | 91.76        | 99.85                 | 5.43 | 2.65   |
| Average | 93.84  | 103.72       |                       | 8.09 | 1.77   |

3.6. Biomass of eucalyptus stands
Biomass is the total amount of organic matter living above the soil surface in a tree which is expressed in oven dry weight per unit area. The amount of carbon stored in a tree or forest can be calculated if the amount of biomass or living tissue of plants in the forest is calculated and a conversion factor is applied [15, 16].

Based on table 7, Eucalyptus stands have the largest component of biomass constituent which was found in the stem of 93.84 kg, and the smallest biomass constituent component was found in the leaves,
which was 1.77 kg. Based on [17], the biggest biomass yield was in the stem, 210.05 kg, and the lowest was in the leaf section of 1.89 kg. This significant difference in numbers is caused by different types of plants, diameter, height, and place of growing plants.

| Plot | Sample | Carbon stocks (kg) | Total carbon stocks (kg) |
|------|--------|--------------------|--------------------------|
|      |        | Stems  | Branch | Leaf  |        |
| 1    | 1      | 40.12  | 2.21   | 0.37  | 42.71  |
|      | 2      | 35.28  | 1.94   | 0.26  | 37.50  |
|      | 3      | 23.04  | 0.84   | 0.13  | 24.01  |
| 2    | 4      | 21.73  | 1.45   | 0.12  | 23.32  |
|      | 5      | 28.90  | 4.13   | 0.56  | 33.60  |
|      | 6      | 46.51  | 3.33   | 0.38  | 50.22  |
| 3    | 7      | 32.79  | 1.53   | 0.58  | 34.90  |
|      | 8      | 30.73  | 1.51   | 0.51  | 32.76  |
|      | 9      | 32.84  | 1.55   | 0.61  | 35.01  |
|      | Average| 32.44  | 2.05   | 0.39  | 34.89  |

The results showed that there were differences in carbon mass in each part of the stand. The largest carbon mass was found in the stem of 32.44 kg, and the lowest was in the leaf, which was 0.39 kg. [17] who conducted research on rubber stands on smallholder plantations in Taran Village, Kee. Silindak showed differences in carbon mass in each plant fraction where the largest carbon mass in the stem was 10.81% and the lowest in the leaves was 1.40%. He stated that the higher the water content, the lower the percentage of biomass. In other words, the water content is inversely proportional with the percentage of biomass.

3.7. Allometric model

An allometric model is a model that links the dimensions of a plant with the value of biomass plant. Each different plant will have a different pattern to form this allometric model. The destructive 5-year-old IND 65 Eucalyptus sampling by cutting down mature trees based on biomass data of 9 examples of Eucalyptus stands has produced allometric equations of biomass and carbon mass. Allometric models that were successfully constructed to estimate biomass and carbon mass of 5-year-old IND Eucalyptus at PT. Toba Pulp Lestari, Aek Nauli Sector, North Sumatra are presented in table 8.

According to [18], estimation of biomass at the tree level using allometric models was carried out by entering estimator variables (diameter at breast height (dbh); tree height (H) into selected biomass allometric models from allometric equations that had been made. It is known that the relationship between W (biomass), D2 (square diameter) and H (total height) has a better level than the allometric relationship between W and D and Hbc (branch free height). The selection of allometric models is best done by testing several models. It can be seen in table 8 that $W = -174.670 + 0.347D^2 + 8.180H$ in the trunk model had the best performance which resulted in standard error (s) of 9.63994, significance of 0.001 and R-Square of 89.9%.

Based on the allometric model selected in this study, it can be managed and calculated based on the dimensions of the crop from the inventory such as diameter (dbh) to obtain data on potential biomass of Eucalyptus in PT. Toba Pulp Lestari, Aek Nauli Sector, North Sumatra. After the calculation results for biomass and carbon stocks in kilograms were obtained, they were converted in tonnes/ha.

The total biomass obtained in this study was in the range of 64.31–82.81 tons/ha with an average of 71.05 tons/ha, while the total mass of carbon obtained in this study was between 23.01–30.55 ton/ha with an average carbon mass obtained was 26.23 tons C / ha. - Suspected factors of influencing the size of carbon stocks are soil fertility, topography, and climatic conditions where this research was conducted, which has low soil fertility and high average of rainfall at 238 mm / month compared to the other three sectors rainfall with the highest is in Aek Nauli Sector, North Sumatra.
Table 8. Allometric models for estimating biomass of each plant part and total biomass from each section of Eucalyptus stands.

| Section  | Allometric models                                                                 | S    | P      | R-Sq (%) |
|----------|-----------------------------------------------------------------------------------|------|--------|----------|
| Stem     | W = 113.050-22.033D+1.326D^3                                                      | 10.31919 | 0.003 | 85.2     |
|          | W = -209.555D^{19.422}                                                          | 9.62384 | 0.000 | 85.0     |
|          | W = -133.223+0.377D^2+5.698H                                                    | 9.11019 | 0.002 | 88.5     |
|          | W = -224.067D^{11.747}H^{5.686}                                                  | 9.23118 | 0.002 | 88.2     |
|          | W = -138.368+0.547D^2+5.339H_{bc}                                                | 9.75527 | 0.002 | 86.8     |
|          | W = -274.491D^{17.001}H_{bc}^{5.590}                                             | 9.74622 | 0.002 | 86.8     |
| Leaf     | W = -209.71+26.985D-0.858D^2                                                     | 0.46536 | 0.013 | 76.5     |
|          | W = -0.913D^{0.172}                                                             | 0.86499 | 0.554 | 5.2      |
|          | W = -4.599-0.012D^2+0.392H                                                      | 0.87613 | 0.579 | 16.7     |
|          | W = -1.831D^{-0.314}H^{0.360}                                                   | 0.88400 | 0.611 | 15.1     |
|          | W = 2.706+0.007D^2-0.145H_{bc}                                                   | 0.93400 | 0.850 | 5.3      |
|          | W = 1.013D^{-2.244}H_{bc}^{-0.166}                                               | 0.92813 | 0.818 | 6.5      |
| Branch   | W = -260.378+32.225D-0.959D^2                                                    | 3.55208 | 0.196 | 41.9     |
|          | W = -27.157D^{-2.257}                                                           | 3.39376 | 0.076 | 38.1     |
|          | W = -36.817-0.018D^2+2.087H                                                     | 3.21796 | 0.108 | 52.3     |
|          | W = -32.483D^{0.560}H^{2.087}                                                   | 3.21874 | 0.109 | 52.3     |
|          | W = 53.246+0.130D^2-4.192H_{bc}                                                  | 2.51273 | 0.025 | 70.9     |
|          | W = 20.854D^{4.047}H_{bc}^{-4.133}                                               | 2.50889 | 0.024 | 71.0     |
| Total of Tree | W = -357.237+37.223D-0.492D^2                                                   | 11.87414 | 0.004 | 84.6     |
|          | W = -237.604D^{21.350}                                                          | 11.00173 | 0.000 | 84.6     |
|          | W = -174.670+0.347D^2+8.180H                                                    | 9.63994 | 0.001 | 89.9     |
|          | W = -258.370D^{10.886}H^{5.137}                                                  | 9.71803 | 0.001 | 89.7     |
|          | W = -82.350+0.684D^2-1.000H_{bc}                                                 | 11.90996 | 0.004 | 84.5     |
|          | W = -252.565D^{21.292}H_{bc}^{1.288}                                             | 11.85400 | 0.004 | 84.7     |

Description: $W =$ biomass (kg); $H =$ total height (cm); $H_{bc} =$ branch free height (cm); R-Sq = determination coefficient; $S =$ standard error; $D =$ diameter at breast height (Dbh) (cm); $P =$ significance

4. Conclusion
Carbon content in parts of eucalyptus was at the stem of 34.66%, in the branch of 25.75%, and in the leaves section of 22.46%. Potential biomass of eucalyptus plants in PT, Toba Pulp Lestari, Tbk, Aek Nauli Sector was 71.05 tons/ha with the best allometric equation was $W = -174.670 + 0.347D^2 + 8$ ($W =$ biomass, $D =$ diameter at breast height, $H =$ total height).

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