Stem Biomass Equation of *Eucalyptus urophylla* S.T. Blake

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ABSTRACT

Eucalyptus urophylla is one of the typical plants of the Province of East Nusa Tenggara, Indonesia whose distribution includes the islands of Timor, Alor, Wetor, Flores, Adonara, Lomblen, and Pantar. The best land for the growth of *E. urophylla* is an area with rainfall above 1000 mm every year. *E. urophylla* dominate the island of Timor hence the potential to absorb carbon and store it in biomass as part of climate change mitigation. This study aims to determine the allometric equation model to predict the potential of *E. urophylla* stem biomass. Calculation of the amount of stem biomass based on allometric equations is an analytical method used in this study. The sample trees used in equation modeling is 100 trees as a result of the inventory. The equations that can be used to estimate the biomass potential of the stem of *E. urophylla* in Timor Island were $\ln Y = -2.12 + 2.472 \ln (D)$ and ($R2= 0.98$); $\ln Y = -3.617 + 1.046 \ln (D^2 \times H)$ and ($R2= 0.99$); and $\ln Y = -3.510 + 2.157 \ln (D) + 0.983 \ln (H)$ and ($R2= 0.99$). The stem biomass potential with the model I amounting to 276.877 tons ha^{-1}, model II of 279.671 tons ha^{-1}, and model III of 280.209 tons ha^{-1}.

Keywords: allometric; ampupu; biomass; East Nusa Tenggara; *Eucalyptus urophylla*

INTRODUCTION

The forest area of Timor Island, Indonesia is one of the forest areas that still has an area with a level of closure in the form of primary forest and secondary forest. The two types of closure are partly dominated by *Eucalyptus urophylla*. For example, the Gunung Mutis Nature Reserve is one of the typical forest areas in East Nusa Tenggara, hence it has a uniform and relatively intact *E. urophylla*. According to Li *et al*. (2015) *E. urophylla* is a family of Myrtaceae which has hardwood that can be used for various purposes and can grow and adapt well to the environment where it grows. *E. urophylla* is one of the plants that dominate Timor Island and is suitable to be used to predict the potential of stand biomass in forest areas in East Nusa Tenggara Province. The information about this biomass potency is very important to implementing climate change mitigation programs (Ochieng, 2017; Alloisio & Borghesi, 2019; CIFOR, 2010). Other research that supports the calculation of the

potential of *Eucalyptus* biomass has been carried out by Latifah & Sulistiyono (2013) and Hernández-Ramos *et al*. (2017).

Allometric equations of *Eucalyptus urophylla* stem biomass on Timor Island are expected to be used as a basis for more accurately predicting *E. urophylla* tree biomass in order to support REDD + programs (Reducing Emissions from Deforestation and Forest Degradation). According to CIFOR (2010) one of the challenges faced in implementing REDD+ programs is the technology for calculating biomass and carbon. The technology for calculating carbon is one of the main challenges of the REDD+ program needs to find a solution and one way is to calculate biomass. Biomass is the amount of total organic matter living above ground in trees including leaves, twigs, branches, main stems and skins expressed in oven-dry weight tons per unit area. Biomass is an important measure to assess changes in forest structure, hence the distribution of forest biomass depends on the

type of forest ecosystem (Grman *et al.,* 2010; Le Toan *et al.,* 2011; Saatchi *et al*., 2011; Achmad *et al*., 2013).

Tree biomass is the measure most often used to describe and study the potency of vegetation carbon storage. This is based on the fact that the estimation of biomass is relatively easier to measure and is an accumulation of the total metabolic processes experienced by plants so this is a fairly representative indicator of growth when associated with the overall appearance of plant growth (Pamoengkas *et al.,* 2000). According to Elias & Wistara (2009) estimation of biomass is a major challenge in tropical forestry research because of the variety of biodiversity and forest types. The main way to calculate biomass is through: Destructive sampling, non-destructive sampling through remote sensing, and modeling (Sutaryo, 2009). Vahedi *et al*., (2014) and Picard *et al.,* (2012) suggested that approaches with destructive methods were used to develop allometric equations that would allow us to estimate tree masses from several simple measurements, which then this equation model could be applied to trees in forest areas.

In comparison, several studies have used allometric equations to predict biomass, including Latifah & Sulistiyono (2013) and Chave *et al.* (2014). Allometric equations in this study represent the form of general equations developed by Chave *et al.* (2005) and Basuki *et al*. (2009). The allometric equation used in this study illustrates the relationship between biomass with diameter and height, Stem biomass is calculated using a volume approach where wood density is used as a conversion factor. The results of these studies indicate that allometric equations are reliable enough to be used in predicting tree biomass content which is known to have a significant relationship between diameter and height with tree biomass. In the case of model applications, allometric equations will give different results if done on different species and locations. However, in terms of the composition of variables and forms of equations, various allometric equations can be compared to get the best model. For the type of *Eucalyptus*, the treatment (irrigation and fertilization) will not affect the allometric equations used because the same allometric equations can be used for all types of treatment given (Stape *et al*., 2008).

Allometric equations to estimate the biomass or volume potential of the genus *Eucalyptus* have been widely developed, among others, for *Eucalyptus deglupta* by Sarmiento & Varela (2015). In the study, they used allometric equations which state the relationship between biomass with diameter and tree height to predict the potential of tree biomass based on age class. According to Forrester *et al*. (2017) allometric equations are generally made based on the specific conditions of the area where it grows. According to Henry *et al*. (2011), allometric equations used to predict tree biomass from botanical features that are tree diameter or height which are key factors to predict the contribution made by forest ecosystems to the carbon cycle. Estimation of individual tree biomass is usually based on allometric between easily measurable dimensions such as diameter at breast height (DBH) and biomass. According to Fonseca *et al.* (2011) the highest carbon stock and tree biomass were found in tree-based biomass at ground level which was 66.3% of the total tree biomass. According to Devine *et al*. (2013) the accuracy of estimates of tree biomass depends on how well allometric equations represent a type of tree. The use of global allometric equations that have been published is often done, because the coefficient of allometric equations varies for each location and species, the use of this global equation can cause a significant error in estimating biomass of vegetation. This study aims to: (1) developing the model for estimating the biomass of *Eucalyptus urophylla* stem, (2) Providing the information of biomass and carbon stock of *Eucalyptus urophylla* stands in the study area.

MATERIALS AND METHODS
Data Collection. Data collection was carried out on inventory in *Eucalyptus urophylla* stands using systematic sampling with random start in three locations. Data collection is provided at every location using the plots form a square with a size of 20 meter x 20 meter at each location. The shape and size

of the plot are also used by Widyasari *et al.* (2010) to predict the potency of tree biomass. The number of tree samples is 30-35 trees in each location. The individuals were grouped into three DBH classes: 11–30, 31–50 and ≥ 51 cm, which is a general diameter classification base on distribution DBH in study area. For each sample tree the DBH and total height (H) of the stand trees were first recorded in all diameter class (Ostadhashemi *et al.* 2014; Vahedi *et al*. 2014.). Sampling locations were carried out in three locations:

1. The first location to position fastening point 9°38'41.31" South latitude and 124°16'24.36" East longitude that the administrator f included in the region Tune Village
2. The second location to tie point position 9°38'43.31" South latitude and 124°16'11:04" east longitude which is administratively included in the Fatumnasi Village
3. The third location with connective point position 9°38'53.40" South latitude and 124°16'4.97" East longitude which is administratively included in Tutem Village.

To estimate wood density, three tress were for every DBH class to represent the diameter distribution reported in the stands. The tree stem should be cut into three parts (base, middle, top) logs to take account of wood density and moisture content variations in the part of stem. Wood density is also different at the top (Iida *et al*., 2012) and base (Greenwood *et al*., 2017) of the tree (young wood near the crown, high proportion of adult wood toward the base but it may also vary according to the condition of the tree's growth including changes in proportion between early and late wood, annual ring width, and changes in cell structure and properties (Genet *et al*., 2013; Pretzsch *et al.,* 2018; Erdene-Ochir *et al*., 2020). Samples about 10 cm (disk) long should be taken of the each part of the stem (Picard *et al.* 2012). About 10 disks should be taken for base, middle and top stem respectively. The number of sub samples analyzed to calculate the wood density is 90 disk. Wood density of the *Eucalyptus urophylla* erectness was

determined according to SNI calculation (Ruslandi & Suprianto, 2012) by taking the base part, middle, and top of wood from sample trees. Then measured for length, diameter, and weighted for its wet weight, after that put into an oven at a temperature of 103±5ºC for 24 hours and then weighted it to obtain its dry weight.

The wood density data from the laboratory analysis was then used to calculate the biomass content of individual trees is aby a product of the volume byand wood density (V x K). For development of the regression equations, we we used 100 sample trees of stand inventory. The biomass of 100 individual trees was calculated by multiplying the volume and wood desitydensity based on diameter class. All empirical relationships 100 trees were included in the existing allometric equations, and the explanatory variables are always diameter at breast height (DBH), tree height (h), or a combination of the two (Table 3).

Data Analysis. Analysis of volume and stem biomass data to be calculated in this study is to branch-free height. Calculation of stem volume and biomass is carried out using the equation that has been used by Ostadhashemi *et al*. (2014) as follows:

$$V = ba \times H \times f \text{ .... (1)}$$

Note: V = Stem volume (m^3), ba = basal area (m^2), H = Branch free height (m), f = correction factor (=0.7).

$$Y = V \times K \text{ .... (2)}$$

Note: $Y = Y$ = Biomass (kg), V = Stem volume (m^3), K = wood density (kg.m^{-3}).

The density of wood from *E. urophylla* stands is based on SNI calculation (Ruslandi & Suprianto, 2012) by taking the base, middle and wood end of the sample tree, then measuring the length, diameter and weighing the wet weight after being put into the oven at 103 ± 5ºC for 24 hours and weighed the dry weight (Yuniati & Kurniawan, 2013). Furthermore, the calculation of wood density was carried out based on the equation used by Latifah & Sulistiyono (2013), fiber Yusuf *et al*. (2014) as follows:

$$K = \frac{M}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Note: K= wood density (kg/m³), M= wood oven-dry weight (kg), V= volume of sample (m³)

The potential of stem biomass for all study areas was carried out using allometric equations to find the relationship between biomass and tree dimensions. According to Ostadhashemi *et al*. (2014) allometric equations are very suitable for calculating aboveground biomass. The nature studies have used some similarities allometric to determine the relationship between the sizes of the tree (diameter or height) with biomass. The value of stem biomass used in preparing the model is obtained from the results of the volume conversion to biomass based on equation 2 by using wood density values. Allometric equations used in this study are equations that have been used by several previous researchers such as Basuki *et al*. (2009), Elias & Wistara (2009), Sutaryo (2009), Widyasari *et al*. (2010), and Vahedi *et al*. (2014). This allometric equation is a development of the equation suggested by Brown (1997) as follows:

$$ln\,Y = Exp\,(a + b\,ln\,D) \ldots\ldots\ldots (4)$$

$$ln\,Y = a + b\,ln\,(D^2 + T) \ldots\ldots\ldots (5)$$
$$ln\,Y = a + b\,ln\,D + c\,ln\,T \ldots\ldots (6)$$

Note: Y= total biomass stem (kg), a, b= regression coefficient, D= diameter at breast height (cm), T= branch free height (m)

To select the allometric equation model produced, validation of the reliability of the model was carried out. The reliability of allometric equation models was tested based on the value of the Determination Coefficient and t (Akbar, 2012; Vahedi *et al*. 2014). The estimation of biomass stem potential of *E. urophylla* stand was performed by using the medium value estimation sampling (Picard *et al*., 2012). with the following equation:

$$\overline{B} \pm t_{n-1} \frac{S_B}{\sqrt{n-1}} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Note: $tn-1$ is the quantile $1 - \alpha/2$ of a Student distribution with $n - 1$ degrees of freedom, and SB is the empirical standard deviation of plot biomass.

$$S_B^2 = \frac{1}{n-1}\sum_{i=1}^{n}(B_i - \bar{B})^2 \ldots\ldots\ldots\ldots (8)$$

Note:
B_i = Biomass of the *i*-th plot
$\overline{B}$ = mean biomass of a plot
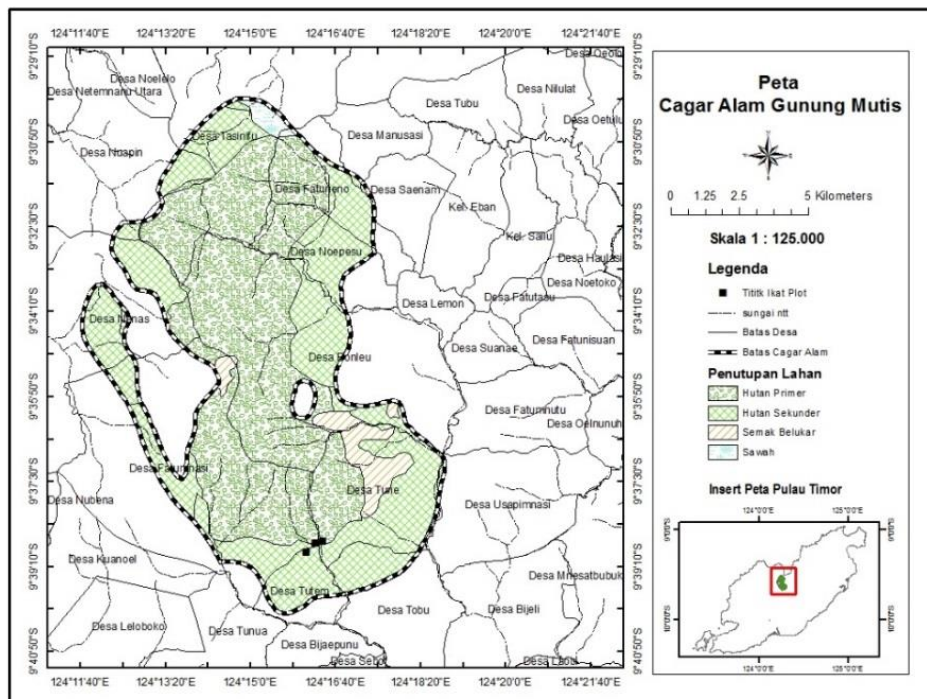S_B^2 = standard deviation of plot biomass

Figure 1. Map of Map of Gunung Mutis Nature Reserve showing three sampling sites

RESULT AND DISCUSSION

Wood Density and Biomass Stem. The calculation of biomass in this study was carried out in the sample tree by taking each part of the stem of the tree as samples to be observed. The sample is then oven until it reaches the dry weight of the furnace. After that, it is weighed to obtain the value of weight or mass of wood in units of grams (equation 3). The results of the analysis of the wood density and biomass of each part of the stem in detail are presented in Table 1.

Table 1. Average wood density and biomass stem of laboratory analysis

Diameter Class	Part of Stem	n	Wood Density (g.cm^{-3})	Volume (m^3)	Biomass (kg)
	Top	3	0.78	0.08	64.80
I	Middle	3	0.90	0.16	142.11
	Bottom	3	0.91	0.29	261.68
	Top	3	0.85	0.58	493.93
II	Middle	3	0.91	0.86	778.84
	Bottom	3	0.94	1.26	1187.21
	Top	3	0.87	1.42	1239.02
III	Middle	3	0.93	2.69	2502.97
	Bottom	3	0.99	3.87	3827.63

The results of the analysis in Table 1 show that the average wood density of individual sample stem diameter class I is 0.86 g.cm^{-3} with a biomass content of 468.59 kg.tree^{-1}. The average value of wood density for trees stem with diameter class II is 0.90 g.cm^{-3} with a biomass content of 2459.99 kg tree-1. The average value of wood density for trees stem with diameter class III is 0.93 g.cm^{-3} with a biomass content of 7569.81 kg.tree^{-1}. The results of the analysis in Table 1 also show that the part of the stem that has the smallest biomass is the top and the biggest part is the base of the stem. This result is also supported by research by Fonseca *et al*. (2011) which states that the highest tree biomass is found in tree-based biomass at ground level which is 66.3% of the total tree biomass.

Allometric Equation Model. Modeling the equation in this study was carried out by a destructive method. The wood density data from the laboratory analysis was then used to calculate the biomass content of trees is a product of volume and wood density (V x K). For development of the regression equations, we measured the diameter and height of 100 trees, which represented the diameter classes (Table 1) in the studied stands. The biomass trees calculated in this study are the result presented in Table 2. Data in table 2 was analyzed using regression analysis based on equations 2, equation 3 and equation 4. In this allometric equation, the value variables analyzed are stem biomass (Y), diameter (D) and tree height (T). The results of the regression analysis of 100 tree samples was presented in Table 3 and Figure 2.

Table 2. Descriptive statistic of tree sample used to build model

	N	Range	Minimum	Maximum	Standar Deviation
Diameter (cm)	100	71.70	11.10	82.80	18.57
Height (m)	100	12.00	8.00	20.00	2.91
Biomass (kg)	100	5857.61	52.72	5910.33	1435.32

Table 3. Description of the equation model for estimating biomass of *Eucalyptus urophylla* stem in the study area

Model	Equation	a	b	c	Standard Error	R^{2}adj (%)	F	Sig.
I	$ln\,Y = a + b\,ln\,(D)$	-2.12	2.47	-	0.15	98.8	8241.42	0.000

II	$ln\,Y = a + b\,ln\,(D^2 \times H)$	-3.62	1.06	-	0.06	99.8	59263.19	0.000
III	$ln\,Y = a + b\,ln\,(D) + c\,ln\,(H)$	-3.51	2.16	0.98	0.06	99.8	30623.32	0.000

Note: Y = Stem Biomass (kg), D = Diameter of human breast height (cm), H = Branch free height (m)
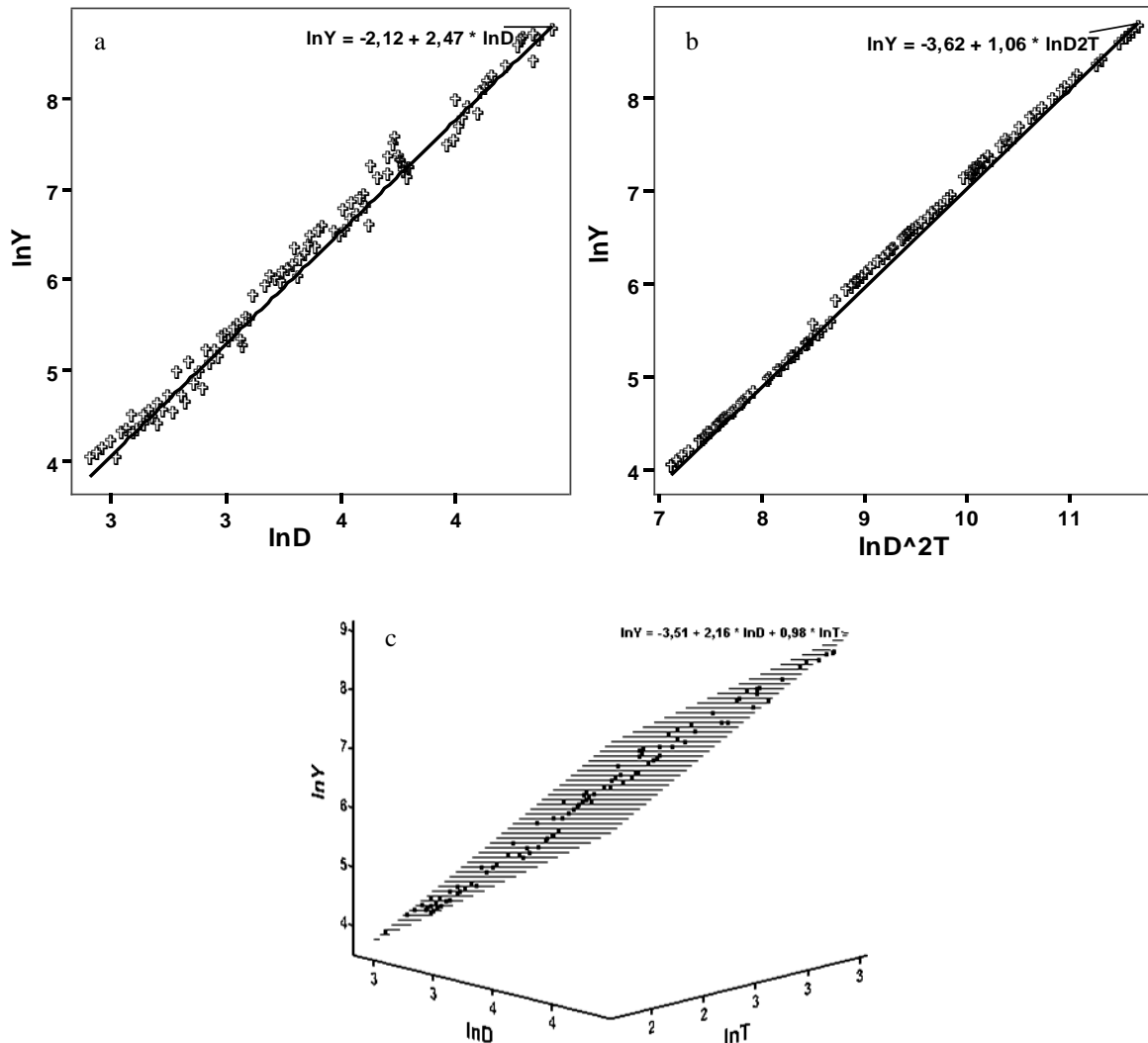

Figure 2. The regression analysis of 100 tree samples: a. Regression between the natural logarithm of stem biomass (kg) and the natural logarithm of the of diameter (cm); b. Multivariate regression between the natural logarithm of stem biomass (kg) and the natural logarithm of the product of square diameter and height (x); c. Multivariate regression between the natural logarithm of stem biomass (kg) and the natural logarithm of the diameter (*x*)(cm) and the natural logarithm of the height (*z*)(m)

The results of the data analysis in Table 3 and Figure 2 shows that there is a very significant relationship between stem biomass and diameter and the height of the *Eucalyptus urophylla* tree. This can be known from the significance value (Sig. <0.01). Table 2 shows that equation II has the largest R and F values. When compared from the data distribution in Figure 2, it can be seen that eq. II and eq. II has the best data distribution. This result also (eq. II dan eq. III) indicates that the allometric models including D, H had a higher precision data than

the models including only diameter. According to Vahedi *et al.* (2014) two different explanatory variables (D and H) was the best estimator for the total aboveground biomass prediction for each single species.

Other relationship patterns also indicated by the coefficient of determination (R^2) with a value for all the models ranged from 98.8% to 99.8%. This value indicates that the independent variable in the form of diameter and height can determine more than 90% of the dependent variable, biomass. This is in line

with the results of research by Basuki *et al.* (2009), Akbar (2012), Latifah & Suistiyono (2013), Huy *et al.* (2016) which uses the same allometric equation model to estimate tree biomass based on the value of diameter and tree height. These equation models are allometric equation models developed by Brown (1997) and linear equation models with the transformation of natural logarithms that have been used by several previous researchers about biomass. The results of the analysis in Table 3 also show that the model II and III equations are the best models because they produce the smallest standard error values and the largest R^2adj.

Further analysis of this equation model was carried out using the t test. This test is carried out on the value of the calculation of the sample tree if it is converted into the model equation

that has been obtained (3 Equation Models). This test is conducted to determine the differences in the results of the equation model. The results of this t-test analysis in detail are presented in Table 4. The results of the analysis in Table 4 show that the model eq. I, model eq. II and model eq. III show results that are not significantly different as indicated by the significance value which is smaller than 0.01 (sig.<0.01).

The results of this equation comparison test (Table 4) are in line with the results of Vahedi *et al.* (2014) which shows that not all allometric equation models used to predict biomass of a plant type are not significantly different. Adding the height to the equation (eq. II and eq. III) can't be affect significant but can be increase F and coefficient correlation.

Table 4. Paired *t*-test at 95% confidence interval of the mean of stem biomass (kg) *Eucalyptus urophylla*

No.	Equation Comparison	N	Standard Deviation	t_{count}	Sig.
1	Model eq. I vs. Model eq. II	100	283.301	- 0.552	0.582
2	Model eq. I vs. Model eq. III	100	263.910	- 0.674	0.502
3	Model eq. II vs. Model eq. III	100	20.534	-1.048	0.297

Biomass Potential and Standing Carbon Content. The results of the analysis of stem biomass potential based on allometric equations previously obtained (Table 5) are then used to calculate the individual biomass 100 trees sample. The potential of stem biomass

calculated and analyzed using the mean value estimation method (eq. 7 and eq. 8). The results of the analysis in Table 3 show that the stem biomass potential with the model I amounting to 276.877 tons ha^{-1}, model II of 279.671 tons ha^{-1}, and model III of 280.209 tons ha^{-1}.

Table 5. Estimated potential of biomass and carbon *Eucalyptus urophylla* study area

Model	Equation	Diameter class	Standard Error	Biomass (ton ha^{-1})	Carbon (ton ha^{-1})
I	$\ln Y = -2.166 + 2.472 \ln (D)$	1	4.023	12.222	5.530
		2	11.948	56.771	25.689
		3	51.654	207.884	94.068
II	$\ln Y = -3.617 + 1.046 \ln (D^2 \times H)$	1	4.168	12.090	5.471
		2	17.420	61.180	27.684
		3	60.953	206.401	93.396
III	$\ln Y = -3.510 + 2.157 \ln (D) + 0.983 \ln (H)$	1	4.158	12.099	5.475
		2	16.949	60.908	27.561
		3	60.429	207.202	93.759

CONCLUSION

The part of the stem that has the smallest wood density is the top and the largest part is the bottom of stem with an average wood density range of 0.78 - 0.99 g.cm^{-3}. The results of the calculation of the stem biomass in this

study indicate that the range value of biomass content of part the stem is 64.80 - 3827.63 kg. The best allometric equation from the results of this study that can be used to estimate the biomass content of *Eucalyptus urophylla* species is: $\ln Y = -2.12 + 2.472 \ln (D)$ and $\ln Y$

= -3.617 + 1.046 ln $(D^2 \times H)$. The stem biomass potential with the model I amounting to 276.877 tons ha^{-1}, model II of 279.671 tons ha^{-1}, and model III of 280.209 tons ha^{-1}.

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