ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVE-GROUND BIOMASS IN PAPUA TROPICAL FOREST

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ABSTRACT

Allometric equations can be used to estimate biomass and carbon stock of the forest. However, so far the allometric equations for commercial species in Papua tropical forests have not been appropriately developed. In this research, allometric equations are presented based on the genera of commercial species. Few equations have been developed for the commercial species of Intsia, Pometia, Palaquium and Vatica genera and an equation of a mix of these genera. The number of trees sampled in this research was 49, with diameters (1.30 m above-ground or above buttresses) ranging from 5 to 40 cm. Destructive sampling was used to collect the samples where Diameter at Breast Height (DBH) and Wood Density (WD) were used as predictors for dry weight of Total Above-Ground Biomass (TAGB). Model comparison and selection were based on the values of F-statistics, R-sq, R-sq (adj), and average deviation. Based on these statistical indicators, the most suitable model for Intsia, Pometia, Palaquium and Vatica genera respectively are Log(TAGB) = -0.76 + 2.51Log(DBH), Log(TAGB) = -0.84 + 2.57Log(DBH), Log(TAGB) = -1.52 + 2.96Log(DBH), and Log(TAGB) = -0.09 + 2.08Log(DBH). Additional explanatory variables such as Commercial Bole Height (CBH) do not really increase the indicators' goodness of fit for the equation. An alternative model to incorporate wood density should be considered for estimating the above-ground biomass for mixed genera. Comparing the presented mixed-genera equation; Log(TAGB) = 0.205 + 2.08Log(DBH) + 1.75Log(WD), R-sq: 97.0%, R-sq (adj): 96.9%, F-statistics 750.67, average deviation: 3.5%; to previously published data shows that this local species-specific equation differs substantially from previously published equations and this site-specific equation is considered to give a better estimation of biomass.

Keywords: Allometric, biomass, wood density, Papua, tropical forest

ABSTRAK

Persamaan-persamaan alometrik sangat berguna untuk pendugaan biomassa dan stok karbon hutan. Namun, hingga saat ini, persamaan alometrik untuk jenis-jenis komersial di hutan tropis Papua masih sangat terbatas. Oleh karena itu, penelitian ini bertujuan untuk menyusun berbagai persamaan allometrik berdasarkan jenis-jenis komersial di Papua, meliputi genus Intsia, Pometia, Palaquium dan Vatica. Selain itu, satu persamaan juga dibangun khusus untuk mewakili kombinasi dari genera tersebut. Pohon contoh yang digunakan dalam penelitian ini berjumlah 49 dengan selang diameter setinggi dada (1,3 m) antara 5 hingga 40 cm. Metode pengambilan contoh menggunakan pendekatan destruktif dengan diameter setinggi dada (diameter at breast height/DBH) dan berat jenis (wood density/WD) digunakan sebagai penduga untuk total biomassa atas tanah (total above ground biomass/TAGB). Perbandingan dan evaluasi model dilaksanakan berdasarkan nilai F-tabel, R-sq, R-sq (adj) dan simpangan rata-rata. Sedangkan untuk memenuhi asumsi penyusunan regresi, maka dilaksanakan uji multicollinearity untuk tiap model persamaan dengan lebih dari satu penduga dan uji normalitas distribusi residual (normal distribution of residuals). Berdasarkan indikator tersebut model yang paling sesuai untuk genera Intsia, Pometia, Palaquium dan Vatica secara berurutan

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adalah Log(TAGB) = -0,76 + 2,51Log(DBH), Log(TAGB) = -0,84 + 2,57Log(DBH), Log(TAGB) = -1,52 + 2,96Log(DBH), and Log(TAGB) = -0,09 + 2,08Log(DBH). Sementara itu, ditemukan bahwa penggunaan tinggi bebas cabang (commercial bole height/CBH) tidak mengindikasikan adanya peningkatan keterandalan model. Dari perbandingan antara persamaan alometrik untuk campuran jenis-jenis komersial sebagai hasil penelitian ini, yaitu Log(TAGB) = 0,205 + 2,08Log(DBH) + 1,75Log(WD), R-sq: 97,00%, R-sq (adj): 96,90%, F-statistics 750,67, average deviation: 3,50%, dengan berbagai persamaan alometrik yang telah dipublikasikan sebelumnya, didapatkan bahwa hasil pendugaan dari persamaan dalam penelitian ini lebih mendekati hasil perhitungan nyata, dan oleh sebab itu, suatu persamaan yang spesifik terhadap lokasi seharusnya lebih dipertimbangkan untuk mendapatkan pendugaan biomassa yang lebih baik.

Kata kunci: Alometrik, biomassa, berat jenis, Papua, hutan tropis

I. INTRODUCTION

Forest ecosystem is an important carbon sink and source and containing the majority of above-ground terrestrial organic carbon. Four main carbon pools in forest ecosystem are including tree biomass, necromass, under-storey and soil organic matters (Hairiah and Rahayu, 2007). The largest carbon stock comes from above-ground tree biomass, but this carbon pool was also the most vulnerable to deforestation and forest degradation. Therefore, the estimation of total above-ground biomass is an important step in quantifying carbon stock of tropical forest (Post et al., 1999; Brown and Masera, 2003; Pearson et al., 2005; IPCC, 2006; Hairiah and Rahayu, 2007).

Basically, the estimation of above-ground biomass can be conducted via two approaches, which are destructive and non-destructive (Samalca, 2007). Direct estimation of above-ground biomass through destructive approach is the most accurate approach, although this approach tends to be more costly, requires more man-power, and time, if compared to the non-destructive approach (Lu, 2006). Generally, destructive approach is used only as a tool in validating the result of the non-destructive approach that was using allometric equations (Clark et al., 2001; de Gier, 2003; Wang et al., 2003). These equations developed based on the correlations between diameter at breast height (DBH), or other tree variables, against its total above-ground biomass (Brown, 1997).

The implementation of species and site-specific allometric equations is strongly suggested, because trees from different site will grow with a different architecture, wood density and other life patterns (Ketterings et al., 2001). In order to achieve the highest level of accuracy, local species and site-specific allometric equations must be established (Samalca, 2007; Basuki et al., 2009). This research aims to produce species and site-specific allometric equations to estimate total above-ground biomass of four genera of commercial species in Papua.

II. MATERIAL AND METHOD

A. Site Description

This research was conducted at four different regencies in Papua and West Papua Province (Figure 1). The number of trees sampled in this research was 49, with diameters (1.30 m above ground or above buttresses) ranging from 5 to 40 cm, which consisted of four different genera as presented in Table 1.

B. Method

DBH was measured prior conducting the destructive sampling. Generally the DBH was measured at 1.30 m above-ground, but for trees with enlargement or buttresses, the diameter was measured at 30 cm above the main enlargement. After felling, the tree height was measured. Diameter was measured at 2 m intervals for the stems and big branches with the diameters of more than 15 cm. In addition, the stump height and its diameter were also measured. These measurements were used to estimate the volume and dry weight. The volume of each section was calculated using Smalian's formula as cited by de Gier (2003). The total volume is the sum of the volume of each section. Due to the difference in moisture content, the tree material was partitioned into leaves, twigs (diameter <3.2 cm), small branches (diameter 3.2–6.4 cm), large branches (diameter >6.4 cm) and stem (Ketterings et al., 2001).

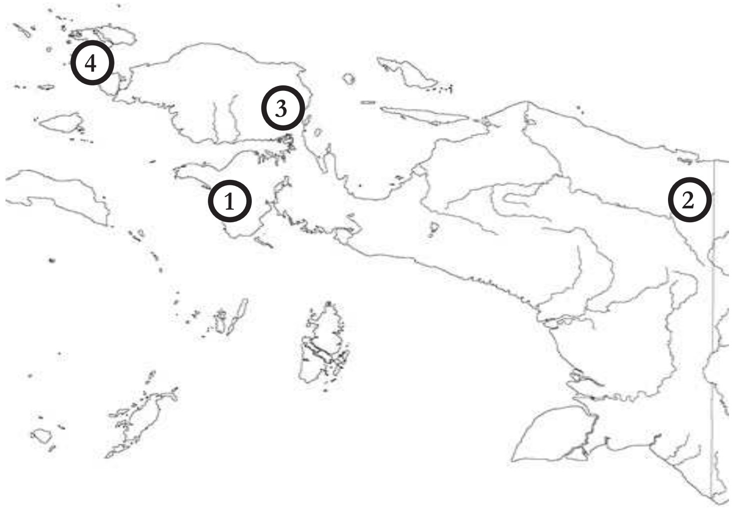

Figure 1. Research site map

Table 1. Details of number of trees taken per genus and location

Research site	Genera	Number of trees	Location	Coordinate	Site characteristics as taken from BPS Papua (2009) and BPS Papua Barat (2011)
1.	Intsia	13	Fak-fak	$2^0$25'0"- $4^0$0'0" S $131^0$30'0" - 138^{04}0'0" E	- 500 m above sea level - daily temperature: 24-31°C - average humidity: 84% - annual rainfall: 3,265 mm/year - soil type: carbosol and yellow-reddish podsolic
2.	Pometia	15	Keerom	$140^0$15'0"-$141^0$0'0" S $2^0$37'0" - $4^0$0'0" E	- 1000 m above sea level - daily temperature: 21.9-33°C - average humidity: 85% - annual rainfall: 4,151 mm/year - soil type: grey-brown and yellow-reddish podsolic
3.	Palaquium	13	Bintuni	$1^0$57'50"-$3^0$11'26" S $132^0$44'59"-$134^0$14'49" E	- 500 m above sea level - daily temperature: 25-31°C - average humidity: 85% - annual rainfall: 3,008.9 mm/year - soil type: alluvial, gleysol and podsolic
4.	Vatica	8	Raja Ampat	0^o10' S - 0^o20' N 130^o0' W- 132^o0'55" E	- 500 m above sea level - daily temperature: 25-30°C - average humidity: 84% - annual rainfall: 3,836.4 mm/year - soil type: alluvial, organosol, grey podsolic and yellow-reddish podsolic

Afterwards, fresh weight from leaves, twigs, branches and stems with maximum diameters of 15 cm were measured directly in the field using hang-up balance of 50 kg capacity with an accuracy of 1%. Moreover, the smaller samples were weighed using a 1000 gr table scale with an accuracy of 0.5%. Three replications were taken for the samples from the partitioned trees and put into sealed plastic bags, and then brought to the laboratory to measure their moisture content. From that point, an analytical balance with maximum capacity of 500 gr and an accuracy of 0.001 gr was utilized to weigh those samples. Dry weights were obtained by drying the samples at 105^{o}C temperature until the constant value was obtained (Stewart et al., 1992; Ketterings et al., 2001).

In order to measure the wood density at the laboratory, samples were taken from the lower and upper parts of the main trunk sections with 2 meters interval for each section. To include the inner and outer parts of the trunks with

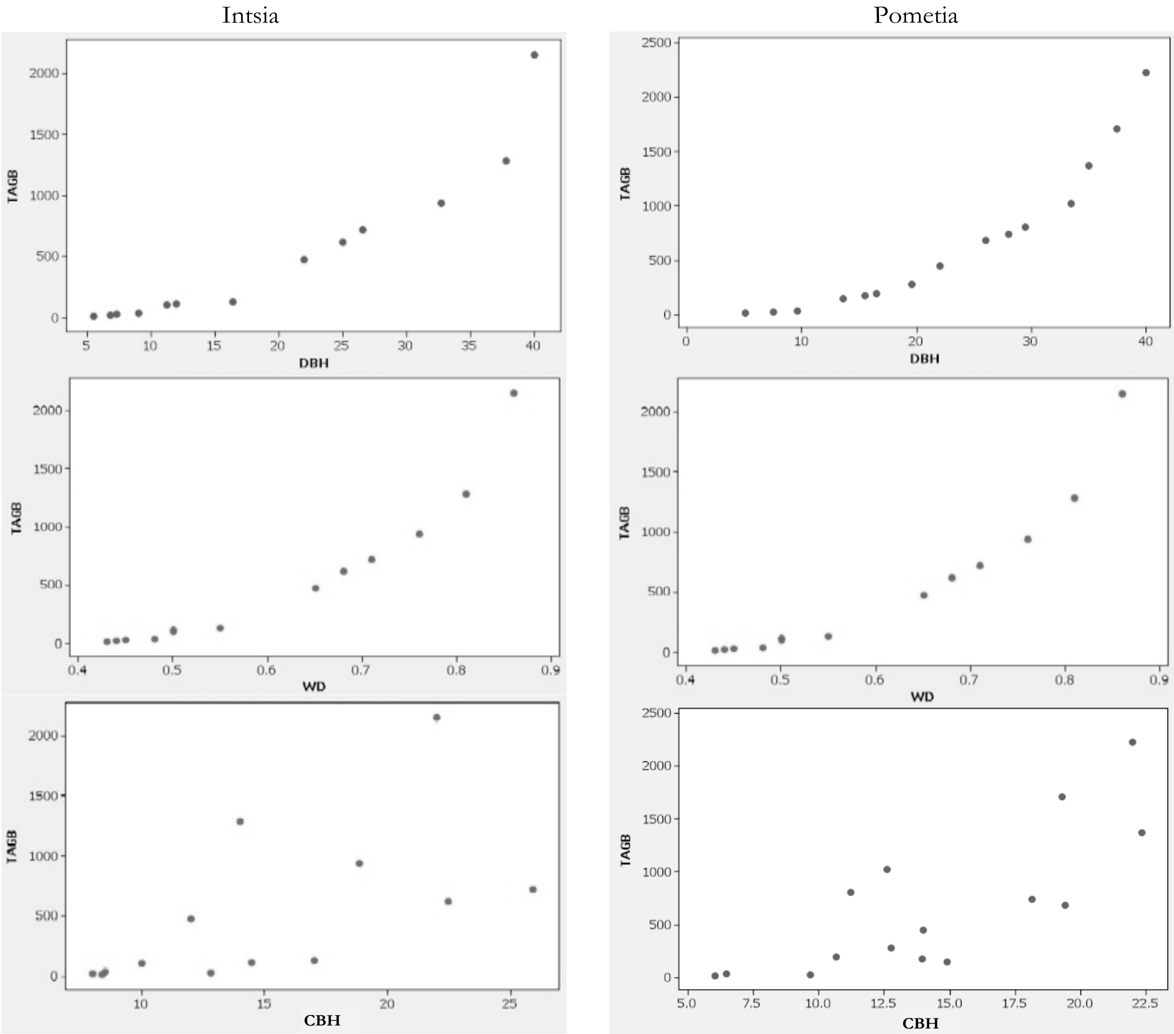

Figure 2. Scatter plots of Intsia and Pometia

Remarks :
TAGB: Total Above-Ground Biomass (kg/tree)
DBH: Diameter at Breast Height (cm)
WD: Wood Density (gr/cm^3)
CBH: Commercial Bole Height (m)

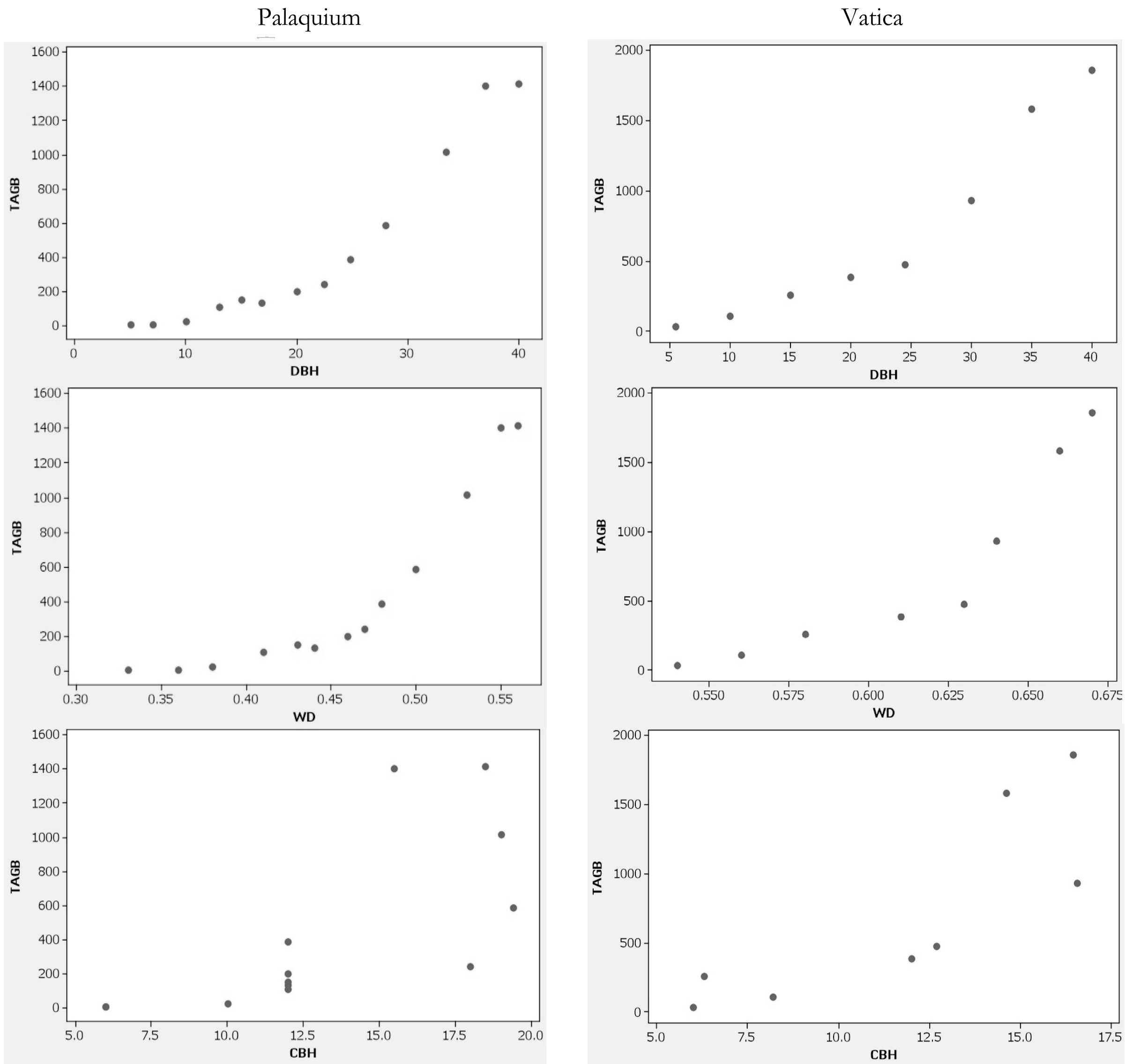

Figure 3. Scatter plot of Palaqium and Vatica

Remarks :
TAGB: Total Above-Ground Biomass (kg/tree)
DBH: Diameter at Breast Height (cm)
WD: Wood Density (gr/cm^3)
CBH: Commercial Bole Height (m)

their barks, the samples were taken as a pie shape or cylinder (Nelson et al., 1999). Water replacement method was used in measuring the wood density. The samples were saturated at first to prevent size contraction during volume measurement. This was conducted through 48 hours rehydration. Each sample's volume was obtained from the displaced water volume when submerged. Finally, the wood density was equal to the oven dry weight divided by saturated volume.

The dry weight of the stumps, stems, and branches with the diameter of >15 cm was calculated by multiplying the fresh volume of each section by wood density. For the other partitioned trees, the dry weight was calculated through fresh weight multiplied by dry weight divide by fresh weight ratio of the corresponding samples. The total dry weight of a tree is the sum of the dry weight of the stump, stem, branches, twigs, and leaves (Stewart et al., 1992).

Based on the data collected, several equations were developed. Firstly, the equations were developed for four individual genera (Intsia, Pometia, Palaquium and Vatica). Secondly, these four genera were mixed to develop an equation for commercial species. Before the establishment of these allometric equations, scatter plots were used to see whether the relationship between independent and dependent variables was linear. Furthermore, several allometric relationships between independent and dependent variables were tested. The independent variables included Diameter at Breast Height (DBH), Commercial Bole Height (CBH) and Wood Density (WD), whereas the dependent variable was the dry weight of the Total Above-Ground Biomass (TAGB). Model comparison and selection was analyzed using the value of standard error of the coefficient, F statistic, R-sq, R-sq (adj) based on Minitab 14.0 software. The chosen model would be the one with not only the highest value for each criterion, but also one that have the lowest value of average deviation among others, as suggested by Basuki et al. (2009). Besides, in order to fulfill assumptions in regression establishment, two tests were conducted, namely Variance Influential Factors (VIF) for multi-collinearity test, which aimed at equations with more than one predictor, and normal distribution of residual test. Meanwhile, in this research allometric equations were established based on logarithmic model taken from Basuki et al. (2009) and quadratic model, as follow:

a.) $Log(TAGB) = c + \alpha Log(DBH)$
b.) $Log(TAGB) = c + \alpha Log(WD)$
c.) $Log(TAGB) = c + \alpha Log(DBH) + \beta Log(WD)$
d.) $TAGB = c + \alpha(DBH) + \beta(DBH)2$
e.) $TAGB = c + \alpha(WD) + \beta(WD)2$

III. RESULT AND DISCUSSION

A. Allometric Equations

The selection of independent variables as predictors in allometric equation were chosen based on the correlation patterns between each independent variable (DBH, CBH, and WD) against its dependent variable (TAGB). Figure 2 and 3 shows that the independent variable Commercial Bole Height (CBH) is forming a random correlation to total above-ground biomass. As a result, CBH cannot be used as an independent variable in the allometric equation because it will not increase the goodness of fit for the equations. Besides that, Figure 2 and 3 also show that DBH and WD are forming an exponential growth pattern to total above-ground biomass. This pattern shows that all of sampled trees were still in the growing stage.

Based on those exponential growth patterns as shown in Figure 2 and 3, there are two

Table 2. Result of measuring wood density and the published data

Species Grouping (Genera)	Number of wood density sample (n)	Range (gr/cm^3)		Average (gr/cm^3)	Standard deviation	PROSEA* (gr/cm^3)
		min	max			
Intsia	92	0.43	0.86	0.6	0.15	0.5-1.04
Pometia	98	0.37	0.75	0.58	0.12	0.39-0.77
Palaquium	86	0.33	0.56	0.45	0.07	0.45-0.51
Vatica	44	0.54	0.67	0.61	0.05	0.6-0.76

Remark: *published data

Table 3. Multi-collinearity test using VIF value

Species Grouping (Genera)	N	Equations	Coefficient		Multi-collinearity Test	
			Symbol	Values	Predictor	VIF
Intsia	13	Log TAGB = *c* + α Log DBH	c	-0.762	Log DBH	-
			α	2.51	-	
		Log TAGB = *c* + α Log WD	c	3.86	Log WD	-
			α	6.92	-	
		TAGB = *c* + α DBH + β DBH²	c	128.3	DBH	24.9
			α	-24.70	DBH²	24.9
			β	1.678	-	
		TAGB = c + α WD + β WD²	c	3090	WD	140.1
			α	-12718	WD²	140.1
			β	13244	-	
Pometia	15	Log TAGB = *c* + α Log DBH	**c**	-0.8406	Log DBH	-
			α	2.572	-	
		Log TAGB = *c* + α Log WD	c	4.267	Log WD	-
			α	7.214	-	
		TAGB = *c* + α DBH + β DBH²	c	232.5	DBH	23.5
			α	-40.46	DBH²	23.5
			β	2.131	-	
		TAGB = c + α WD + β WD²	c	4632	WD	118.1
			α	-20620	WD²	118.1
			β	22886	-	
Palaquium	13	Log TAGB = *c* + α Log DBH	**c**	-1.52	Log DBH	-
			α	2.96	-	
		Log TAGB = *c* + α Log WD	c	6.217	Log WD	-
			α	11.59	-	
		TAGB = *c* + α DBH + β DBH²	c	111.30	DBH	20.9
			α	24.13	DBH²	20.9
			β	1.489	-	
		TAGB = c + α WD + β WD²	c	6618	WD	167.3
			α	35000	WD²	167.3
			β	46043	-	
Vatica	8	Log TAGB = *c* + α Log DBH	**c**	-0.0975	Log DBH	-
			α	2.086	-	
		Log TAGB = *c* + α Log WD	c	6.368	Log WD	-
			α	17.67	-	
		TAGB = *c* + α DBH + β DBH²	c	130.90	DBH	22.4
			α	21.50	DBH²	22.4
			β	1.658	-	
		TAGB = c + α WD + β WD²	c	51612	WD	1198.7
			α	182565	WD²	1198.7
			β	161565	-	
Commercial Species (Mixed)	49	Log TAGB = *c* + α Log DBH	c	-0.881	Log DBH	-
			α	2.580	-	
		Log TAGB = *c* + α Log WD	c	4.065	Log WD	-
			α	6.455	-	
		Log TAGB= c + α Log DBH + β Log WD	**c**	0.205	Log DBH	2.8
			α	2.08	Log WD	2.8
			β	1.75	-	
		TAGB = *c* + α DBH + β DBH²	c	152.49	DBH	22.9
			α	-28.764	DBH²	22.9
			β	1.7689	-	
		TAGB = c + α WD + β WD²	c	-7	WD	67.1
			α	-1928	WD²	67.1
			β	5070	-	-

methods for approaching the established equations in order to achieve highest level of accuracy, first by establishing an equation following quadratic model and second by following logarithmic model based on basic equation model as suggested by Basuki et al.

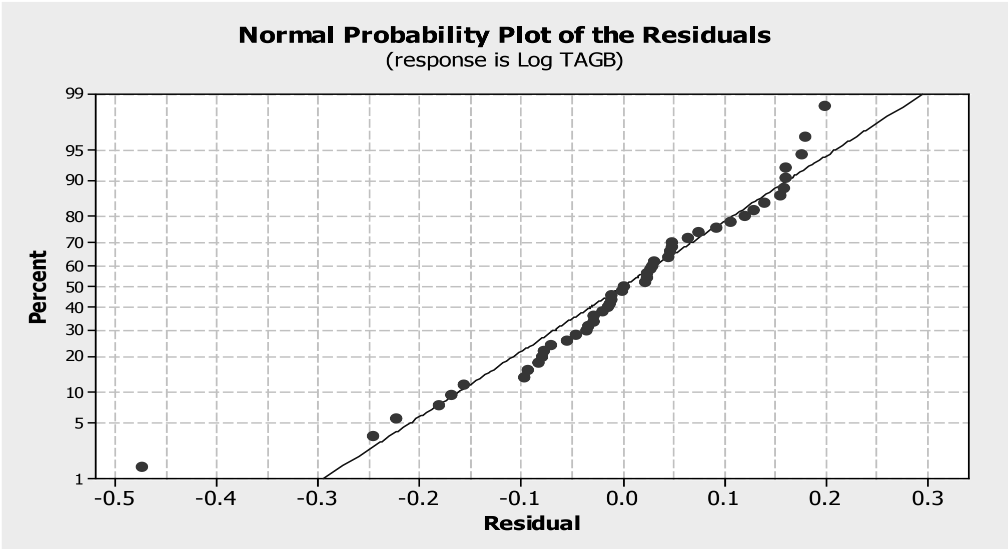

Figure 4. Normal distribution of residual graph for allometric model of mixed species

(2009). Similarly, Grant et al. (1997) and Stewart (1998) also declared that the exponential growth relationship can be explained through quadratic equations, and it will raise the accuracy level of the estimated values if converted to a regression which relies on logarithmic models.

It is possible that during the equations establishment process in this study, the differences in wood density among tree sections were the biggest source of errors. This source of error is in agreement with Basuki et al. (2009). Wood density differs among the tree sections; it tends to be higher at the breast height than at the top of the bole and also higher at the base of the tree stem than at the base of the living crown (Nogueira et al., 2005).

In this study, although the samples for wood density analyses were taken from the upper and lower part of each main trunk section with 2 m interval. These data were also used to estimate the weight of the big branches that were impossible to be weighed. This possibly caused an over-estimation of the weight for individual trees. Wood density data for all genera are presented in Table 2.

Before evaluating established allometric equations, multi-collinearity test was conducted on every equation that used more than one predictor, such as TAGB = c + α(DBH) + β(DBH)2; TAGB = c + α(WD) + β(WD)2; and Log(TAGB)= c + α Log(DBH) + β Log(WD). The result of this test is shown in Table 3. Based on this table, it is apparently clear that the utilization of DBH and DBH2 as predictors simultaneously in one equation produced a high value of Variance Influential Factors (VIF) that is more than 10. Similarly, the use of WD and WD2 together in one equation is also resulted in more than 10 points of VIF value. This finding implies that model TAGB = c + α(DBH) + β(DBH)2 and TAGB = c + α(WD) + β(WD)2 indicate the existence of multicollinearity due to high correlation among their predictors. As described by Fahrmeir et al. (2013), if VIF value goes beyond 10, it is highly likely that the regression predictors need to be concerned due to multi-collinearity that may become problematic in the prediction of the results of the model. In contrast, the use of Log DBH and Log WD simultaneously in Log(TAGB)= c + α Log(DBH) + β Log(WD) model, has only produced 2.8 points of VIF value. This means that although there is an indication of low degree of correlation among its predictors, the value of VIF is not enough to be overly concerned about (Fahrmeir et al.,

Table 4. Results of establishing allometric equations

Species Grouping (Genera)	N	Equations	Coefficient Symbol	Coefficient Values	Standard Error of the Coefficient	T-Stat	R^2 (%)	R^2 Adj (%)	F-Stat	Average Deviation (%)
Intsia	13	Log TAGB = c + α Log DBH	c	-0.762	0.1097	6.95	98.60	98.50	797.51	1.70
			α	2.51	0.0889	28.24				
		Log TAGB = *c* + α Log WD	c	3.86	0.1032	37.41	96.40	96.00	291.52	3.90
			α	6.92	0.4051	17.07				
		TAGB = *c* + α DBH + β DBH^2	c	128.3	167.1	0.77	94.90	93.90	93.03	27.65
			α	-24.70	18.84	1.31				
			β	1.678	0.4188	4.01				
		TAGB = c + α WD + β WD^2	c	3090	741.8	4.17	97.60	97.10	204.60	46.06
			α	-12718	2463	5.16				
			β	13244	1948	6.80				
Pometia	15	Log TAGB = c + α Log DBH	c	-0.8406	0.102	8.21	98.80	98.70	1090.5	1.56
			α	2.572	0.078	33.02				
		Log TAGB = *c* + α Log WD	c	4.267	0.066	64.43	98.50	98.40	839.64	1.92
			α	7.214	0.249	28.98				
		TAGB = *c* + α DBH + β DBH^2	c	232.5	123.5	1.88	97.80	97.40	267.56	40.72
			α	-40.46	12.44	3.25				
			β	2.131	0.269	7.90				
		TAGB = c + α WD + β WD^2	c	4632	771.7	6.00	97.40	97.00	223.77	43.92
			α	-20620	2840	7.26				
			β	22886	2526	9.06				
Palaquium	13	Log TAGB = c + α Log DBH	c	-1.52	0.1899	8.01	97.30	97.10	396.85	4.74
			α	2.96	0.1482	19.92				
		Log TAGB = *c* + α Log WD	c	6.217	0.2365	26.28	96.50	96.20	302.46	7.97
			α	11.59	0.6666	17.39				
		TAGB = *c* + α DBH + β DBH^2	c	111.30	85.08	1.31	98.30	97.90	284.40	33.92
			α	24.13	8.677	2.78				
			β	1.489	0.1887	7.89				
		TAGB = c + α WD + β WD^2	c	6618	855.6	7.73	97.40	97.00	284.23	37.17
			α	35000	3863	9.06				
			β	46043	4288	10.74				
Vatica	8	Log TAGB = c + α Log DBH	c	-0.0975	0.1143	0.85	99.00	98.80	569.13	0.69
			α	2.086	0.08742	23.86				
		Log TAGB = *c* + α Log WD	c	6.368	0.3444	18.49	95.40	94.60	124.31	0.86
			α	17.67	1.585	11.15				
		TAGB = *c* + α DBH + β DBH^2	c	130.90	161.1	0.81	98.20	97.40	133.08	7.64
			α	21.50	16.3	1.32				
			β	1.658	0.3507	4.73				
		TAGB = c + α WD + β WD^2	c	51612	12972	3.98	96.40	94.90	66.07	28.20
			α	182565	43019	4.24				
			β	161565	35504	4.55				
Commercial Species (Mixed)	49	Log TAGB = *c* + α Log DBH	c	-0.881	0.1101	8.00	95.10	94.90	903.08	8.23
			α	2.580	0.08584	30.05				
		Log TAGB = *c* + α Log WD	c	4.065	0.155	26.23	74.70	74.20	138.76	38.33
			α	6.455	0.548	11.78				
		Log TAGB= c + α Log DBH + β Log WD	c	0.205	0.2047	0.95	97.00	96.90	750.67	3.50
			α	2.08	2.0840	18.59				
			β	1.75	1.7491	5.53				
		TAGB = *c* + α DBH + β DBH^2	c	152.49	80.71	1.89	95.20	95.00	454.86	51.79
			α	-28.764	8.426	3.41				
			β	1.7689	0.1843	9.60				
		TAGB = c + α WD + β WD^2	c	-7	1006	0.01	64.30	62.80	41.47	38.97
			α	-1928	3578	0.54				
			β	5070	3083	1.64				

2013).

The results of establishing allometric equations and their evaluation are shown in Table 4. Based on Table 4, the most appropriate equation to estimate TAGB for each genus is Log(TAGB) = c + α Log(DBH), this model uses only a single predictor, the DBH, and produces a range of prediction values closer

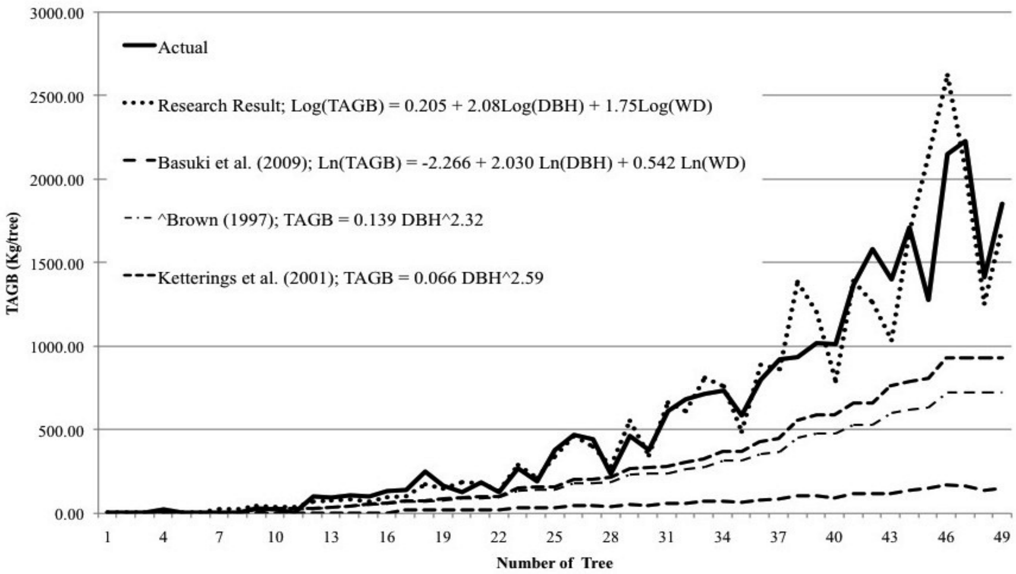

Figure 5. The comparison graph of TAGB estimation values based on published equations

to the upper and lower limits of the observed mean. Wood density is an important factor for estimating the biomass for mixed species, therefore, Log(TAGB) = c + α Log(DBH) + β Log(WD) is the most appropriate equation to estimate total above-ground biomass of mixed commercial species. Further evaluating the allometric model of this mixed commercial species the normal distribution test of the residual is harnessed and the result of this test is showed in Figure 4. Based on this figure, it can be seen that residual points fall near to a straight line in the normal probability plot. According to Fahrmeir et al. (2013), this illustrates that errors during observation are distributed normally in every x-value and the normality of residual assumption is valid.

B. Comparison with Previously Published Equation

From the aspect of model application, allometric equation is specific to certain site and species. Therefore, allometric equation is incomparable for different species and sites, because a different species and site will produce a different tree form and growth rate. But, the structure of the variable and the model form of various allometric equations can be examined to find the highest-level for estimation of the accuracy (Maulana and Asmoro, 2010). In this part, in order to prove that a specific site and species equation will produce the highest estimation accuracy, allometric equation for estimating TAGB of a mixed commercial species from this study is then examined against previously published equations by Basuki et al. (2009), Brown (1997), and Ketterings et al. (2001), as shown in Table 5.

Basuki et al. (2009) developed allometric equations for tropical lowland dipterocarp forest in East Kalimantan. Brown (1997) developed allometric equations for tropical forests using data collected from Kalimantan and other tropical regions. Ketterings et al. (2001) established an allometric equation in mixed secondary forest in Sumatra, but that forest was not classified as Dipterocarp forest. Table 4 shows that the chosen equation in this study has a similar basic form as the other three equations, which were previously published. According to Ketterings et al. (2001), the selection of DBH as independent variable will raise measuring efficiency in the field, and also reduce the uncertainty in the estimation of the result based on established equations. The comparison of estimation value based on equations in Table 5 is shown in Figure 5.

IV. CONCLUSION

Based on data analysis, it can be concluded that the most appropriate equation to estimate TAGB on each genus is Log(TAGB) = c + α Log(DBH), this model uses only a single predictor, the DBH, and produces a range of prediction values closer to the upper and lower limits of the observed mean. Wood density is an important factor for estimating the biomass for mixed species, as a result, Log(TAGB) = c + α Log(DBH) + β Log(WD) is the most appropriate equation to estimate total above-ground biomass of mixed commercial species. Based on the application of the proposed model to the previously published data and the application of the published equation to the current data, it can be concluded that the application of species and site-specific equation must be considered.

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