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The allometric relationships for estimating above-ground biomass and carbon stock in an abandoned traditional garden in East Kalimantan, Indonesia

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Abstract. *Karyati, Widiati KY, Karmini, Mulyadi R. 2021. The allometric relationships for estimating aboveground biomass and carbon stock in an abandoned traditional garden in East Kalimantan, Indonesia. Biodiversitas 22: 751-762.* The existence of traditional gardens after abandonment process has a role based on ecological and economic aspects. To estimate the biomass and carbon stock in the abandoned traditional gardens, specific allometric equations are required. The aim of this study was to develop allometric equations to estimate biomass of plant parts (leaf, branch, trunk, and aboveground biomass (AGB)) through tree dimensions variables (diameter at breast height (DBH), total tree height, and tree bole height). The relationships between stem biomass, AGB and tree dimensions were very strong indicated by the relatively high adjusted R^2 value. The moderately strong relationships were shown between branch biomass and tree dimensions, meanwhile, the relationship between leaf biomass and tree dimensions was very weak. The specific allometric equations for estimating biomass and carbon stocks that are suitable for tree species and/or forest stands at a particular site are very useful for calculating the carbon stocks and sequestration. The appropriate biomass and carbon stock calculation are needed to determine policies related to global climate change.

Keywords: Bukit Pinang area, destructive method, regression, tropics, wood

INTRODUCTION

Sustainable forest management plays an important role in increasing the resilience of ecosystems and communities, optimizing the benefits of trees in the forest to absorb and store carbon, and provide other environmental services (FAO 2016). One of the causes of the increase in secondary forest areas is the use of forests for agricultural purposes (Lanly 1982). Agricultural expansion is the main cause of reduction of forested areas, on the other hand, addition of forested areas may also occur due to natural expansion of forests, e.g., ecological succession of abandoned agricultural land, or through reforestation or afforestation activities (FAO and UNEP 2020). Most of the aboveground biomass (AGB) in tropical forests is stored in tree components. Tree biomass is described as wood volume which is influenced by tree diameter and height, physiognomy, and wood density (Vieira et al. 2008). In addition, tree biomass varies from region to region where its content varies according to species density, climatic factors, and soil properties (Agevi et al. 2017). The difference in aboveground biomass values of a secondary forest area with other areas is due to difference in disturbance and recovery time (Stas 2011).

The application of allometric models to estimate aboveground biomass in tropical forests is required for studying carbon storage and exchange (Vieira et al. 2008). The use of different allometric models will result in variations in the calculation of the amount of biomass in secondary forests. This shows that the allometric model is very specific for location and forest type (Stas 2011). One of the reasons for the formation of secondary forests in abandoned and undisturbed traditional gardens is that they have not been managed by the owner for a long time. The existence of abandoned land with a history of land use after shifting cultivation and traditional gardening has high ecological and economic value (Karyati et al. 2013; Karyati et al. 2018; Karmini et al. 2020a; Karmini et al. 2020b).

Apart from its ecological and economic roles, abandoned land after shifting cultivation in the tropics also has a high potential for carbon sequestration through biomass in tree parts. Several previous studies have built allometric equations to estimate aboveground biomass in secondary forests with mixed types in East Kalimantan Province (Hashimoto et al. 2004; Kiyono and Hastaniah 2005; Basuki et al. 2009). In addition, allometric equations for estimating aboveground biomass on abandoned land formed after shifting cultivation in Kalimantan have already been reported (Karyati et al. 2019a; 2019b). The area of secondary forest that was previously used as traditional gardens and then not properly managed or tends to be abandoned is increasing. These traditional gardens were owned by individuals or local residents and previously planted with various types of fruit trees and multi-purpose tree species (MPTS). However, still limited studies which focused on the allometric equation to estimate above-ground biomass in abandoned traditional garden, the equation for calculating aboveground biomass specifically used for secondary forest on abandoned traditional garden land is deemed necessary. This study aims to develop allometric equations to estimate aboveground biomass and carbon stock in abandoned traditional gardens in the tropics. Information on allometric equations specifically for estimating aboveground biomass and carbon stock in abandoned traditional gardens can be used as consideration and decision-making in the management of the large number of traditional gardens in tropical areas in general, especially East Kalimantan, Indonesia.

MATERIALS AND METHODS

Study site

The study was carried out on abandoned land in Bukit Pinang area, Samarinda Ulu sub-district, Samarinda City, East Kalimantan Province, Indonesia. The study site was an abandoned traditional garden more than 44 years ago.

Traditional garden is defined as land planted with various beneficial trees that can be integrated into forest ecosystems such as fruit and other multi-purpose tree species (MPTS) that are owned and managed by individuals or local residents. The study plot was located at the coordinate points of 0°25′32.8″S 117°05′56.8″E (Figure 1).

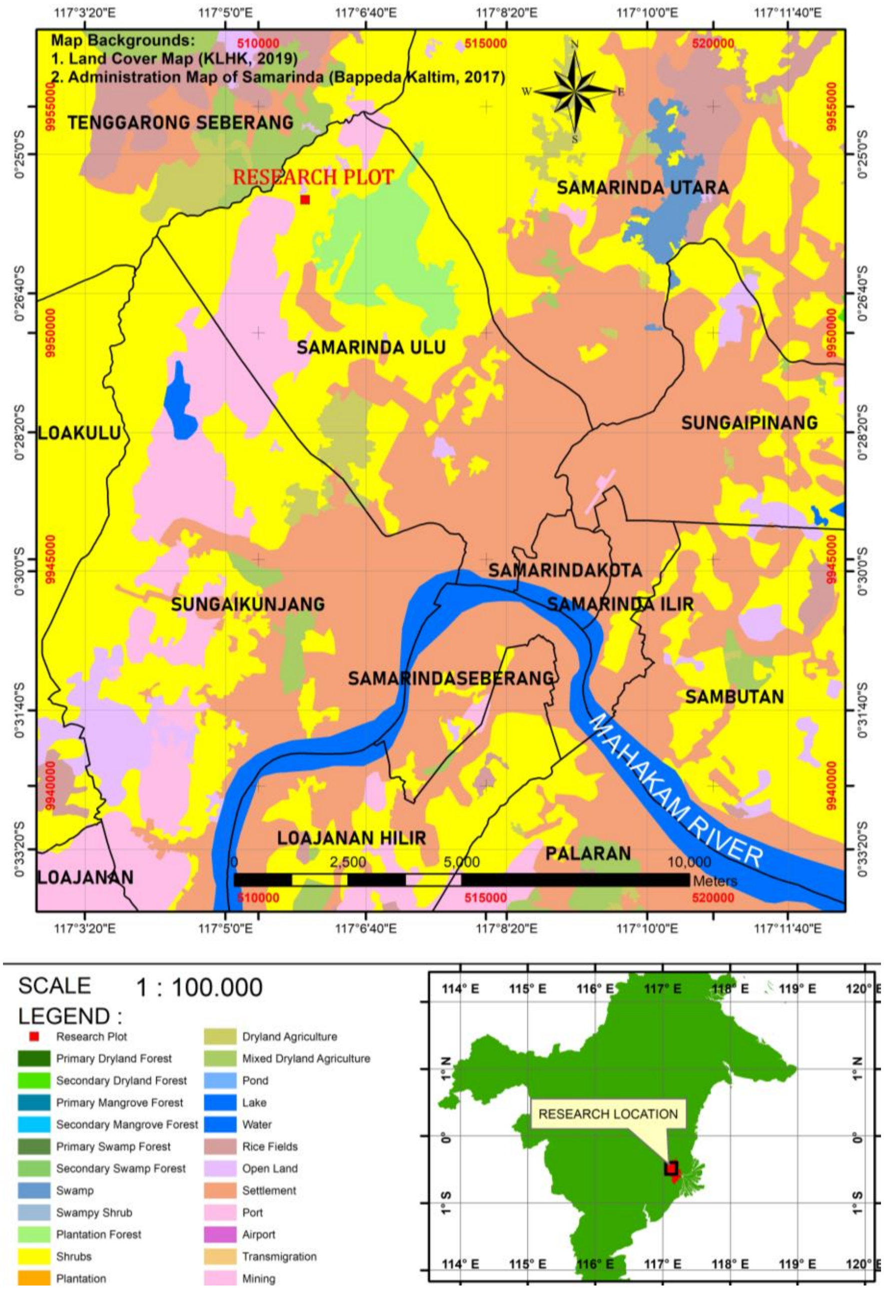

Figure 1. Map of study site in Bukit Pinang area, Samarinda, East Kalimantan Province, Indonesia

The same sites had been studied previously for ecological and economic value (Karmini et al. 2020b). During 20 years (2009-2019), the study site receives average annual 2,306.7 mm year-1 of rainfall, 27.75ºC of average temperature, and 81.64% of average relative humidity (BMKG 2020). A total of 56.51% of the total area of 71,800 ha of Kota Samarinda is included in the slope class of less than 15%, followed by slope class 15- <25% (14.81%), 25-40% (15.67%), and> 40% (13.02%) (BPS Kota Samarinda 2020). According to the Schmidt-Ferguson classification system (1951), the climate of Samarinda City is characterized as type A with Q (Quotient) of 8.9% were very humid area with vegetation of tropical rain forest. The study site is situated approximately 20 km southeast, half an hour drive, from Samarinda City. The previous land-use history was also traditional garden as informed by landowners.

Data collection

Assessment of biomass in the field

A total of 30 tree samples with DBH of > 10 cm were selected to represent species and DBH classes in abandoned traditional garden land (Table 2). The determination of 30 sample trees is considered sufficient to represent the population of the number of trees in the study location to create an allometric regression equation. The number of trees with DBH≥5 cm were 192 trees in the 0.4-hectare research plot (Karmini et al. 2020b). The diameters at breast height (DBH) of standing sample trees were measured using standard diameter tape. The felling of sample trees was done by chainsaw following proper harvesting rules. After the tree had fallen, the measurement of total height and bole height were conducted by using tape. Following the procedure of BSN (2011), the trunk of the fallen trees was divided into several fractions where each fraction measured 1 meter in length. Furthermore, the tree parts were separated into leaves, branches, and trunks

The fresh weight of all fractions of tree parts was weighed using digital balance of precision at least 1 gram at the earliest after felling of the trees in the field. To calculate the dry weight of tree trunks, three samples of 2-5 cm thick stem disks were taken when the felled trees had less than 10 fractions, and four disk samples were taken when there were more than 10 fractions. Further, five samples of branches with a length of 20-30 cm and five samples of leaves weighing 100-300 grams each were collected from each sample tree. For the purposes of measuring the density of wood for each sample tree, samples of stem disks were also taken and fresh weight measured in the field.

Analysis of dry-weight in the laboratory

All samples of stem and branch fractions were dried in an oven in the laboratory at 105ºC for 96 hours until constant weight was achieved. Meanwhile, leaf samples were roasted in an oven at 80ºC for 48 hours until their weight was constant. After drying in the oven, the process of weighing all samples of leaf, branch, and stem fractions was carried out at the earliest using a digital analytical balance of precision of at least 0.01 grams.

Wood density was measured for each disk sample that was taken using the water-displacement method (Bowyer et al. 2003; Chave 2006). The saturated volume of each sample was measured using a container filled with water and weighed using a digital scale that had a precision of at least 0.01 grams. Weighing of oven-dried sample was carried out by drying the sample in a well-ventilated oven at 105ºC for 48-72 hours until it reached a constant weight.

Data analysis

The wood density of each disk sample was determined using the formula (Bowyer et al. 2003; Chave 2006; Marklund 1986):

$$WD = dw / V \quad [1]$$

Where: WD = wood density (g cm^{-3});

The total oven-dry weight of each tree parts was measured using the following formula (Hairiah et al. 2001; Hairiah & Rahayu 2007; BSN2011):

$$dw = (sdw \times fw) / sfw \quad [2]$$

Where: dw = total dry weight (kg); V = saturated volume (cm^3); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of the sample (g).

The three selected allometric equations of AGB were tested (Equations 3-4):

$$y = ax^b \quad [3]$$

$$(\ln y) = a + b (\ln x) \quad [4]$$

Where: y = total dry weight or biomass of each plant part, such as trunk, branch, leaf, and aboveground biomass (AGB) (kg); x = diameter at breast height (DBH, cm), tree total height (Ht, meter), tree bole height (Hb, meter), and ($DBH^2 \times H$) (cm^2 m); ‘a’ and ‘b’ = coefficients estimated by regression.

Regression analysis was carried out using SPSS version 18 for windows (SPSS Japan, Tokyo, Japan). The evaluation of precision among all tested allometric equations was determined by R^2 value and *P*-value. The best regression was selected based on the goodness of fit with focusing on the suitable scatter plot, good *P*-value, the high value of adjusted R^2, and the smallest root mean squared error (RMSE0 among two tested regressions.

Accumulation of carbon stock was estimated using the following formula (IPPC 2008):

$$\text{Carbon stock} = AGB \times 0.47 \quad [5]$$

RESULTS AND DISCUSSION

Selected samples of trees

The distributions of DBH classes, total height classes, bole height classes, and wood density classes of sample trees to developed allometric equations are illustrated in Figure 2 and Table 2. 10, 8 and 7 number of sample trees had DBH class distribution in the range of 15.1-20.0 cm, 10.0-15.0 cm, and 25.1-30.0 cm were 10, 8, and 7 trees, respectively. While, 3 and 2 sample trees were belonging to DBH classes of 20.1-25.0 cm and $\geq$30.0 cm respectively. The number of selected trees was dominated by total height class 10.1-15.0 m (11 trees), followed by total height class 5.0-10.0 m (10 trees) and $\geq$15.0 m (9 trees). The bole height class was distributed into three classes, i.e., 5.1-8.0 m (12 trees), $\geq$8.0 m (10 trees), and 2.0-5.0 m (8 trees). The wood density classes of the sample trees were divided into 0.4-0.6 cm g^{-3} (20 trees), 0.3-0.4 cm g^{-3} (8 trees), and $\geq$0.60 cm g^{-3} (2 trees). The relationships between DBH-total height and DBH-bole height of sample trees which were developed into allometric equations were illustrated in Figure 3.

The increase in DBH (cm) of sample trees was followed by an increase in total height and bole height as described in Figure 3.The relationship between DBH and total height was explained by the equation "Ht=0.3658(DBH)+4.9457" (n=30), while the relationship between DBH and bole height was "Hb=0.0975(DBH)+4.5065" (n=30), where, Ht = total height (m) and Hb = bole height (m).

The largest number of sample trees was in the diameter distribution class (15.1-20.0 cm), the total height class (10.1-15.0 m), the bole height class (5.1-8.0 m), and wood density (0.40-0.60 g cm-3). In general, the larger the tree size both in diameter and height, the aboveground biomass and individual carbon stocks tend to be higher. There is a positive correlation between tree height and aboveground biomass as well as the relationship between height and diameter of trees and lianas in early succession (Selaya et al. 2007). The amount of carbon sequestrated in forests changes constantly according to growth, mortality, vegetation decomposition (Gorte 2007), species composition, age structure, and forest health (Harmon et al. 1990). Conversely, wood basic density is not a significant predictor of AGB in species-specific models, implying that the variation in wood basic density within a species is narrow (Tetemke et al. 2019).

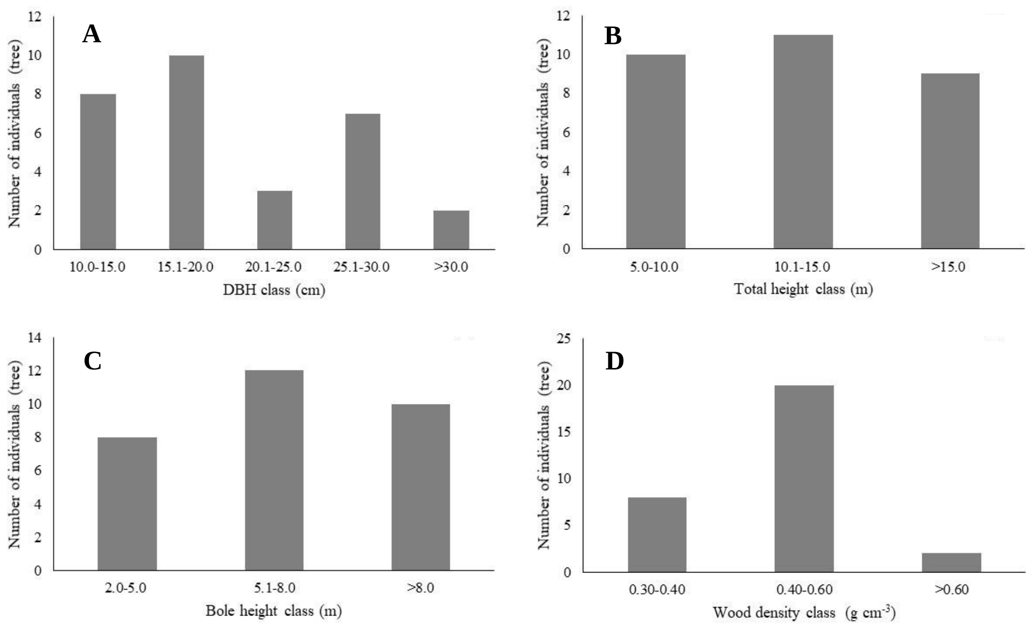

Figure 2. The distributions of (A) DBH classes, (B) total height classes, (C) bole height classes, (D) wood density classes of sampled trees

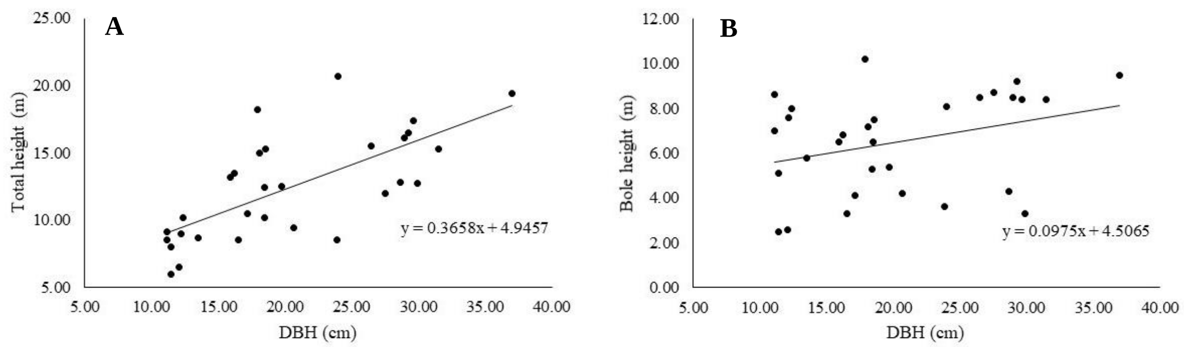

Figure 3. The relationship between (A) DBH and total height, (B) DBH and bole height of sampled trees

Tree variables

The biomass of leaves, branches, stems, and AGB of the selected sample trees ranged from 3.32-24.07 kg, 6.57-50.65 kg, 18.47-146.17 kg, and 28.83-216.99 kg respectively. The selected sample trees had a DBH range of 11.14-37.00 cm, a total height of 6.00-20.70 m, a bole height of 2.5-10.20 m, and a wood density of 0.30-0.77 g cm^{-3}. The Pearson's correlation coefficients between DBH, total height, bole height, wood density, and leaves biomass, branches biomass, trunk biomass, AGB, and parameters of destructive biomass are summarized in Table 1. All biomass of tree parts (leaves, branches, trunk, and total biomass) had a strong correlation with DBH (P<0.01). In line with these results, branch, trunk, and AGB also strongly correlated with total tree height (P<0.01), except that there was no correlation between leaf biomass and tree total height.

The results showed that there was no correlation between the biomass of all tree parts (leaves, branches, stems, and total biomass) on bole height and wood density. The relationship between tree parameters showed that the correlation between DBH - total height and total height - bole height was very strong (P<0.01).

Following Karmini et al. (2020b) the sample tree species (both dominant and rare) sampled to develop allometric equation were selected in terms of Importance Value Index (IVI). The basis for selection was also based on the representation of the DBH distribution. Thirty selected tree samples included 13 species from 10 genera from 8 different families. The four sample trees were *Trema orientalis* (Cannabaceae) as presented in Table 2. Three sample trees each belonged to *Vernonia arborea* (Asteraceae), *Macaranga tanarius* (Euphorbiaceae), *Artocarpus lacucha* (Moraceae), and *Artocarpus odoratissimus* (Moraceae). The trees of *Oroxylum indicum* (Bignoniaceae), *Eusideroxylon zwageri* (Lauraceae), *Artocarpus tamaran* (Moraceae), *Baccaurea parvifolia* (Phyllanthaceae), and Glochidion obscurum (Pyllenthaceae) were selected two sample trees each, respectively. Four other species, namely *Macaranga gigantea* (Euphorbiaceae), *Mallotus paniculatus* (Euphorbiaceae), *Cratoxylum arborescens* (Hypericaceae), and *Artocarpus anisophyllus* (Moraceae) were selected for one sample tree each.

The different tree species tend to cause differences in tree structure and physiognomy in terms of growth, stratification, and canopy cover (Karyati et al. 2019b), leading to differences in the tree biomass (tree parts/ total). The difference in biomass is also indicated by different tree individuals from the same species. The largest sample tree (*Artocarpus anisophyllus*) with DBH of 37.00 cm had the largest trunk biomass (146.17 kg) and AGB (216.99 kg) as well. On the other hand, *Macaranga tanarius* with DBH of 11.14 cm was the smallest sample tree having the smallest biomass of leaves (3.32 kg) and branches (6.57 kg) among the sampled trees. In addition, the smallest trunk biomass (18.47 kg) and AGB (28.83 kg) were observed from *Oroxylum anisophyllus* with DBH 11.14 as well. The highest total height (20.70 m) and bole height (10.20 m) were measured from two sample trees *Trema orientalis* with DBH of 24.00 cm and 17.92 cm, respectively. *Eusideroxylon zwageri* with DBH 11.46 cm was the shortest tree based on total height and bole height. The largest leaf biomass (24.07 kg) was from the sample trees *Artocarpus lacucha* (DBH of 29.28 cm), while the largest branch biomass (50.65 kg) was measured from *Artocarpus tamaran* (DBH of 31.50 cm).

The developed allometric equations

The developed allometric equations for predicting plant part biomass of subject trees in the study plot are shown in Table 3. The results of the regression analysis on tree dimensions such as DBH, (DBH^2×Ht), (DBH^2×Hb), Ht, and Hb as independent variables and leaf dry biomass as the dependent variable using the three tested equations showed very weak correlation. The relationship between DBH, (DBH^2×Ht), and (DBH^2×Hb) to leaf dry biomass was very significant (P <0.01) and significant (P<0.05), except the relationship between (DBH^2×Hb) and leaf dry biomass (P>0.05). Meanwhile, the relationship between Ht and Hb to leaf dry biomass was not significant (P>0.05). Testing between tree and leaf dry biomass dimensions with exponential ($y = ax^b$) and log-linear ($\ln y = a + b.\ln x$) equations showed the adjusted R^2 value of less than 0.198.

Table 1. Results of Pearson's correlation between DBH, total height, bole height, wood density and leaves biomass, branches biomass, trunk biomass, AGB, and parameters of destructive biomass. ns = not significant at the 0.05 level (P>0.05); * and ** = correlation significant at the 0.05 and 0.01 level (2-tailed) respectively

	Pearson's correlation (n=30)				Mean	Standard deviation	Range
	DBH (cm)	Total height (m)	Bole height (m)	Wood density (g cm^{-3})			
Leaf biomass (kg)	0.518**	0.286^{ns}	0.001^{ns}	-0.154^{ns}	9.40	6.50	3.32 – 24.07
Branch biomass (kg)	0.784**	0.529**	0.077^{ns}	-0.080^{ns}	27.26	13.65	6.57 – 50.65
Trunk biomass (kg)	0.911**	0.579**	0.316^{ns}	-0.176^{ns}	72.48	45.40	18.47 – 146.17
AGB (kg)	0.904**	0.577**	0.252^{ns}	-0.165^{ns}	109.14	61.30	28.83 – 216.99
DBH (cm)	1	0.690**	0.323^{ns}	-0.275^{ns}	20.34	7.36	11.14 - 37.00
Total height (m)	0.690**	1	0.703**	-0.398*	12.39	3.90	6.00 - 20.70
Bole height (m)	0.323^{ns}	0.703**	1	-0.418*	6.49	2.22	2.50 – 10.20
Wood density (g cm^{-3})	-0.275^{ns}	-0.398*	-0.418*	1	0.47	0.10	0.30 - 0.77

Table 2. Dataset of biomass, density, and tree dimension variables derived from sampled trees in abandoned traditional garden

Tree no.	Species	Family	DBH (cm)	Total height (m)	Bole height (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	AGB (kg)	WD (g cm^{-3})
1	*Artocarpus tamaran*	Moraceae	12.41	10.20	8.00	3.38	6.60	22.70	32.68	0.38
2	*Trema orientalis*	Cannabaceae	29.67	17.40	8.40	6.29	36.85	127.51	170.65	0.44
3	*Trema orientalis*	Cannabaceae	17.92	18.20	10.20	8.75	18.88	56.52	84.15	0.41
4	*Macaranga tanarius*	Euphorbiaceae	11.14	8.50	7.00	3.32	6.57	39.28	49.18	0.51
5	*Macaranga tanarius*	Euphorbiaceae	13.53	8.70	5.80	3.91	19.73	37.74	61.39	0.49
6	*Trema orientalis*	Cannabaceae	18.56	15.30	7.50	3.72	29.91	51.68	85.31	0.46
7	*Trema orientalis*	Cannabaceae	24.00	20.70	8.10	9.11	31.38	93.29	133.79	0.56
8	*Macaranga tanarius*	Euphorbiaceae	12.20	9.00	7.60	4.45	8.50	22.11	35.05	0.55
9	*Mallotus paniculatus*	Euphorbiaceae	18.50	12.40	6.50	6.09	24.13	37.93	68.15	0.51
10	*Artocarpus tamaran*	Moraceae	31.50	15.30	8.38	3.40	50.65	144.02	198.07	0.48
11	*Oroxylum indicum*	Bignoniaceae	16.23	13.50	6.80	4.02	8.94	28.64	41.59	0.46
12	*Oroxylum indicum*	Bignoniaceae	11.14	9.10	8.60	3.56	6.80	18.47	28.83	0.46
13	*Artocarpus anisophyllus*	Moraceae	37.00	19.40	9.50	24.05	46.77	146.17	216.99	0.47
14	*Artocarpus odoratissimus*	Moraceae	23.87	8.50	3.60	18.50	29.71	76.98	125.18	0.48
15	*Artocarpus odoratissimus*	Moraceae	16.55	8.50	3.30	17.80	27.56	53.07	98.43	0.45
16	*Artocarpus odoratissimus*	Moraceae	11.46	8.00	5.10	3.43	7.96	19.89	31.27	0.39
17	*Vernonia arborea*	Asteraceae	19.74	12.50	5.40	9.85	48.40	77.52	135.77	0.51
18	*Vernonia arborea*	Asteraceae	28.65	12.80	4.30	4.96	29.19	71.04	105.19	0.54
19	*Vernonia arborea*	Asteraceae	17.19	10.50	4.10	4.77	20.76	38.97	64.50	0.56
20	*Cratoxylum arborescens*	Hypericaceae	20.69	9.40	4.20	9.83	32.93	97.96	140.72	0.54
21	*Baccaurea parvifolia*	Phyllanthaceae	18.14	15.00	7.20	8.09	37.55	51.29	96.93	0.36
22	*Artocarpus lacucha*	Moraceae	29.28	16.50	9.20	24.07	48.26	143.03	215.36	0.39
23	*Artocarpus lacucha*	Moraceae	28.97	16.10	8.50	21.04	41.23	140.98	203.25	0.38
24	*Artocarpus lacucha*	Moraceae	26.48	15.50	8.50	16.92	38.29	134.66	189.87	0.40
25	*Baccaurea parvifolia*	Phyllanthaceae	15.92	13.20	6.50	10.95	23.48	32.75	67.18	0.31
26	*Glochidion obscurum*	Phyllanthaceae	27.53	12.00	8.70	4.19	26.70	141.81	172.70	0.49
27	*Eusideroxylon zwageri*	Lauraceae	11.46	6.00	2.50	10.40	26.40	47.24	84.04	0.72
28	*Eusideroxylon zwageri*	Lauraceae	12.10	6.50	2.60	12.48	28.12	50.95	91.55	0.77
29	*Macaranga gigantea*	Euphorbiaceae	29.92	12.70	3.30	15.34	43.12	134.97	193.43	0.30
30	*Glochidion obscurum*	Phyllanthaceae	18.46	10.20	5.30	5.49	12.31	35.26	53.06	0.41
	Total		610.21	371.60	194.68	282.15	817.70	2174.42	3274.27	14.19
	Average		20.34	12.39	6.49	9.40	27.26	72.48	109.14	0.47
	Minimum		11.14	6.00	2.50	3.32	6.57	18.47	28.83	0.30
	Maximum		37.00	20.70	10.20	24.07	50.65	146.17	216.99	0.77
	Standard deviation		7.36	3.90	2.22	6.50	13.65	45.40	61.30	0.10

Note: DBH: diameter at breast height; AGB: aboveground biomass; WD: wood density

The relationships between tree dimensions and branch dry biomass were very significant (P<0.001 and P<0.01), except the relationship between Hb and branch dry biomass, was not significant (P>0.05). The correlation between tree dimensions and branch dry biomass had the highest adjusted R^2 values of 0.526 and 0.571 for exponential and log-linear equations. Similarly, there were very significant relationships between DBH, (DBH^2×Ht), and (DBH^2×Hb) to trunk dry biomass (P<0.001) as well as the relationship between Ht and trunk dry biomass (P<0.01). In contrast, there was no significant relationship between Hb and trunk dry biomass (P>0.05). The correlations between DBH (DBH^2×Ht), and (DBH^2×Hb) to trunk dry biomass by using two tested equations showed high values of adjusted R^2 (0.579-0.783 for exponential equations and 0.563-0.782 for log-linear equations).

The regression analysis between DBH, (DBH^2×Ht), and (DBH^2×Hb) to AGB showed very significant relationships (P<0.001) with high adjusted R^2 values. The relationships between DBH and AGB using two tested regression equations had adjusted R^2 values ranging from 0.733 to 0.748. The adjusted R^2 values for the relationship between (DBH^2×Ht) and AGB ranged from 0.579 to 0.651. The adjusted R^2 ranged between 0.492-0.515 was analyzed for the relationships between (DBH^2×Hb) and AGB. Although the relationships between Ht and AGB were very significant (P<0.01), but these relationships had very low adjusted R^2 (0.253-0.280). However, there was no significant relationship between Hb and AGB (P>0.05).

The best selected allometric equations

From all the regression analysis results that have been tested, the best allometric equations are selected in terms of P value (<0.001), adjusted R^2 (>0.400), and the smallest root mean squared error (RMSE). The selected allometric equations for predicting plant part biomass of subject trees in the study plot were presented in bold figures in Table 3. Two equations were selected for the relationship between tree dimensions and branch dry biomass. These two equations are "(branch dry biomass)=6.121×$DBH^{0.065}$ (P<0.001; adjusted R^2=0.526; RMSE=4.454) and "ln(branch dry biomass)=0.813-0.472×ln(DBH^2×Ht)"

(P<0.001; adjusted R^2=0.500; RMSE=5.216).A total of three allometric equations were selected to estimate trunk dry biomass using tree dimensions as well as the relationship between AGB and tree dimensions. These selected equations describes relationships between DBH and trunk dry biomass had the high adjusted R^2 such as "(trunk dry biomass) =11.458×(DBH)$^{0.081}$" (P<0.001; adjusted R^2=0.783; RMSE=7.611), "(trunk dry biomass) = 32.989×(DBH^2×Ht)$^{0.001}$" (P<0.001; adjusted R^2=0.628; RMSE = 6.262), and "(trunk dry biomass) = 33.932×(DBH^2×Hb)$^{0.001}$ (P<0.001; adjusted R^2=0.579; RMSE = 6.188).

Table 3. The allometric equations for predicting plant part biomass of subject trees in the study plot; best-selected equations (P<0.001), adjusted R^2 (>0.400), and the smallest root mean squared error (RMSE) are indicated in bold

Dependent variable (y)	Independent variable (x)	Equations	
		$y = ax^b$	(ln y) = a + b (ln x)
Leaf dry biomass (kg)	DBH (cm)	$y = 3.211\ x^{0.042}$ (P<0.01; Adj R^2=0.190; RMSE=2.402)	ln y = 0.518 – 0.862 ln x (P<0.01; Adj R^2=0.198; RMSE=3.044)
	(DBH^2×Ht) (cm^{2}m)	$y = 5.485\ x^{0.046}$ (P<0.05; Adj R^2=0.169; RMSE=1.157)	ln y = 0.340 – 0.283 ln x (P<0.05; Adj R^2=0.149; RMSE=3.044)
	(DBH^2×Hb) (cm^{2}m)	$y = 5.774\ x^{0.001}$ (P<0.05; Adj R^2=0.112; RMSE=1.894)	ln y = 0.396 + 0.211 ln x (P>0.05; Adj R^2=0.054; RMSE=1.313)
	Ht (m)	$y = 4.262\ x^{0.046}$ (P>0.05; Adj R^2=0.041; RMSE=2.152)	ln y = 0.908 + 0.452 ln x (P>0.05; Adj R^2=0.015; RMSE=17.127)
	Hb (m)	$y = 9.248\ x^{-0.031}$ (P>0.05; Adj R^2=-0.025; RMSE=0.811)	ln y = 2.578 – 0.308 ln x (P>0.05; Adj R^2=0.000; RMSE=1.336)
Branch dry biomass (kg)	DBH (cm)	**$y = 6.121\ x^{0.065}$ (P<0.001; Adj R^2=0.526; RMSE=4.454)**	ln y = 0.883 – 1.363 ln x (P<0.001; Adj R^2=0.571; RMSE=5.216)
	(DBH^2×Ht) (cm^{2}m)	$y = 14.616\ x^{0.001}$ (P<0.001; Adj R^2=0.389; RMSE=3.538)	**ln y = 0.813 – 0.472 ln x (P<0.001; Adj R^2=0.500; RMSE=5.216)**
	(DBH^2×Hb) (cm^{2}m)	$y = 15.389\ x^{0.001}$ (P<0.01; Adj R^2=0.305; RMSE=3.428)	ln y = 0.034 + 0.403 ln x (P<0.01; Adj R^2=0.303; RMSE=1.629)
	Ht (m)	$y = 14.616\ x^{0.001}$ (P<0.001; Adj R^2=0.389; RMSE=3.550)	ln y = 0.806 + 0.945 ln x (P<0.01; Adj R^2=0.194; RMSE-1.780)
	Hb (m)	$y = 24.05\ x^{-0.009}$ (P>0.05; Adj R^2=0.035; RMSE=1.896)	ln y = 3.366 – 0.127 ln x (P>0.05; Adj R^2=-0.029; RMSE=2.046)
Trunk dry biomass (kg)	DBH (cm)	**$y = 11.458\ x^{0.081}$ (P<0.001; Adj R^2=0.783; RMSE=7.611)**	ln y = 0.697 – 1.619 ln x (P<0.001; Adj R^2=0.782; RMSE=8.512)
	(DBH^2×Ht) (cm^{2}m)	**$y = 32.989\ x^{0.001}$ (P<0.001; Adj R^2=0.628; RMSE=6.262)**	ln y = 0.619 – 0.562 ln x (P<0.001; Adj R^2=0.687; RMSE=8.512)
	(DBH^2×Hb) (cm^{2}m)	**$y = 33.932\ x^{0.001}$ (P<0.001; Adj R^2=0.579; RMSE=6.188)**	ln y = 0.145 – 0.549 ln x (P<0.001; Adj R^2=0.563; RMSE=8.512)
	Ht (m)	$y = 17.636\ x^{0.098}$ (P<0.01; Adj R^2=0.301; RMSE=7.072)	ln y = 1.295 + 1.128 ln x (P<0.01; Adj R^2=0.278; RMSE=3.105)
	Hb (m)	$y = 40.192\ x^{0.059}$ (P>0.05; Adj R^2=0.005; RMSE=5.270)	ln y = 3.669 + 0.227 ln x (P>0.05; Adj R^2=-0.016; RMSE=3.638)
Aboveground biomass (kg)	DBH (cm)	$y = 20.523\ x^{0.074}$ (P<0.001; Adj R^2=0.733; RMSE=9.144)	**ln y = 0.117 + 1.492 ln x (P<0.001; Adj R^2=0.748; RMSE=1.963)**
	(DBH^2×Ht) (cm^{2}m)	$y =54.088\ x^{0.001}$ (P<0.001; Adj R^2=0.579; RMSE=7.389)	**ln y = 0.207 + 0.515 ln x (P<0.001; Adj R^2=0.651; RMSE=2.447)**
	(DBH^2×Hb) (cm^{2}m)	$y =55.927\ x^{0.001}$ (P<0.001; Adj R^2=0.515; RMSE=7.265)	**ln y = 0.788 + 0.485 ln x (P<0.001; Adj R^2=0.492; RMSE=2.809)**
	Ht (m)	$y = 30.480\ x^{0.089}$ (P<0.01; Adj R^2=0.280; RMSE=8.436)	ln y = 2.002 + 1.020 ln x (P<0.01; Adj R^2=0.253; RMSE=3.550)
	Hb (m)	$y = 72.981\ x^{0.035}$ (P>0.05; Adj R^2=0.020; RMSE=5.604)	ln y = 4.346 + 0.096 ln x (P>0.05; Adj R^2=-0.032; RMSE=4.165)

Note: P values of the regression analysis are shown, R^2 coefficient of determination, DBH: diameter at breast height, Ht: total tree height, Hb: bole tree height, RMSE root mean squared error

The best recommended allometric equations between the tree dimensions and AGB "ln(AGB)=1.492×ln(DBH)+ 0.117" ($P<0.001$; adjusted $R^2=0.748$; RMSE=1.963), "ln(AGB)=0.515×ln(DBH^2×Ht)+0.207" ($P<0.001$; adjusted $R^2=0.651$; RMSE=2.447), and "ln(AGB)=0.485×ln(DBH^2×Hb)+ 0.788" ($P<0.001$; adjusted $R^2=0.492$; RMSE=2.809). The significant correlations showed by mixed-species allometric equations that related AGB and diameter at stump height ($R^2=0.78$; $P<0.01$) and tree height ($R^2=0.41$, $P<0.05$) (Mokria et al. 2018). The strong correlations (adjusted R^2= 0.59-0.95) were showed by relationships between trunk dry biomass and AGB with diameter at breast height (DBH) and height in the different age secondary forests (5, 10, and 20 years after abandonment). The correlations between leaf and branch dry biomass with height were relatively weak (adjusted R^2=0.36-0.50) (Karyati et al. 2019a). The very weak relationships between leaves and branches dry biomass of trees and plant dimensions were reported in the abandoned land after shifting cultivation. The developed allometric equations showed relatively low R^2 (<0.60) (Karyati et al. 2019b).

The allometric equation which was constructed to estimate the biomass of plant parts in secondary forest is thought to be due to the various types of plants that grow. Differences in plant species and individuals tend to cause differences in plant structure and physiognomy. The carbon content varies greatly between species and between individual trees (Lamlom and Savidge 2003). The growth of different tree species varies at the level of certain species and characters based on site conditions (Parlucha 2017). The regression between the trunk biomass and tree dimensions by using exponential and natural logarithm equations was illustrated in Figure 4. Figure 5 illustrated regression between the total aboveground biomass and tree dimensions by using exponential and natural logarithm equations.

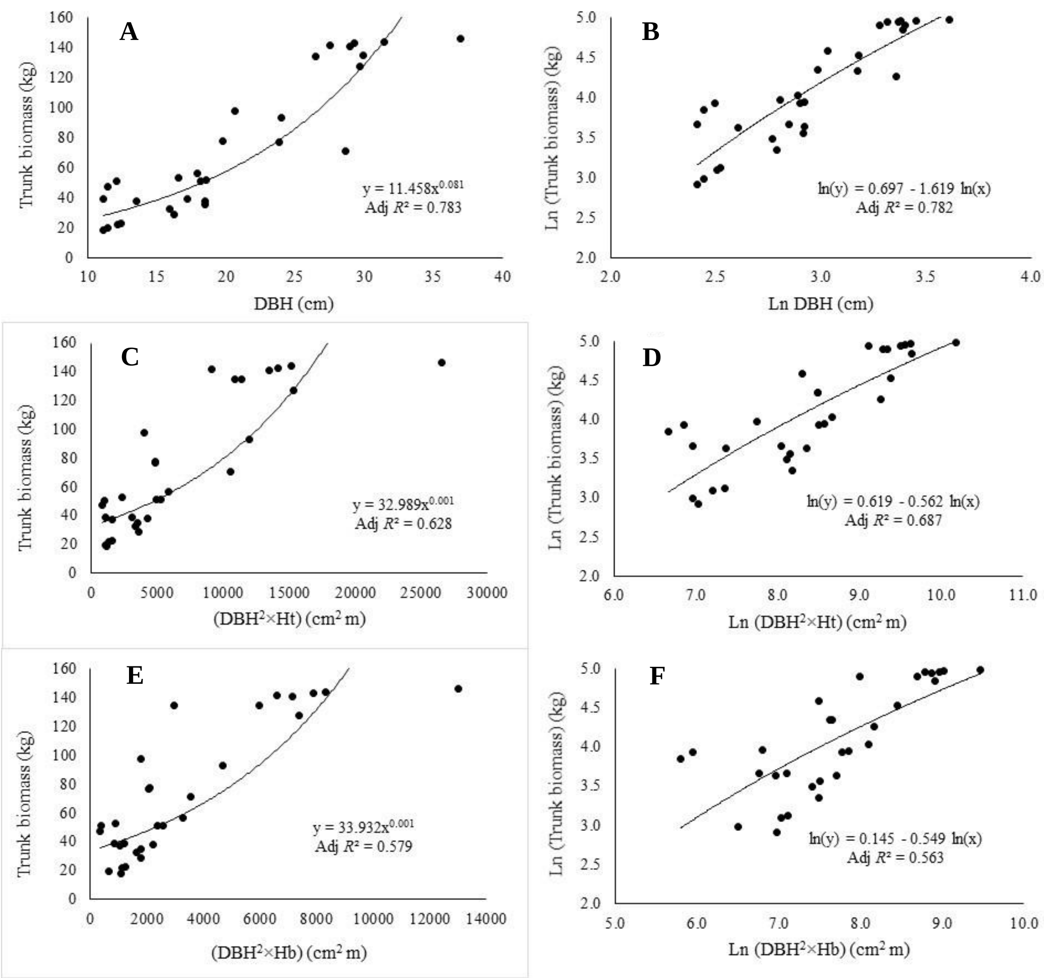

Figure 4. Regression between the trunk biomass (kg) and DBH (cm) (a-b); the product of square DBH and total height (cm^2 m) (c-d) and the product of square DBH and bole height (cm^2 m) (e-f) by using exponential and natural logarithm's equations

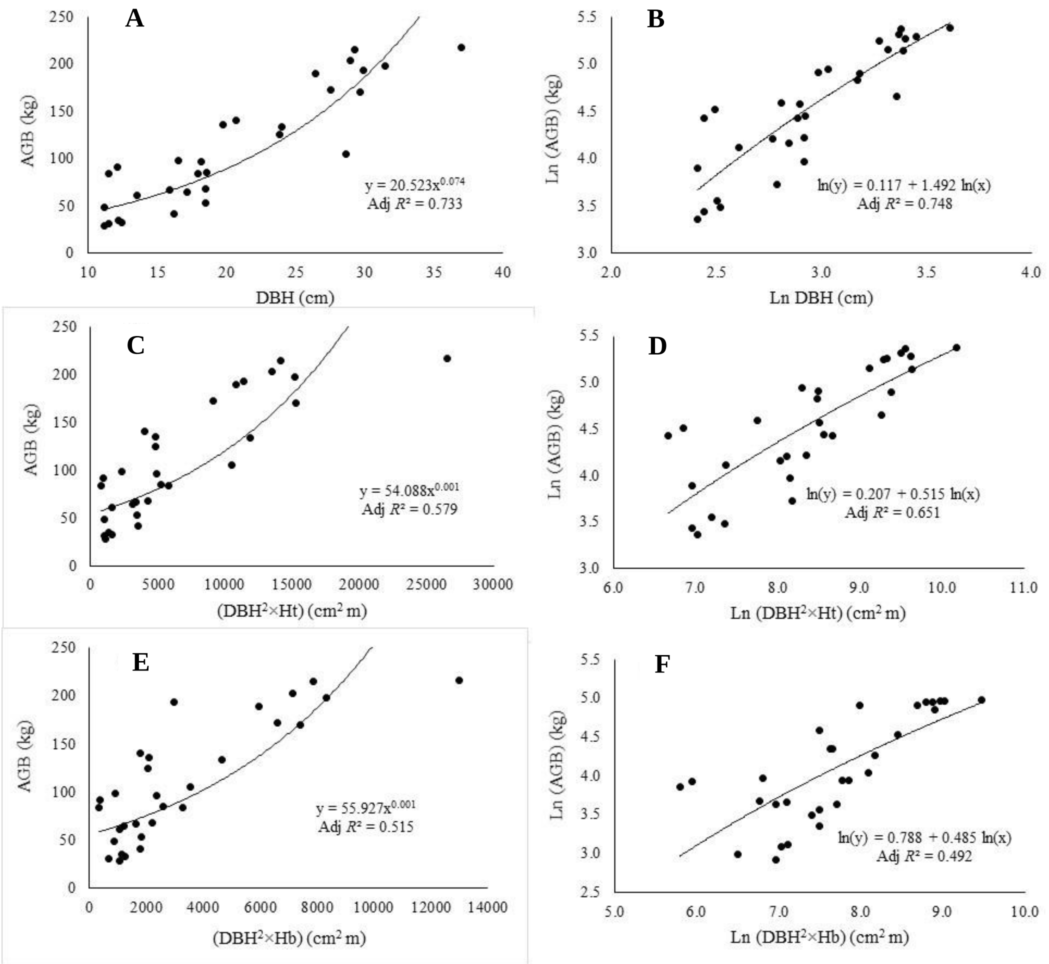

Figure 5. Regression between the aboveground biomass (AGB) (kg) and DBH (cm) (a-b); the product of square DBH and total height (cm^2 m) (c-d) and the product of square DBH and bole height (cm^2 m) (e-f) by using exponential and natural logarithm's equations

Comparison among various allometric equations

The estimation of AGB and carbon stock using various reported relationships in the study plot is presented in Table 4. The AGB estimation using two selected allometric equations in the study location ranged from 29.98 to 30.30 Megagram per hectare (Mg ha^{-1}), while the carbon stock range was 14.09-14.24 Mg ha^{-1}. The large AGB (30.30 Mg ha^{-1}) and carbon stock (14.24 Mg ha^{-1}) were estimated using log-linear equations with (DBH^2×Ht) as predictor variables for AGB. The other selected log-linear allometric equation also estimates relatively high AGB and carbon stock. This equation applied DBH as predictor of AGB. The use of (DBH^2×Ht) as the independent variable estimates AGB and stock carbon of 30.30 and 14.24 Mg ha^{-1}. Meanwhile the estimation of AGB through DBH in the log-linear equation yields AGB of 29.98 Mg ha^{-1} and carbon stock of 14.09 Mg ha^{-1}.

Generally, the estimation of AGB and carbon stock use the selected developed allometric equations is lower than the estimation using the previously reported equations of Chambers et al. (2001) (87.55 and 41.15 Mg ha^{-1}), Manuri et al. (2017) (67.02 and 31.50 Mg ha^{-1}), and Kiyono and Hastaniah (2005) (61.18 and 28.75 Mg ha^{-1}). The application of equations of Nelson et al. (1999), Kenzo et al. (2009b), Kettering et al. (2001), Sierra et al. (2007), and Karyati et al. (2019a) also estimate higher AGB and carbon stock compared to using the selected equations. The use of these equations estimates AGB and stock carbon of (57.84 and 27.18 Mg ha^{-1}), (51.82 and 24.36 Mg ha^{-1}), (47.36 and 22.26 Mg ha^{-1}), (47.03 and 22.10 Mg ha^{-1}), and (48.36 and 22.73 Mg ha^{-1}), respectively.

The estimation of AGB and carbon stock using the selected allometric equation yields similar values with using equations of Hashimoto et al. (2004) and Kenzo et al. (2009a). The equation of Hashimoto et al. (2004) estimates AGB of 37.66 Mg ha^{-1} and stock carbon of 17.70 Mg ha^{-1}. Meanwhile, AGB (37.24 Mg ha^{-1}) and carbon stock (17.50 Mg ha^{-1}) were estimated using Kenzo et al. (2009a). However, the application of the selected equations estimated the higher AGB and stock carbon than using Karyati et al. (2019b)'s equation (AGB of 14.03 Mg ha^{-1} and stock carbon of 6.59 Mg ha^{-1}). The comparison among various allometric relationships between AGB and DBH estimated in the study plot was illustrated in Figure 6.

Table 4. Estimation of AGB and carbon stock for trees using various reported relationships, with reference to the current study plot

Equation	Author	Estimate of AGB ($Mg\ ha^{-1}$)	Estimate of C stock ($Mg\ ha^{-1}$)
ln(AGB)=2.413×ln(DBH)-1.997	Nelson et al. (1999)	57.84	27.18
ln(AGB)=2.55×ln(DBH)-2.010	Chambers et al. (2001)	87.55	41.15
ln(AGB)=2.59×ln(DBH)-2.75	Kettering et al. (2001)	47.36	22.26
ln(AGB)=2.44×ln(DBH)-2.51	Hashimoto et al. (2004)	37.66	17.70
ln(AGB)=2.422×ln(DBH)-2.232	Sierra et al. (2007)	47.03	22.10
$AGB=0.1008 \times DBH^{2.5264}$	Kiyono and Hastaniah (2005)	61.18	28.75
$AGB=0.0829 \times DBH^{2.43}$	Kenzo et al. (2009a)	37.24	17.50
$AGB=0.1525 \times DBH^{2.34}$	Kenzo et al. (2009b)	51.82	24.36
$AGB=0.071 \times DBH^{2.667}$	Manuri et al. (2017)	67.02	31.50
ln(AGB)=2.3207×ln(DBH)-1.89	Karyati et al. (2019a)	48.36	22.73
ln(AGB)=0.808×ln(DBH)+1.277	Karyati et al. (2019b)	14.03	6.59
Current study plot			
ln(AGB)=1.492×ln(DBH)+0.117		29.98	14.09
$\ln(AGB)=0.515 \times \ln(DBH^2 \times Ht)+0.207$		30.30	14.24

Note: AGB = aboveground biomass; C = carbon ; DBH = diameter at breast height (cm) ; Ht = total height (m)

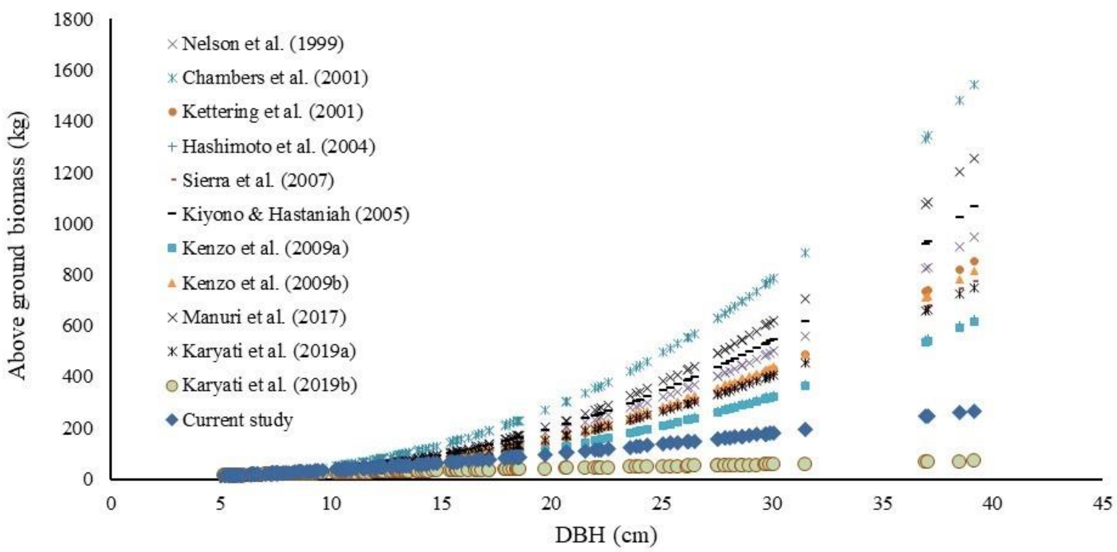

Figure 6. Comparison among various allometric relationships between aboveground biomass (AGB) and diameter at breast height (DBH) in the study site

The use of several previously reported allometric equations estimated the higher biomass and carbon stock than using developed allometric equations in the study site. This may be related to variation of wood density of the sample trees. The wood density is a basic property of woody plants which are important for demonstrating ecological characteristics and performance in plant communities. The wood density also determines tree and forest biomass in carbon cycle studies (Vieilledent 2018). The variation of sample trees tends to cause variation of wood density. The wood density of sample trees ranged from 0.30 to 0.77 cm g^{-3}. Most of the tree samples had a low wood density, which was less than 0.56 cm g^{-3}, except for two samples of *Eusideroxylon zwageri* having a density of 0.72 and 0.77 cm g^{-3} respectively (Table 2). The low wood density of tree species may differ in allometric equations significantly (Hashimoto et al. 2004).

The application of Hashimoto et al. (2004) and Kenzo et al. (2009a)'s equations estimate the similar AGB and carbon stock using the developed allometric equation. The wood density of sample trees used to develop Kenzo et al. (2009a)'s equations was 0.35 cm g^{-3}. Meanwhile, the wood densities of sample trees in Basuki et al.'s equation (2009), and Kiyono and Hastaniah's equation (2005) were 0.40-0.79 cm g^{-3}, 0.32-0.86 cm g^{-3}, and 0.67 cm g^{-3}, respectively. The allometric equation for mixed species in the tropical forest of Kalimantan reported by Kenzo et al. (2009a) with wood density of 0.35 cm g^{-3}, Kettering et al. (2001) with wood density of 0.35 to 0.91 cm g^{-3}, Karyati et al. (2019a) with wood density of 0.24-0.44 cm g^{-3}, and Kenzo et al.

(2009b) with wood density of 0.35 cm g^{-3}. The tree species, stand characteristics, wood density, and tree height affect the AGB estimation directly, while the characteristics of the biogeographical area have only a slight effect on the developed AGB equation (Manuri et al. 2017).

This study developed allometric equations for abandoned lands, especially pioneer tree species in abandoned traditional gardens. The selection of a suitable allometric equation will result in accurate estimates of biomass and carbon stock. These specific allometric equations for abandoned traditional gardens on tropical land would supplement the previously reported allometric equations and shall provide an alternative to the existing equations.

In conclusion, the specific allometric equations to estimate the aboveground biomass in abandoned traditional gardens is need to be developed. The use of these equations is expected to produce a more accurate estimate of aboveground biomass and carbon stock. Besides ecological and economic aspects, the calculation of aboveground biomass and carbon stock on abandoned land is important because its area tends to increase from year to year.

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REFERENCES

Agevi H, Onwonga R, Kuyah S, Tsingalia M. 2017. Carbon stocks and stock changes in agroforestry practices: a review. Tropical and Subtropical Agroecosystems 20: 101-109.

Basuki TM, van Laake PE, Skidmore AK, Hussin YA. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. For Ecol Manag 257: 1684-1694. DOI: 10.1016/j.foreco.2009.01.027

BMKG. 2020. Accessed from http://dataonline.bmkg.go.id/home

Bowyer JL, Schmulsky R, Haygreen JG. 2003. Forest Products and Wood Science: An Introduction. 4th ed. Iowa State Press, Iowa.

BPS Kota Samarinda. 2020. Samarinda Municipality in Figures 2020. BPS-Statistics of Samarinda Municipality, Samarinda. [Indonesian]

BSN. 2011. SNI 7725: 2011 Penyusunan Persamaan Allometrik untuk Penaksiran Cadangan Karbon Hutan Berdasarkan Pengukuran Lapangan (Ground Based Forest Carbon Accounting). BSN, Indonesia.

Chamber JQ, dos Santos J, Ribeiro RJ, Higuchi N. 2001. Tree damage, allometric relationship, and above-ground net primary production in central Amazon forest. For Ecol Manag 152: 73-84. DOI: 10.1016/S0378-1127(00)00591-0.

Chave J. 2006. Measuring Wood Density for Tropical Forest Trees: A Field Manual. Sixth Framework Programme (2002-2006). Project for the Advancement of Networked Science in Amazonia, France. http://www.rainfor.org/upload/ManualsEnglish/wood_density_english%5B1%5D.pdf on 19.12.2020.

FAO and UNEP. 2020. The State of the World's Forests 2020: Forests, Biodiversity, and People. Food and Agriculture Organization of the United Nations. Rome. DOI: 10.4060/ca8642en

FAO. 2016. State of the World's Forests 2016. Forests and Agriculture: Land-use Challenges and Opportunities. Food and Agriculture Organization of the United Nations. Rome.

Gorte RW. 2007. Carbon Sequestration in Forest. CSR Report for Congress. Congressional Research Service. Accessed from https://fas.org/sgp/crs/misc/RL31432.pdf.

Hairiah K, Rahayu S. 2007. Pengukuran "Karbon Tersimpan" di Berbagai Macam Penggunaan Lahan. World Agroforestry Centre-ICRAF, Bogor, Indonesia. [Indonesian]

Hairiah K, Sitompul SM, Van Noordwijk M, Palm C. 2001. Methods for Sampling Carbon Stocks Above and Below Ground. ASB Lecture Note 4B. International Centre for Research in Agroforestry. Bogor, Indonesia.

Harmon EH, Ferrell WK, Franklin JF. 1990. Effects on carbon storage of conservation of old-growth forests to young forest. Science 297: 699-702. DOI: 10.1126/science.247.4943.699

Hashimoto T, Tange T, Masumori M, Yagi H, Sasaki S, Kojima K. 2004. Allometric equations for pioneer tree species and estimation of the aboveground biomass of a tropical secondary forest in East Kalimantan. Tropics 14: 123-130. DOI: 10.3759/tropics.14.123.

IPPC. 2008. 2006 IPPC Guidelines for National Greenhouse Gas Inventories – A Primer. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Miwa K, Srivastava N, Tanabe K (eds). IGES, Japan.

Karmini, Karyati, Widiati KY. 2020a. The role of tropical abandoned land relative to ecological and economic aspects. For Soc 4: 181-194. DOI: 10.24259/fs.v4i1.8939.

Karmini, Karyati, Widiati KY. 2020b. The ecological and economic values of secondary forest on abandoned land in Samarinda, East Kalimantan Province, Indonesia. Biodiversitas 21: 5550-5558. DOI: 10.13057/biodiv/d211164.

Karyati, Ipor IB, Jusoh I, Wasli ME, Seman IA. 2013. Composition and diversity of plant seedlings and saplings at early secondary succession of fallow lands in Sabal, Sarawak. Acta Biologica Malaysiana 2: 85-94.

Karyati, Ipor IB, Jusoh I, Wasli ME. 2018. Tree stand floristic dynamics in secondary forests of different ages in Sarawak, Malaysia. Biodiversitas 19: 767-773. DOI: 10.13057/biodiv/d190302

Karyati, Ipor IB, Jusoh I, Wasli ME. 2019a. Allometric equations to estimate the above-ground biomass of trees in the tropical secondary forests of different ages. Biodiversitas 20: 2427-2436. DOI: 10.13057/biodiv/d200901

Karyati, Widiati KY, Karmini, Mulyadi R. 2019b. Development of allometric relationships for estimate above-ground biomass of trees in the tropical abandoned land. Biodiversitas 20: 3508-3516. DOI: 10.13057/biodiv/d201207

Kenzo T, Furutani R, Hattori D, et al. 2009b. Allometric equations for accurate estimation of above-ground biomass in logged-over tropical rainforests in Sarawak, Malaysia. J For Res 14: 365-372. DOI: 10.1007/s10310-009-0149-1.

Kenzo T, Ichie T, Hattori D, et al. 2009a. Development of allometric relationships for accurate estimation of above- and below-ground biomass in tropical secondary forests in Sarawak, Malaysia. J Trop Ecol 25: 371-386. DOI: 10.1017/S0266467409006129.

Ketterings QM, Coe R, van Noordwijk M, Ambagau Y, Palm CA. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. For Ecol Manag 146: 199-209. DOI: 10.1016/S0378-1127(00)00460-6.

Kiyono Y, Hastaniah. 2005. Pattern of slash-and-burn land use and their effects on forest succession: Swidden-land forests in Borneo. Bull For For Prod Res Inst 4: 259-282.

Lamlom SH, Savidge RA. 2003. A reassessment of carbon content in wood: Variation within and between 41 North American species. Biomass Bioenergy 25: 381-388. DOI: 10.1016/S0961-9534(03)00033-3.

Lanly JP. 1982. Tropical Forest Resources. FAO Forestry Paper 30. Rome, Italy: FAO.

Manuri S, Brack C, Rusolono T, et al. 2017. Effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region. Ann For Sci 74: 1-14. DOI: 10.1007/s13595-017-0618-1.

Marklund LG. 1986. Wood Biomass – A Potential Resource for Energy and Industry. Food and Agriculture Organization of the United Nations, Bangkok.

Mokria MG, Mekuria W, Gebrekirstos A, Aynekulu E, Belay B, Gashaw T, Brauning A. 2018. Mixed-species allometric equations and

estimation of aboveground biomass and carbon stocks in restoring degraded landscape in northern Ethiopia. Environ Res Lett 13: 1-14. DOI: 10.1088/1748-9326/aaa495.
Nelson BW, Mesquita R, Pereira JLG, et al. 1999. Allometric regressions for improved estimate of secondary forest biomass in the Central Amazon. For Ecol Manag 117: 149-167.DOI: 10.1016/S0378-1127(98)00475-7.
Parlucha J, Barbadillo N, Sedenio P. 2017. Species-site matching based on growth performance evaluation of mixed native and exotic secondary forest in Musuan Bukidnon. J Biodiv Environ Sci 10: 62-70.
Selaya NG, Anten NPR, OOmen RJ, Matthies M, Werger MJA. 2007. Above-ground biomass investments and light interception of tropical forest trees and lianas early in succession. Ann Bot 99: 141-151. DOI: 10.1093/aob/mcl235.
Sierra CA, del Valle JI, Orrego SA, et al. 2007. Total carbon stocks in a tropical forest landscape of the Porce Region, Colombia. For Ecol Manag 243: 299-309. DOI: 10.1016/j.foreco.2007.03.026.
Stas S. 2011. Aboveground biomass and carbon stocks in a secondary forest in comparison with adjacent primary forest on Limestone in Seram, the Moluccas, Indonesia. Collaborative Land Use Planning and Sustainable Institutional Arrangements for Strengthening Land Tenure, Forest and Community Rights in Indonesia (CoLUPSIA). CIFOR, Bogor.
Tetemke BA, Birhane E, Rannestad MM, Eid T. 2019. Allometric models for predicting aboveground biomass of trees in the dry Afromontane forests of Northern Ethiopia. Forests 10 (12): 1-15. DOI: 10.3390/f10121114.
Vieilledent G, Fischer FJ, Chave J, et al. 2018. New formula and conversion factor to compute basic wood density of tree species using a global wood technology database. Am J Bot 105: 1-9. DOI: 10.1002/ajb2.1175.
Vieira SA, Alves LF, Aidar M, et al. 2008. Estimation of biomass and carbon stocks: the case of the Atlantic Forest. Biota Neotrop 8: 21-29. DOI: 10.1590/S1676-06032008000200001