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BIOMASS ESTIMATION AND ALLOMETRIC EQUATION FOR TREE SPECIES IN DRY FOREST OF EAST NUSA TENGGARA, INDONESIA

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Abstract

In this study, we developed allometric equations for approximating tree biomass components in dry forests in Kupang regency, Indonesia. Biomass allocation was examined and allometric equations were developed using tree height and DBH as variable for individual tree species with DBH<20 cm and DBH>20 cm, respectively. Allometric equations were elaborated for leaf, branch, stem, root biomass and overall tree biomass. Based on the results, leaf, branch, stem and root accounted for 7 %, 16 %, 66 % and 11 % of overall tree biomass. The values of leaf, branch, stem, root and total tree biomass (t) with DBH>20 cm was 0.033±0.016, 0.067±0.034, 0.289±0.082, 0.049±0.023 and 0.441±0.156, respectively. It was also found that the tree biomass (t) with DBH<20 cm was 0.039±0.014. All allometric equation models of tree biomass have a high quality-of-fit as shown by high constancy value (R^2), which indicated significant linear relationships between biomass and the predictors (DBH and tree height).

Key words: constancy value, DBH, Kupang, predictor, tree height.

Introduction

The importance of forests in carbon (C) cycling has gained increasing attention in recent years. With the current interest in greenhouse gas emissions, and their impact on global climate change, accurate, precise, and verifiable estimation of carbon stocks in forests have become insistently requirement (Lewis et al. 2013). Accurate estimation of tropical tree biomass is essential to determine geographic patterns in carbon stocks, the magnitudes of fluxes due to land-use change, to quantify avoided carbon emissions (Basuki et al. 2009), and for appraising productivity and carbon sequestration (Ounban et al. 2016). Henry et al. (2010) informed that measurements to elaborate allometric equations could be done by both direct and indirect methods. An allometric equation is a statistical model linking tree biomass to a set of predictors such as tree diameter and/or height, forest type, or wood specific gravity (Chave et al. 2005) and morphological characters, i.e. basal diameter (or area), canopy diameter, or canopy volume (Kuyah et al. 2016). These standards can be applied individually, or merged in one allometric model (Brown 2002). Forest inventory data can be converted into biomass estimates at tree-level by applying allometric equation, and the sum of all data for the trees allows a biomass estimate to be attained at plot level (Chave et al. 2004).

The use of indirect methods gives fast results, however negatively impact on the accuracy in estimating tree carbon (Gbemavo et al. 2014). It is a non-destructive method, based on indirect and randomized branch sampling of the plant parts for overall biomass determination (Gregoire et al. 1995). There are a lot of techniques used to approximate forest biomass at different spatial scales, but they all eventually depend on ground and destructive measurements of individual tree biomass to adjust to allometric equations (Gibbs et al. 2007). Through new allometric models, we are able to improve the preciseness of biomass assessment protocols (Chave et al. 2004). Species-specific allometric equations developed on site provides better biomass approximation than generalized equations (Pilli et al. 2006), because the use of generalized equations can lead to a bias in estimating biomass for a particular species (Cairns et al. 2003, Litton et al. 2006). Furthermore, the locations within a specific continent have been found to explain almost 50 % of variations in tree allometry (Banin et al. 2012). Moreover, recent approaches incorporating data on wood density hold more promise (Chave et al. 2005).

Allometric equations should be able to represent the diversity of biomass from various tree species (Henry et al. 2011). Destructive harvesting for developing allometric models has rarely been conducted in the tropics, while few studies which have developed the allometric models, have opted smaller size of sample plots than the scale of species variety patterns; therefore, the results may not be representative (Mc William et al. 1993). The species are grouped all together and use generalised allometric relationships for broad forest types or ecological zones (Brown 2002). Although Brown (1997) and Chave et al. (2005) have reported general allometric equations for tropical dry, moist- and rainforests, there is still scarcity of allometric equations, especially for tree species of tropical dry forest (but see: Chaturvedi et al. 2010, Chaturvedi et al. 2012, Chaturvedi and Raghubanshi 2013, Chaturvedi and Raghubanshi 2015), where habitat conditions are highly heterogeneous (Chaturvedi 2010). Moreover, according to Anitha et al. (2015), we did not find any biomass equations from Nusa Tenggara regions, particularly in East Nusa Tenggara, Indonesia. The objectives of this study were to: 1) develop allometric equations for approximating the biomass carbon stock of tree species in Kupang regency, East Nusa Tenggara, Indonesia; and 2) validate the newly developed equations for 20 sampled tree species.

Materials and Methods

Study area

This study covered the Mutis Timau Protected Forest Management Unit (Mutis Timau PFMU), which consists of three regencies: Kupang, Timor Tengah Selatan and Timor Tengah Utara (latitude 90°20′00" – 90°45′10" South and longitude 123°42′30" – 124°20′00" E) in Eastern Indonesia (Fig. 1). Data for this study

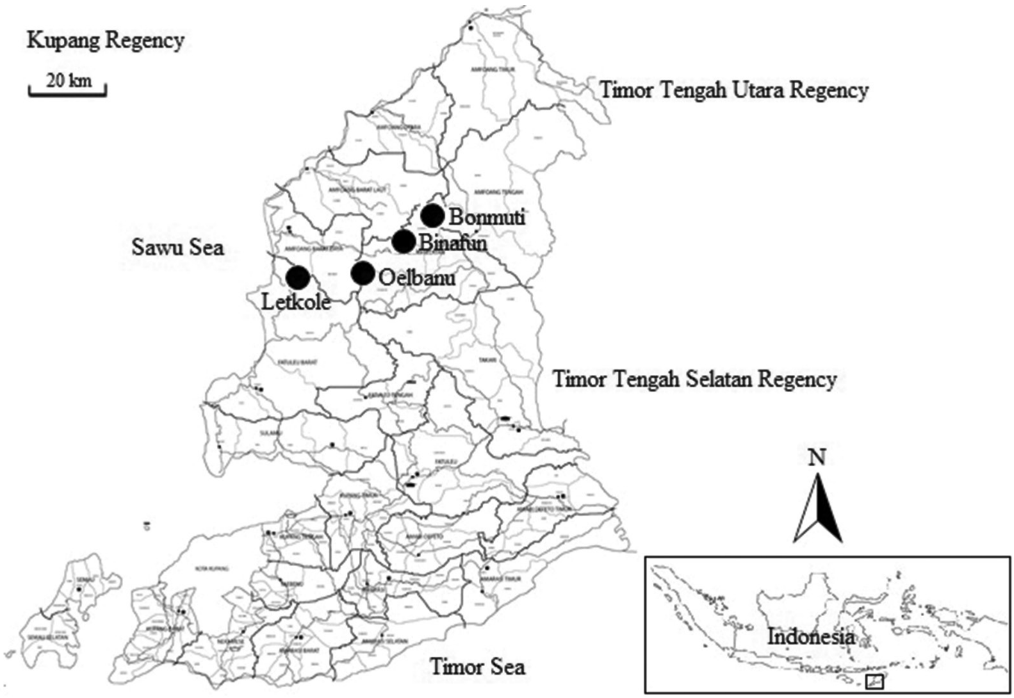

Fig. 1. Location of research sites at Mutis Timau PFMU, East Nusa Tenggara province, Indonesia.

were collected from 4 dry forest study sites named Binafun, Bonmuti, Letkole and Oelbanu, each study site contained two 10,000 m² sampling plots.

The research sites represent the dry forests of East Nusa Tenggara, Indonesia, and surrounding areas are the wettest areas on the island of Timor. Although the rain falls almost every month, the highest frequency of rainfall occurs during November to July. According to Fisher et al. (1999) the high-intensity rainfall (2000–3000 mm/year) at our study sites occurs during the rainy season with average temperatures ranging from 14 °C to 29 °C, and in extreme conditions can even decrease up to 9 °C. The high-speed winds occur in November until March. Around 71 % area are hilly (15–30 % slope) to mountainous (>30 % slope).

Data analysis

The breast height diameter (DBH) of all trees in the sample plots was quantified. We divided sample trees into two groups: tree species with DBH<20 cm and DBH>20 cm, each group of 20 species. The height and DBH of trees was quantified after felling. The harvested trees were dissected to categorize them into their component parts (leaf, branch, stem, root). Subsamples of approximately 200–300 g were taken for dry-weight determination in the laboratory for every component. The samples were dried at 80 °C until constant weight was achieved to obtain dry weights to the nearest 0.1 g. For calculating water content (*WC*) from the field weighed disc weight (*FW*) and oven dried disc weight (*DW*), the equation

(1) was used:

$$WC = \frac{FW - DW}{FW} \quad (1)$$

For estimating total wood dry mass, the wet mass of leaf, branch, stem, root was multiplied by (1–*WC*). Because of the large variations in *WC* of branches for large trees, *WC* was estimated separately after the branches were partitioned in different size classes (Chaturvedi and Raghubanshi 2015).

All sample trees were measured and recorded for species, the activity was carried out on the height variable for tree sample with DBH<20 cm and DBH variable for tree sample with DBH>20 cm. Linear regressions were used to determine the allometric equation model of each tree components such as leaf biomass, branch biomass, stem biomass, root biomass, total biomass, leaf carbon, branch carbon, stem carbon, root carbon, total carbon. In the present study, we transformed the observed data using logarithmic transformation which is commonly used in dimension analysis studies to fit appropriate allometric equations (Sprugel 1983, Istrefi et al. 2019).

All allometric equations in this study were validated in term of *RMSE* (%), Akaike Information Criteria (*AIC*) and determination value (R^2) (Mayer and Butler 1993). All statistical analyses were done using Xlstat version 2014 (equation 2):

$$RMSE\,(\%) = 100\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - \hat{y}_i}{y_i}\right)^2}, \quad (2)$$

where: *n* is trees number applied for model development, and y_i and $\hat{y}_i$ are observed and predicted biomass.

Akaike Information Criteria (AIC) (equation 3):

$$AIC = n.\ln\left(\frac{SSE}{n}\right) + 2.p, \quad (3)$$

where: *SSE* is the sum of squares of the errors, *n* – sample size, and *p* – number of regression coefficients in the model being evaluated (including the intercept). The *AIC* value was minimized by the best validated model.

Results and Discussion

The ranges of d*iameter at breast height* (DBH) and tree height (H) for each tree sample species are shown in Table 1. The values of measured mean DBH reported in this study for *Terminalia mollis* M.A. Lawson at DBH>20 cm are lower compared to other tree samples and were higher for individuals with greater mean H (144.500 cm ±55.905 cm) at DBH<20 cm. In the present study, *Pipturus argenteus* Wedd. was found *larger in* size with 22.225 cm ±7.539 cm mean DBH, and was representing 11.5–31.5 cm DBH ranges, while the highest H was represented as 152.813±57.849 cm across all tree samples.

In Table 2, specific results of tree component biomass are shown. The results showed that the mean biomass per components for trees with DBH<20 cm for leaf, branch, stem, root, total biomass was 0.033 t, 0.067 t, 0.289 t, 0.049 t, 0.441 t and 0.039 t, respectively. The mean biomass per tree species was highest for *Vitex parviflora* accounting 0.082 t and 0.162 t for both leaf and branch components. The highest biomass of stem and root was 0.403 t and 0.089 t for *Terminalia mollis* and *Garuga floribunda*, respectively. The mean total biomass of tree sample at DBH>20 cm (0.441 t) represented more than a ten time of tree sample at DBH<20 cm (0.039 t).

Table 1. Character of biomass values in each sample tree species.

No	Species	DBH > 20 cm				DBH < 20 cm			
		min DBH, cm	max DBH, cm	mean DBH, cm	SD DBH	min H, cm	max H, cm	mean H, cm	SD H
1	*Alstonia scholaris* (L.) R. Br.	10.21	29.55	19.714	6.669	95	195	150.625	34.15
2	*Broussonetia papyrifera* (L.) Vent.	10.21	35	21.678	8.805	90	200	147.813	41.189
3	*Euodia macrophylla* Blume	10.21	30	20.926	6.536	90	200	145.625	35.538
4	*Ficus glomerata* Roxb.	10.21	32.5	22.064	7.599	75	200	141.5	44.706
5	*Pipturus argenteus* G.Forst.	10.55	32.5	22.225	7.539	75	250	152.813	57.849
6	*Oroxylum indicum* (L.) Kurz	10.22	30	21.201	7.038	70	210	136.563	56.737
7	*Hibiscus tiliaceus* L.	11.5	31.5	22.188	7.038	75	215	140.625	54.768
8	*Macaranga tanarius* (L.) Mull. Arg, Di DC	10.5	25	17.75	5.604	60	200	135	56.774
9	*Eucalyptus urophylla* S.T. Blake	10.25	30	18.625	6.933	75	250	144.688	57.979
10	*Nauclea orientalis* (L.) L.	11.5	30	19.313	6.511	70	220	139.75	60.263
11	*Litsea diversifolia* Blume	12.5	30	20.844	6.853	75	215	139.75	56.824
12	*Mangifera indica* L.	10.5	30	20.844	7.786	78	240	144.25	55.979
13	*Peltophorum inerma* Roxb.	12.5	30	19.781	5.933	80	210	145.313	48.252
14	*Homalium tomentosum* (Vent.) Benth	12	30	19.563	7.341	75	210	142.5	49.933
15	*Bauhinia malabarica* Roxb.	10.5	30	18.644	7.349	90	210	146.875	46.039
16	*Alstonia villosa* Blume.	11	32	20.75	8.048	75	225	143.438	56.501
17	*Tamarindus indica* L.	11	30	19.844	7.002	80	250	146.25	56.994
18	*Terminalia mollis* M.A. Lawson.	10	30	16.875	7.27	70	220	144.5	55.905
19	*Garuga floribunda* Decne.	10	34	20.438	8.647	70	210	145.625	55.644
20	*Vitex parviflora* Juss.	10.5	30	19.25	6.387	90	215	146.563	49.79

Table 2. Biomass values for each sample tree species.

No	Species	DBH > 20 cm				DBH < 20 cm, t
		Leaf, t	Branch, t	Stem, t	Root, t	
1	*Alstonia scholaris* (L.) R. Br.	0.027±0.008	0.071±0.013	0.399±0.077	0.035±0.005	0.071±0.024
2	*Broussonetia papyrifera* (L.) Vent.	0.024±0.008	0.064±0.015	0.364±0.074	0.031±0.006	0.061±0.002
3	*Euodia macrophylla* Blume	0.020±0.004	0.050±0.018	0.339±0.063	0.027±0.005	0.052±0.022
4	*Ficus glomerata* Roxb.	0.014±0.003	0.036±0.009	0.283±0.045	0.023±0.005	0.037±0.020
5	*Pipturus argenteus* G.Forst.	0.010±0.002	0.024±0.007	0.229±0.064	0.018±0.005	0.021±0.014
6	*Oroxylum indicum* (L.) Kurz	0.008±0.001	0.022±0.017	0.225±0.072	0.016±0.004	0.015±0.008
7	*Hibiscus tiliaceus* L.	0.008±0.003	0.020±0.011	0.186±0.068	0.014±0.004	0.013±0.010
8	*Macaranga tanarius* (L.) Mull. Arg, Di DC	0.008±0.003	0.023±0.021	0.159±0.083	0.015±0.006	0.012±0.013
9	*Eucalyptus urophylla* S.T. Blake	0.011±0.004	0.032±0.027	0.192±0.060	0.030±0.010	0.019±0.013
10	*Nauclea orientalis* (L.) L.	0.019±0.008	0.039±0.018	0.230±0.060	0.063±0.032	0.030±0.009
11	*Litsea diversifolia* Blume	0.025±0.012	0.054±0.022	0.287±0.090	0.073±0.043	0.037±0.010
12	*Mangifera indica* L.	0.027±0.012	0.060±0.032	0.244±0.086	0.073±0.041	0.036±0.009

13	*Peltophorum inerma* Roxb.	0.041±0.021	0.076±0.041	0.309±0.111	0.081±0.053	0.041±0.012
14	*Homalium tomentosum* (Vent.) Benth	0.046±0.022	0.069±0.037	0.274±0.091	0.057±0.024	0.041±0.014
15	*Bauhinia malabarica* Roxb.	0.053±0.025	0.096±0.050	0.339±0.090	0.061±0.020	0.052±0.026
16	*Alstonia villosa* Blume.	0.047±0.024	0.095±0.068	0.288±0.120	0.053±0.020	0.044±0.010
17	*Tamarindus indica* L.	0.063±0.041	0.107±0.057	0.319±0.098	0.066±0.033	0.047±0.021
18	*Terminalia mollis* M.A. Lawson.	0.069±0.049	0.145±0.105	0.403±0.136	0.079±0.046	0.044±0.012
19	*Garuga floribunda* Decne.	0.073±0.054	0.143±0.096	0.340±0.119	0.089±0.075	0.055±0.018
20	*Vitex parviflora* Juss.	0.082±0.043	0.162±0.085	0.360±0.084	0.077±0.040	0.047±0.014
21	All species	0.033±0.016	0.067±0.034	0.289±0.082	0.049±0.023	0.039±0.014

For tree sample at DBH<20 cm, the mean tree biomass was 0.124 t, 0.095 t, 0.267 t and 0.133 t for tree height class at 50–100 cm, 100–150 cm, 150–200 cm and 200–250 cm, respectively. The biomass proportion also varied between the tree components and between species. Between tree components the proportion of tree biomass was 20.0 % for tree height class at 50–100 cm; 15.4 % for tree height class at 100–150 cm; 43.2 % for tree height class at 150–200 cm and 21.5 % for tree height class at 200–250 cm. Compared to other tree species, *Alstonia scholaris* had the highest mean tree biomass at 100–150 cm (0.255 t) and 150–200 cm (0.750 t) tree height class. Same pattern was observed for *Alstonia villosa* (0.247 t) and *Garuga floribunda* (0.331 t) at 50–100 cm and 200–250 cm tree height class (Fig. 2).

We found that biomass among DBH classes (i.e., 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm and 30–35 cm) differed among the sample tree species. DBH class of 10–15 cm (24.9 %), 25–30 cm (23.9 %) and 30–35 cm (20.4 %) contributed predominantly to tree biomass

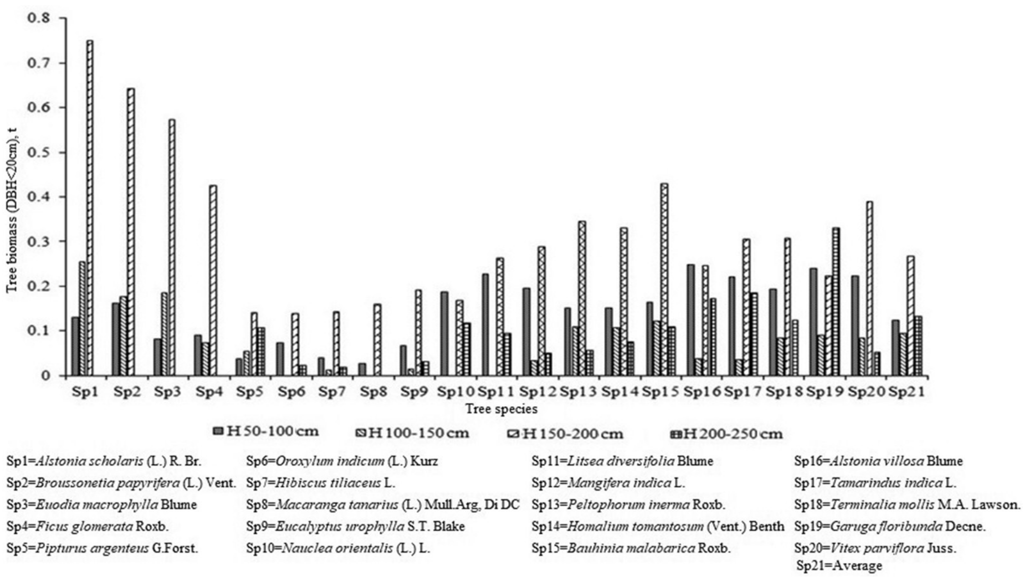

Fig. 2. The values of tree biomass by class tree height (DBH<20 cm).

accumulation, whereas DBH class of 15–20 cm (11.3 %), 20–25 cm (19.7 %) were responsible for a small proportion of the overall tree biomass. *Terminalia mollis* (4.979 t), *Vitex parviflora* (2.662 t), *Vitex parviflora* (3.470 t), *Tamarindus indica* (4.090 t) and *Alstonia villosa* (2.539 t) had the highest biomass in each DBH class (Fig. 3).

Table 3 shows the regression models developed for estimating tree biomass components of all tree species. The RMSE, AIC and R^2 values indicated that the developed models were good and useful for the estimation of biomass of all components for all species. However, the lowest values of R^2 are found in several tree species, such as *Ficus glomerata*, *Oroxylum indicum*, *Hibiscus tiliaceus*, *Macaranga tanarius*, *Eucalyptus urophylla*, *Bauhinia malabarica*, and *Vitex parviflora*.

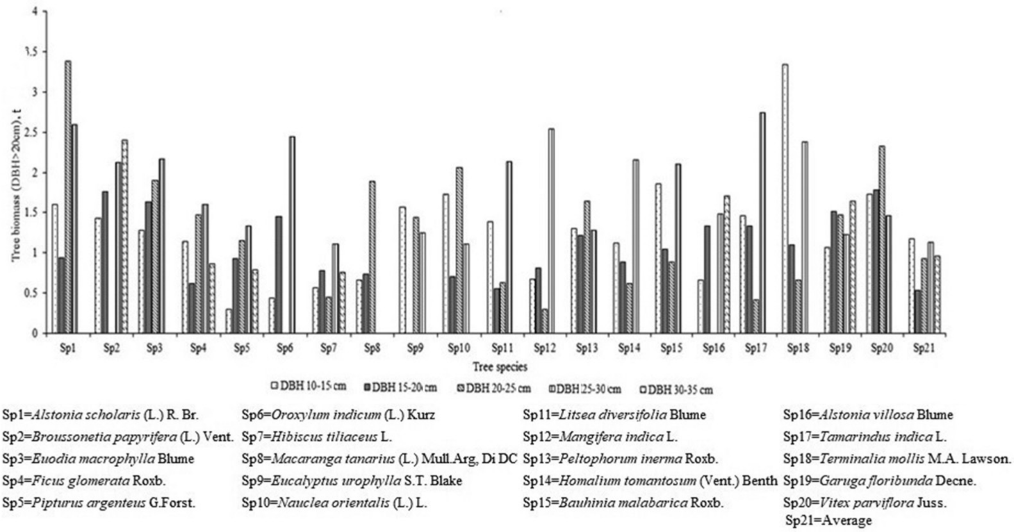

Fig. 3. The values of tree biomass by class DBH (DBH>20 cm.

Table 3. Biomass equation for all sample species.

No	Tree species and DBH class	Tree component	Allometric equation	RMSE	AIC	R^2
1	*Alstonia scholaris*					
	DBH<20 cm		B=-0.027+0.001·H	0.01	-145.532	0.84
	DBH>20 cm	Leaf	LB=0.007+0.001·DBH	0.003	-179.573	0.805
		Branch	BB=0.035+0.002·DBH	2.857	-192.101	0.968
		Stem	SB=0.177+0.011·DBH	0.017	-128.961	0.956
		Root	RB=0.022+0.001·DBH	0.003	-182.852	0.681
		Total	TB=0.240+0.015·DBH	0.02	-122.921	0.962
2	*Broussonetia papyrifera*					
	DBH<20 cm		B=-0.008+0.0004·H	0.011	-141.508	0.757
	DBH>20 cm	Leaf	LB=0.007+0.001·DBH	0.004	-173.852	0.76
		Branch	BB=0.031+0.002·DBH	0.008	-153.648	0.764
		Stem	SB=0.190+0.008·DBH	0.023	-118.499	0.908

No	Tree species and DBH class	Tree component	Allometric equation	RMSE	AIC	R^2
		Root	RB=0.017+0.001·DBH	0.003	-182.559	0.772
		Total	TB=0.244+0.011·DBH	0.033	-107.718	0.904
3	*Euodia macrophylla*					
	DBH<20 cm		B=-0.033+0.001·H	0.008	-152.898	0.88
	DBH>20 cm	Leaf	LB=0.007+0.001·DBH	0.002	-197.357	0.81
		Branch	BB=-0.006+0.003·DBH	0.004	-177.571	0.961
		Stem	SB=0.143+0.009·DBH	0.017	-129.114	0.935
		Root	RB=0.011+0.001·DBH	0.002	-201.722	0.905
		Total	TB=0.155+0.013·DBH	0.02	-123.39	0.954
4	*Ficus glomerata*					
	DBH<20 cm		B=-0.018+0.0004·H	0.01	-145.746	0.764
	DBH>20 cm	Leaf	LB=0.005+0.0003·DBH	0.001	-212.073	0.864
		Branch	BB=0.025+0.001·DBH	0.008	-151.051	0.187
		Stem	SB=0.155+0.006·DBH	0.009	-148.785	0.962
		Root	RB=0.01+0.001·DBH	0.002	-202.712	0.885
		Total	TB=0.195+0.007·DBH	0.014	-134.158	0.942
5	*Pipturus argenteus*					
	DBH<20 cm		B=-0.013+0.0002·H	0.006	-159.886	0.818
	DBH>20 cm	Leaf	LB=0.005+0.0002·DBH	0.000	-250.056	0.948
		Branch	BB=0.004+0.001·DBH	0.003	-189.35	0.875
		Stem	SB=0.051+0.008·DBH	0.021	-122.511	0.903
		Root	RB=0.004+0.001·DBH	0.001	-217.396	0.959
		Total	TB=0.065+0.01·DBH	0.022	-119.794	0.92
6	*Oroxylum indicum*					
	DBH<20 cm		B=-0.0004+0.0001·H	0.005	-165.646	0.597
	DBH>20 cm	Leaf	LB=0.004+0.0001·DBH	0.000	-253.57	0.94
		Branch	BB=-0.007+0.001·DBH	0.015	-132.125	0.295
		Stem	SB=0.019+0.01·DBH	0.024	-117.374	0.897
		Root	RB=0.004+0.001·DBH	0.001	-215.885	0.932
		Total	TB=0.02+0.012·DBH	0.036	-104.863	0.854
7	*Hibiscus tiliaceus*					
	DBH<20 cm		B=-0.007+0.0001·H	0.006	-161.943	0.651
	DBH>20 cm	Leaf	LB=0.001+0.0003·DBH	0.001	-211.825	0.767
		Branch	BB=-0.002+0.001·DBH	0.008	-152.152	0.456
		Stem	SB=-0.01+0.009·DBH	0.028	-112.241	0.838
		Root	RB=0.001+0.001·DBH	0.001	-211.757	0.92
		Total	TB=-0.011+0.011·DBH	0.038	-103.204	0.814
8	*Macaranga tanarius*					
	DBH<20 cm		B=-0.01+0.0001·H	0.01	-146.934	0.493
	DBH>20 cm	Leaf	LB=-0.0003+0.0004·DBH	0.001	-210.523	0.806
		Branch	BB=-0.013+0.002·DBH	0.018	-125.82	0.284
		Stem	SB=-0.082+0.014·DBH	0.033	-107.548	0.853
		Root	RB=-0.003+0.001·DBH	0.002	-205.563	0.939
		Total	TB=-0.098+0.017·DBH	0.05	-94.07	0.798

No	Tree species and DBH class	Tree component	Allometric equation	RMSE	AIC	R^2
9	*Eucalyptus urophylla*					
	DBH<20 cm		B=-0.005+0.0001·H	0.008	-151.698	0.6
	DBH>20 cm	Leaf	LB=0.0002+0.001·DBH	0.002	-201.743	0.854
		Branch	BB=-0.016+0.003·DBH	0.021	-121.834	0.444
		Stem	SB=0.035+0.008·DBH	0.014	-135.267	0.951
		Root	RB=0.005+0.001·DBH	0.004	-173.157	0.843
		Total	TB=0.024+0.013·DBH	0.037	-103.547	0.863
10	*Nauclea orientalis*					
	DBH<20 cm		B=0.013+0.0001·H	0.005	-167.275	0.681
	DBH>20 cm	Leaf	LB=-0.003+0.001·DBH	0.003	-186	0.875
		Branch	BB=-0.011+0.003·DBH	0.007	-156.357	0.858
		Stem	SB=0.062+0.009·DBH	0.02	-123.199	0.895
		Root	RB=-0.028+0.005·DBH	0.008	-152.175	0.939
		Total	TB=0.02+0.017·DBH	0.028	-112.826	0.945
11	*Litsea diversifolia*					
	DBH<20 cm		B=0.015+0.0001·H	0.005	-168.358	0.781
	DBH>20 cm	Leaf	LB=-0.008+0.002·DBH	0.005	-168.047	0.834
		Branch	BB=-0.002+0.003·DBH	0.012	-140.745	0.733
		Stem	SB=0.025+0.013·DBH	0.026	-114.982	0.922
		Root	RB=-0.048+0.006·DBH	0.017	-129.461	0.862
		Total	TB=-0.034+0.023·DBH	0.049	-94.943	0.916
12	*Mangifera indica*					
	DBH<20 cm		B=0.015+0.0001·H	0.004	-174.074	0.797
	DBH>20 cm	Leaf	LB=-0.002+0.001·DBH	0.006	-163.292	0.796
		Branch	BB=-0.011+0.003·DBH	0.018	-127.094	0.705
		Stem	SB=0.059+0.009·DBH	0.053	-92.363	0.649
		Root	RB=-0.028+0.005·DBH	0.016	-129.523	0.847
		Total	TB=0.018+0.018·DBH	0.081	-78.558	0.772
13	*Peltophorum inerma*					
	DBH<20 cm		B=0.011+0.0002·H	0.008	-154.355	0.651
	DBH>20 cm	Leaf	LB=-0.025+0.003·DBH	0.008	-153.781	0.873
		Branch	BB=-0.048+0.006·DBH	0.018	-126.243	0.817
		Stem	SB=-0.023+0.017·DBH	0.052	-93.011	0.799
		Root	RB=-0.076+0.008·DBH	0.025	-116.196	0.792
		Total	TB=-0.171+0.034·DBH	0.093	-74.064	0.836
14	*Homalium tomantosum*					
	DBH<20 cm		B=0.01+0.0002·H	0.009	-148.366	0.611
	DBH>20 cm	Leaf	LB=-0.009+0.003·DBH	0.009	-150.529	0.859
		Branch	BB=-0.022+0.005·DBH	0.013	-136.822	0.88
		Stem	SB=0.058+0.011·DBH	0.043	-98.929	0.794
		Root	RB=-0.001+0.003·DBH	0.012	-140.094	0.779
		Total	TB=0.026+0.021·DBH	0.063	-86.585	0.87
15	*Bauhinia malabarica*					
	DBH<20 cm		B=-0.005+0.0003·H	0.019	-124.841	0.478
	DBH>20 cm	Leaf	LB=-0.004+0.003·DBH	0.011	-141.728	0.812

No	Tree species and DBH class	Tree component	Allometric equation	RMSE	AIC	R^2
		Branch	BB=-0.026+0.007·DBH	0.015	-132.357	0.916
		Stem	SB=0.131+0.011·DBH	0.038	-102.772	0.834
		Root	RB=0.015+0.002·DBH	0.008	-151.102	0.83
		Total	TB=0.116+0.023·DBH	0.059	-88.448	0.898
16	*Alstonia villosa*					
	DBH<20 cm		B=0.02+0.0001·H	0.004	-178.761	0.88
	DBH>20 cm	Leaf	LB=-0.01+0.003·DBH	0.010	-145.295	0.836
		Branch	BB=-0.061+0.008·DBH	0.031	-108.803	0.798
		Stem	SB=0.025+0.013·DBH	0.065	-85.802	0.728
		Root	RB=0.006+0.002·DBH	0.008	-153.085	0.853
		Total	TB=-0.04+0.025·DBH	0.103	-70.909	0.806
17	*Tamarindus indica*					
	DBH<20 cm		B=0.001+0.0003·H	0.012	-139.548	0.704
	DBH>20 cm	Leaf	LB=-0.035+0.005·DBH	0.023	-118.618	0.707
		Branch	BB=-0.042+0.007·DBH	0.022	-119.726	0.855
		Stem	SB=0.061+0.013·DBH	0.039	-102.179	0.856
		Root	RB=-0.019+0.004·DBH	0.014	-135.104	0.836
		Total	TB=-0.035+0.03·DBH	0.090	-75.135	0.851
18	*Terminalia mollis*					
	DBH<20 cm		B=0.015+0.0002·H	0.004	-175.286	0.899
	DBH>20 cm	Leaf	LB=-0.032+0.006·DBH	0.024	-118.151	0.786
		Branch	BB=-0.081+0.013·DBH	0.041	-100.187	0.856
		Stem	SB=0.132+0.016·DBH	0.072	-82.531	0.74
		Root	RB=-0.021+0.006·DBH	0.017	-128.96	0.876
		Total	TB=-0.001+0.041·DBH	0.120	-66.081	0.871
19	*Garuga floribunda*					
	DBH<20 cm		B=0.013+0.0002·H	0.009	-148.647	0.775
	DBH>20 cm	Leaf	LB=-0.037+0.005·DBH	0.027	-113.479	0.761
		Branch	BB=-0.065+0.01·DBH	0.040	-100.928	0.837
		Stem	SB=0.091+0.012·DBH	0.059	-88.931	0.775
		Root	RB=-0.051+0.007·DBH	0.048	-95.211	0.62
		Total	TB=-0.062+0.035·DBH	0.117	-66.693	0.875
20	*Vitex parviflora*					
	DBH<20 cm		B=0.019+0.0001·H	0.010	-144.453	0.464
	DBH>20 cm	Leaf	LB=-0.042+0.006·DBH	0.013	-136.956	0.914
		Branch	BB=-0.082+0.013·DBH	0.029	-111.385	0.892
		Stem	SB=0.129+0.012·DBH	0.035	-105.213	0.835
		Root	RB=-0.039+0.006·DBH	0.012	-140.359	0.921
		Total	TB=-0.034+0.037·DBH	0.078	-79.789	0.908
21	All species					
	DBH<20 cm		B=0.001+0.0002·H	0.006	-160.848	0.828
	DBH>20 cm	Leaf	LB=-0.012+0.002·DBH	0.006	-162.155	0.877
		Branch	BB=-0.026+0.005·DBH	0.012	-138.478	0.878
		Stem	SB=0.058+0.011·DBH	0.020	-122.878	0.943
		Root	RB=-0.014+0.003·DBH	0.008	-154.064	0.897
		Total	TB=0.005+0.022·DBH	0.040	-101.058	0.938

Among the tree components the mean leaf biomass (tree/ha) was 0.032 ±0.015 (range 0.009–0.071) (Fig. 4), branch biomass 0.067 ±0.033 (range 0.026–0.149), stem biomass 0.288 ±0.079 (range 0.142–0.444), root biomass 0.048 ±0.022 (range 0.02–0.104) and total biomass 0.441 ±0.151 (range 0.201–0.775). The values of tree biomass for each component also varied along the diameter at breast height (DBH). Generally, tree components biomass increased with DBH for whole species. Among the tree components, tree species biomass had high coefficient of determination (R^2 for different components are: leaf = 0.877, branch = 0.877, stem = 0.943, root = 0.897, total = 0.938).

We compared the aboveground biomass for all species generated in our study using a generic equation (Fig. 5). The results indicated an average total biomass of 0.387 t (this study), 0.967 t (Chaturvedi et al. 2012), 0.213 t (Chakraborty et al. 2016) and 1.670 t (Sato et al. 2015). The total above-ground biomass model compared with previously published equations indicated that the current equation diverged considerably from them. The total above-ground biomass was overestimated when they were applied to a data set taken from the present study.

In our study, stems (66 %) of all tree species have more biomass than the leaf, branch and root components, while the value of tree biomass with DBH<20 cm (0.039 ±0.014) was almost similar to leaf biomass (0.033 ±0.016) (Table 2). Henry et al. (2011) reported similar pattern, and they discovered percentage stem biomass (69 %) to be higher than for branch (27 %) and leaf (4 %). However, Geldenhuys and Golding (2008) reported that more than

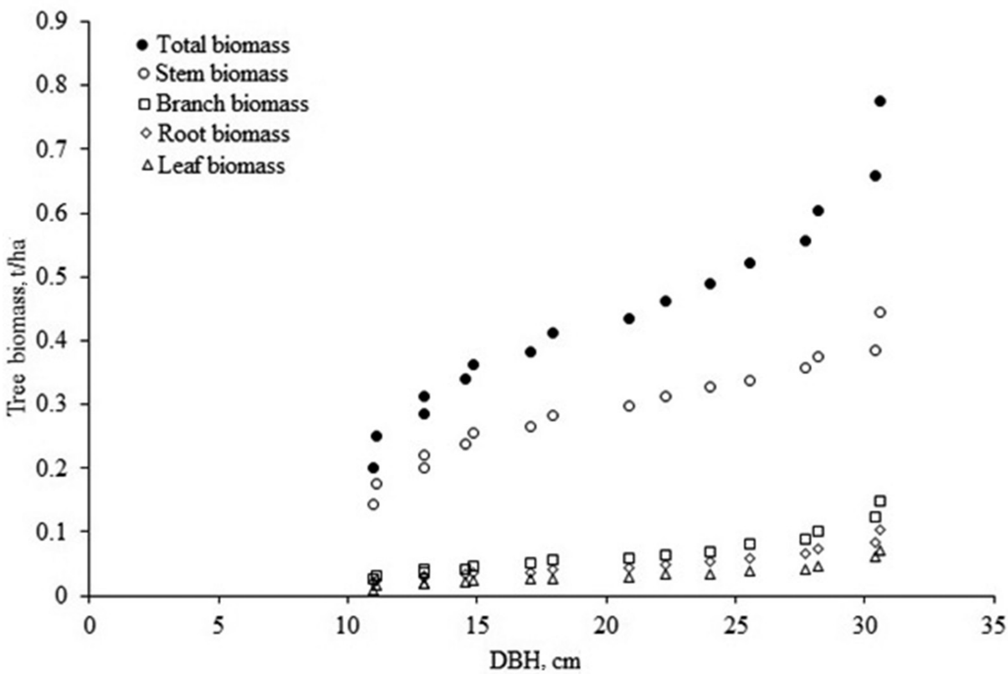

Fig. 4. The mean values of tree biomass in each tree components.

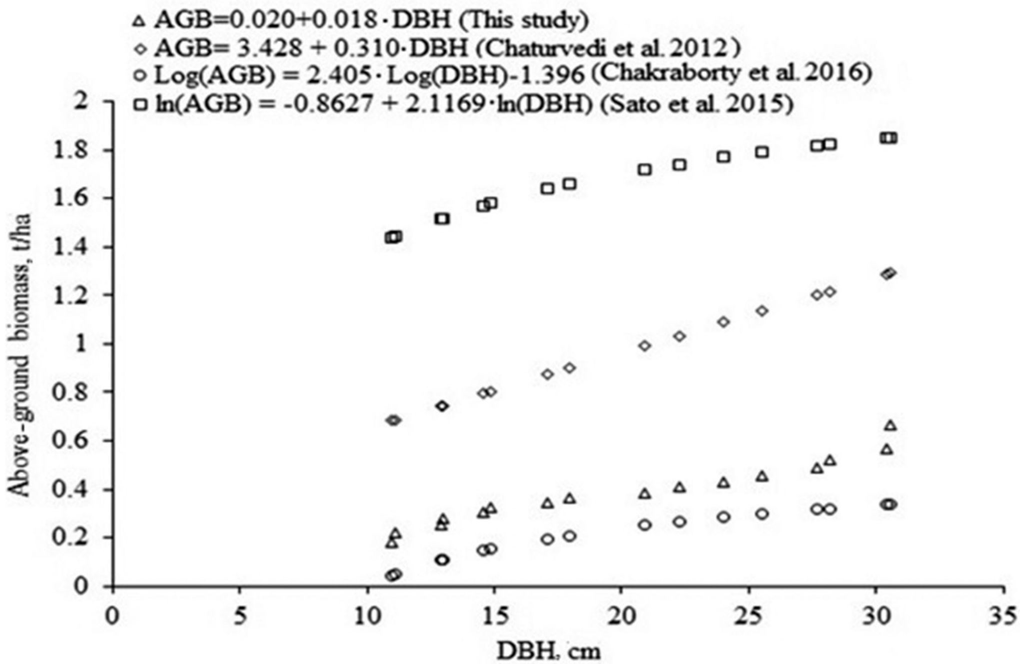

Fig. 5. Comparative values of aboveground biomass by different equation.

50 % of the timber in woodlands is branch biomass. In another study in the Miombo woodland stands, Chamshama et al. (2004) discovered a very high percentage biomass for branches than stems among species. The biomass distribution among different tree components might be relevant to the site conditions where the trees are growing. In dense forests with strong competition for light and space, the trees tend to develop smaller branches and foliage biomass than in open forest types (Segura and Kanninen 2005).

Almost all of the allometric equations presented in this study satisfied the recent criterion of proposed selection for biomass estimation models (R^2>80 % and low values of RMSE and AIC). It was indicated that the inclusion of DBH variable only in this study was the *good* predictor for estimation of tree biomass. Basuki et al. (2009) reported that adding height into allometric equations did not elevate the accuracy of the estimation, whereas the model with single variable (DBH only) has higher reliability than generic models with up to three variables (Huy et al. 2016). In addition, it is difficult to measure height of trees accurately in tropical dense forest. According to Ishihara et al. (2015), the key to evaluating forest ecosystem functions and the global carbon cycle depends on how accurate the estimated tree and forest biomass are. Most allometric equations are site specific, usually developed from a small number of trees harvested in a small area and are either species specific or ignore interspecific differences in allometry. Due to less site-specific allometries, general equations are often used to sites for which they were not originally developed (foreign sites), sometimes causing large errors in biomass estimates.

The mean total above-ground biomass estimated by four of the previous equations differed significantly (P<0.001) from that of the recent study. Amazingly, the allometric equation developed from a data set of European beech growing on dry sites (Chakraborty et al. 2016) provided the lowest overestimation. Among the previous equations, there was developed from data sets of three varied sites from three countries, therefore, this equation was considered more common equation which could be applied better in other forest ecosystems in the tropics. This indicates that allometric equations of the same region may be more similar in their approximation of tree biomass. The need for site specific models to be encouraged for accurate determination of tree components biomass in dry forests has been revealed by the comparison of the previous equations to the current one. However, where site specific allometric equations are not available, care must be taken in choosing allometric equations for forests. In that case, the exploration of equations within the same region or continent should be carried out (Addo-Fordjour and Rahmad 2013).

Conclusions

This information source is essential for the development of conventional and sustainable management plans of tropical dry forest ecosystems. In addition, it is crucial for many applications to have the accurate approximation of tree components biomass in dry forests, from the commercial management of timber to the global carbon cycle. Some relationships of allometric were developed for liana stem and total above-ground biomass using liana diameter, length, diameter squared, and a combination of them as predictors. One type of allometric equations was developed by models fitted to untransformed data. The diameter was a good estimator of all tree components biomass. Therefore, the models that used only diameter as the parameter estimate are recommended for use. A comparison of the total above-ground allometric equation elaborated in this study with previously published models indicated that the previous equations overestimated total above-ground biomass of tree by at least 44 %. According to the application of the proposed model to the previously published data and the application of the published equation to the recent data, conclusion could be drawn that it is a must to consider the application of site specific equation (Basuki et al. 2009).

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