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Allometric Models for Estimating Above Ground Biomass of *Bambusa tulda* Roxb. and *Melocanna baccifera* (Roxb.) Kurz

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Abstract

Allometric equations are used to estimate the biomass and carbon stock of forests. There is a dearth of species-specific allometric equations for bamboos growing in Bangladesh. *Bambusa tulda* and *Melocanna baccifera* are the two most common bamboo species of commercial importance in Bangladesh. This study reports allometric equations for estimating biomass of bamboo compartments (leaf, branches, and stem) and total above-ground biomass. Data was collected from natural bamboo forests of different locations of Khagrachhari district. A total of 50 bamboos (25 *B. tulda* and 25 *M. baccifera*) were sampled following the destructive method. Bamboo leaf, branch, and stem were measured for fresh weight in the field. Sub-samples were collected in sufficient amounts and processed in the laboratory for density and oven-dry weight to derive fresh to oven-dry weight ratio. Commonly used 10 candidate equations were tested using Diameter at Breast Height (DBH), diameter at base (D_5), and height (H) as explanatory variables to find the best fitted allometric equation. In total, the study developed 60 models with 10 for each component of the two species. Applying the goodness-of-fit statistics, 4 best-fitted models were selected for estimating stem and total above-ground biomass (TAGB) of the two bamboo species. The best fit allometric biomass models for *M. baccifera* were, $Ys = 0.398*DBH^{1.542}$ and $Yt = 0.627*DBH^{1.382}$, where, Ys = stem biomass and Yt = total above-ground biomass. On the other hand, best fit allometric biomass models for *B. tulda* were, $Ys = 0.041*DBH^{1.0658}*H^{1.2311}$, and $Yt = 0.235*D_5^{1.867}$, where, D_5 is diameter at the base (5 cm above the ground). The relationship between the biomass and dendrometric variables in the form of best-fitted models was statistically significant at $p < 0.05$ levels. The allometric models developed by this study will be useful for better estimation of biomass and sequestered carbon in the plain land homestead forests of Bangladesh.

Keywords: Khagrachhari, Bamboo, Carbon sequestration, *Bambusa tulda* and *Melocanna baccifera*

Introduction

The atmospheric concentration of Carbon dioxide (CO_2) - the most critical of greenhouse gases contributing to global climate change (Miah et al. 2020)– is poised to increase through direct and indirect emissions as IPCC predicted (Korner and Basler 2010, Pachauri et al. 2014). Sequestrating the atmospheric carbon as tree biomass is a cost-effective mean to reduce atmospheric carbon (Baral and Guha 2004). Therefore, estimation of the accumulated floral biomass is important to assess the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned productivity and sustainability of the forest

(Keith et al. 2009, Sedjo and Sohngen 2012, Hiraishi et al. 2014). Moreover, it gives an indication of the amount of carbon that can be removed from the atmosphere by natural or afforested ecosystems (Kebede and Soromessa 2018). Consequently, the fast-growing species like bamboo are inherently potent for carbon sequestration initiatives (Lobovikov et al. 2009, Nath et al. 2015a, b). Bangladesh is home to 33 species of bamboo of which *Bambusa tulda Rox*b. (Mitinga bansh) dominates bamboo groove in the rural homesteads throughout the country while *Melocanna baccifera* (Roxb.) Kurz (Muli bansh) dominates the bamboo grooves in the hill forests of Bangladesh (Bystriakova et al. 2003, Latif 2008). Bamboo can be harvested as little as three years of age due to its high biomass yield – as much as 40 tons per hectare per year (Piouceau et al. 2014). Yet, only a handful of studies are available on carbon sequestration potential of bamboo species (Yen et al. 2010; Xu et al., 2018).

Estimation of carbon stock in bamboos may vary considerably depending on estimation method, geographic range, and species. Biomass can be estimated by direct method, i.e., destructive techniques or by indirect method, i.e., developing an allometric relationships (Poudel et al. 2013). Destructive technique is time consuming and expensive as it depends on collection and processing of a large amount of biomass (Poudel et al. 2013). In contrary, allometric relationship yields a less precise indirect measurement of different biomass components and is often the preferred approach as it is fast and less expensive. Globally, allometric equations - a basic prerequisite for studying biomass production, carbon balance and carbon sequestration in different compartments (i.e., stem, branches, leaf, rhizome) of bamboo - are essential yet scarce. Given this context, this study aimed to develop a best-fit allometric equation to estimate stem, leaf, and total biomass of Mintinga (*Bambusa tulda* Roxb.**)** and Muli (*Melocanna baccifera* (Roxb.) Kurz – the two most common bamboo species in Bangladesh. These two bamboo species are selected due to their wide availability, their pivotal role in the rural life and livelihood and their potentials towards climate change mitigation. The finding of this study will help future estimations of biomass and carbon in bamboo groves of Mitinga and Muli in rural homesteads and forests for their sustainable management.

Materials and Methods

Study area

The culms of both the species were selected for sampling from 3 villages *viz.,* Payong Para, Moratila, and Podini Para of Panchari Upazila of Khagrachhari district which covers an area of 334 km^2 and located between 23°12' to 23°28' north latitudes and 91°50' to 92°00' east longitudes (Fig. 1). Topography of these localities features medium to high hills (Rahman et al. 2018). Monsoon climate of the area has three prominent seasons - the rainy season that lasts from May to October accounting for almost 90% of the total rainfall (Khatun et al. 2016). The mean annual temperature range is 13°C to 34.6°C while the mean annual rainfall is 3031 mm. The sampling area lies within the natural distribution range of bamboo. *M. baccifera* grows in pure brakes in the hill forests while *B. tulda* grows sporadically in small patches or grooves in the rural settings and hill forests of Bangladesh (Banik 1998). Considering the morphology of these species, this study assumed uniform physical properties of the culms for both the species across their geographical ranges in Bangladesh.

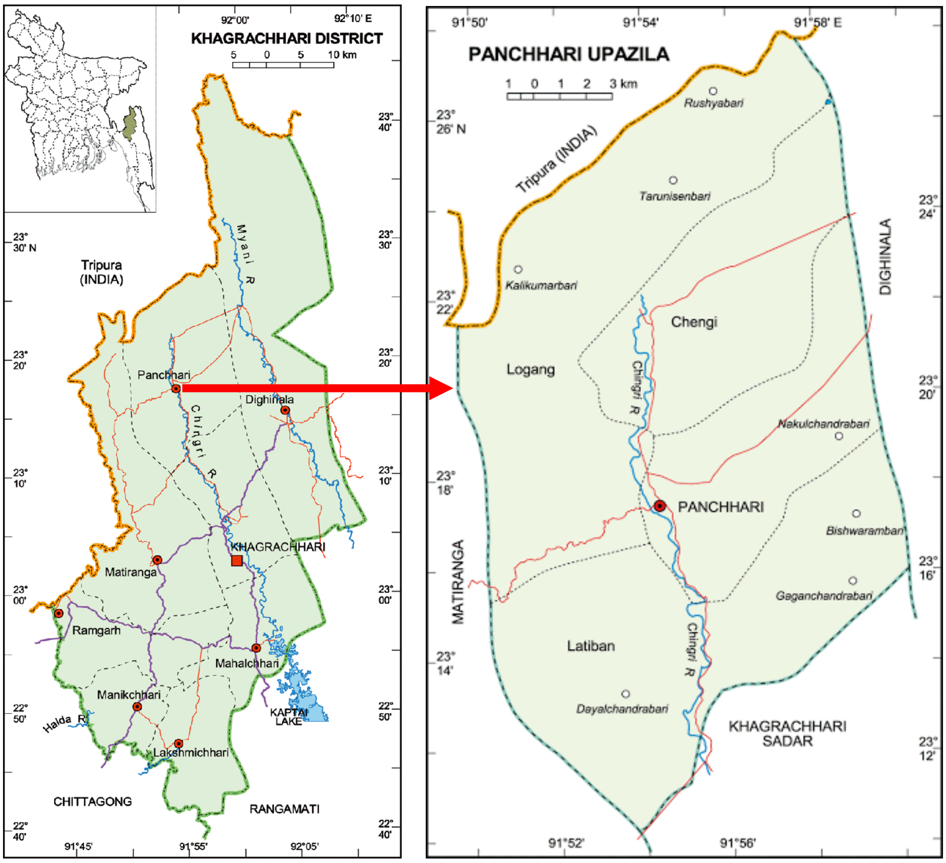

Fig. 1: Location of the area from where bamboo species were selected for sampling

Sampling the bamboo

The sample consisted of 50 culms with 25 for each of *M. baccifera and B. tulda* and represented the diameter and height ranges for both the species in the sampling area. Diameter at Breast Height (DBH) of *M. baccifera* ranged from 2.2-6.1 cm with an average of 4.43 ± 0.19 cm while DBH for *B. tulda* ranged from 3.1-6.2 cm with an average of 4.86 ± 0.18 cm. The mean total height of *M. baccifera* was 10.9 ± 0.39 m with a range of 7.3-14.2 m while the respective values for *B. tulda* were 10.93 ± 0.34m and 7.4-13.4 m.

Field data collection and laboratory analysis

Before felling, DBH of all the selected bamboo culms were measured. The culms were felled using a hand saw at <20 cm height from the ground. The leaves and branches were severed from the culm. Since the branches were very small in diameter, they were mixed with leaves and weighed with a portable digital measuring scale (**Figure 2**). Then culms were sectioned to measure the fresh weight with a digital hanging scale. The top section of the bamboo was separated at the point where its diameter was 2 cm. The top was weighted separately. Fresh weight of a total of 20 sub-samples (10 per species) of culms and leaves were measured in the field and after bringing the samples to the laboratory their oven dry (105°C) weights were obtained. The fresh to oven dry weight ratio. Moreover, bamboo culm samples taken from bottom, middle and top portions were cut into one-inch squares. Oven dry weights of these samples were measured separately in air and in water to calculate the density (Eq. 1 and 2).

$V = W_a - W_w$ ------------------ Eq (1)

$D = \frac{W_o}{V}$ ---------------------- Eq (2)

where, W_a = weight in air (g), W_w = weight in water (g), W_o = oven dry weight (g), D = density (g/cc), V = volume (oven dry) in cubic center.

Biomass calculation

The total fresh weight of the bamboo compartments (i.e., leaves & branches, and stem) were converted to oven dry weight by using fresh to oven dry weight ratio. The total biomass of each sampled bamboo was then computed as the sum of the oven dry weights of the compartments (Hossain et al. 2018).

Development of allometric equations

Descriptive statistics were calculated for the explanatory (DBH, Diameter at base, height) and output variables. Ten candidate allometric equations that are commonly used for plants in pantropical regional were tested for the prediction of biomass for bamboo compartments (leaf & branches, and stem) and total above ground biomass (AGB) of the two bamboo species (**Table 1**). R (version 4.0.2) statistical software was used for testing the allometric equation.

Table 1: Candidate models for development of allometric equations

Model No.	Candidate equation	Reference
1	$Y = a + bD$	Khan and Faruque 2010
2	$Y = \ a + b(D^2 \times H)$	Khan et al. 2005
3	$Y = aD^b$	Gao et al. 2015
4	$Y = a + bD_5$	Kebede and Soromessa 2018
5	$Y = a + b(D_5)^2 \times H$	Paul et al. 2013
6	$Y = a(D_5)^b$	Gao et al. 2015
7	$Y = a + bH$	Gurmessa et al. 2012
8	$Y = aH^b$	Baharuddin and Malamassam 2016
9	$Y = a(D^b \times H^c)$	Basuki et al. 2009
10	$Y = a + bLN(D)$	Djomo and Chimi 2017

Model selection and validation

The best-fit model was selected based on the goodness-of-fit statistics. The model having the lowest Akaike Information Criterion (AIC), and Residual Standard Error (RSE), and the highest adjusted coefficient of determination (R^2) values was selected as the best fit model (Sileshi 2014a, Vickers 2017). The predicted biomass was plotted against the observed biomass to validate the model. Significance of slope (b = 1) and intercept (a = 0) were also evaluated to graphically understand the over- or under-estimation of the biomass for each model (Pineiro et al. 2008; Sileshi 2014a). The alpha level for all statistical analyses was 0.05 unless stated otherwise.

Results

Bamboo density

The density of bamboo stems of both *M. baccifera* and *B. tulda* were analyzed separately for bottom, middle and top portions. Density was high for samples from the middle portion for both species which were 0.945 (±0.01) g/cc for *M. baccifera* and 0.904 (±0.03) g/cc for *B. tulda* (**Table 2**). *M. baccifera* stem showed slightly higher mean density (0.849±0.02 g/cc) than *B. tulda* (0.844±0.02 g/cc). Abdullah et al. (2017) reported varying densities for five bamboo species in Indonesia within the range 0.54-0.76 g/cc. In comparison, both bamboo species in the present study showed higher densities over Indonesian species, maybe due to climatic and geographic variations.

Table 2: Density of the culm of the two bamboo species in different portions

Location of sample in the stem	***Melocanna baccifera***		***Bambusa tulda***	
	Density (g/cc)	SE	Density (g/cc)	SE
Bottom	0.804	0.03	0.796	0.02
Middle	0.945	0.01	0.904	0.03
Top	0.842	0.06	0.833	0.03
Average	0.849	0.02	0.844	0.02

Descriptive statistics of allometric data

The leaf fresh to OD weight conversion ratios were respectively 0.551 (±0.05) and 0.624 (±0.03) for of *B. tulda* and *M. baccifera* (**Table 3**). The respective mean fresh and oven dry weights of stem were 7.03 (±0.50) and 4.40 (±0.32) kg/culm. Including the leaf oven dry biomass, the mean total biomass of *B. tulda* was 5.13 (±0.36) kg/culm. On the other hand, respective mean fresh and oven dry weights of stem of *M. baccifera* were 6.04(±0.39) and 4.07(±0.26) kg/culm. The total oven dry biomass of the individual *M. baccifera* bamboo is 5.0 (± 0.29) kg/culm.

Table 3: Descriptive statistics of the fresh biomass, fresh to OD weight conversion ratio, and OD biomass of different bamboo compartment [Here, OD = oven dry, Wt = weight]

Species	**Stem fresh (kg/culm)**	**Leaf fresh weight (kg/culm)**	**Leaf & branch fresh to OD weight ratio**	**Stem fresh to OD weight ratio**	**OD weight of stem (kg/culm)**	**OD weight of leaf (kg/culm)**	**Total OD biomass (kg/culm)**
B. tulda	7.03 ± 0.50	1.64 ± 0.18	0.551±0.05	0.627±0.03	4.40 ± 0.32	0.91 ± 0.10	5.31 ± 0.36
M. baccifera	6.04 ± 0.39	1.50 ± 0.14	0.624±0.03	0.673±0.03	4.07 ± 0.26	0.93 ± 0.08	5.0 ± 0.29

Best fit allometric models

Three best fitted allometric equations were identified for each species from each of the three compartments from the 30 allometric equations tested including 10 for leaves-branches biomass, 10 for stem biomass and 10 for total AGB, (**Table 4**). The adjusted R^2, residual standard error (RSE) and Akaike Information Criterion (AIC) values of the allometric model for leaf, stem and total above ground biomass varied widely with the candidate equations. Few models for bamboo stem and total AGB indicated a good relationship between the explanatory variables and biomass. Model 3 was the best fit allometric equation for leaf and branch, stem and total above ground biomass of *M. baccifera*. The value of goodness of fit statistics (RSE, AIC and Adj-R^2) were strong enough for selection of the stem and total above ground biomass models. But, in cases of leaf and branch the value of statistics did not indicate a good relationship of biomass of leaf and branch with DBH.

Table 4: Best fitted allometric equation for *M. baccifera*

Component	**Model No.**	**Allometric model**	**Adj-R^2**	**RSE**	**AIC**	**P value**
Leaf and branches	3	$Y_l = 0.282D^{0.757}$	0.158	0.396	28.54	0.028
Stem	3	$Y_l = 0.398D^{1.542}$	0.767	0.211	-2.90	5.89e-09
Total Above Ground Biomass	3	$Y_l = 0.627D^{1.382}$	0.783	0.181	-10.60	2.619e-09

In contrary, for *B. tulda*, Model 9 and Model 6 were the best fit allometric equations for stem and total above ground biomass, respectively (Table 5). The value of goodness of fit statistics (RSE, AIC and Adj-R^2) were supportive in the selection of models for stem and total above ground biomass. Alike *M. baccifera,* no model indicated good relationship between leaf and branch biomass of *B. tulda* with the explanatory variables. However, considering the value of goodness of fit statistics, Model 3 indicated a better relationship between biomass of leaves and branch with DBH.

Table 5: Best fitted allometric equation for B. tulda

Component	Model No.	Allometric model	Adj-R²	RSE	AIC	P value
Leaf and branches	3	$Y_l = 0.174(D^{0.9824})$	0.145	0.4375	34.41	0.06846
Stem	9	$Y_l = 0.041(D^{1.0658} \times H^{1.2311}$	0.8654	0.158	-16.51	1.012e-10
Total Above Ground Biomass	6	$Y_t = 0.253(D_{10})^{1.867}$	0.819	0.1701	-13.71	3.121e-10

Model validation

The predicted and observed stem and total above ground biomass from the selected best-fit models of the two species were plotted to show the relationship and prediction efficiency (Fig. 2). There was no significant deviation between the biomass estimation from the line of the significance of slope (b = 1) and intercept (a = 0). These visualizations indicated the accuracy of best-fit models for the estimation of aboveground dry biomass from the observed values. However, scopes always exist for further improvement of the models with more data.

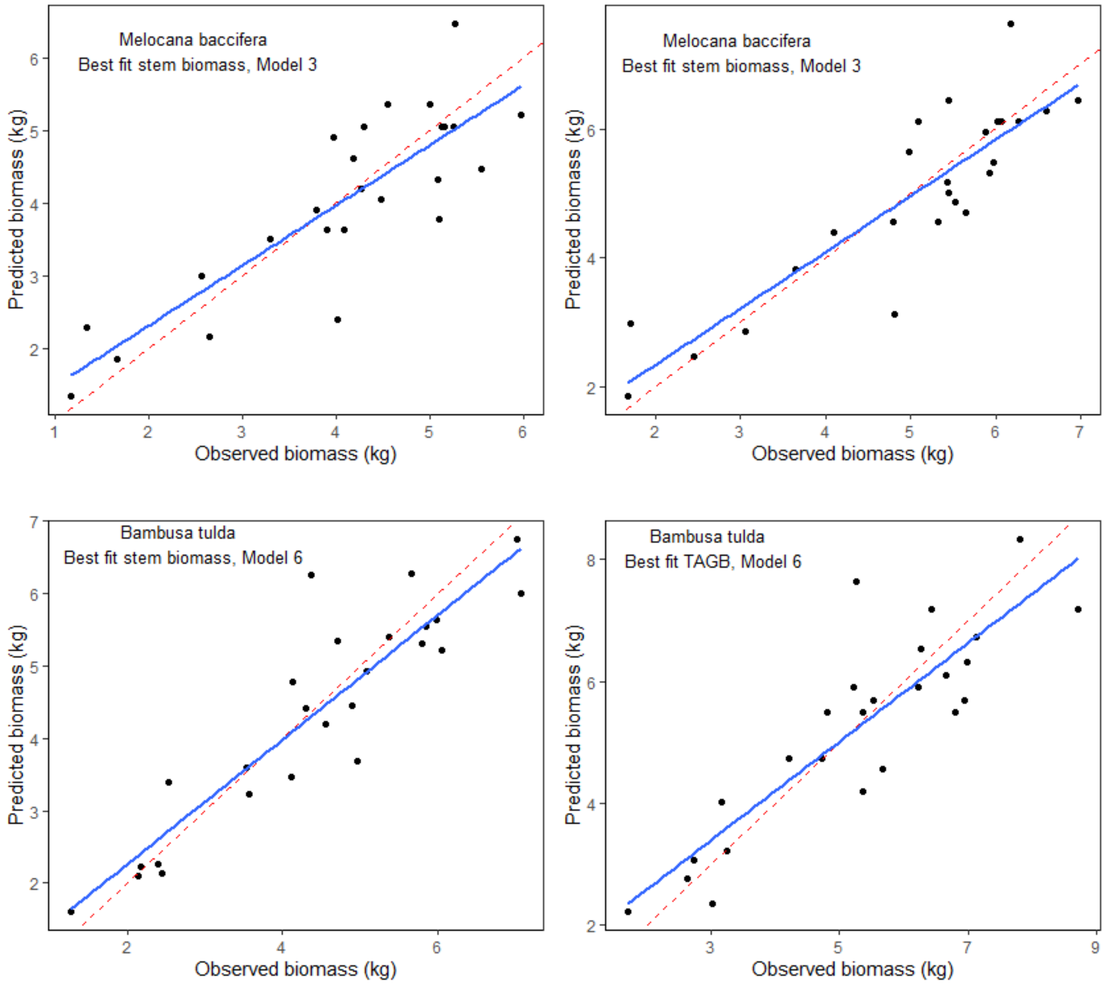

Fig. 2: Observed and predicted stem and total above ground biomass of *B. tulda* and *M. baccifera* in Bangladesh. [Note: The solid line is the regression line, and the dotted line is the significance of slope (b = 1) and intercept (a = 0).]

Discussion

Allometric model is critical to estimate the total above ground biomass of both tree and bamboo species (Nam et al., 2016). Model accuracy and the inclusion of predictor(s) are important considerations in selecting the best-fit models (Sileshi, 2014b). This study indicated slightly higher average density (0.849±0.02 g/cc) of *M. baccifera* than that of *B. tulda* (0.844±0.02 g/cc). In *B. tulda* and *M. baccifera*, bamboo stem respectively represented about 83% and 81% of the total OD biomass, which was in line with that (80-85%) reported by Shanmughavel and Francis (2001) and Nath et al. (2009).

The best-fit models are based on DBH as predictor except one model that estimated stem biomass of *B. tulda* based on both DBH and Height as explanatory variables. The simple allometric models with one independent variable will be helpful due to requirements of less efforts in the field measurements. The best-fit models of this study - particularly the DBH based power models - are similar to those recommended for bamboo by Melo et al. (2015) and Yen et al. (2010). Moreover, the predictability of the models in terms of coefficient of determinants (R^2) were higher (0.77-0.87) for stem and total AGB while not for the biomass of leaves & branches in both *B. tulda* and *M. baccifera.* However, the models proposed by Gao et al. (2015) reported a better predictability (R^2 = 0.5-0.7) for foliage and branch biomass of *Phyllostachys edulis*. The proposed best-fit models from the study can be used for estimating the above ground biomass of *B. tulda* and *M. baccifera*. Although the best-fit models are appropriate for estimating the total AGB of bamboo using predictor variables, these are not applicable for leaf and branch component.

Conclusions

Bamboo – the poor men's timber - is one of the most important non-timber forest products in Bangladesh with *Bambusa tulda* and *Melocanna baccifera* being the two main bamboo species of economic and ecological importance. Due to the heavy extraction and shifting cultivation in hilly areas - the stock of bamboo in hilly areas are rapidly decreasing. Bamboo has great potential to play a great role in organic carbon sequestration. Dearth of allometric equations for these two species for quick estimation of carbon sequestration by them - the study established 4 best fit allometric models for *B. tulda* and *M. baccifera*. These models are expected to provide reliable estimates for stem biomass and total above ground biomass for *B. tulda* and *M. baccifera*. The equations will play a pivotal role to assess biomass and thus organic carbon in bamboo (stem and total above ground biomass). These allometric models will also help develop the methodology and estimation procedure for organic carbon stock and biomass of *Bambusa tulda* and *Melocanna baccifera* in the future.

References

Baharuddin SD, Malamassam D. 2016. Allometric equation for estimating the total biomass and carbon stock in Parring Bamboo (*Gigantochloa* atter) from community forests.

Banik 1998. Bamboo resources, management and utilization in Bangladesh. Bamboo Conservation, Diversity, Ecogeography, Germplasm, Resource Utilization and Taxonomy. Proceedings of Training Course Cum Workshop, 25–30.

Basuki TM, Van Laake PE, Skidmore AK, Hussin YA. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. Forest Ecology and Management 257(8): 1684–1694.

Bystriakova N, Kapos V, Lysenko I, Stapleton CMA. 2003. Distribution and conservation status of forest bamboo biodiversity in the Asia-Pacific Region. Biodiversity Conservation 12: 1833–1841.

Djomo AN, Chimi CD. 2017. Tree allometric equations for estimation of above, below and total biomass in a tropical moist forest: Case study with application to remote sensing. Forest Ecology and Management 391: 184–193.

Gao X, Jiang Z, Guo Q, Zhang Y, Yin H, He F, Qi L, Shi L. 2015. Allometry and Biomass Production of Phyllostachys Edulis Across the Whole Lifespan. Polish Journal of Environmental Studies 24(2): 511-517

Gurmessa F, Gemechu T, Soromessa T, Kelbessa E. 2012. Allometric Equations to Estimate the Biomass of *Oxytenanthera Abyssinica* (A. Rich.) Munro. (Ethiopian Lowland Bamboo) in Dicho Forest, Oromia Region, Western Ethiopia 13-30.

Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, Troxler TG 2014. 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. IPCC, Switzerland.

Hossain M, Siddique MRH, Islam SMZ, Abdullah SMR, Matieu H, Iqbal MZ, Akhter M 2018. Applicability of semi-destructive method to derive allometric model for estimating aboveground biomass and carbon stock in the Hill zone of Bangladesh. Journal of Forestry Research. https://doi.org/https://doi.org/10.1007/s11676-019-00881-5

Kebede B, Soromessa T. 2018. Allometric equations for aboveground biomass estimation of Olea europaea L. subsp. Cuspidata in Mana Angetu Forest. Ecosystem Health and Sustainability, 4(1): 1–12.

Keith H, Mackey BG, Lindenmayer DB. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world’s most carbon-dense forests. Proceedings of the National Academy of Sciences 106(28):11635–11640.

Khan, Faruque O. 2010. Allometric relationships for predicting the stem volume in a Dalbergia sissoo Roxb. Plantation in Bangladesh. IForest-Biogeosciences and Forestry 3(6): 153-158. https://doi.org/10.3832/ifor0554-003

Khan, Suwa R, Hagihara A. 2005. Allometric relationships for estimating the aboveground phytomass and leaf area of mangrove *Kandelia candel* (L.) Druce trees in the Manko Wetland, Okinawa Island, Japan. Trees 19(3): 266–272.

Khatun MA, Rashid MB, Hygen HO 2016. Climate of Bangladesh. MET Report, 08, 2387–4201. https://www.coursehero.com/file/45300068/MET-report-08-2016pdf/

Körner C, Basler D. 2010. Phenology under global warming. Science 327(5972): 1461–1462.

Latif MA. 2008. Bamboo species, their distribution, habitat, rehabilitation and uses in Bangladesh. Document no-1, market development of bamboo and rattan products with potentials, Bangladesh Forest Research Institute, Chittagong.

Lobovikov M, Lou Y, Schoene D, Widenoja R. 2009. The poor man’s carbon sink: Bamboo in climate change and poverty alleviation. Non-Wood Forest Products Working Document, pp 8.

Melo LC, Sanquetta CR, Dalla Corte AP, Mognon F. 2015. Methodological alternatives in the estimate of biomass for young individuals of *Bambusa* genus. Bioscience Journal 31(3): 791-800.

Miah MD, Islam KN, Kabir MH, Koike M. 2020. Allometric models for estimating aboveground biomass of selected homestead tree species in the plain land Narsingdi district of Bangladesh. Trees, Forests and People 2: 100035.

Nath AJ, Das G, Das AK. 2009. Above ground standing biomass and carbon storage in village bamboos in North East India. Biomass and Bioenergy 33(9): 1188–1196. https://doi.org/10.1016/j.biombioe.2009.05.020

Nath AJ, Lal R, Das AK, 2015a. Ethnopedology and soil quality of bamboo (*Bambusa* sp.) based agroforestry system. Science of the Total Environment 521–522: 372–379. https://doi.org/10.1016/j.scitotenv.2015.03.059

Nath AJ, Lal R, Das AK, 2015b. Managing woody bamboos for carbon farming and carbon trading. Global Ecology and Conservation 3: 654–663.

Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P. 2014. Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCCC 23-45.

Paul KI, Roxburgh SH, England JR, Ritson P, Hobbs T, Brooksbank K, Raison RJ, Larmour JS, Murphy S, Norris J. 2013. Development and testing of allometric equations for estimating above-ground biomass of mixed-species environmental plantings. Forest Ecology and Management, 310: 483–494.

Piñeiro G, Perelman S, Guerschman JP, Paruelo JM 2008. How to evaluate models: Observed vs. predicted or predicted vs. observed? Ecological Modelling, 216(3–4): 316–322.

Piouceau J, Panfili F, Bois G, Anastase M, Dufossé L, Arfi V. 2014. Actual evapotranspiration and crop coefficients for five species of three-year-old bamboo plants under a tropical climate. Agricultural Water Management 137(1): 15-22.

Poudel B, Gautam S, Bhandari D 2013. Above-ground tree biomass and allometric relationships of Cinnamomum tamala grown in the western hill regions of Nepal. Banko Janakari 21(1):3–12.

Rahman M, Parvin W, Sultana N, Tarek S. 2018. Conservation of bamboo species in a mini urban ecosystem of Bangladesh. Journal of Biodiversity Conservation and Bioresource Management 3(2): 35–42.

Sedjo R, Sohngen B. 2012. Carbon Sequestration in Forests and Soils. Annual Review of Resource Economics 4(1): 127–144. https://doi.org/10.1146/annurev-resource-083110-115941

Shanmughavel P, Francis K. 2001. Bioproductivity and nutrient cycling in bamboo and acacia plantation forests. Bioresource Technology 80(1):45-48

Sileshi GW. 2014a A critical review of forest biomass estimation models, common mistakes and corrective measures. Forest Ecology and Management 329:237–254.

Sileshi GW. 2014b. A critical review of forest biomass estimation models, common mistakes and corrective measures. Forest Ecology and Management 329: 237–254.

Vickers NJ 2017. Animal communication: When i'm calling you, will you answer too? Current Biology, 27(14): R713–R715.

Xu M, Ji H, Zhuang S. 2018a. Carbon stock of Moso bamboo (*Phyllostachys pubescens*) forests along a latitude gradient in the subtropical region of China. PloS One 13(2): e0193024 https://doi.org/10.1371/journal.pone.0193024

Yen TM, Ji YJ, Lee JS. 2010. Estimating biomass production and carbon storage for a fast-growing makino bamboo (*Phyllostachys makinoi*) plant based on the diameter distribution model. Forest Ecology and Management 260(3): 339–344.