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Allometric models for estimation of aboveground biomass of *Gmelina arborea* Roxb. in pulpwood plantations of Bangladesh

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Gmelina arborea Roxb. is a fast-growing, deciduous tree species native to Bangladesh. It has been widely planted since 1992 for commercial production of pulpwood in hilly areas of Bangladesh. The purpose of this study was to derive well-fitting allometric models for estimation of aboveground biomass, and carbon and nutrient (nitrogen, phosphorus and potassium) stocks in *G. arborea* to ensure sustainable production and management of this species. Eight linear models with 64 regression equations were tested for estimation of aboveground biomass, carbon and nutrient stocks in different parts (leaves, branches, bark and stem) of the plant. The best-fitting allometric models were selected in accordance with various relevant statistical criteria.

Keywords: allometry, biomass, carbon, *Gmelina arborea*, nutrients

Introduction

Gmelina arborea Roxb. has been widely planted in Southeast Asian, tropical African and Latin American countries (Evans 1982). This species has also been widely planted and managed for the commercial production of pulp in Bangladesh (KPM 1992). Karnaphuli Paper Mills Ltd (KPM) is the largest and first-established paper mill in Bangladesh and bamboo was the main raw material of this mill following its establishment in 1953. During the mid-1980s, bamboo stocks became depleted due to uncontrolled Jhum (shifting) cultivation and encroachment in its natural habitat, which resulted in a shortage of raw material supply to the mill. Given the shortage of raw material, the Forest Department started to plant *G. arborea* for 12-year rotation (KPM 1992). KPM received 7 851 tonnes (air-dry weight) of *G. arborea* as raw material during 1992. However, the annual supply of *G. arborea* decreased to 1 377 tonnes during 2015 (KPM 2016).

Biomass and volume estimation have many applications, such as estimations for timber extraction, productivity, carbon stocks and nutrient cycles (Komiya et al. 2008). The biomass of a stand can be estimated using a semi-destructive method whereby the whole or partial weight of a tree can be estimated from measurable tree dimensions (diameter at breast height [DBH] and height) and allometric equations (Ketterings et al. 2001; Mahmood et al. 2016a). Many researchers have developed generalised allometric models for different forests and tree species (Chave et al. 2005; Basuki et al. 2009). However, it is preferable to use species- and site-specific allometric models for the accurate estimation of biomass (Soares and Schaeffer-Novelli 2005). Latif et al. (1984) derived a volume allometric equation for *G. arborea* in Bangladesh.

However, no allometric equations for biomass estimation for *G. arborea* in Bangladesh have been developed. Such an equation will play an important role in the sustainable supply of pulpwood to KPM. The objectives of the present study were to derive allometric models for estimation of aboveground biomass, and of nutrient and carbon stocks of *G. arborea* in Bangladesh.

Materials and methods

Study area

The present study was conducted at the Rowangchhari and Tarachha localities of the Bandarban Pulpwood Forest Division, Bangladesh, which was established in 1985 with an area of about 8 720 ha. The geographical extent of the study area ranged between 22°08' to 22°11' N and 92°15' to 92°21' E (Figure 1). The sites consisted of hills and terraces, the soil is loamy with a pH of about 5, and is poor in organic matter and nutrients. Mean annual rainfall, relative humidity and temperature of the study area is 2 528 mm, 82% and 25.9 °C, respectively (Hassan et al. 2017).

Sample collection and processing

Biomass allometric models consist of two up-scaling steps, i.e. sampling of an individual tree to the stand level and statistical models (Seifert and Seifert 2014). First, sampling of individual trees of *G. arborea* was undertaken in the plantations. The trees were divided into five classes depending on age (<3, 3–6, 6–9, 9–12 and >12 years). Two sample plots (20 m × 20 m) were established in the

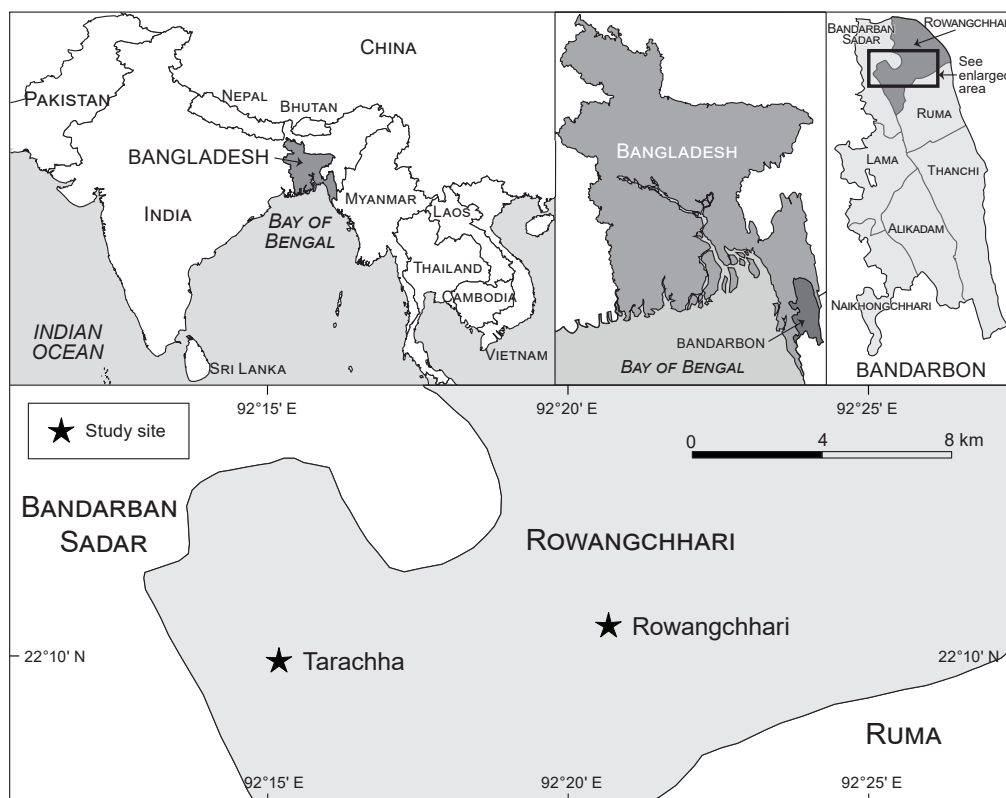


Figure 1: Map of the study area

plantation for each age class to determine the range of DBH values. A corresponding DBH range was derived for each age class and the DBH classes were 5–10, 10–15, 15–20, 20–25 and 25–30 cm for plantation ages of <3, 3–6, 6–9, 9–12 and >12 years, respectively. A minimum of three individual trees were sampled from each DBH class to get representation of age differences. In total, 16 individuals with DBH ranging from 5 to 15 cm were selected subjectively from the study area. The DBH and total height of the selected individuals were measured and the trees were felled at ground level. The felled trees were separated into leaves, small branches (diameter <2 cm), large branches (diameter >2 cm) and the stem. The fresh weight of each part was measured in the field using a portable digital hanging balance (Mahmood et al. 2015). The stem was divided into suitable sections <100 kg in mass. The stump was cut, weighed and finally added to the stem. At least 10 sections (1 m long) from different positions (base, middle and top) of the stem were debarked in the field to obtain the fresh weight ratio of stem and bark. Thus, stem biomass was divided into bark and stem wood. Ten subsamples (0.25 kg) from each part (leaves, small branches, large branches, bark and stem) of the sampled trees were collected randomly using a portable laboratory balance and transported to the laboratory to determine the fresh to oven-dry weight conversion ratio at 105 °C (Snowdon et al. 2002; Mahmood et al. 2012). The respective conversion factor was then multiplied by the total fresh weight of each part to derive the total oven-dry weight. The total oven-dry weight of a sample tree was obtained by summing the oven-dry weight of all parts. The

mean biomass proportion for each part was estimated in accordance with the DBH classes.

Nutrient and carbon contents in plant parts

The oven-dried and processed subsamples of tree parts were digested (Allen 1989). The nitrogen concentration in the sample extracts was measured in accordance with the method of Baethgen and Alley (1989). Tri-acid digestion was adopted to determine the phosphorus and potassium concentrations in the sample extracts (Allen 1989). The carbon content in the samples was measured using the 'loss of ignition method' (Allen 1989). Nutrient and carbon concentrations in the plant parts were compared by means of one-way analysis of variance (ANOVA) followed by the Duncan multiple range test using SAS 6.12 statistical software (SAS Institute, Cary, NC, USA).

Allometric models

A total of eight linear models ($Y = a + bX$, $\sqrt{Y} = a + b\sqrt{X}$, $Y = a + \log X$, $\log Y = a + bX$, $\log Y = a + b \log X$, $Y = a + b \ln X$, $\ln Y = a + bX$ and $\ln Y = a + b \ln X$), where Y = biomass (in kg), X = independent variable, i.e. diameter at breast height (D), total height (H), $D \cdot H$ and $D^2 \cdot H$, b = intercept and a = slope, with 64 regression equations were tested to derive the most suitable allometric biomass model for each plant part of *G. arborea* (Mahmood et al. 2015). Significance of regression equations were tested using SAS 6.12 statistical software. A correction factor (CF) was derived to counteract the bias that was introduced in the log- and ln-transformed equations (Sprugel 1983). The best-fitting regression equations were selected with

consideration of the lowest values of the corrected Akaike information criterion (AICc), Furnival index (FI), root mean square error (RMSE), and mean square error (MSerror), and the highest coefficient of determination (R^2) (Furnival 1961; Anderson et al. 1994; Mahmood et al. 2016b).

Results and discussion

The mean biomass proportion of the different components of *G. arborea* was found to vary with DBH class. Comparatively higher proportions of leaf biomass ($4.53\% \pm 0.07\%$) were observed for the 15–20 cm DBH class, whereas a higher proportion of branch biomass ($22.94\% \pm 0.64\%$) was observed for the same DBH class (15–20 cm). However, almost similar proportions of stem biomass ($71.53\% \pm 3.46\%$ to $74.84\% \pm 2.53\%$) and bark biomass ($8.73\% \pm 0.42\%$ to $9.14\% \pm 0.31\%$) were observed for all DBH classes. Age variation among the trees of different DBH classes may be responsible for the difference in biomass proportion of different components of the sample trees. Moreover, tree architecture varies with the growth stage (seedlings, saplings and mature trees) of tree species, which ultimately controls the biomass proportion of each individual part of plants (Mahmood et al. 2015, 2016a). This variation is also attributed to species, site and age class (Mugasha et al. 2015). Nutrients and carbon concentration in plant components

varied significantly ($p < 0.05$). The highest contents of nitrogen (26.85 mg g^{-1}) and potassium (16.08 mg g^{-1}) were observed in the leaves, whereas the bark showed the highest content of phosphorus (0.12 mg g^{-1}). Higher concentrations of carbon were observed in the large branches (48.86%) and the stem (48.35%) (Table 1). Structural parts of plants contained lower amounts of nutrients (nitrogen, phosphorus and potassium) compared with those of physiologically active tissues of the plant, whereas a comparatively higher concentration of carbon was observed in the stem and branches (Marschner 1995).

The majority of the tested regression equations were significant ($p < 0.05$) and the majority were excluded on the basis of a pre-determined minimum R^2 value. These minimum exclusion R^2 values were 0.70 for leaves, 0.80 for branches, and 0.97 for bark, stem without bark and total aboveground biomass. The preliminary selected equations were compared to identify the best-fitting allometric equation or model. The equations $\ln \text{Biomass} = -6.89 \ln \text{DBH} + 2.661$, $\ln \text{Biomass} = -5.293 \ln \text{DBH} + 2.786$, $\ln \text{Biomass} = -5.344 \ln \text{DBH}^2 \times \text{Height} + 0.907$, $\ln \text{Biomass} = -3.240 \ln \text{DBH}^2 \times \text{Height} + 0.907$, and $\ln \text{Biomass} = -3.028 \ln \text{DBH}^2 \times \text{Height} + 0.925$ were the best-fitting models for leaves, branches, bark, stem without bark and total aboveground biomass, respectively, with consideration of the lowest values of AICc, RMSE and MSerror (Table 2). Biomass of

Table 1: Nutrients and carbon concentration (mean $\pm$ SE) in different parts of *Gmelina arborea* trees. Values followed by the same superscript letter within a column indicates a non-significant difference ($p > 0.05$)

Plant part	Nitrogen (mg g^{-1})	Phosphorus (mg g^{-1})	Potassium (mg g^{-1})	Carbon (%)
Leaf	26.85 ± 1.61^a	0.12 ± 0.01^b	16.08 ± 0.39^a	46.12 ± 0.11^b
Stem	6.64 ± 0.38^d	0.01 ± 0.00^e	4.51 ± 0.10^e	48.35 ± 0.43^a
Bark	18.15 ± 5.38^b	0.50 ± 0.07^a	9.51 ± 0.10^c	45.74 ± 0.03^c
Large branch (diameter >2 cm)	7.08 ± 0.35^d	0.08 ± 0.01^c	6.86 ± 0.26^d	48.86 ± 0.01^a
Small branch (diameter <2 cm)	11.67 ± 1.77^c	0.04 ± 0.01^d	12.94 ± 0.20^b	47.13 ± 0.50^b

Table 2: Selected allometric models for different parts of *Gmelina arborea* trees. Models marked with an asterisk (*) indicates the best-fitting equation. a = slope, b = intercept, RMSE = root mean square error, MSerror = mean square error, AICc = corrected Akaike information criterion, FI = Furnival index, CF = correction factor

Plant part	Equation	R^2	a	b	RMSE	MSerror	AICc	FI	CF
Leaf	$\ln Y = a + b \ln(D)^*$	0.763	-6.896	2.661	0.841	0.707	0.305	2.261	1.283
	$\ln Y = a + b \ln(D^2H)$	0.755	-6.975	0.955	0.856	0.733	0.893	2.303	1.366
	$\ln Y = a + b \ln(DH)$	0.745	-6.976	1.482	0.872	0.760	1.481	2.346	1.398
	$\ln Y = a + b D$	0.742	-2.663	0.173	0.878	0.770	1.692	2.361	1.346
Branch	$\ln Y = a + b \ln(D)^*$	0.933	-5.293	2.786	0.424	0.180	-21.578	3.034	1.016
	$\ln Y = a + b \ln(D^2H)$	0.927	-5.399	1.003	0.441	0.195	-20.329	3.155	1.022
	$\ln Y = a + b \ln(DH)$	0.919	-5.413	1.559	0.466	0.217	-18.605	3.330	1.028
	$\ln Y = a + b D$	0.836	-1.096	0.298	1.139	1.297	10.029	8.148	
Bark	$\sqrt{Y} = a + b \sqrt{(D)}$	0.820	-5.477	2.369	1.191	1.420	11.468	8.523	
	$\ln Y = a + b \ln(D^2H)^*$	0.994	-5.344	0.907	0.112	0.013	-64.249	0.561	1.000
	$\ln Y = a + b \ln(D)$	0.992	-5.220	2.507	0.130	0.017	-59.385	0.653	1.000
	$\ln Y = a + b \ln(DH)$	0.990	-5.373	1.412	0.146	0.021	-55.663	0.733	1.000
Stem	$\sqrt{Y} = a + b \sqrt{(D^2H)}$	0.988	0.272	0.042	0.176	0.031	-49.677	0.884	
	$\ln Y = a + b \ln(D^2H)^*$	0.994	-3.240	0.907	0.112	0.013	-64.249	1.605	1.000
	$\ln Y = a + b \ln(D)$	0.992	-3.116	2.507	0.130	0.017	-59.385	1.868	1.000
	$\ln Y = a + b \ln(DH)$	0.990	-3.270	1.412	0.146	0.021	-55.663	2.098	1.000
Total above-ground biomass	$\sqrt{Y} = a + b \sqrt{(D^2H)}$	0.988	0.777	0.120	0.505	0.255	-16.025	7.242	
	$\ln Y = a + b \ln(D^2H)^*$	0.991	-3.028	0.925	0.135	0.018	-58.2109	2.321	1.000
	$\ln Y = a + b \ln(D)$	0.991	-2.907	2.561	0.139	0.019	-57.2575	2.391	1.000
	$\ln Y = a + b \ln(DH)$	0.986	-3.054	1.441	0.172	0.029	-50.5359	2.950	1.001
	$\sqrt{Y} = a + b \sqrt{(D^2H)}$	0.978	0.834	0.146	0.832	0.692	-0.0162	14.305	

leaves and branches seems to vary widely compared with that of the stem of trees (Mahmood et al. 2015, 2016a). This may be the reason for not finding a well-fitting allometric model for leaf and branch biomass, even using different transformations of variables and the inclusion of total height in the process of model development. However, model fit improved with the addition of total height for bark and stem biomass, but this addition had no effect on total aboveground biomass (Table 2). The derived models showed similar total aboveground biomass with the common model of Nam et al. (2016), but the model of Chave et al. (2005) underestimated the total aboveground biomass for trees with the higher DBH class. In addition, the present study showed similar results for estimation of stem biomass with the biomass estimated using a volume equation derived by Latif et al. (1984). From this comparison it can be concluded that the derived allometric models can be efficiently used to estimate the aboveground biomass, and nutrient and carbon stocks in plantations of *G. arborea* in Bangladesh.

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References

- Allen SE. 1989. *Chemical analysis of ecological materials*. Oxford: Blackwell Scientific Publications.
- Anderson DR, Burnham KP, White GC. 1994. AIC model selection in overdispersed capture–recapture data. *Ecology* 75: 1780–1793.
- Baethgen WE, Alley MM. 1989. A manual colorimetric procedure for measuring ammonium nitrogen in soil and plant Kjeldahl digests. *Communications in Soil Science and Plant Analysis* 20: 961–969.
- 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: 1684–1694.
- Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D et al. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87–99.
- Evans J. 1982. *Plantation forestry in the tropics*. Oxford: Clarendon Press.
- Furnival GM. 1961. An index for comparing equations used in constructing volume tables. *Forest Science* 7: 337–341.
- Hassan M, Hassan R, Pia HI, Hassan MA, Ratna SJ, Aktar M. 2017. Variation of soil fertility with diverse hill soils of Chittagong Hill tracts, Bangladesh. *International Journal of Plant and Soil Science* 18: Art. no. IJPSS.34975.
- Ketterings QM, Coe R, Noordwijk MV, Amagau Y, Palm CA. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management* 146: 199–209.
- Komiyama A, Ong JE, Pongparn S. 2008. Allometry, biomass, and productivity of mangrove forests: a review. *Aquatic Botany* 89: 128–137.
- KPM (Karnaphuli Paper Mills). 1992. Agreement between the Forest Department and the Bangladesh Chemical Industries Corporation for felling, logging, extraction and transportation of pulp wood from Kaptai pulpwood plantation division to the Karnaphuli Paper Mills Ltd. Dhaka: BCIS.
- KPM. 2016. Yearly capacity of Karnaphuli Paper Mills Ltd. Chittagong: KPM.
- Latif MA, Islam MN, Choudhury JH. 1984. Tree volume tables for *Gmelina arborea* Roxb. (Gamar). In: Choudhury JH, Davidson J (eds), *Tree volume tables for four species grown in plantation in Bangladesh*. Inventory Division, Bangladesh Forest Research Institute Bulletin 2. Chittagong: Bangladesh Forest Research Institute. pp 93–121.
- Mahmood H, Saha C, Abdullah SMR, Saha S, Siddique MRH. 2016a. Allometric biomass, nutrient and carbon stock models for *Kandelia candel* of the Sundarbans, Bangladesh. *Trees* 30: 709–717.
- Mahmood H, Siddique MRH, Akhter M. 2016b. A critical review and database of biomass and volume allometric equation for trees and shrubs of Bangladesh. *IOP Conference Series, Earth and Environmental Science* 39: 012057.
- Mahmood H, Siddique MRH, Bose A, Limon SH, Saha S, Chowdhury MRK. 2012. Allometry, above-ground biomass and nutrient distribution in *Ceriops decandra* (Griffith) Ding Hou dominated forest types of the Sundarbans mangrove forest, Bangladesh. *Wetlands Ecology and Management* 20: 539–548.
- Mahmood H, Siddique MRH, Saha S, Abdullah SMR. 2015. Allometric models for biomass, nutrients and carbon stock in *Excoecaria agallocha* of the Sundarbans, Bangladesh. *Wetlands Ecology and Management* 23: 765–774.
- Marschner H. 1995. *Mineral nutrition of higher plants*. New York: Academic Press.
- Mugasha WA, Mwakalukwa EE, Luoga E, Malimbwi RE, Zahabu E, Silayo DS, Sola G, Crete P, Henry M, Kashindye A. 2015. Allometric models for estimating tree volume and aboveground biomass in lowland forests of Tanzania. *International Journal of Forestry Research* 2016: Art. ID 8076271.
- Nam VT, van Kuijk M, Anten NPR. 2016. Allometric equations for aboveground and belowground biomass estimations in an evergreen forest in Vietnam. *PLoS ONE* 11: e0156827.
- Seifert T, Seifert S. 2014. Modelling and simulation of tree biomass. In: Seifert T (ed.), *Bioenergy from wood: sustainable production in the tropics*. *Managing Forest Ecosystems* vol. 26. Dordrecht: Springer. pp 43–65.
- Snowdon P, Raison RJ, Keith H, Ritson P, Grierson P, Adams M et al. 2002. Protocol for sampling tree and stand biomass. *National Carbon Accounting System Technical Report* no. 31. Canberra: Australian Greenhouse Office.
- Soares MLG, Schaeffer-Novelli Y. 2005. Above-ground biomass of mangrove species. I. Analysis of models. *Estuarine, Coastal and Shelf Science* 65: 1–18.
- Sprugel DG. 1983. Correcting for bias in log-transformed allometric equations. *Ecology* 64: 209–210.