

# Allometric equations for estimating the above-ground biomass of *Castanopsis indica* at juvenile stage

S. K. Bhandari<sup>1</sup> and H. Neupane<sup>2</sup>

Most of the *Castanopsis indica* forest of Nepal in the midhill region was degraded in the recent past especially due to policy conflict between government and local users. But after the introduction of community forestry system, these forests have been rejuvenated gradually. Therefore, the proportion of the juvenile plants in forests is very high and the contribution of juvenile plants on total biomass production cannot be overlooked. Therefore this study was carried out to develop juvenile biomass models. We measured diameter at 10 cm above ground level (D), total height (H), density ( $\rho$ ) and total biomass (W) of *indica* juveniles. The models were estimated using “library (minpack.lm)” in R. The estimated models were evaluated by using numerical fit statistics and graphical analyses. The selected model  $\hat{W}_i = 52.28 (D_i^2 H_i)^{0.89}$  explained >95% juvenile biomass of *indica* with RSE=42.34g, AIC=406.8 and average deviation=13.26.

**Key words:** Biomass, *Castanopsis indica*, juvenile, model, Nepal

*Castanopsis indica* (Roxb.) Miq. (family *Fagaceae*), commonly known as Indian Chestnut, is a broadleaved evergreen tree species of middle hills of Nepal. It is generally found in association with *Schima wallichii* in high rainfall area of Annapurna region and eastern Nepal. This species is found between 1200 m to 2900 m above the mean sea level (Jackson, 1994). The main stem of this species is commonly used as construction timber, leaves as fodder and raw materials for local plates, branches as fuelwood and fruits as food. Most of the *C. indica* forest of Nepal in the midhill region was degraded in the recent past specially due to policy conflict between government and local users. But after the introduction of community forestry system, these forests have been rejuvenated gradually. Therefore, the proportion of the juvenile plants (defined as a plant  $\geq 30$  cm in height and  $< 10$  cm in stem circumference at 10 cm above ground surface (Chaturvedi *et al.*, 2012)) is very high. Almost 5% contribution was recorded from juvenile stage plants in total biomass production (Francis, 2000). Juvenile plants also contribute significantly for the protection of land through minimization of soil erosion. Therefore, juvenile plants play a vital role in maintaining the balance in overall ecosystem of forest and cannot be overlooked in forest biomass and carbon assessment.

The study of size-correlated variations in organic form and process in biological sciences is traditionally called “allometry” (Greek allos, “other” and metron, “measure”) (Niklas, 1994). The allometric equations can be used to estimate the above ground biomass and carbon of the particular forest area (Hosoda and Iehara, 2010; Chaturvedi *et al.*, 2012; Subedi and Sharma, 2012). However some other direct methods (Cutting of plants and weighing of their parts to estimate biomass) can also be used to estimate the biomass and carbon in a forest stand (Ketterings *et al.*, 2001; Basuki *et al.*, 2009). Since the area of the forest is large (in most of the cases), the estimation of biomass through destructive felling is not possible and not beneficial also in all cases. Therefore uses of indirect methods such as using allometric equations are considered better option in comparison to direct methods (Hosoda and Iehara, 2010; Chaturvedi *et al.*, 2012; Subedi and Sharma, 2012).

Large sized forest plants have been extensively used in biomass estimation and preparation of allometric equations (Keith *et al.*, 2000; Segura and Kanninen, 2005; Zianis *et al.*, 2005; Muukkonen, 2007). But very few studies can be found in which small sized plants have been used for biomass studies (Wagner and Ter-Mikaelian, 1999; Geudens *et al.*, 2004; Chaturvedi and

<sup>1</sup> Department of Social Forestry and Forest Management, Institute of Forestry, Nepal, Email: shesu15@yahoo.com

<sup>2</sup> Department of Forests, Ministry of Forests and Soil Conservation, Kathmandu, Nepal

Raghubanshi, 2013; Chaturvedi *et al.*, 2012; Chapagain *et al.*, 2014). In most of the cases, biomass and carbon are estimated by excluding the juvenile plants and therefore underestimation is also realized. One of the reasons for this is the unavailability allometric equations for juvenile stage plants. Therefore, it is worthwhile to include juvenile plants in biomass studies. Though Tamrakar (2000) has developed biomass table for *C. indica* and Shrestha (2013) has developed biomass models for large sized *C. indica*, so far, to the authors' knowledge, no biomass studies have been conducted for juveniles of *C. indica* in Nepal. Therefore this study was carried out to develop allometric equations for juveniles of *C. indica* which is expected to contribute to the carbon trade programs of Nepal in front of the international community.

## Materials and methods

### Study site

This study was carried out in Bhakarjung Community Forest of Dhikurpokhari Village Development Committee (VDC) of Kaski District (Fig. 1) (28°06' N to 28°36' N latitude and 83°40' E to 84°12' E longitude) Western Nepal. The total forest area in the district is 93,649.85 ha (46.43%) out of which 65,073.61 ha (69.49%) area is covered by Annapurna Conservation Area (ACA) and the remaining 28,575.48 ha (30.51%) is managed by District Forest Office (DFO), Kaski. The altitudinal range of this district varies from 490 m to 8091 m from the sea level. Its average maximum temperature is 33°C

and average minimum temperature is 5.6°C and the mean annual precipitation is 3,068 mm to 3,353.3 mm. The forest has been managed as community forest. The forest is natural uneven and mixed in composition of *S. wallichii* (Chilaune), *C. indica* (Dhale Katus), *Alnus nepalensis* (Utis), *Quercus semecarpifolia* (Khasru), *Rhododendron* spp. (Laliguras), *Bombax ceiba* (Simal) and others.

### Data collection

The existed variation in the population was detected from operational plan of the community forest. We selected 39 juveniles of *C. indica* purposively from the whole study area to represent existed variation of site, mode of origin, density, age and size (Adinugroho and Sidiyasa, 2006; Dorado *et al.*, 2006; Edwards Jr *et al.*, 2006). Vernier Calliper (precision 1 mm) was used to measure diameter of each individual juvenile at 10 cm above the ground level by following the rules of Chaturvedi and Khanna (2011). Similarly, the linear tape (precision 1 cm) was used to measure the total length from base to tip of the plant after destructive felling. The stem, leaves and branches were isolated and weighed (precision 0.1g) after felling. Samples for oven dry weight was collected from stem, leaves and branches and dried at 105°C at the laboratory of Institute of Forestry, Pokhara. The volume of stem was estimated using the principle of water displacement. The descriptive statistics of the data used for modeling is given in table 1.

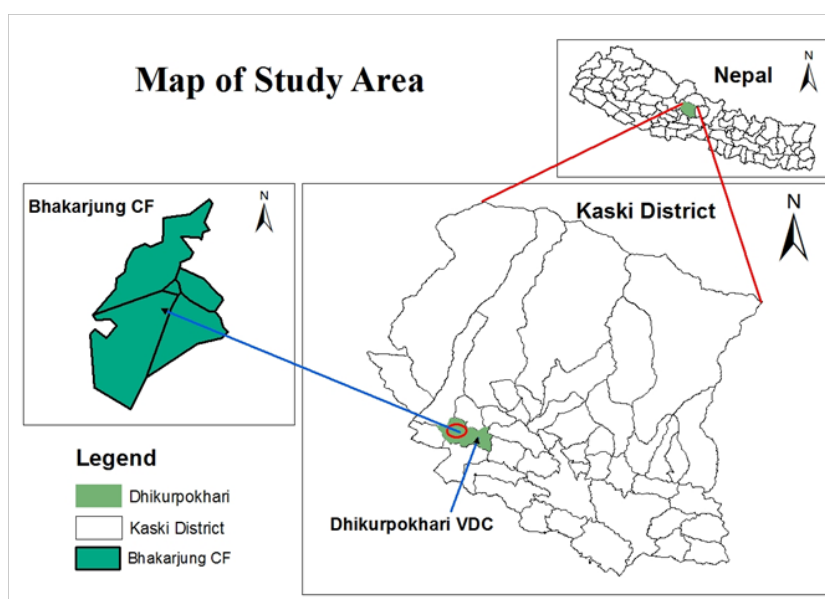


Fig.1: Location of study site

**Table 1: Descriptive statistics of the data used for modelling**

Diameter class	Variables	Mean ± std. error (range)
0-1	Diameter (cm)	0.873±0.022 (0.82-0.96)
	Height (m)	1.26±0.073 (0.91-1.4)
	Wood density (gcm <sup>-3</sup> )	0.46±0.045 (0.36-0.60)
	Biomass (g)	48.12±4.834 (34.00-61.43)
	Number	6
1-2	Diameter (cm)	1.50±0.051 (1.03-1.92)
	Height (m)	2.07±0.096 (1.22-3.01)
	Wood density (gcm <sup>-3</sup> )	0.48±0.007 (0.42-0.54)
	Biomass (g)	211.28±19.948 (54.71-477.91)
	Number	26
2-3	Diameter (cm)	2.33±0.090 (2.09-2.73)
	Height (m)	2.47±0.113 (2.04-2.90)
	Wood density (gcm <sup>-3</sup> )	0.46±0.017 (0.39-0.53)
	Biomass (g)	570.78 ±46.996 (481.85-816.63)
	Number	7
Overall	Diameter (cm)	1.55±0.078 (0.82-2.73)
	Height (m)	2.02±0.088(0.91-3.01)
	Wood density (gcm <sup>-3</sup> )	0.48±0.008 (0.36-0.60)
	Biomass (g)	249.72 ±30.187 (34-816.63)
	Number	39

**Data Analysis**

Dimensional analysis, the most common method, is used to predict individual tree biomass (Whittaker and Woodwell, 1968). This method basically depends on the consistency of an allometric relationship between plant dimensions (usually dbh and/ or height) and biomass for a given species, group of species, or growth form. The juvenile biomass of *C. indica* was modeled by using diameter alone (D, D<sup>2</sup>), diameter and height combined (DH, D<sup>2</sup>H), diameter and wood density combined (ρD, ρD<sup>2</sup>) and diameter, height and wood density combined (ρDH, ρD<sup>2</sup>H). Juvenile biomass models were designated by applying each of the eight independent variables and termed first model category for a model with D alone, second model category for a model with D<sup>2</sup> and third model category for a model with DH and so on resulting in eight different model categories in total and these eight model categories consist 13 models of different forms (i.e. 8 × 13 = 104 alternative models, see Table 2 for details).

The least square regression technique was used to develop biomass models. The models were estimated using “library (minpack.lm)” package in which lm (for linear models), nls and

**Table 2: Candidate models considered**

Specification	Model form	References
M1	$W_i = \beta_0 X_i^{\beta_1} + \epsilon_i$	Huxley and Teissier (1936)
M2	$W_i = \beta_0 \exp(\beta_1 X_i) + \epsilon_i$	Rizvi <i>et al.</i> (2008)
M3	$W_i = \beta_0 \exp(-\beta_1 / X_i) + \epsilon_i$	Schumacher (1939)
M4	$W_i = \beta_0 [1 - \exp(-\beta_1 X_i)]^3 + \epsilon_i$	Bertalanffy (1949)
M5	$W_i = \beta_0 \exp(\beta_1 / X_i) + \epsilon_i$	Modified after Schumacher (1939)
M6	$W_i = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + \epsilon_i$	Brown (1997)
M7	$W_i = \beta_0 + \beta_1 X_i^2 + \epsilon_i$	Sharma (2011)
M8	$W_i = \beta_0 + \beta_1 / X_i + \beta_2 X_i^2 + \epsilon_i$	Sharma (2011)
M9	$W_i = \beta_0 + \beta_1 X_i + \epsilon_i$	Spurr (1952)
M10	$W_i = \beta_0 + X_i^{\beta_1} + \epsilon_i$	Subedi and Sharma (2012)
M11	$W_i = X_i / (\beta_0 + \beta_1 X_i) + \epsilon_i$	Hosoda and Iehara (2010)
M12	$W_i = X_i^2 / (\beta_0 + \beta_1 X_i) + \epsilon_i$	Modified after Hosoda and Iehara (2010)
M13	$W_i = X_i^2 / (\beta_0 + \beta_1 X_i^2) + \epsilon_i$	Modified after Hosoda and Iehara (2010)

**Note:**  $W_i$  = biomass of individual  $i$  (g),  $x_i$  = independent variable for juvenile  $i$  [eight independent variable alternatives such as (1)  $D$ ; (2)  $D^2$ ; (3)  $DH$ ; (4)  $D^2H$ ; (5)  $\rho D$ ; (6)  $\rho D^2$ ; (7)  $\rho DH$ ; and (8)  $\rho D^2H$ ],  $D_i$  = diameter (cm);  $H_i$  = height (m);  $\rho$  = wood density (gcm<sup>-3</sup>), and  $b_1, b_2, b_3$  = parameters to be estimated, and  $\epsilon_i$  = unexplained error.

nlsLM (for non linear models) commands in R (R Core Team, 2012). The models were evaluated by applying various criteria such as significance of parameter estimates, residual standard error (RSE), adjusted coefficient of determination (R<sup>2</sup>adj), Akaike Information Criterion (AIC), Average deviation and Graphs of residuals, scaled and quantile-quantile (Q-Q).

**Comparing the equations to previously published equations**

We used model of Chapagain *et al.* (2014) to the current data to compare with the best selected model. The allometric equation developed by Chapagain *et al.* (2014) for juvenile of *Shorea robusta*, *Acacia catechu* and *Terminalia tomentosa* is:

$$W_i = 49.415 + (\text{dia} * \text{height})^{(1.239 - 0.033 / (\text{dia} * \text{height}))} \text{ for } S. \text{ robusta}$$

$$W_i = 47.904 + (\text{dia} * \text{height})^{(1.239 - 0.033 / (\text{dia} * \text{height}))} \text{ for } A. \text{ catechu}$$

$$W_i = 50.926 + (\text{dia} * \text{height})^{(1.239 - 0.033 / (\text{dia} * \text{height}))} \text{ for } T. \text{ tomentosa}$$

Where *W<sub>i</sub>* is total above ground biomass in gram/ juvenile, dia is the diameter (cm) measured 10 cm above the ground level and height is the total length (m) of plant from ground level to top of the juvenile. The equation of Chapagain *et al.* (2014) was constructed from the data collected from 40 juvenile individual for each species of *S. robusta*, *A. catechu* and *T. tomentosa*. The diameters used to establish this equation ranged from 0.22 to 3.17 cm (*S. robusta*), 0.17 to 3.15 cm (*A. catechu*) and 0.23 to 3.17 cm (*T. tomentosa*).

**Results and discussion**

**Developing allometric equation**

Parameter estimates of 83 models out of 104 models (8\*13=104 models or 13 models in each model category, Table 2) were found to be significant at 95% confidence interval. This shows that 79.8% of the models (83 significant models) tested in this study are more likely to be genuine and unlikely to have occurred by random chance to the data. RSE = 42 g i.e. unexplained error by the models was still left unexplained inspite of well fitting of the models to the modelling data. Table 3 shows the fit statistics and parameter estimates of the best models from each model category.

M1 from fourth model category, M7 from first model category and M9 from second model category showed the best fits (smallest RSE, AIC, average deviation and largest R<sup>2</sup>adj) among the models. The model M1, appeared in the fourth, third, first, first, second, first, first and first rank within the models from the first, second, third, fourth, fifth, sixth, seventh and eighth model category, respectively, which is the most widely used model to develop biomass model (Ter-Mikaelian and Korzukhin, 1997; Sharma, 2011; Miksys *et al.*, 2007). From the evaluation of fit statistics, M1 seems to be the most accurate and precise among the fourth model category and followed by the model M7 of the first model category, M9 of the second model category, M1 from the eighth model category, M1 from the third model category, M1 from sixth model category, M1 from seventh model category and M3 from fifth model category. Graphs of model residuals, scaled and normal Q-Q were also examined.

**Table 3: The value of coefficient and fit statistics of the best model of each model category**

Model category	Model	Explanatory variable*	Parameter estimates			Fit Statistics		
			β <sub>0</sub>	β <sub>1</sub>	R <sup>2</sup> adj.	RMSE	AIC	Average Deviation (%)
1	M7	D	-35.73	109.7	0.9338	49.15	418.43	19.02
2	M9	D <sup>2</sup>	-35.73	109.7	0.9338	49.15	418.43	19.02
3	M1	DH	40.20	1.45	0.9198	50.08	425.89	15.09
4	M1	D2H	52.28	0.89	0.9508	42.34	406.8	13.26
5	M14	ρD	3137.95	1.94	0.8169	81.73	458.09	24.00
6	M1	ρD <sup>2</sup>	186.05	1.18	0.9033	59.38	433.17	19.53
7	M1	ρDH	111.11	1.51	0.8407	76.25	452.67	20.57
8	M1	ρD·H	91.11	0.97	0.9310	50.15	420	14.67

The unstandardized residuals against the fitted values with a smooth superimposed curve for model M1 from model category fourth, model M7 from model category first and model M9 from model category second is shown in figure 2. Here we are looking for evidence of curvature and outliers. The graph of M1 from category fourth shows negligible curvature and outliers in comparison to remaining two models. Absence of curvature in M1 category fourth suggests us the absence of local bias in the model. The figure 3 shows the square root of the standardized residuals against fitted value along with smooth line. Departure from horizontal lines signify heteroskedasticity contradicting the model assumption “ $\epsilon_i$  have constant variance”, (Robinson and Hamann, 2011) but the model M1 from category fourth shows the less heteroskedasticity than other models. Similarly, figure 4 shows a Q-Q plot of the standardized residuals against the normal distribution. Here the ideal plot is a straight line, although modest departures from straightness are often acceptable (due to large-sample theory). Departures from a straight line in this plot may indicate non-normality of the residuals or non-constant variance, or both (Robinson and Hamann, 2011). But in our analysis, we found all the points are in a reasonably straight line which indicates the normal distribution of residuals.

The independent variable  $D^2H$  (combination of diameter and total height) demonstrated strong capacity to predict juvenile biomass in case

of model M1 from model category fourth in comparison to others. Therefore, the following model M1 was selected for the estimation of juvenile biomass of *C. indica* from the first stage of model development. Here after this selected model is referred as M14 for further analysis and comparison with previously published models.

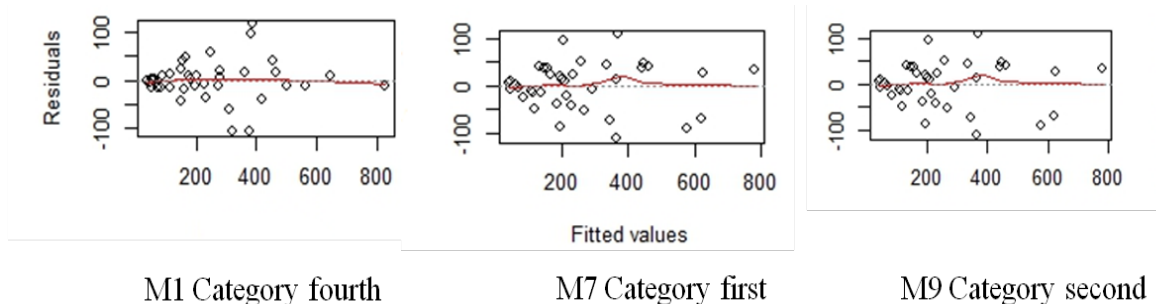
$$\hat{W}_i = 52.28(D_i^2H)^{0.89} \dots\dots\dots M14$$

**Comparison of M14 with previously published equations**

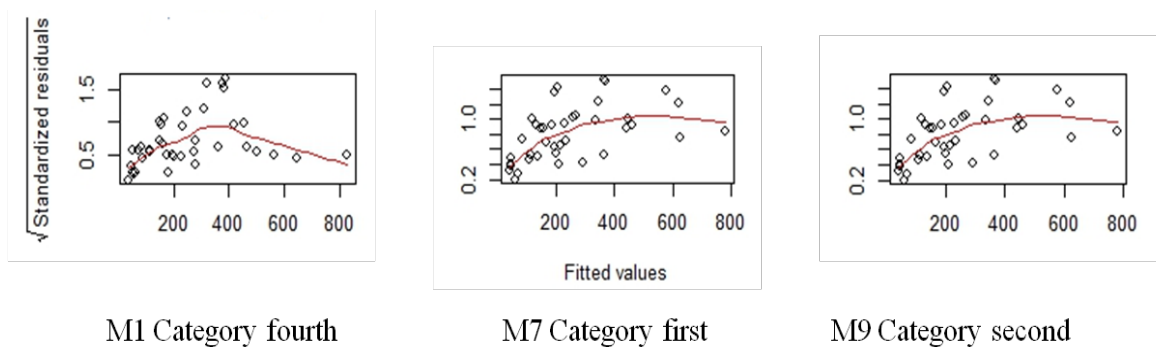
**Table 4: The average deviation and AIC values of various models**

Model	Average Deviation (%)	AIC
M14	13.26	406.8
Chapagain <i>et al.</i> (2014) <i>S. robusta</i>	64.85	428
Chapagain <i>et al.</i> (2014) <i>A. catechu</i>	65.41	428
Chapagain <i>et al.</i> (2014) <i>T. tomentosa</i>	64.29	428

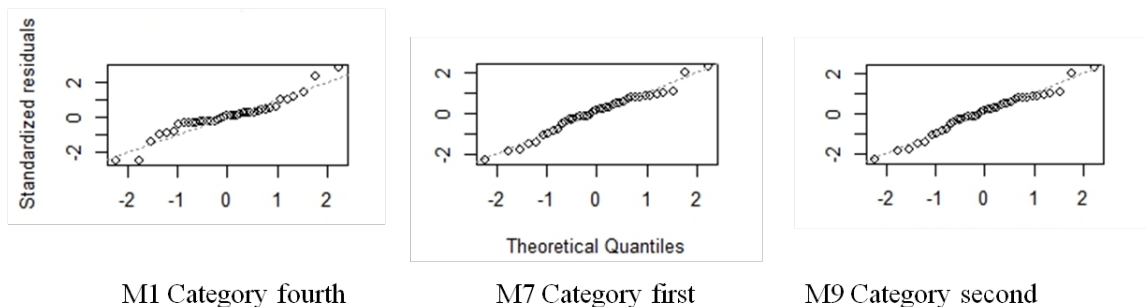
The average deviation for individual trees of the model M14 is smaller than that of previously published models (Table 4). Similarly, the AIC value for the model M14 is also smaller than that of previously published models (Table 4). The AIC values of the model of Chapagain *et al.* (2014) for all three species is same because of the same



**Fig. 2: Residual vs Fitted value**



**Fig. 3: Scale location**



**Fig. 4: Normal Quantile-Quantile plot**

form of the model except for the difference in the values of intercept and coefficients. When the equations of Chapagain *et al.* (2014) for all three species were applied to our data, the predicted values were underestimated. This proof can be seen from confidence interval (CI) values given in table 5. At 95% CI, upper and lower limit of the mean biomass from the model of Chapagain *et al.* (2014) for all three species were smaller than the observed values. While analyzing the lower and upper limit of CI, the model M14 is closer to the mean value of the observed biomass (Table 5). A possible justification for lower prediction when applying the model of Chapagain *et al.* (2014) to the data from this study is the differences in the species and their form. Though data for both of the studies were collected from Nepal, the variation in site and tree form might have some role in variation in total biomass.

Apart from this, the analysis of paired sampled t-test from table 6 shows that for two tailed at 95% confidence interval, the mean of the observed data and the proposed model is statistically significantly different from the predicted mean using the model of Chapagain *et al.* (2014) for all the three species. But there is no statistical significant difference between the observed data and the model M14. On the other hand the model M14 has statistical significant difference with the

model of Chapagain *et al.* (2014) for all three species.

**Table 6: Paired t-test at 95% confidence interval of the mean biomass**

Pairs	t-statistic	Significance (Two tailed)
Observed – Chapagain <i>et al.</i> 2014 ( <i>S. robusta</i> )	6.672	0.00
Observed – Chapagain <i>et al.</i> 2014 ( <i>A. catechu</i> )	6.723	0.00
Observed – Chapagain <i>et al.</i> 2014 ( <i>T. tomentosa</i> )	6.621	0.00
M14 – Chapagain <i>et al.</i> 2014 ( <i>S. robusta</i> )	6.923	0.00
M14 – Chapagain <i>et al.</i> 2014 ( <i>A. catechu</i> )	6.977	0.00
M14 – Chapagain <i>et al.</i> 2014 ( <i>T. tomentosa</i> )	6.869	0.00
Observed – M14	0.592	0.558

From the analysis of application of proposed models and previously developed models, it would be better to consider site specific model for precise estimation of forest biomass. Similar findings were reported by Basuki *et al.* (2009), Cairns *et al.* (2003) and Nelson *et al.* (1999) when they applied previously published models to their data. In contrast to these results, Chave *et al.*

**Table 5: The confidence interval (CI) of the mean from various models**

Parameters	Observed	M14	Chapagain <i>et al.</i> (2014) <i>S. robusta</i>	Chapagain <i>et al.</i> (2014) <i>A. catechu</i>	Chapagain <i>et al.</i> (2014) <i>T. tomentosa</i>
Mean biomass (g)	252.47	248.48	53.99	52.48	55.50
95% CI Lower limit of mean biomass (g)	193.24	192.47	53.08	51.57	54.59
95% CI Upper limit of mean biomass (g)	311.70	304.49	54.89	53.38	56.40
The number of Juvenile plants	39	39	39	39	39

(2005) stated that local species specific models are not needed; instead, generalized allometric relationships can be employed. The effective way might be the grouping of species by broad forest types or ecological zones than developing models for specific species because the local species specific equations do not improve the accuracy significantly. The prediction using Chapagain *et al.* (2014) showed that the upper limit of prediction is much lower than the observed values (Table 5) at 95% confidence interval. The upper boundaries of the observed data, prediction using model M14 and prediction using Chapagain *et al.* (2014) are 816.63, 805.82, and 62.28 (*S. robusta*), 60.77 (*A. catechu*) and 63.79 (*T. tomentosa*) respectively. The table 5 paired sampled t-test supports the CI mentioned above. The mean of the observed and M14 are significantly higher than the mean of the models of Chapagain *et al.* (2014) for all three species. Therefore, from the analysis of fit statistics while developing the models and comparison of developed model with previously published models, the M14 is selected for the estimation of above ground biomass of juvenile stage plants of *C. indica*.

## Conclusion

The most suitable allometric equation to estimate the above ground biomass of juvenile plants of *C. indica* is M14 i.e.  $\hat{W}_i = 52.28 (D_i^2 H_i)^{0.89}$ . This model explained >95% juvenile biomass of *C. indica* with RSE=42.34 g, AIC=406.8 and average deviation=13.26. On the other hand, the selected model M14 is comparatively closer to the observed values than the other models.

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