Int.J.Curr.Microbiol.App.Sci (2020) Special Issue-11: 3247-3256

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 Special Issue-11 pp. 3247-3256
Journal homepage: http://www.ijcmas.com

Original Research Article

Allometric Equations for Estimating Biomass Carbon of Important North-Western Himalayan Tree Species in Himachal Pradesh

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A B S T R A C T

The study was carried out in Kotgarh Forest Division of Himachal Pradesh to develop allometric models for estimation tree biomass carbon of important north-western Himalayan tree species viz., *Pinus roxburghii, Pinus wallichiana, Cedrus deodara, Abies pindrow, Picea smithiana* and *Quercus leucotrichophora*. Various linear and non-linear relationships were developed taking DBH and tree Height as predictor variables individually. Out of linear and non-linear function derived for the estimation of biomass carbon, the power functions were best fitted for all the species with significant adjusted R^2 with diameter at breast height as independent variable were as: *Pinus wallichiana* (0.99), *Picea smithiana* and *Pinus roxburghii* (0.98), *Abies pindrow* and *Cedrus deodara* (0.97), *Quercus leucotrichophora* (0.96). Similarly, adjusted R^2 values for biomass carbon with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.88), *Abies pindrow* and *Picea smithiana* (0.87), *Quercus leucotrichophora* (0.75). However, model comparison and selection was based on adjusted R^2, chi-square test of goodness of fit and thereafter-using Theil's-U statistics model was cross-validated to ensure further adequacy. Hence, the allometric models developed can be utilized for future estimation of tree biomass carbon of species under study as it fit the data well and enable the user to predict biomass carbon for the DBH and tree height for these temperate species. The importance of incorporating allometric equations in calculation of biomass carbon, and its role in atmospheric carbon assimilation has thus been highlighted through the findings of this study.

Keywords

DBH, height, Thiel-U test, Chi-square, Linear and Non-linear

Introduction

Forests play an important role in regional and global carbon cycles because they store large quantities of carbon in vegetation and soil. Exchange of carbon with the atmosphere through photosynthesis and respiration and sources of atmospheric carbon when they are disturbed by human or natural causes, become atmospheric carbon sinks during re-growth after disturbance, and can be managed to sequester or conserve significant quantities of C on the land (Brown *et al.*, 1996; Sharma *et al.*, 2011). This global importance of forest ecosystem emphasizes the need to accurately determine the amount of carbon stored in different forest ecosystem (Nizami, 2010). Quantification of amount of biomass, and subsequent C, is presently an important component in the REDD+ initiatives.

REDD+ is a system of financing mechanisms and incentives aiming at mitigating climate change by reducing deforestation and forest degradation. Participating countries in REDD+ projects are required to produce accurate estimates for their forest C stocks and changes through robust Measurements, Reporting and Verification (MRV) schemes.

There are two main approaches to estimation of tree biomass. One is to obtain biomass as a product of tree volume and wood density. However, since most of the volume equations consider only the merchantable part of the tree, a biomass expansion factor that expands merchantable volume directly to total aboveground biomass is usually applied. The second approach is the direct use of biomass models. As the field methods are quite labour intensive, time consuming and difficult, there is need to develop simplified and efficient procedures of carbon estimation for forest crops. The most common and accurate approach involves the use of models for prediction of tree dry weight, from which C stock may be derived (Brown, 1997; Chave *et al.*, 2005; 2014). Now a day, allometric models are being used for quantifying biomass and carbon storage in terrestrial ecosystems. Regression models are used to estimate the biomass of the standing trees depend diameter at breast height (DBH), total tree height (ht), crown diameter and wood density (ρ) (Cannell, 1984; Chave *et al.*, 2005; Goodman *et al.*, 2014) are the most common and important tree parameters. Allometric equations, relating to the biomass with one or more tree dimensions are frequently used to compute average tree biomass (Whittakar and Woodwell, 1968).

The forest area surveyed has been classified broadly classified into Himalayan moist temprate forest Coniferous Forest and Broad-leaved Forests (Champion and Seth, 1968). Chil, Oaks, Deodar, Kail, Fir and Spruce inhibit larger area of the state and so far, no local biomass tables or allometric equations have been developed for biomass carbon estimation of the species under study. Global models have the advantage of being in principle, applicable anywhere. However, due to great variation in climatic and edaphic factors, such models can yield large error locally. Thus a model developed on data from the similar region will within that region gives more accurate estimates. Similarly, a model developed generally for a large number of species is more versatile in application phase, but will yield estimates with large errors for those species that are a typical relative to mean relationships between response and the input variables. The present study is therefore, an attempt to compare performance of various linear and non-linear relationships between standing biomass carbon and tree parameters. Consequently, the best fitted function has been validated and tested for its accuracy.

Materials and Methods

Study area

The experimental area is located between latitude 31^{o}8′40″ to 31^{o}42′50″ N latitude and the longitude 72o18′50″ to 77o58′E in the mid-hill zone of Kotgarh Forest Division of Himachal Pradesh with an elevation from 1050-3215 m above mean sea level (a.m.sl) (Fig. 1).

The natural stands of *Pinus roxburghii* mixed with *Quercus leucotrichophora* were selected distributed at elevation from 1100 to 2000m (a.m.sl.) near Kingal and Galani of Kumarsain Range. For *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow and Picea smithiana* stands were selected in Chhichar forest (Narkanda) distributed at elevation from 1500m to 3000m respectively of Kumarsain Range.

Climate

The area was a transitional zone between sub-tropical to temperate and semi arctic areas due to altitudinal variations. There was considerable variation in the seasonal and diurnal temperature of experimental site.

In general, May and June were the hottest months and November to February, were the coldest months and the area experiences severe heavy snowfall during the winter. On an average the annual rainfall varies from 1000-1400 mm, bulk of which was received during monsoons i.e. July-September with few pre-monsoon showers. Snowfall during winter starting from November until March/April in high altitude. The mean minimum and mean maximum temperature varied from -5^{o}C during winter (January) to 25^{o}C during summer (June), whereas mean annual temperature (mat) was 18^{o}C.

Topography and Soil

The study area was mountainous in nature with moderate to steep slope and precipitous. Forest soil was of two types i.e., acidic and neutral soil. Forest soil, which had alluvium base rich in humus found in deodar and fir forest (working plan kotgarh forest division, 2012-2013).

Geology and Rock

The study area lies between inner Himalayas and consisted of metamorphic rocks mostly micaceous schists and chloritic schists with genesis, granite phyllites, slates, shales and quartzite. (working plan kotgarh forest division, 2012-2013).

Experimental Methods

After through survey of the area, 30 trees each of eight DBH class (10-20cm to 80-90cm) table 1 and in each DBH class, ten trees each representing trees of height range i.e. large, medium and small height were selected and in total 240 trees each for *Pinus roxburghii, Quercus leucotrichophora, Pinus wallichiana, Cedrus deodara, Abies pindrow* and *Picea smithiana* were measured for diameter at breast height (DBH) with the help of vernier caliper and tree Height with the Speigel Relaskop.

Volume

Volume of standing trees was calculated by Pressler's formula (1865) and expressed in cubic meters.

$$V = ff \times h \times g$$

Where,

V = Volume. ff = Form factor, h = Total height, g = Basal area

Form factor

The form factor was calculated using the formula given by Pressler (1865) and Bitterlich (1984).

$$Ff = \frac{2h_1}{3h}$$

Where,

ff = form factor, h_1 = Height at which diameter is half of DBH, h =Total height

Branch and foliage biomass of each species was estimated using BEF and root biomass of trees was calculated by using root-shoot ratio (IPCC, 2003).

Woody biomass was calculated by multiplying total volume of the biomass with Specific gravity.

Woody Biomass = Specific gravity of stem wood x volume

Branch and foliage biomass was estimated by multiplying the volume of each species with their corresponding biomass expansion factors. Biomass expansion factor is ratio of total tree biomass to volume of the stem. the Biomass Expansion Factor was developed by using the following equation (Lehtonen *et al.*, 2004).

$$BEF = \frac{W}{V}$$

Where,

BEF = Biomass expansion factor (kg/m^3), W =Total tree biomass (kg),V= Volume of the stem (m^3)

The total aboveground biomass of the tree was comprised of the sum of stem biomass, branch biomass and the leaf biomass.

Total aboveground biomass carbon = Stem carbon + Branch carbon + Leaf carbon

Root biomass = Aboveground biomass x Root: shoot ratio.

Carbon stock = Total Biomass x 0.5 (IPCC default value 2006)

The actual data on DBH and total Height and total biomass carbon were used in the calibration of various linear and non-linear models with the help of SPSS software.

The functions having high value of adjusted R^2, lowest calculated chi-square values and lowest Theil's-U statistic values were preferred for further investigation and selected functions were finally subjected to cross-validation to ensure its adequacy.

Results and Discussion

Regression analysis

Various linear and non-linear functions employed to study the relationship between stem biomass carbon and tree parameters are significant (Table 3). The results revealed that non-linear functions outperform the linear functions when biomass carbon was regressed with various tree parameters. Out of linear and non-linear function derived for the estimation of biomass carbon, the power functions were best fitted for all the species with diameter at breast height as independent variable. The significant adjusted R^2 were as: *Pinus wallichiana* (0.99), *Picea smithiana & Pinus roxburghii* (0.98), *Abies pindrow & Cedrus deodara* (0.97), *Quercus leucotrichophora* (0.96). Similarly, adjusted R^2 values for tree biomass carbon with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.88), *Abies pindrow & Picea smithiana* (0.87), *Quercus leucotrichophora* (0.75). The results are at par with the study conducted by Sharma and Nanda (2008) has reported logarithmic and power functions as the best fit for the estimation of volume of *Pinus roxburghii* stand based on DBH and height independently. However, Chaturvedi and singh (1982) have developed significant linear relationship between biomass of different tree components to girth at breast height (GBH) and D^2H for *Pinus roxburghii*. The results are in line with the findings of Navar (2009) who have reported DBH as the best indicator for aboveground biomass estimation of *Quercus* spp based on DBH with power function. Rawat and singh (1988) while studying structure and function of Himalayan oak forest developed significant allometric equations relating biomass of different tree components to GBH (girth at breast height) in *Quercus leucotricophora*, *Quercus floribunda* and *Rododendron arborium* Ahmad *et al.,* (2014) have reported quadratic linear regression equation developed on Deodar, Kail, Fir and spruce jointly, as the best fit for estimation of biomass and basal area of the forests. The present value of R^2 are more or less similar to values as reported by Ali *et al.,* (2016) who have reported power and log linear function as the best fit for estimation of aboveground biomass for *Cedrus deodara.* Similarly, Chave *et al.,* (2005) have developed nonlinear models (power function) using DBH, tree height and wood density separately for the estimation of aboveground biomass of dry tropical forests. However, Brown and Schroeder (1999) reported exponential and sigmoidal models to be highly significant with stronger relationship between aboveground biomass and DBH for southern and eastern softwood species (fir & spruce) in the United States (Table 2).

Model evaluation

The equations based on DBH variable were considered for further testing as adjusted R^2 value cannot only be used as the sole criterion for choosing the best-fitted function. More criteria were taken to choose the best one i.e., the adjusted R^2, goodness of fit and Theil's-U Statistics. On comparison the adjusted R^2 values of DBH of different functions (Table 3) it was revealed that power function ($C= a \times D^b$) performed well when DBH was taken as predictor for estimation of biomass carbon of *Pinus roxburghii*, *Quercus leucotrichophora Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow* and *Picea smithiana* with reasonable accuracy.

The application of Chi-square test of goodness of fit and Theil's-U statistics revealed that power function using DBH as independent variable was best fit (Table 4). The Theil's-U values were approaching to zero. Thus, models based on power function indicated close correspondence between the observed and estimated values.

Cross validation

Before a model is recommended, it needs the validation. For checking the adequacy, power biomass carbon function having highest values of R^2 and lowest chi-square were subjected to cross-validation. All 240 observations on DBH were selected and the model selected was cross validated and fitted. The fitted model was used to predict the biomass carbon of actual 120 observations which were used in the calibration and then the apparent error, true error, excess error and Chi-square values of original and independent entire data was computed. Model selected for cross validation were as under:

$$C = a(D)^b$$

In all the sets, apparent error as well as true error were found to be negligible, which reflects that the model prediction (Table 5) is nearly correct and selected variable for the model is correct. Following the same procedure, Sharma and Nanda (2008) reported negligible apparent error as well as true error after cross validating the best fitted power function for estimation of stem volume based on crown volume for *Pinus roxburghii*. The linear models satisfying all statistical assumptions suffered from problems of outliners whereas non-linear performed well then the linear models for precision and validation therefore such findings are in proximity with those of Ajit *et al.,* (2000) and Shrivastva *et al.,* (2000) who have computed value of the Chi-square for original set, independent set and both the sets when taken together were found to be non-significant thereby proving the validity of selected models.

Table.1 Distribution of sample trees in different diameter classes

Standard diameter class	Diameter range (cm)	Number sample trees taken in each class
V	D_1:10-20	30
IV	D_2:20-30	30
III	D_3:30-40	30
IIA	D_4:40-50	30
IIB	D_5:50-60	30
IA	D_6:60-70	30
IB	D_7 :70-80	30
IC	D_8:80-90	30

Table.2 Biomass Expansion Factor (BEF), Specific gravity (SG) and Root-Shoo ratio (R:S) of different forest tree species

SAMPLE TREES	BEF	REFRENCES	SG	REFRENCES	R:S Ratio	REFRENCES
Pinus roxburghii	1.91	Rawat and Tandon (1993)	0.491	Rajput *et al*. (1985)	0.21	IPCC (2003)
Pinus wallichiana	1.91	Rana and Singh (1990)	0.427	Kumar S. (1998)	0.27	IPCC (2003)
Cedrus deodara	1.40	IPCC (2003)	0.468	Rajput *et al*. (1985)	0.27	IPCC (2003)
Abies pindrow	1.51	Haripriya (2000)	0.340	IPCC (2003)	0.21	IPCC (2003)
Picea smithiana	1.51	Haripriya, (2000)	0.380	IPCC (2003)	0.21	IPCC (2003)
Quercus leucotrichophora	1.91	Rana and Singh (1990)	0.826	Raturi *et al*. (2002)	0.39	IPCC (2003)

SG=specific gravity, BEF = biomass expension factor, R:S ratio = root shoot ratio

Table.3 Linear and non-linear functions for biomass carbon with diameter at breast height (D)

Sample trees	Linear	Adj. R^2	Power	Adj. R^2	Sigmoidal/ Exponential	Adj. R^2
Pinus roxburghii	C=−1.611+0.066D	0.93	$C=0.000012D^{2.93}$	0.98	C=exp(2.292-94.989/D)	0.97
	C=−2.071+0.172H	0.73	$C=0.000066H^{3.14}$	0.95	$C = 0.009e^{0.201H}$	0.92
Pinus wallichiana	C = −1.587+0.064D	0.88	$C = 0.000021D^{2.767}$	0.99	C = exp(1.988-84.397/D)	0.93
	C = −2.344+0.171H	0.79	$C = 0.000019H^{3.454}$	0.93	$C = 0.011e^{0.181H}$	0.92
Cedrus deodara	C = −1.051+0.044D	0.88	$C = 0.000010D^{2.889}$	0.97	C = exp(1.770-87.986/D)	0.96
	C = −1.142+0.096H	0.60	$C = 0.000102H^{2.788}$	0.88	$C = 0.008e^{0.175H}$	0.87
Abies pindrow	C = −0.919+0.037D	0.85	$C = 0.000021D^{2.641}$	0.97	C = exp(1.400-79.84/D)	0.93
	C = −1.504+0.094H	0.71	$C = 0.000006H^{3.529}$	0.87	$C = 0.007e^{0.161H}$	0.83
Picea smithiana	C = −1.067+0.041D	0.84	$C = 0.000010D^{2.824}$	0.98	C = exp(1.372-81.495/D)	0.88
	C = −1.146+0.096H	0.83	$C = 0.000084H^{2.779}$	0.87	$C = 0.015e^{0.149H}$	0.85
Quercus leucotrichophora	C = −2.230+0.86D	0.81	$C = 0.000053D^{2.603}$	0.96	C = exp(2.204-82.365/D)	0.91
	C =−3.303+0.364H	0.73	$C = 0.00037H^{3.012}$	0.75	$C = 0.29e^{0.241H}$	0.74

C = Carbon D = diameter at breast height (cm) H = tree Height (m)
* Significant at 5% level of significance

Table.4 Comparison of power function for biomass carbon estimation based on DBH

Sample trees	Adjusted R^2	χ^2	Theil-U statistics
Pinus roxburghii	0.98	7.35	0.07
Pinus wallichiana	0.99	4.22	0.04
Cedrus deodara	0.97	12.62	0.11
Abies pindrow	0.97	7.10	0.08
Picea smithiana	0.98	5.55	0.07
Quercus leucotrichophora	0.96	22.40	0.09

Significant at 5% level of significance

Table.5 Cross validation result of biomass carbon model

Sample trees	Model	Adjusted R^2	AE	TE	EE	X^2 original	X^2 (independent)	X^2 (Overall)
Pinus roxburghii	$C= 0.000012D^{2.923}$	0.98	7.8	-0.1	-7.9	25.9	26.9	1.0
Pinus wallichiana	$C = 0.000021D^{2.767}$	0.99	4.8	0.0	-4.8	10.7	11.6	0.9
Cedrus deodara	$C = 0.000010D^{2.889}$	0.97	6.0	-0.1	-6.1	32.5	33.5	0.8
Abies pindrow	$C = 0.000021D^{2.641}$	0.97	4.0	0.0	-4.0	12.2	12.6	0.3
Picea smithiana	$C = 0.000010D^{2.824}$	0.98	1.3	0.0	-1.3	25.8	26.2	0.4
Quercus leucotrichophora	$C = 0.000053D^{2.603}$	0.96	10.0	0.1	-10.0	74.2	77.1	3.0

D = diameter at breast height C = Carbon TE = Total Error EE = Excess Error AE = Apparent error

Fig.1

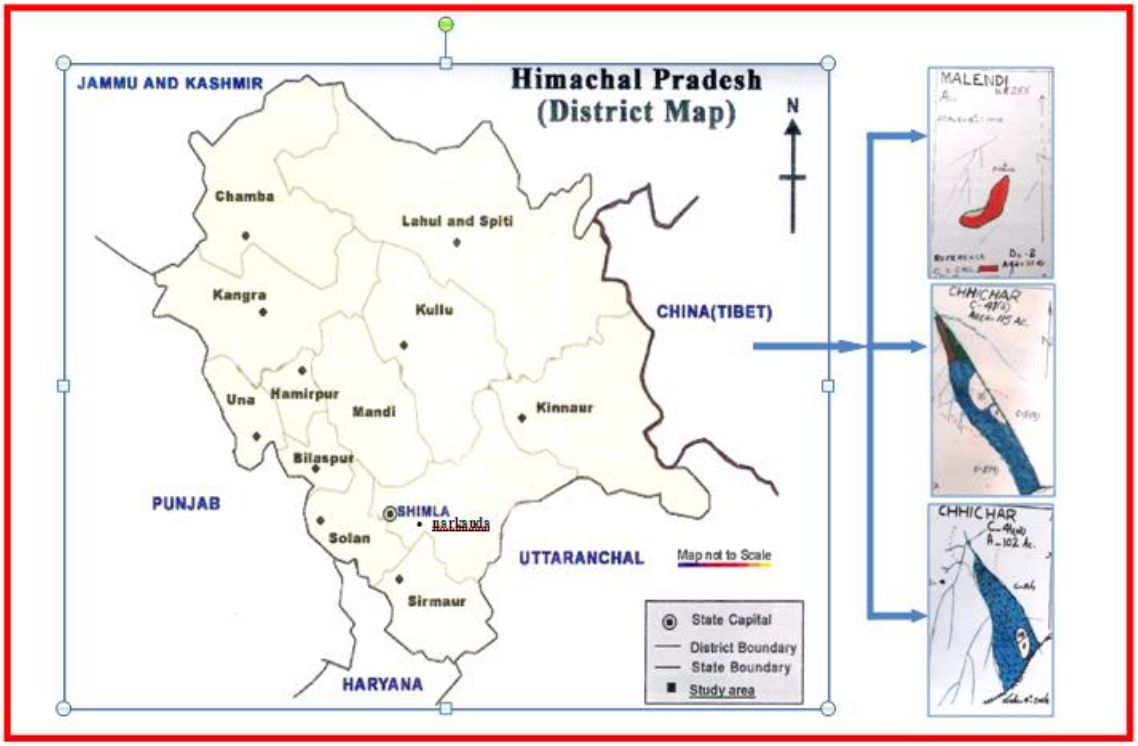

Fig. 1 Map showing study area

The study demonstrates that both log-linear and power functions performed better among all functions based on adjusted R^2. However, the power function outperformed the log-linear function as far as chi-square test of goodness of fit and Theil-U test is concerned. The model prediction was nearly correct and selected variables for the model are correct among the DBH and tree height; DBH proved to be the best predictive variable for estimation of biomass carbon and the proposed model seems to meet the standard of accuracy. The biomass carbon prediction models are as; *Pinus roxburghii* ($C = 0.000012D^{2.923}$), *Quercus leucotrichophora* ($C = 0.000053D^{2.603}$), *Pinus wallichiana*($C = 0.000021D^{2.767}$), *Cedrus deodara* ($C = 0.000010D^{2.889}$), *Abies pindrow* ($C = 0.000021D^{2.641}$) and *Picea smithiana* ($C = 0.000010D^{2.824}$). Similarly, adjusted R^2 values for tree biomass carbon with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.88), *Abies pindrow & Picea smithiana* (0.87), *Quercus leucotrichophora* (0.75). More authentic estimation of biomass and carbon sequestration in the forest would require development of allometric equations for all the tree species. Finally, to the scope of future work, the proposed model formulated and validated may be tested for large number of sample trees with different diameter classes using advanced validation techniques. The results of this study will also improve the biomass estimates of the region, and bring agreement about the contribution of natural forest in global carbon cycle and would be of great help to the stakeholders such as forest department, foresters and forest biometricians in particular for the estimation of volume and biomass carbon temperate tree species.

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