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# Allometric equations to predict stem volume of important north-western himalayan tree species in Himachal Pradesh

**Aditi Sharma, DP Sharma, Jaya Shree Behera**
Department of Silviculture and Agroforestry, College of Forestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh, India

**Abstract**
The study was conducted in Kotgarh Forest Division of Himachal Pradesh to develop allometric models for estimation of tree volume where tree species *viz*., *Pinus roxburghii, Pinus wallichiana, Cedrus deodara, Abies pindrow, Picea smithiana* and *Quercus leucotrichophora* were studied. Various linear and non-linear relationships developed taking DBH and tree Height as predictor variables individually. Out of linear and non-linear function, the power functions were best fitted for all the species with significant adjusted $R^2$ with diameter at breast height as independent variable 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 stem volume with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.86), *Abies pindrow & 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 were cross-validated to ensure further adequacy. The allometric models developed can be utilized for future estimation of tree volume and biomass carbon of species under study as it fit the data well and gives user the opportunity to predict stem volume from the DBH and tree height for these temperate species. The role of allometric equations in volume estimation has thus been highlighted through the findings of this study.

**Keywords:** DBH, height, thiel-U test, chi-square linear, non-linear

## Introduction

Volume estimation with the use of different growth parameters is a new approach in practical forestry. volume tables were used earlier to assess the total volume of the standing crop but today allometric equations are being used on a large scale as they are more feasible and reduce the time of operation. Now a days Regression analysis are done to investigate or measure the mutual relationship among volume and volume contributing parameters. In this way, the parameters pertaining to maximum volume production are studied. The allometric relationship considering tree parameters i.e. Diameter at Breast Height (DBH) and height is the important, most common, and easily measured to predict the volume than any other characteristics. Regression models used to estimate the biomass of the standing trees depend on several variables including diameter at breast height (DBH), total tree height (ht), crown diameter and wood density (ρ) (Cannell, 1984; Chave *et al*., 2005).

As the field methods are quite labour intensive and difficult to perform, there is need to develop simplified and efficient procedures of volume estimation for forest crops. Regression equations that describe volume increment of trees in response to change in different tree parameters like diameter at breast height, tree height and taper are classified as allometric models and have been put to use extensively to predict stem volume of standing forest crop (Mittal *et al.*, 1991; Negi *et al.*, 1998; Pant, 2001; Forslund, 1982; Pohjonen, 1991 and Sharma and Nanda, 2008) [17, 14, 16, 10, 19, 23]. The volume equations earlier developed by FRI (1996) and FSI (1996) for softwood and hardwood using multiple regression methods in which basal area, girth or DBH along with height or form factor were used to predict volume and biomass. These volume equations have further been used by Singh *et al.* (2011) and Salunkhe *et al.* (2016) [25] for biomass estimation.

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 give 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 variables. A species-specific model has a more narrow range of application, but will give better estimate for that particular species.

These forests maintain environmental stability, and supply the essential requirements of the people on a renewable basis. Larger area of North-Western Himalayas is inhibited by chil, oaks, deodar, kail, fir and spruce. so far no local allometric equations have been developed for volume estimation. The present study is therefore, an attempt to compare performance of various linear and non-linear relationships between stem volume and tree parameters.

## Material and Methods

### Study Area

The experimental area is located between latitude 31º8′40″ to 31º42′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 were 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 -5ºC during winter (January) to 25ºC during summer (June), whereas mean annual temperature (mat) was 18ºC.

**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 1and 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.

**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 |

**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

**Result and Discussion**

**Regression Analysis**

Various linear and non-linear functions employed to study the relationship between stem volume and tree parameters are significant (Table1). The results revealed that non-linear functions out Perform the linear functions when stem volume was regressed with various tree parameters. Out of linear and nonlinear function derived for the estimation of stem volume, 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 & Pinus roxburghii* (0.98), *Abies pindrow & Cedrus deodara* (0.97), *Quercus leucotrichophora* (0.96). Similarly, adjusted $R^2$ values for stem volume with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.86), *Abies pindrow & Picea smithiana* (0.87), *Quercus leucotrichophora* (0.75). The present findings are in conformity with the findings of Ahmad *et al.* (2014) [2-3] who reported highly significant quadratic linear relationship between stem volume and DBH for *Pinus roxburghii*. Nizami *et al.* (2009) [15] on the other side have reported strong linear relationships for *Pinus roxburghii* with basal area as independent variable. However, Sharma and Nanda (2008) [23] reported the logarithmic and power functions as the best fit for the estimation of stem volume of *Pinus roxburghii* stand based on dbh and height independently while taking crown parameters as predictor variables. FRI (1996) and FSI (1996) has already developed volume equations for softwood species using multiple regression methods in which basal area, girth or DBH and $D^2H$ along with height or form factor are used to predict volume of *Pinus roxburghii*, *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow* and *Quercus leucotrichophora*. On the contrary, Canadell and Roda (1991) [6] who have reported logarithmic equation with DBH as independent variable as the best fit for volume estimation of *Quercus ilex*. Raqeeb *et al.* (2014) [21] who developed highly significant allometric equations relating volume in *Pinus wallichiana* with DBH and tree Height respectively. Similarly, Ahmad *et al.* (2014) [2-3] who have reported quadratic regression equations for volume of *Picea smithiana* trees due to tree DBH and tree height when used separately and basal area explained 96 variations when used alone.

### 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 for different functions (Table 1) it was revealed that power function ($V = a \times D^b$) performed well when DBH was taken as predictor for estimation of stem volume 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 2). The Theil's-U values were approaching to zero. Thus models based on power function indicated close correspondence between the observed and estimated values. variable.

### Cross validation

Before a model is recommended, it needs the validation. For checking the adequacy, power stem volume 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 stem volume 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:

• $V = a (D)^b$

In all the sets, apparent error as well as true error were found to be negligible, which reflects that the model prediction (Table 3) is nearly correct and selected variable for the model is correct. Following the same procedure, The results are in accordance with the findings of Anderson *et al.* (1982) [1], Verbyla and Fisher (1989) [26], Ferreire *et al.* (1991) [11], Chauhan and Sahoo (1997) [8], and Pandey *et al.* (1998) [20]. Sharma and Nanda (2008) [23] 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) [22] and Shrivastva *et al.* (2000) [22] 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 2:** Linear and non-linear functions for stem volume (V) with diameter at breast height (D), tree height (H).

| Sample trees | Linear | Adj. $R^2$ | Power | Adj. $R^2$ | Sigmoidal/ Exponential | Adj. $R^2$ |
|---|---|---|---|---|---|---|
| *Pinus roxburghi* | $V=-2.038+0.084D$ | 0.93 | $V= 0.000016D^{2.912}$ | 0.98 | $V=\exp(2.514-94.427/D)$ | 0.97 |
| | $V=-2.619+0.218H$ | 0.72 | $V= 0.000088H^{3.115}$ | 0.95 | $V = 0.12e^{0.200H}$ | 0.92 |
| *Pinus wallichiana* | $V = -2.244 +0.090D$ | 0.88 | $V= 0.000030D^{2.767}$ | 0.99 | $V= \exp(2.329-84.281/D)$ | 0.93 |
| | $V = -3.317+0.242H$ | 0.79 | $V= 0.000027D^{3.445}$ | 0.93 | $V = 0.016e^{0.180D}$ | 0.92 |
| *Cedrus deodara* | $V = -2.063 +0.087D$ | 0.88 | $V= 0.000019D^{2.886}$ | 0.97 | $V= \exp(2.439-87.770/D)$ | 0.96 |
| | $V = -2.238 +0.188H$ | 0.60 | $V= 0.00021H^{2.778}$ | 0.88 | $V = 0.016e^{0.173H}$ | 0.87 |
| *Abies pindrow* | $V = -2.337 +0.095D$ | 0.85 | $V= 0.000054D^{2.642}$ | 0.97 | $V= \exp(2.333-79.861/D)$ | 0.93 |
| | $V = -3.821 +0.240H$ | 0.71 | $V= 0.000015H^{3.530}$ | 0.87 | $V = 0.018e^{0.161H}$ | 0.83 |
| *Picea smithiana* | $V = -2.435 +0.094D$ | 0.84 | $V= 0.000022D^{2.833}$ | 0.98 | $V= \text{Exp}(2.194-81.694/D)$ | 0.87 |
| | $V = -2.609 +0.218H$ | 0.71 | $V= 0.00019H^{2.854}$ | 0.87 | $V = 0.34e^{0.149H}$ | 0.83 |
| *Quercus leucotrichophora* | $V = -1.514+0.058D$ | 0.81 | $V= 0.000036D^{2.602}$ | 0.96 | $V= \exp(1.816-82.349D)$ | 0.91 |
| | $V = -2.247+0.248H$ | 0.73 | $V= 0.000257H^{3.011}$ | 0.75 | $V = 0.19e^{0.241H}$ | 0.74 |

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

**Table 3:** Comparison of power function for stem volume estimation based on DBH Sample trees Adjusted $R^2$

| Sample trees | Adjusted $R^2$ | $\chi^2$ | Theil-U statistics |
|---|---|---|---|
| *Pinus roxburghii* | 0.98 | 6.58 | 0.07 |
| *Pinus wallichiana* | 0.99 | 4.47 | 0.03 |
| *Cedrus deodara* | 0.97 | 9.54 | 0.09 |
| *Abies pindrow* | 0.97 | 8.44 | 0.08 |
| *Picea smithiana* | 0.98 | 13.01 | 0.12 |
| *Quercus leucotrichophora* | 0.96 | 5.84 | 0.09 |

Significant at 5% level of significance

**Table 4:** Cross validation result of stem volume model

| Sample trees | Model | Adjusted $R^2$ | AE | TE | EE | $X^2$ orignal | $X^2$ (independent) | $X^2$ (Overall) |
|---|---|---|---|---|---|---|---|---|
| *Pinus roxburghii* | $V= 0.000016D^{2.912}$ | 0.98 | 0.1 | -0.1 | -0.2 | 43.4 | 44.9 | 1.5 |
| *Pinus wallichiana* | $V= 0.000030D^{2.767}$ | 0.99 | 0.0 | -0.1 | -0.1 | 19.9 | 21.5 | 1.6 |
| *Cedrus deodara* | $V= 0.000019D^{2.886}$ | 0.97 | 0.1 | -0.1 | -0.1 | 90.9 | 94.8 | 3.9 |
| *Abies pindrow* | $V= 0.000022D^{2.833}$ | 0.97 | 0.0 | 0.0 | 0.0 | 71.2 | 72.9 | 1.7 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Picea smithiana* | $V= 0.000036D^{2.602}$ | 0.98 | 2.4 | 0.0 | -2.4 | 49.6 | 51.1 | 2.1 |
| *Quercus leucotrichophora* | $V= 0.000036D^{2.602}$ | 0.96 | 7.0 | 0.0 | -6.9 | 34.1 | 35.5 | 1.4 |

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

## Conclusions

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. Both DBH and tree Height independently were significant variables for the estimation of tree volume. 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 tree volume and the proposed model seems to meet the standard of accuracy. The tree volume 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 stem volume with tree Height as independent variable were as: *Pinus roxburghii* (0.95), *Pinus wallichiana* (0.93), *Cedrus deodara* (0.86), *Abies pindrow & Picea smithiana* (0.87), *Quercus leucotrichophora* (0.75).. 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 veolume stimates of the region under study, and bring agreement about the contribution of natural forest in global carbon cycle and would be of great help to the foresters and forest biometricians in particular for the estimation of volume and biomass carbon of species under study.

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