MODELLING TREE GROWTH FOR ESTIMATION AND VALIDATION OF STEM VOLUME EQUATIONS

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ABSTRACT

Linear and non-linear stem volume models have wide-ranging applications in forest resource management owing to their ability to provide reliable estimates of independent variables. In the present study, we have used, diameter at breast height (DBH) and tree height data of Pinusroxburghii and Cedrusdeodara to model stem volume in Pithoragarh district of Uttarakhand. To model tree volume, different stem volume equations were used to develop the relationship. Parameters of volume equations are estimated by regression analysis and the best fit model equation was selected. Validation of modelled equation are performed by using various statistics;coefûcient of determination (R^2), root mean square error (RMSE), mean deviation (MD), and mean absolute deviation (MAD) to determine best model fit. The results of the study shows that the models $V=a+bD+cD^2$ for Pinusroxburghiiand $V=a+bD^2H$ for Cedrusdeodara performed best in almost all fit statistics in comparison with other model equations. These models would provide better calculation of volume stock and helps in future management of forest.

Keyword : *Breast hight, Perametter Estimation, Sustanable Validation.*

1. INTRODUCTION

The precise knowledge of volume generated by forest is largely required for maintaining forest resource management. For forest resource management, the volume generated by forest which is also called forest stock is mainly characterized by stem volume and modelling this stem volume, volume equations are extensively applied using diameter at breast height (DBH) and tree height to determine stem volume (Avery & Burkhart, 2002).In addition, forest stock is also use to estimate biomass which is essential to determine carbon stored by forests.Equations that provide accurate estimation of total stem volume are one of the basic structure of a forest development and yield simulation system (Huiquan& Hamilton, 1998). When a volume equation is created, accurate statistics on stem volume and important predictor variables of the sample trees are required. Two species namely;Chir pine (*Pinusroxburghii*) and deodar (*Cedrusdeodara*) are dominating in the Indian Himalayan region and provides a variety of wide ranged goods and services and used for various purposes including house building, doors and windows, shingles, flooring blocks, packing boxes, boards, railway sleepers and in the manufacture of pulp and paper. Stem volume can be estimated through field measurements of diameter at breast height (DBH) and total height and by allometric equation development (Teshome, 2005; Gonzalez-Benecke et al., 2014). In India, stem volume equations for various important tree species have been reported in different studies (FSI, 1996; Chaturvedi, 1973a,b). However, these volume models were mostly established with very limited samples and measurements. Therefore, validating these equation using field measurements are needed in order to provide accurate and appropriate volume prediction on different sampled these commercially important tree species.

2. MATERIAL AND METHODS

2.1. Study area and data used

The Pithoragarh district is located in the Kumaun region of North western Himalaya India covering the geographical area approximate 7090 km^2 (Fig.1).The data of tree height and diameter at breast height (DBH) ~1.37m was collected in four sites of PihoragarhDistrict. The data of *Pinus roxburghii* was sampled from Digtoli forest, Pithoragarh, District and data of *Cedrusdeodara* was collected from four sites Hanera,Hatkalikaand Patalbhuwneswar,Pithoragarh District. A total of 130 tree of *Pinus roxburghii*

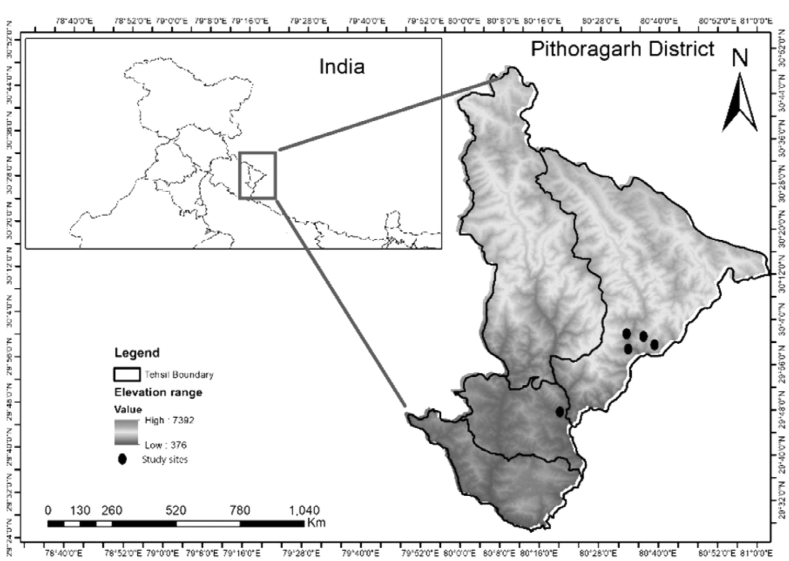


Fig. 1.Locations of sampled trees in Pithoragarh District

and 140 samples of *Cedrusdeodara*were sampled from study sites.

Table 1. Models considered for the study

S.No.	Model Type	Equation	No. of parameters
1	**V=f(DBH)**	$V=a+bD^2$	2
2		$V=a+bD+cD^2$	3
3		$V=aD+bD^2$	2
4	**V=f(DBH, height)**	$V=a+bD^2H$	2
5		$V=a+bD^cH^d$	4
6		$V=D^2/(a+b/H)$	2

2.2. Stem volume equations and parameter estimation

The present study used six different volume equations to calculate volume and fit height -DBH relationship. These equations are robust and standard used by various studies to fit tree volume models(Schumacher & Hall, 1933; Spurr,1952; Beck,1963; Honer, 1965; Baskerville, 1972; Burkhart,1977).Two different types of volume equation have used: when volume is a function of independent variable DBH only .i.e.=f(DBH) and when volume is a function of two independent variables; height and DBH .i.e. V=f(DBH, height).The brief descriptions of all the six models are shown in Table.1.

The parameters were estimated using a least-squares procedure in STATISTICA 8.0 version software. For model validation, coefûcient of determination (R2), root mean square error (RMSE), mean deviation (MD), and mean absolute deviation (MAD) were used to evaluate and determine the best model. The fitted models were then evaluated using all of the following criteria:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(V_i - \hat{V_i})^2}{\sum_{i=1}^{n}(V_i - \bar{V})^2}\right]$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(V_i - \hat{V_i})^2}{n}}$$

$$\text{MD} = \frac{\sum_{i=1}^{n}(V_i - \hat{V_i})^2}{n}$$

$$\text{MAD} = \sum_{i=1}^{n}\left|V_i - \hat{V_i}\right| / n$$

$$\text{MAD} = \frac{\sum_{i=1}^{n}|V_i - \hat{V_i}|}{n}$$

Where; V_i= measured volume for the ith tree, $\hat{V}$ = predicted volume for the ith tree, V = measured mean tree volume, n = the total number of trees.

3. RESULTS AND DISCUSSION

3.1. Parameter estimation of model equations

Stem volume equation was tested using DBH and tree height data for species *Pinusroxburghii* and *Cedrusdeodara*. The brief details of estimated parameters for both species are shown in Table 2. Parameter estimates of *Pinus roxburghii* species shows, volume equation$V=a+bD+cD^2$ is best fitted in comparison to other model equations. Parameter estimates of the above equation statistically significant ($p<0.05$) showed higher R^2 value, low RMSE and MAD representative of best appropriate volume equations for *Pinus roxburghii.* Parameter estimate using species *Cedrusdeodara* shows, among the used volume equations, two variable volume equation $V=a+bD^2H$ had significant performance ($p<0.05$) as well low values of errors which signify suitable model for this species. The biological interpretation rather than better fit statistics of the model should be imperativeto understandheight growth models (Vanclay&Skovsgaard, 1997; Ratkowsky, 1990; Schabenberger& Pierce, 2002). Such models revealed juvenile treegrowth trends such as, in early stage of tree, height growth rate shows increased DBHup to a certain limit, however, at the later phaseit shows declining pattern with increasing DBH. In the later phase, the growth of diameter must be quicker than height growth as tree needs more strength to decisivelysurvive itself against exogenous factors such as wind blow by the coagulating of its stem as tree grows to larger and taller sizes (Khanna &Chaturvedi, 1994; Cato et al., 2006).

Table 2. Summary statistics of model parameter estimates

Species	Equation	a	b	c	d	R^2	RMSE	MD	MAD
Pinus roxburghii	$V=a+bD^2$	-2.27	12.15			0.8213	0.103	0	0.0783
	$V^*=a+bD+cD^2$	*-6.0715*	*7.3832*	*8.7568*		*0.91*	*0.0641*	*0.00049*	*0.0332*
	$V=aD+bD^2$	-4.1787	13.9815			0.8263	0.101	0.00001	0.0765
	$V=a+bD^2H$	-0.0789	0.2836			0.9991	0.0231	-0.0013	0.024
	$V=a+bD^c*H^d$	-0.4575	0.2775	-2.3687	-1.612	0.9759	0.0512	0.0121	0.0414
	$V=D^2/(a+b/H)$	-0.0007	3.5733			0.9732	0.0504	0.0112	0.0326
	Equation	**a**	**b**	**c**	**d**	**R^2**	**RMSE**	**MD**	**MAD**
Cedrusdeodara	$V=a+bD^2$	2.5365	9.3185			0.9814	0.032	-0.0011	0.038
	$V=a+bD+cD^2$	10.4687	-1.1108	-0.0001		0.9998	0.0641	0.053	0.0231
	$V=aD+bD^2$	0.2767	9.3412			0.9913	0.083	0.0512	0.0418
	$V^*=a+bD^2H$	*-0.0789*	*0.2836*			*0.1499*	*0.5311*	*0*	*0.0013*
	$V=a+bD^c*H^d$	4.462	2.9419	5.7767		0.5451	0.3416	0.0021	0.0181
	$V=D^2/(a+b/H)$	0.0572	-0.0295			0.0011	0.0001	0	0.00021

* *represents statistically significant ($p<0.05$) parameter estimates*

3.2. Comparison and validation of stem volume equations

To identify the best model, the observed data was comparedto the predicted data (Fig.2&3).The selected model equations was compare to previously developed volume equations. For *Cedrusdeodara*, the volume equation V=”0.0789+0.2836D^2H was developed by Chaturvedi(1973).When comparing this with volume equation V=”0.0789+0.2836D2H, it is not significant (p=0.091).It means previously developed volume equation is well matched with stem volume equation developed by present study in case of *Cedrusdeodara*.The volume equation V=0.276739–3.068630D+12.40992$D^2$for *Pinus roxburghii*has been previously developed by Forest Survey of India (FSI, 1976).The comparison between volume equation developed by FSI and present study shows significant differences ($p<0.05$) by t-test (Two tailed).It revealed that the volume equation for *Pinus roxburghii* species may be site specific and vary may be due to change in varying environment conditions. The predicted volume explained 99.1% variance over the FSI

Figure.2 (a-f). Scatter plot of diameter at breast height versus volume of the *Pinus roxburghii* trees in Pithoragarh District.

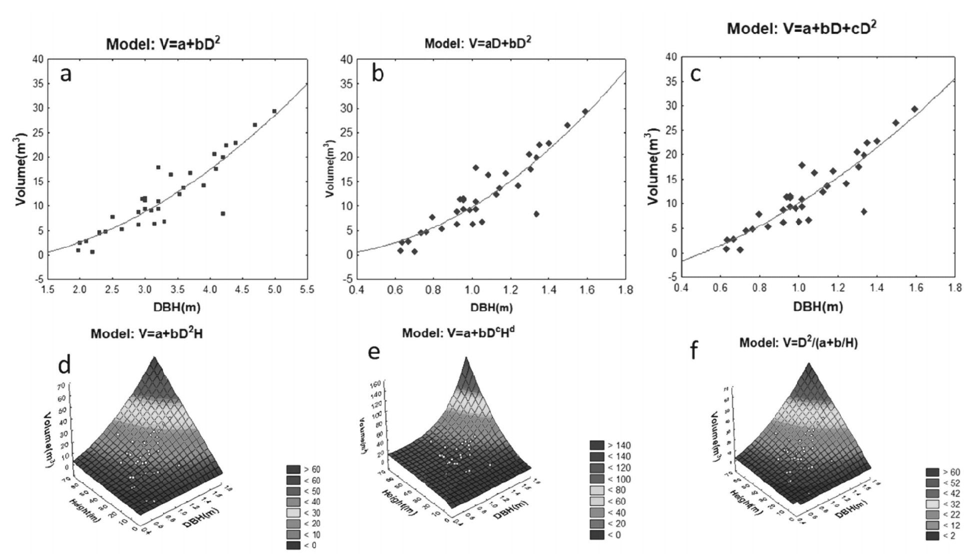


Fig.3(a-f). Scatter plot of diameter at breast height versus volume of the *Cedrusdeodara* trees in Pithoragarh District.

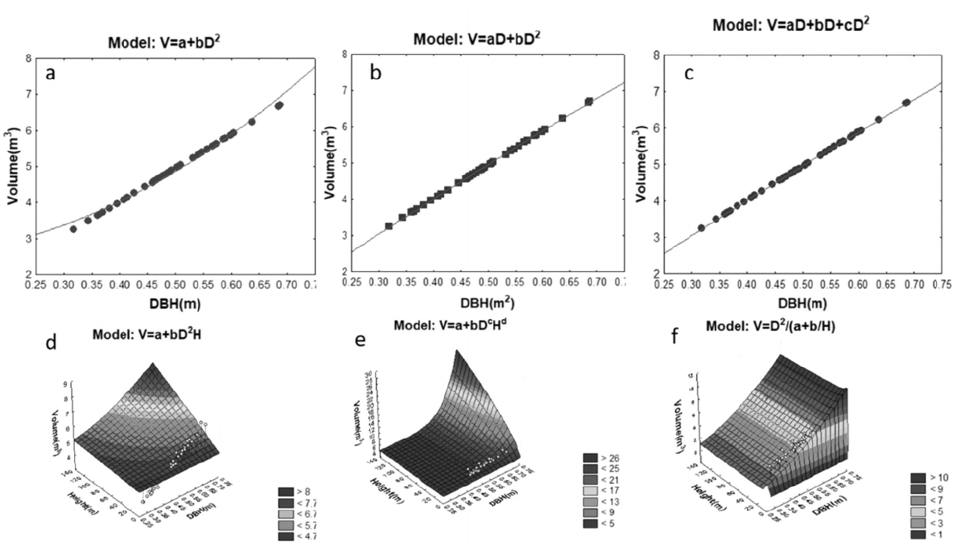
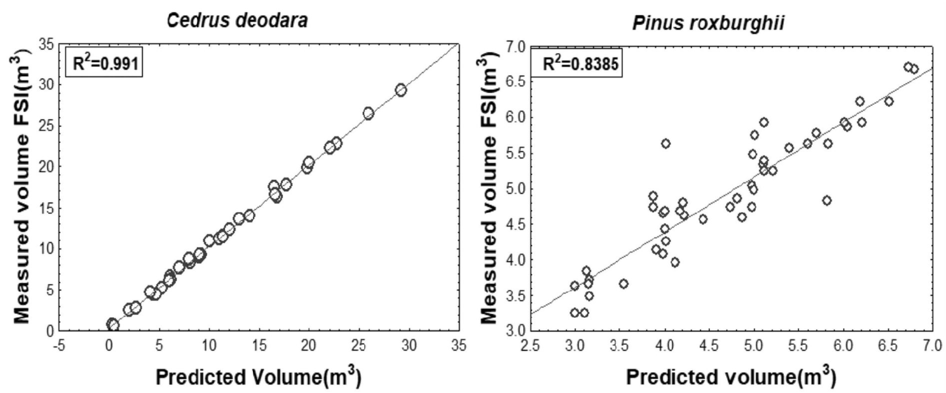


Fig.4.Comparision between Predicted and measured volume for(a) *Cedrusdeodara* and (b) *Pinus roxburghii*using best model selection



measured volume for *Cedrusdeodara* whereas predicted volume for *Pinus roxburghii* explained 83.8% variance over the measured volume Fig.2a,b.

4. CONCLUSION

The present study attempted to validate stem growth equation using field based observations of tree growth data. The results of the study shows that the models integrating only DBH ($V=a+bD+cD^2$) for *Pinusroxburghii*and DBH and height ($V=a+bD^2H$) for *Cedrusdeodara* as predicator variables performed best in almost all fit statistics in comparison with other model equations.The validated new stem volume equations will serve as a baseline model for studied species and helps to estimate growing stock in effective manners. Therefore, applying thesevolume model can help forest managers in sustainably managing forest as these model provides more reliable estimates of the growing stock stem volume.

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