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Statistical Investigations on *Abies pindrow* in Himachal Pradesh, India

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A B S T R A C T

An attempt was made to construct one way and two way volume tables for *Abies pindrow* in Shimla district of Himachal Pradesh during the year 2016-17. For the study, primary data for diameter and height was collected. 100 trees of *Abies pindrow* (fir) were recorded from Shimla forest site and volume was collected from the State Forest Department. Regression analysis was done to estimate the volume of fir for the construction and prediction of one way volume tables and two way volume tables on the basis of maximum value of R^2 and, $\bar{R}^2$ minimum RMSE and Theil's U-statistic, whereas validation was tested by half-split method and Chow test. Cubic and linear models were used for the construction of one way and two way volume table respectively of *Abies pindrow*.

Introduction

Abies pindrow belong to the family Pinaceae, is a fir native to western Himalaya and adjacent mountains, from northeast Afghanistan east through northern Pakistan and India to central Nepal. It grows at altitudes of 2,400–3,700 metres (7,900–12,100 ft) in forests together with deodarr, blue pine and morinda spruce, typically occupying cooler, moister north-facing slopes. Himachal Pradesh is rich repository of conifers and a hilly state which is situated between 30^o 22′ N to 33^o 13′ N latitude and 75^o 23′ to 79^o 4′ E longitude. Himachal Pradesh is a north-west Himalayan state having about 1.7 per cent of the India's total geographical area and has vast potential of coniferous wealth. Volume equations have been used to estimate tree and stand volume and played an important role in forest inventories and management for more than a hundred years. Studies of tree volume began in the early nineteenth century. Around 1804 Heinrich Cotta was the first forester to introduce the concept of a volume table (Clark, 1902). However, an extensive study to collect data for constructing the first volume table was carried out many years later and was mainly of Norway spruce. Volume tables showing the contents of trees of given size according to some unit of measure which are essential to most of the forestry work. They are used to estimate standing timber for timber sales, forest management plans and forest surveys, appraisal of damage and forest

valuation in general (Gevorkiantz, 1955). The variables used for volume table preparation are diameter at breast height (DBH) and height. For smaller and restricted area diameter alone is enough. Volume tables have been described as a form of forest growth model (Pretzsch *et al.*, 2008) and were traditionally intended as a means of estimating future timber production based on long term series of successive measurements.

Materials and Methods

The present investigation was conducted on high density plantation of *Abies pindrow* raised naturally or by plantations in Shimla district of Himachal Pradesh. Shimla has an average altitude of 2,206 meters (7,238 ft). The climate in Shimla is predominantly cool during winters and moderately warm during summer. Temperature typically ranged from −4 °C (25 °F) to 31 °C (88 °F) over the course of a year. The average temperature during summer is between 19 and 28 °C (66 and 82 °F), and between −1 and 10 °C (30 and 50 °F) in winter. Monthly precipitation varied between 15 mm in November and 434 mm in August. The data on diameter at breast height (DBH) and height of 300 trees of Abies *pindrow* were recorded from Shimla forest circle and volume was collected from the State Forest Department. The diameter at breast height (DBH) for each selected tree was recorded using vernier caliper and measuring tape. Height of each selected tree was measured with the help of Ravi multimeter and as an ocular estimate. Two sides of tree were selected from where the top and base of the tree were visible and observations were recorded. The average of these readings was taken as the height of the tree in meters. Volume of tree on DBH and height was collected from the State Forest Department of Himachal Pradesh in different selected circles as per their prementioned formats.

Various linear and non-linear models (logarithmic, quadratic, cubic, inverse, compound, growth, exponential and S model) were tried to estimate the volume of *Abies pindrow* on the basis of dbh and height. F-test and t-test was used for testing the significance of overall regression analysis and regression coefficients. R^2, $\bar{R}^2$, root mean square error and Theil's inequality coefficient was used for testing the goodness of fit. Validation of model was done through half splitting method and chow test. Further best fitted valid model was used for the construction of one and two way volume tables. For the construction of one way volume table, diameter at breast height was considered as independent variable while for the construction of two way volume table, diameter at breast height and height (D^2H) were considered as independent variable.

Results and Discussion

Various statistical parameters was calculated for diameter, height and volume and presented in table 1. Mean diameter, height and volume of *Abies pindrow* was 59.74 cm, 12.71 m and 3.51 m^3 with standard errors 1.93, 0.29 and 0.20 respectively. Fudicial limits for diameter, height and volume were 55.96-63.52 cm, 12.15-13.27 cm, and 3.11-3.91 respectively. Coefficient of variation was maximum for volume followed by diameter and height.

Regression analysis and validation of models

Various linear and non-linear (straight line, logarithmic, inverse, quadratic, cubic, compound, power, S, growth and exponential) functions were tried for the estimation of volume of *Abies pindrow* and best fitted function was used for the construction of one way and two way volume tables. Different models were judged on the basis of

coefficient of determination (R^2), adjusted R^2 ($\bar{R}^2$), root mean square error (RMSE) and Theil's U-statistic. The values of model coefficients obtained by applying various equations to the data set are given in table 2. The RMSE (0.571), high value of R^2 and $\bar{R}^2$ (0.956 and 0.955) respectively and low Theil's U-statistic (0.0158) indicated the appropriateness of cubic model ($V = 2.606 - 0.225\ D + 0.006\ D^2 - 3.136\times10^{-5}\ D^3$) for the construction of one way volume table for *Abies pindrow*.

Further**,** various linear and non-linear functions were fitted for the estimation of volume on the basis of joint consideration of diameter at breast height and height and a new variable (I) defined as D^2H. The parameter estimates and goodness of fit statistic of different linear and non-linear functions tested for estimating volume on the basis of D^2H (I) for *Abies pindrow* in Shimla are presented in table 3. High value of R^2 and $\bar{R}^2$ (0.899 and 0.898) respectively, minimum RMSE (0.888) and Theil's U-statistic (0.1686) of linear model gave good results for the volume estimation followed by power and cubic model. Thus linear model ($V = 0.689 + 4.136\times10^{-5}$ I) used for construction of two way volume table of *Abies pindrow*.

$F_{cal.}$ (2.623) for linear and $F_{cal.}$(0.961) for power model was less than $F_{tab.}$(3.026) at 5% level of significance. Hence, fitted models were valid and can be used for construction of one way volume table. Similarly for two way volume tables of *Abies pindrow*, power model was found to be best fit followed by linear as $F_{cal.}$(2.927) for power and $F_{cal.}$(2.136) for linear is less than $F_{tab.}$(3.026).

Table.1 Statistical parameters for diameter (cm), height (m) and volume (m^3) of *Abies pindrow* trees

Parameters	**Mean**	Range	SE	Fudicial limits	CV (%)
Diameter	59.74	25.00-115.00	1.93	55.96-63.52	32.32
Height	12.71	6.50-19.50	0.29	12.15-13.27	22.51
Volume	3.51	0.39-8.78	0.20	3.11-3.91	58.16

Table.2 Linear and non-linear functions for volume estimation diameter at breast height (D) for *Abies pindrow*

Models	**Equations**	**SE (β_i)**	**R^2**	**$\bar{R}^2$**	**RMSE**	**Theil's U -statistic**
Linear	$V = -3.305 + 0.123D$	0.002	0.926	0.925	0.739	0.0267
Logarithmic	$V = -19.702 + 5.901\ln D$	0.157	0.826	0.825	1.132	0.0627
Inverse	$V = 7.917 - 203.741/D$	9.507	0.606	0.605	1.701	0.1416
Quadratic	$V = -2.402 + 0.088\ D + 4.15\times10^{-3}D^2$	0.010, 8.0×10^{-5}	0.929	0.928	0.724	0.0255
Cubic	$\mathbf{V = 2.606 - 0.225\ D + 0.006\ D^2 - 3.136\times10^{-5}\ D^3}$	0.024, 4.2×10^{-4} 2.3×10^{-6}	**0.956**	**0.955**	**0.571**	**0.0158**
Compound	$V = 0.140 \times 1.051^{D}$	0.001	0.817	0.816	0.500	0.6769
Power	$V = 4.887\times10^{-5} \times D^{2.724}$	0.038	0.945	0.945	0.274	0.1156
S	$V = \exp(3.151 - 109.538/D)$	1.578	0.942	0.942	0.283	0.0328
Growth	$V = \exp(-1.968 + 0.050\ D)$	0.001	0.817	0.816	0.500	0.6769
Exponential	$V = 0.140\ e^{0.050\ D}$	0.001	0.817	0.816	0.500	0.6769

Table.3 Linear and non-linear functions for volume estimation using D^2H (I) for *Abies pindrow* in Shimla

Models	Equations	SE (β_i)	R^2	$\bar{R}^2$	RMSE	Theil's U -statistic
Linear	**$V = 0.689 + 4.136\times10^{-5}$ I**	**1.2×10^{-4}**	**0.899**	**0.898**	**0.888**	**0.1686**
Logarithmic	$V = -20.400 + 2.272 \ln I$	6.927	0.802	0.800	1.734	0.1895
Inverse	$V = 4.227 - 8844.915 / I$	148760.860	0.169	0.160	7.291	0.3581
Quadratic	$V = -0.425 + 8.256\times10^{-5} I - 1.687\times10^{-10} I^2$	3.6×10^{-4} 1.8×10^{-9}	0.820	0.819	1.092	0.1993
Cubic	$V = -0.309 + 7.584\times10^{-5} I - 9.737\times10^{-11} I^2 - 1.828\times10^{-16} I^3$	0.001 8.3×10^{-9} 2.3×10^{-19}	0.830	0.829	1.087	0.1991
Compound	$V = 0.799 \times 1.000^{I}$	1.7×10^{-6}	0.570	0.565	0.691	0.6352
Power	$V = 2.272\times10^{-5} I^{1.066}$	0.050	0.865	0.865	1.056	1.1536
S	$V = \exp(1.194 - 6705.085/ I)$	1377.135	0.531	0.526	0.753	0.6051
Growth	$V = \exp(-0.224 + 1.517\times10^{-5} I)$	1.1×10^{-6}	0.570	0.565	0.691	0.6352
Exponential	$V = 0.799\, e^{0.0000151\, I}$	1.1×10^{-6}	0.570	0.565	0.691	0.6352

Table.4 One way volume table (Overbark) for *Abies pindrow*

Diameter (cm)	Volume (m^3)	Diameter (cm)	Volume (m^3)	Diameter (cm)	Volume (m^3)
10	0.9246	40	1.1990	70	5.4995
11	0.8153	41	1.3056	71	5.6529
12	0.7158	42	1.4166	72	5.8049
13	0.6261	43	1.5317	73	5.9554
14	0.5459	44	1.6506	74	6.1042
15	0.4752	45	1.7733	75	6.2510
16	0.4135	46	1.8995	76	6.3957
17	0.3609	47	2.0291	77	6.5381
18	0.3171	48	2.1618	78	6.6780
19	0.2819	49	2.2975	79	6.8153
20	0.2551	50	2.4360	80	6.9497
21	0.2366	51	2.5771	81	7.0810
22	0.2261	52	2.7205	82	7.2091
23	0.2234	53	2.8662	83	7.3338
24	0.2285	54	3.0139	84	7.4548
25	0.2410	55	3.1635	85	7.5720
26	0.2608	56	3.3147	86	7.6853
27	0.2877	57	3.4673	87	7.7943
28	0.3216	58	3.6213	88	7.8990
29	0.3622	59	3.7763	89	7.9992
30	0.4093	60	3.9322	90	8.0946
31	0.4628	61	4.0889	91	8.1850
32	0.5224	62	4.2460	92	8.2703
33	0.5880	63	4.4035	93	8.3504
34	0.6594	64	4.5612	94	8.4249
35	0.7364	65	4.7188	95	8.4937
36	0.8189	66	4.8761	96	8.5567
37	0.9065	67	5.0331	97	8.6136
38	0.9992	68	5.1894	98	8.6642
39	1.0968	69	5.3450	99	8.7084

Table.5 Two way volume table (Overbark) for *Abies pindrow* in Shimla circle

Height (m)	Diameter (cm)									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	0.7097	0.7717	0.8751	1.0199	1.2060	1.4335	1.7023	2.0125	2.3641	2.7570
6	0.7138	0.7883	0.9123	1.0861	1.3094	1.5824	1.9050	2.2772	2.6991	3.1706
7	0.7180	0.8048	0.9496	1.1522	1.4128	1.7313	2.1076	2.5419	3.0341	3.5842
8	0.7221	0.8214	0.9868	1.2184	1.5162	1.8802	2.3103	2.8066	3.3691	3.9978
9	0.7262	0.8379	1.0240	1.2846	1.6196	2.0291	2.5130	3.0713	3.7041	4.4114
10	0.7304	0.8544	1.0612	1.3508	1.7230	2.1780	2.7156	3.3360	4.0392	4.8250
11	0.7345	0.8710	1.0985	1.4169	1.8264	2.3269	2.9183	3.6007	4.3742	5.2386
12	0.7386	0.8875	1.1357	1.4831	1.9298	2.4758	3.1210	3.8654	4.7092	5.6522
13	0.7428	0.9041	1.1729	1.5493	2.0332	2.6246	3.3236	4.1302	5.0442	6.0658
14	0.7469	0.9206	1.2101	1.6155	2.1366	2.7735	3.5263	4.3949	5.3792	6.4794
15	0.7510	0.9372	1.2474	1.6816	2.2400	2.9224	3.7290	4.6596	5.7142	6.8930
16	0.7552	0.9537	1.2846	1.7478	2.3434	3.0713	3.9316	4.9243	6.0493	7.3066
17	0.7593	0.9702	1.3218	1.8140	2.4468	3.2202	4.1343	5.1890	6.3843	7.7202
18	0.7634	0.9868	1.3590	1.8802	2.5502	3.3691	4.3370	5.4537	6.7193	8.1338
19	0.7676	1.0033	1.3963	1.9463	2.6536	3.5180	4.5396	5.7184	7.0543	8.5474
20	0.7717	1.0199	1.4335	2.0125	2.7570	3.6669	4.7423	5.9831	7.3893	8.9610
21	0.7759	1.0364	1.4707	2.0787	2.8604	3.8158	4.9449	6.2478	7.7243	9.3746
22	0.7800	1.0530	1.5079	2.1449	2.9638	3.9647	5.1476	6.5125	8.0594	9.7882
23	0.7841	1.0695	1.5452	2.2110	3.0672	4.1136	5.3503	6.7772	8.3944	10.2018
24	0.7883	1.0861	1.5824	2.2772	3.1706	4.2625	5.5529	7.0419	8.7294	10.6154
25	0.7924	1.1026	1.6196	2.3434	3.2740	4.4114	5.7556	7.3066	9.0644	11.0290

One way volume table (Overbark) for *Abies pindrow*

One way volume table was constructed for *Abies pindrow* by using cubic model ($V = 2.606 - 0.225\ D + 0.006\ D^2 - 3.136\times10^{-5}\ D^3$) as it was best model among all fitted models and is presented in table 4.

Two way volume table on the basis of D^2H

For the construction of two way volume table for *Abies pindrow* volume was taken as dependent variable and D^2H was taken as an independent variable. Table 5 presents the volume overbark of *Abies pindrow* for different diameters ranges from 10 to 100 cm and height ranges from 5 to 25 m, which was calculated by using proposed linear equation as ($V = 0.689 + 4.136 \times 10^{-5}$ I).

Tewari *et al.,* (2001) suggested the use of combined variable (D^2H) for the construction of volume tables which are in line with the present investigation.

The present study was carried out to provide a handy tool to foresters/scientists in order to know rough estimate of wood volume of conifers at any farm without using any destructive method.

One way volume table was prepared using volume as dependent variable and dbh as independent variable, whereas for the construction of two way volume table, a combined variable i.e. D^2H (I) was considered as independent variable.

Cubic and linear models were used for the construction of one way and two way volume table of *Abies pindrow*.

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