Original Research Article

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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, $R^2$ 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*.

**Keywords**

*Abies pindrow*, Regression equation, Volume table.

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**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° 22’ N to 33° 13’ N latitude and 75° 23’ to 79° 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
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 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 + 4.136×10^{-5} I) used for construction of two way volume table of *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 were given in table 2. High value of R^2 and R^2 (0.956 and 0.955) respectively and low Theil’s U-statistic (0.0158) indicated the appropriateness of cubic model. Thus linear model (V = 0.689 + 4.136×10^{-5} I) used for construction of two way volume table of *Abies pindrow*.

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

| Models       | Equations                                                                 | SE (β_i) | R^2   | 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 + 5.901lnD                                                   | 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 + 4.15×10^{-1}D^2                                   | 0.010, 8.0×10^{-5} | 0.929 | 0.928 | 0.724   | 0.0255              |
| Cubic        | V = 2.606−0.225 D + 0.006 D^2 − 3.136×10^{-5} D^3                       | 0.024, 4.2×10^{-4} | 0.956 | 0.955 | 0.571   | 0.0158              |
| Compound     | V = 0.140 × 1.051^H                                                      | 0.001    | 0.817 | 0.816 | 0.500   | 0.6769              |
| Power        | V = 4.887×10^{-3} × D^{1.24}                                             | 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^{0.050D}                                                    | 0.001    | 0.817 | 0.816 | 0.500   | 0.6769              |
Table 3 Linear and non-linear functions for volume estimation using D²H (I) for *Abies pindrow* in Shimla

| Models    | Equations                                                                 | SE (β₀) | R²     | R²     | RMSE    | Theil's U-statistic |
|-----------|----------------------------------------------------------------------------|---------|--------|--------|---------|---------------------|
| Linear    | V = 0.689 + 4.136×10⁻⁵ 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 + 8.256×10⁻⁵ I − 1.687×10⁻¹⁰ I²                                 | 3.6×10⁻⁴| 0.820  | 0.819  | 1.092   | 0.1993              |
| Cubic     | V = −0.309 + 7.584×10⁻⁵ I − 9.737×10⁻¹¹ I² − 1.828×10⁻¹⁶ I³                 | 0.001  | 2.3×10⁻⁹| 0.830  | 0.829  | 1.087   | 0.1991              |
| Compound  | V = 0.799 × 1.000⁰                                                        | 1.7×10⁻⁶| 0.570  | 0.565  | 0.691   | 0.6352              |
| Power     | V = 2.272×10⁻³ I¹⁰⁶                                                       | 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 + 1.517×10⁻⁵ I)                                          | 1.1×10⁻⁶| 0.570  | 0.565  | 0.691   | 0.6352              |
| Exponential | V = 0.799 e⁻¹⁰⁰⁰₀₀₀₁⁰³¹¹                                                 | 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 (m³) | Diameter (cm) | Volume (m³) | Diameter (cm) | Volume (m³) |
|---------------|------------|---------------|------------|---------------|------------|
| 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 | 6.0568 |
| 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 \( V = 2.606 - 0.225 \, D + 0.006 \, D^2 - 3.136 \times 10^{-5} \, D^3 \) 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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