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# Predicting Lumber Volume and Value of Young-Growth True Firs: User's Guide

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## Abstract

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Equations are presented for predicting the volume and value of young-growth red, white, and grand firs. Examples of how to use them are also given. These equations were developed on trees less than 140 years old from areas in southern Oregon, northern California, and Idaho.

Keywords: Lumber recovery, lumber yield, lumber value, young-growth stands, red fir, *Abies magnifica*, white fir, *Abies concolor*, grand fir, *Abies grandis*, volume determination, volume (merchantable).

## Contents

## Introduction

A significant proportion of the commercial true fir sawtimber volume in the West is in young-growth trees. As the old-growth timber is removed, young growth becomes more important as a raw material base for the timber industry. Log grades developed for old-growth timber do not adequately predict the volume or value of the young growth. Therefore, a new system using prediction equations to estimate volume and value of young-growth true firs was developed. This paper explains how this system can be used to predict the volume and value of lumber in standing young-growth true fir trees. These equations were developed from data on red fir (Abies magnifica A. Murr.) and white fir (Abies concolor (Gord & Glend.) Lindl. ex Hildbr.) in Oregon and California and on grand fir (Abies grandis (Dougl. ex D. Don) Lindl.), in Idaho. Accuracy tests on a sample of 94 trees showed that predicted volumes and values were only 0.9 percent from actual volumes and 1.0 percent from actual values (Ernst 1982).

## Data

The data used to develop these equations were collected in studies conducted by the Timber Quality Research Project, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Portland, Oregon. Trees were selected from National Forests and U.S. Department of the Interior Bureau of Land Management (BLM) lands in southern Oregon, northern California, and Idaho (fig. 1). The sample was selected from even-aged stands less than 140 years old and stratified by diameter at breast height (d.b.h.) and presence or absence of defect. D.b.h., total height, and crown class information were recorded, and the first 16 feet of each tree was diagramed (Jackson and others. 1963, Pong and Jackson 1971). Logs from these trees were sawn into lumber, and the volume and grade of lumber from each tree were measured and recorded.

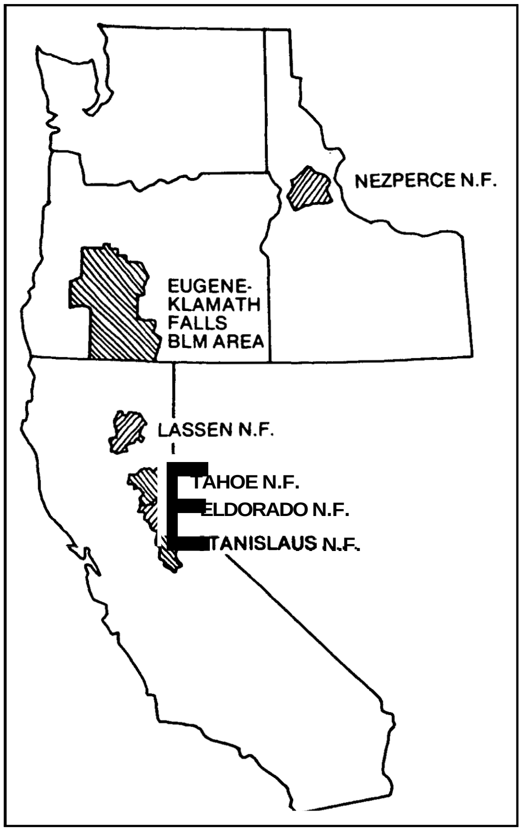


Figure 1.--Location of sample areas.

## Methods

Similar to past approaches by Lane and others (1970), Snellgrove and others (1973), Plank and Snellgrove (1978), and Fahey (1980), two models were developed--one to predict lumber volume and one to predict lumber value. Unlike past approaches, lumber volume was derived from gross volume of the tree and the corresponding lumber recovery, each of which were modeled separately. An attempt to model defect separately proved unsuccessful because of limitations of the data. Two methods were used to model lumber value. The first predicted the volume of lumber in each lumber grade, and the second predicted an index of relative prices of the lumber grades. A detailed presentation of the modeling techniques used to develop the various equations is found in Ernst (1982).

The following basic steps and equations are used to predict the lumber volume and value of young-growth red, white, and grand firs; then a step-by-step example is provided.

## Lumber Volume

1. Field measurements

The first step is to obtain the following measurements:

a. Diameter at 4.5 feet on the uphill side of the tree (D);
b. Total height (H);
c. Presence or absence of defect (I) such as basal scars, lightning scars, conks, cankers, frost cracks, and snowbreaks;
d. Presence or absence of crook (C)--any abrupt deviation from the main axis of the tree, especially pistol butt.

2. Estimates of gross cubic volume of trees

The second step is to choose and solve a gross cubic volume equation based on species and geographic location:

For WHITE and **RED** FIRS (WR) in northern California and southern Oregon:

$$VOL(WR) = D^2H(0.00159412 + 0.0025682(1/H) + 0.000000811(H^2/D)).$$

For **GRAND** FIR (G) in Idaho:

$$VOL(G) = D^2H(0.00187129 + 0.021574(1/H) + 0.000000755(H^2/D)).$$

3. Recovery estimates

The third step is to choose and solve a recovery equation. Recovery is defined as the cubic-foot volume of rough-green lumber produced from a cubic foot of the gross volume of a tree. Recovery equations vary by type of mill and species; therefore, mill users should use the appendix to determine the mill that most closely matches their own. A common equation (COMMON) is provided for those who are not using the estimates for a specific mill.

Recovery (REC) equations by mill (mills at Grangeville, Idaho; Burney and Martell, California; and Medford, Oregon) and species:

COMMON $$REC = 0.628 - 6.751(1/D^{1.5}) - 0.203(I) + 0.00763(IH/^{0.5}).$$

Grangeville/grand fir $$REC = 0.678 - 2.416(1/D) - 0.00037(IH/D) + 0.000044\,(IH^2).$$

Martell/white fir $$REC = 0.295 + 10.047(1/D) - 177.580(1/D^2) + 0.0140(I) - 0.0980(C) + 0.666H/D^2.$$

Burney/white fir $$REC = 0.674 - 1.735(1/D) - 18.950(1/D^2) - 0.0550(I) + 0.175(H/D^2).$$

Burney/red fir $$REC = 0.610 - 23.980(1/D^2) - 0.310(I) + 0.050(IH/D).$$

Medford/white fir $REC = 1.0.$

No specific recovery equation was developed for the Medford/white fir data group, so the recovery for that mill should be equal to 1.0.

4. Final correction coefficients

A final correction factor is applied to the product of gross cubic volume and recovery to predict the cubic-foot volume of lumber produced from each tree.

Final correction coefficients by mill and species--lumber volume $(ft^3) = B_1$(gross volume)(recovery):

| | $B_1$ |
|---|---|
| COMMON | 0.9713 |
| Grangeville/grand fir | .9.386 |
| Martell/white fir | .9648 |
| Medford/white fir | .5068 |
| Burney/white fir | .9670 |
| Burney/red fir | .8354 |

5. Ratio of board feet to cubic feet of lumber

To enable the user to convert cubic feet of rough-green lumber to board feet of finished lumber, we estimated the ratio of board feet to cubic feet of lumber for each mill and species group and for all the data combined. The ratio of board feet to cubic feet of lumber (Fahey and Woodfin 1976) is the ratio of the board-foot volume of surfaced-dry lumber (nominal sizes) to the cubic volume of rough-green lumber (actual sizes). The board-foot volume of lumber is found by multiplying the cubic-foot volume of lumber in step 4 by the board-foot:cubic-foot ratio.

Ratios of board feet to cubic feet:[1/]

| Mill/species | Ratio |
|---|---|
| COMMON | 13.844 |
| Grangeville/grand fir | 13.512 |
| Martell/white fir | 13.713 |
| Medford/white fir | 12.620 |
| Burney/white fir | 14.103 |
| Burney/red fir | 14.034 |

Results of each of the above steps for predicting lumber volume are illustrated for nine white fir trees in table 1. These trees were selected to represent a range of diameters from a lumber recovery study done in southern Oregon. Total height, diameter at breast height, and presence or absence of defect and crook for each tree are presented in the table. The calculations needed to predict the lumber volume are shown for the first tree, and the answers for the other eight trees are listed.

Predicted volumes were compared with the actual volumes to give some estimate of the reliability of these equations. Although the individual predicted lumber volumes may vary from the actual volumes, the volumes for the overall sample of nine trees had only a 0.3 percent difference between the actual and the predicted volumes. The variation in a larger test sample of 94 trees was only 0.9 percent (Ernst 1982).

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[1/] One board foot of lumber in nominal sizes can be expressed as 1 by 12 inches by 1 foot, which in actual sizes could be 0.95 by 11.7 inches by 1 foot. In this example, the board-foot-per-cubic-foot ratio would be 1/(0.95x11.7/144) = 12.955.

Table 1--Results of the step-by-step approach to predicting lumber volume of standing white fir trees[1]

| Field measurements | | | | Gross tree volume[3] (VOL) | Recovery[4] (REC) | Lumber volume (LV) | | |
|---|---|---|---|---|---|---|---|---|
| D.b.h. (D) | Height (H) | Defect[2] (I) | Crook[2] (C) | | | Predicted[5] | Actual | Predicted[6] |
| Inches | Feet | | | Cubic feet | | -- Cubic feet -- | | Board feet |
| 7.7 | 56.4 | 0 | 0 | 6.60 | 0.31 | 1.99 | 0.81 | 27.55 |
| 9.0 | 44.9 | 1 | 0 | 6.67 | .29 | 1.88 | 3.11 | 26.03 |
| 10.5 | 54.2 | 0 | 0 | 11.16 | .43 | 4.66 | 2.34 | 64.51 |
| 11.7 | 63.2 | 0 | 0 | 16.54 | .46 | 7.39 | 9.09 | 102.31 |
| 13.1 | 67.2 | 1 | 0 | 22.05 | .42 | 9.00 | 8.37 | 124.60 |
| 15.1 | 79.2 | 0 | 0 | 35.46 | .51 | 17.56 | 17.90 | 243.10 |
| 16.0 | 94.9 | 0 | 0 | 50.48 | .52 | 25.50 | 29.27 | 353.02 |
| 18.8 | 72.9 | 1 | 0 | 47.89 | .47 | 21.86 | 18.49 | 302.63 |
| 23.5 | 128.5 | 0 | 0 | 154.98 | .57 | 85.80 | 86.86 | 1,187.82 |
| Total | | | | | | 175.64 | 176.24 | |

[1] Sample calculations for the 1st tree are in footnotes 3, 4, 5, and 6.

[2] 1 means defect or crook is present; 0 means absent.

[3] Equation for estimating gross cubic volume of red and white fir trees--

$VOL(WR) = D^2H(0.00159412 + 0.0025682(1/H) + 0.000000811(H^2/D))$.

$VOL(WR) = (7.7)^2(56.4)(0.00159412 + 0.0025682(1/(56.4)) + 0.000000811((56.4)^2/7.7))$;

$VOL(WR) = 6.60$.

[4] COMMON equation for estimating recovery--

$REC = 0.628 - 6.751(1/D^{1.5}) - 0.203(I) + 0.00763(IH/D^{0.5})$.

$REC = 0.628 - 6.751/(7.7)^{1.5} - 0.203(0) + 0.00763(0)(56.4)/(7.7)^{0.5}$;

$REC = 0.31$.

[5] COMMON equation for final correction coefficients for lumber volume--

$LV\ (ft^3) = B_1$(gross cubic tree volume)(recovery).

$LV\ (ft^3) = 0.9713(6.60)(0.31)$;

$LV\ (ft^3) = 1.99$.

[6] COMMON equation for lumber volume in board feet per cubic foot of lumber--

LV (bd ft) = lumber volume ($ft^3$) X bd ft/$ft^3$ ratio.

LV (bd ft) = 1.99(13.844);

LV (bd ft) = 27.55.

## Lumber Value

Two methods were developed to predict the total value of a tree. Both were developed to be used with current prices instead of having the prices built into the equation. The first method, volume by grade, is designed for users who wish to know the average volume of lumber in each grade produced from a tree with a given diameter. The second method predicts the total tree value by use of a relative index of lumber prices and volumes. It is much easier to use than the volume by grade method. Because the equations for these two methods were derived separately and predict either average volume by grade or total tree volume by use of a relative price index, the final total tree values may not be the same.

1. Volume by grade

Equations were developed to predict the average proportional volume (PV) of lumber in each lumber grade. These proportional volumes can be multiplied by the lumber volume of the tree and the current selling price for each grade of lumber--Standard and Better (Std & Btr), Utility (Util), and Economy (Econ)--to find the total tree value. Equations could not be produced for Medford/white fir, Martell/white fir, and Grangeville/grand fir data groups, so average PV's by grade across all diameters are given for them as follows:

| | Average proportional volumes | | |
|---|---|---|---|
| | Std and Btr | Util | Econ |
| Grangeville/grand fir | 0.857 | 0.029 | 0.114 |
| Martell/white fir | .713 | .080 | .207 |
| Medford/white fir | .780 | .068 | .152 |

The proportional volumes by grade did vary by diameter for Burney/white fir and Burney/red fir data groups and all the data combined, so equations were developed for these three data sets. The average PV's were made cumulative, so only two equations had to be developed to predict the three lumber grades. In this case, the PV of Economy lumber is found by subtracting the PV of Utility and Better (Util & Btr) from 100 percent. Likewise, the PV of Utility is found by subtracting the PV of Standard and Better from the PV of Utility and Better. The form of the final equation is as follows:

$$\text{Proportional volume in a given lumber grade} = 1.0/(1.0 + e^{(-(b_0 + b_1(D^2)))});$$

where, $e = 2.7182818$;

and constants by mill, species, and grade of lumber are:

| | | $b_0$ | $b_1$ |
|---|---|---|---|
| COMMON | Std and Btr | 0.574 | 0.00137 |
| | Util and Btr | 1.532 | .00355 |
| Burney/white fir | Std and Btr | .203 | .00250 |
| | Util and Btr | 1.146 | .00508 |
| Burney/red fir | Std and Btr | .317 | .00151 |
| | Util and Btr | 1.295 | .00314 |

Lumber values are predicted for the same nine trees using the volumes by grade method (table 2) and the relative index method (table 3). Again the calculations are shown for the first tree, and the answers for the other eight trees are listed in the tables. Predicted and actual prices are based on 1980 Western Wood Products Association prices, where the price of Standard and Better is \$210/M (\$210 per thousand board feet), Utility is \$129/M, and Economy is \$78/M.[2]

The predicted and actual values were also compared. Again, the individual tree values varied, but the overall sample predicted value varied only −5.4 percent from the actual value for the volume by grade method. The relative index predicted value varied −3.5 percent from the actual value for the overall sample. In another test of 94 trees, the variation for the relative index equations was only 1.0 percent.

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[2] Mention of companies or products is for the convenience of the reader and does not constitute an endorsement by the U.S. Department of Agriculture.

Table 2--Volume by grade method for determining lumber value in white fir trees, the step-by-step approach of predicting the proportional volume of lumber in each lumber grade[1]

| D.b.h. | Proportional volume by grade | | | | Total tree value[6] | |
|---|---|---|---|---|---|---|
| | Standard & Better[2] | Utility & Better[3] | Utility[4] | Economy[5] | Predicted | Actual |
| Inches | | | | | Dollars per thousand board feet | |
| 7.7 | 0.658 | 0.851 | 0.193 | 0.149 | 4.79 | 1.75 |
| 9.0 | .665 | .861 | .196 | .139 | 4.58 | 8.02 |
| 10.5 | .674 | .873 | .199 | .127 | 11.43 | 6.94 |
| 11.7 | .682 | .883 | .201 | .117 | 18.24 | 22.41 |
| 13.1 | .692 | .895 | .203 | .105 | 22.39 | 18.07 |
| 15.1 | .708 | .912 | .204 | .088 | 44.21 | 52.05 |
| 16.0 | .716 | .920 | .204 | .080 | 64.57 | 81.39 |
| 18.8 | .742 | .942 | .200 | .058 | 56.33 | 50.84 |
| 23.5 | .791 | .971 | .180 | .029 | 227.58 | 238.42 |
| Total | | | | | 454.14 | 479.89 |

[1] Sample calculations for the 1st tree are in footnotes 2, 3, 4, 5, and 6.

Proportional volume (PV) in a given lumber grade = $1.0/(1.0 + e^{(-(b_0 + b_1(D2)))})$.

[2] COMMON equation--

PV in Std & Btr = $1.0/(1.0 + e^{(-(0.574 + 0.00137((7.7)^2)))})$;

PV in Std & Btr = 0.658.

[3] PV in Util & Btr = $1.0/(1.0 + e^{(-(1.532 + 0.00355((7.7)^2)))})$;
PV in Util & Btr = 0.851.

[4] PV in Util = PV in Util & Btr - PV in Std & Btr.
PV in Util = 0.851 - 0.658;
PV in Util = 0.193.

[5] PV in Econ = 1.0 - PV in Util & Btr.
PV in Econ = 1.0 - 0.851;
PV in Econ = 0.149.

[6] Value = total tree lumber volume (bd ft)(PV(Std & Btr)($/M)
+ PV(Util)($/M) + PV(Econ)($/M)).
Predicted value = 27.55 (0.658($210/M) + 0.193($129/M) + 0.149($78/M)).
Predicted value = 27.55 (0.658(0.210) + 0.193(0.129) + 0.149(0.078));
predicted value = $4.81.

2. Relative index equations by mill and species

The total tree value is found by predicting a relative index[3/] of lumber prices and volumes and multiplying the relative index by the current price of Standard and Better lumber.

Relative index value = $B_0 + B_1$ lumber volume (bd ft).

| | $B_0$ | $B_1$ |
|---|---|---|
| COMMON | -5.510 | 0.9268 |
| Grangeville/grand fir | -4.312 | .9347 |
| Martell/white fir | -7.794 | .9348 |
| Medford/white fir | 2.368 | .8959 |
| Burney/white fir | -6.726 | .9103 |
| Burney/red fir | -.295 | .8640 |

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[3/] The dependent variable (relative index value) was calculated this way: All the prices were made proportional to the price of Standard and Better. Then the actual lumber volumes in each grade were multiplied by these relative prices and added together. Thus, the index relates all the lumber volume to the price of Standard and Better.

Table 3--Results of the approach to predicting the tree value by the relative index method[1]

| D.b.h. | Relative index[2] | Predicted value[3] | Actual value |
|---|---|---|---|
| Inches | | Dollars per thousand board feet | |
| 7.7 | 20.02 | 4.20 | 1.75 |
| 9.0 | 18.61 | 3.91 | 8.02 |
| 10.5 | 54.28 | 11.40 | 6.94 |
| 11.7 | 89.31 | 18.76 | 22.41 |
| 13.1 | 109.97 | 23.09 | 18.07 |
| 15.1 | 219.80 | 46.16 | 52.05 |
| 16.0 | 321.67 | 67.55 | 81.39 |
| 18.8 | 274.97 | 57.74 | 50.84 |
| 23.5 | 1,095.36 | 230.02 | 238.42 |
| Total | | 462.83 | 479.89 |

[1]Sample calculations for the 1st tree are in footnotes 2 and 3.

[2]COMMON equation--
Relative index (RI) = $B_0 + B_1$ lumber volume (bd ft).
RI = -5.510 + 0.9268(27.55);
RI = 20.02.

?/Predicted value = RI($/M Std & Btr).
Predicted value = 20.02 (0.210);
predicted value = $4.20.

## Metric Equivalents

1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 cubic foot = 0.02832 cubic meter

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## Appendix

The mill at Martell, California, had one 9-foot double-cut bandsaw with a 54-inch carriage, a 9-foot single-cut bandsaw with a 72-inch carriage, two edgers, one line-bar resaw, one trimmer, and a 24-tray automatic sorter. Mill production averaged 150,000 board feet of lumber per shift.

The mill at Medford, Oregon, had one single-cut, 7-foot bandsaw, a 4- by 66-inch single edger, a 32-foot gang trimmer, a twin-band vertical line-bar resaw, and a single band resaw on the green chain. Mill production averaged 90,000 board feet of lumber per shift.

The mill at Burney, California, had one quad-band headsaw, one debarker, one single-band resaw, two double-arbor edgers, one trimmer, an automatic drop sorter, and a lumber stacking and stickering machine. Mill production averaged 150,000 board feet of lumber per shift.

The mill at Grangeville, Idaho, one 9-foot, single-cut band headsaw, one 16-inch chip-n-saw, two debarkers, one twin-band resaw, one gang bull edger, two single edgers, one trimmer, and a drop sorter. Mill production averaged 150,000 board feet of lumber per shift.

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