Green lumber grade yields from factory grade logs of three oak species

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Abstract

Multivariate regression models were developed to predict green board foot yields for the seven common factory lumber grades processed from white, black, and chestnut oak factory grade logs. These models use the standard log measurements of grade, scaling diameter, log length, and proportion of scaling defect. Any combination of lumber grades (such as 1 Common and Better) or total yield from a log can be predicted with these models. The coefficients presented here can be used in computer programs related to sawmill simulations, economic modeling, or log-yard inventory systems.

Tables for estimating lumber grade yields from factory grade logs were developed by Hanks et al. for 18 hardwood species (3). These tables expressed dry board foot yields by lumber grade as a percentage of total lumber tally volume. To apply the percentages, an independent estimate of lumber tally volume is required, using an appropriate log rule and estimated mill overruns. The tables provide good estimates of log value, but are difficult to incorporate into computer software for inventory, simulation, or economic modeling of a sawmill. Most sawmill simulators require estimates of green yields rather than dry yields so that the drying process can be isolated from the sawing process.

In this study we present similar information as Hanks et al. (3) for white (*Quercus alba* L.), black (*Quercus velutina*), and chestnut (*Quercus prinus*) oak. However, it is presented as multivariate regression equations for predicting green board foot lumber grade yields. This has been done for northern red oak (*Quercus rubra*) (6) and, in somewhat the same manner, for five Lake States species (5). These equations are easily programmed into a computer or handheld calculator.[1]

Data

The logs used in this study were sawed at bandsawmills in Tennessee, North Carolina, Virginia, and West Virginia, and were part of the data used in Hanks et al. (3). The resulting lumber was graded immediately after sawing by graders certified by the National Hardwood Lumber Association. The following lumber grades were used:

Lumber grade	Abbreviation
Firsts and Seconds	FAS
FAS One Face	F1F
Selects	SEL
One Common	1C
Two Common	2C
Three A Common	3A
Three B Common	3B

When originally graded, "worm holes no defect" (WHND) specifications were included in the chestnut oak lumber grades. In this study, the WHND lumber grades were converted to the standard grades as suggested in Hanks et al. (3):

WHND grade	Standard grade
FAS-WHND	1C
F1F-WHND	2C
SEL-WHND	2C
1C-WHND	2C

In the original data collection, a "sound wormy" grade was tabulated for white and black oak. This volume was combined with the 2C standard grade for this study. Table 1 includes the average log measurements by log grade (4) for the three species.

Model development

Multivariate regression analysis was used to develop the prediction equations. The seven lumber grade yields constituted the dependent variables while log measurements were the independent variables. The general linear model can be represented as:

$$y = Bx$$

where:

y = a column vector of the seven lumber grade yields

x = a column vector of the independent variables

B = a matrix of coefficients determined by regression analysis

[1]ROLOGY. Documentation for HP-41CV calculator program number 41F036, written by T.W. Beers, Ph.D., Dept. of Forestry and Natural Resources, Purdue Univ., West Lafayette, IN.

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TABLE 1. — *Averages and ranges of log measurements for white, black, and chestnut oak.*

Species variable	Avg.	Minimum	Maximum	Standard deviation
White oak				
Log Grade 1 (131 logs)				
Scaling diameter (in.)	18.5	13.0	29.0	3.6
Length (ft.)	14.5	10.2	16.7	2.1
Scaling defect (proportion)	0.03	0.00	0.23	0.05
Log Grade 2 (298 logs)				
Scaling diameter	15.4	10.0	34.0	3.5
Length	13.5	8.0	16.8	2.4
Scaling defect	0.03	0.00	0.29	0.05
Log Grade 3 (414 logs)				
Scaling diameter	13.3	8.0	30.0	3.6
Length	13.0	8.2	18.4	2.6
Scaling defect	0.04	0.00	0.47	0.07
Black oak				
Log Grade 1 (96 logs)				
Scaling diameter	19.3	13.0	29.0	3.7
Length	15.1	10.2	16.8	2.0
Scaling defect	0.02	0.00	0.21	0.04
Log Grade 2 (168 logs)				
Scaling diameter	15.9	10.0	28.0	3.5
Length	14.4	8.3	16.8	2.3
Scaling defect	0.04	0.00	0.39	0.06
Log Grade 3 (221 logs)				
Scaling diameter	13.4	8.0	25.0	3.2
Length	13.5	8.2	17.5	2.2
Scaling defect	0.03	0.00	0.29	0.04
Chestnut oak				
Log Grade 1 (142 logs)				
Scaling diameter	18.5	13.0	30.0	3.8
Length	14.0	10.0	16.6	2.3
Scaling defect	0.06	0.00	0.37	0.07
Log Grade 2 (295 logs)				
Scaling diameter	15.0	10.0	28.0	3.3
Length	13.2	8.1	16.8	2.6
Scaling defect	0.07	0.00	0.46	0.07
Log Grade 3 (292 logs)				
Scaling diameter	12.2	8.0	26.0	3.4
Length	12.2	8.0	16.6	2.8
Scaling defect	0.05	0.00	0.40	0.07

A weighted regression model by Bruce (1) served as a basis for this analysis:

$$Y/(D^2L) = b_0 + b_1/D + b_2/D^2 + b_3 \cdot P$$

where:

Y = lumber yield
D = scaling diameter of the log in feet
L = log length in feet
P = proportion of the log that is considered defective
b_j = coefficients to be determined by regression, j = 0, 1, 2, 3

In this study, as in Yaussy and Brisbin (6), this equation was expanded to include factory log grades and multiple lumber grade yields. Since log grade is a classification variable with three levels, dummy variables (G_1 and G_2) were used to account for variations in lumber grade yield due to differences in log grades (2). The different combinations for the three log grades are:

Log grade	G_1	G_2
One	1	0
Two	0	1
Three	0	0

The expanded model used for fitting the data was:

$$\begin{aligned} Y_i/(D^2L) = {} & b_{i0} + b_{i1}/D + b_{i2}/D^2 + b_{i3} \cdot P \\ & + b_{i4} \cdot G_1 + b_{i5} \cdot G_1/D + b_{i6} \cdot G_1/D^2 + b_{i7} \cdot G_1 \cdot P \\ & + b_{i8} \cdot G_2 + b_{i9} \cdot G_2/D + b_{i10} \cdot G_2/D^2 + b_{i11} \cdot G_2 \cdot P \end{aligned} \quad [1]$$

where:

Y_i = green board foot volume for the ith lumber grade, i = 1,...,7; Y_i = FAS,...,3B
b_{ij} = coefficient determined by regression for the ith lumber grade and the jth independent variable, j = 1,...,11

TABLE 2. — *Matrix of coefficients (b_{ij}) for white, black, and chestnut oak.*

			Independent variables (j)								
Lumber grade	(i)	D^2L 0	DL 1	L 2	D^2LP 3	D^2LG_1 4	DLG_1 5	D^2LPG_1 6	D^2LG_2 7	DLG_2 8	LG_2 9
White oak											
FAS	1	0.0028	−0.0508	0.2397	0.0005	0.0135	−0.0882	−0.0322	0.0050	−0.0551	0
F1F	2	0.0061	−0.1217	0.6105	2.24E-5	0.0059	−0.0183	−0.0193	0.0006	0.0037	0
SEL	3	0.0011	−0.0234	0.1293	−0.0006	0.0004	0.0125	−0.0027	0.0004	−0.0017	0
1C	4	0.0408	−0.6974	3.0548	−0.0220	−0.0099	0.2205	0.0077	0.0043	−0.0144	0
2C	5	0.0090	0.3488	−3.2523	−0.0219	−0.0116	0.0733	0.0149	−0.0111	0.1340	0
3A	6	−0.0129	0.4470	−2.2411	0.0099	0.0042	−0.1058	−2.64E-6	0.0016	−0.0332	0
3B	7	0.0018	−0.0266	1.3371	0.0003	0.0024	−0.0999	0.0118	0.0016	−0.0599	0
Black oak											
FAS	1	0.0169	−0.3739	2.0299	−0.0086	0.0179	−0.1477	−0.0464	−0.0098	0.3350	−2.3626
F1F	2	0.0107	−0.1986	0.9399	−0.0125	−0.0019	0.1414	−0.0022	−0.0082	0.2943	−1.8929
SEL	3	0.0005	−0.0034	−0.0009	−0.0030	0.0015	−0.0131	−0.0037	0.0040	−0.1222	1.0561
1C	4	0.0363	−0.5613	2.2713	−0.0274	−0.0191	0.3221	0.0646	−0.0147	0.5636	−3.8617
2C	5	0.0096	0.2022	−1.4786	−0.0185	−0.0125	0.0600	0.0260	−0.0122	0.0834	0.5004
3A	6	−0.0122	0.4470	−1.9653	0.0106	0.0056	−0.1364	−0.0268	0.0103	−0.3353	2.2455
3B	7	−0.0097	0.3156	−1.3052	0.0118	0.0054	−0.1245	0.0036	−0.0007	0.0882	−1.6021
Chestnut oak											
FAS	1	0.0006	−0.0159	0.0910	0.0005	0.0044	−0.0167	−0.0123	0	0	0.0980
F1F	2	0.0028	−0.0556	0.2817	−0.0002	0.0004	0.0448	−0.0061	0	0	0.1433
SEL	3	−0.0006	0.0137	−0.0578	−2.32E-5	−0.0007	0.0216	−0.0008	0	0	0.1016
1C	4	0.0247	−0.4823	2.4015	−0.0035	0.0024	0.1021	−0.0155	0	0	0.5654
2C	5	0.0093	0.3613	−3.1239	−0.0282	−0.0071	0.0540	0.0226	0	0	0.2712
3A	6	−0.0081	0.3266	−1.6470	−0.0012	0.0059	−0.1292	0.0016	0	0	0.0314
3B	7	0.0091	−0.0457	0.9564	0.0118	0.0010	−0.1310	−0.0013	0	0	−1.0345

TABLE 3. — *Averages of actual and predicted green board foot volumes and Wilks-Lambda statistic for white, black, and chestnut oak.*

Lumber grade		Log grade 1		Log grade 2		Log grade 3	
		Actual	Predicted	Actual	Predicted	Actual	Predicted
White oak							
Wilks-Lambda	0.226						
FAS		47.1	45.0	7.5	7.3	1.2	1.2
F1F		29.7	29.7	6.5	6.1	2.0	1.9
SEL		6.4	6.4	1.2	1.7	0.3	0.3
1C		71.9	73.1	42.3	42.2	17.9	17.4
2C		50.4	51.8	46.9	47.2	38.4	37.9
3A		15.8	15.9	18.5	18.6	17.3	17.3
3B		9.4	9.4	11.4	11.6	17.3	17.3
Total		230.7	231.3	134.3	134.7	94.4	93.3
Black oak							
Wilks-Lambda	0.148						
FAS		73.3	72.8	12.0	12.0	2.9	2.4
F1F		46.0	46.2	16.1	15.8	3.2	3.1
SEL		6.0	5.9	3.2	3.3	0.4	0.4
1C		69.4	69.6	56.4	56.1	20.2	20.0
2C		37.7	37.9	38.7	39.1	39.2	39.5
3A		19.6	19.7	23.7	23.5	23.6	23.7
3B		13.1	12.9	12.4	12.2	15.6	15.4
Total		265.1	265.0	162.5	162.0	105.1	104.5
Chestnut oak							
Wilks-Lambda	0.359						
FAS		15.0	14.0	1.7	1.5	0.0	0.1
F1F		15.4	14.8	3.9	3.1	0.3	0.6
SEL		1.2	1.2	1.1	1.2	0.2	0.0
1C		66.2	64.1	21.4	19.8	5.4	5.6
2C		72.3	72.5	54.9	55.1	31.7	30.9
3A		17.7	17.4	17.8	17.6	12.7	12.6
3B		20.0	21.7	19.9	20.9	23.3	24.0
Total		207.8	205.7	120.7	119.2	73.6	73.8

The multivariate Wilks-Lambda criterion used is equivalent to using the Type III sums of squares in the univariate case. Each independent variable was tested at the 5 percent significance level assuming all other independent variables were included in the model. Coefficients that were not significantly different from zero were dropped from the equation.

Results

The independent variables, G_1/D^2 and $G_2{\bullet}P$, were not significant for any of the three species and were dropped from Equation [1]. For use, the weighted Equation [1] is rewritten by multiplying both sides of the equation by D^2L. The final form is:

$$Y_i = b_{i0}{\bullet}D^2{\bullet}L + b_{i1}{\bullet}D{\bullet}L + b_{i2}{\bullet}L + b_{i3}{\bullet}D^2{\bullet}L{\bullet}P + b_{i4}{\bullet}D^2{\bullet}L{\bullet}G_1 + b_{i5}{\bullet}D{\bullet}L{\bullet}G_1 + b_{i6}{\bullet}D^2{\bullet}L{\bullet}P{\bullet}G_1 + b_{i7}{\bullet}D^2{\bullet}L{\bullet}G_2 + b_{i8}{\bullet}D{\bullet}L{\bullet}G_2 + b_{i9}{\bullet}L{\bullet}G_2$$

The coefficients for the data set are listed in Table 2. A few coefficients were not significantly different from zero for some species; therefore, these are represented as zero in Table 2.

A comparison of the actual and predicted average yields for the three species is shown in Table 3. Included in the table is the Wilks-Lambda statistic for each overall model. The r^2 statistic is a univariate, least-squares statistic and is not applicable outside this context. The Wilks-Lambda statistic is a close counterpart in multivariate least-squares regression. In a univariate regression, the Wilks-Lambda statistic is equivalent to $1\text{-}r^2$. This implies that the smaller the statistic, the better the fit of the model. Therefore, these models work well.

Applications

Table 4 is a tabular example of the volume estimated by the multivariate model for grade 3, 12-foot chestnut oak logs with 5 percent scaling defect. This table does not show the flexibility of the model. If log grade, scaling diameter, log length, and the proportion of defect are known, the board foot volume for each of seven lumber grades can be estimated.

TABLE 4. — *Predicted green board foot lumber grade yields (chestnut oak, log grade 3, log length 12, defect .05).*

Scaling diameter	Lumber grade yields							
	FAS	F1F	SEL	1C	2C	3A	3B	Total
(in.)								
8	0	0	0	1	3	5	15	24
9	0	0	0	1	9	8	16	34
10	0	0	0	0	15	10	18	43
11	0	0	0	1	22	12	20	55
12	0	0	0	2	28	13	22	65
13	0	0	0	3	35	15	24	77
14	0	1	0	5	42	16	27	91
15	0	1	0	8	49	17	29	104
16	0	1	0	12	56	18	33	120
17	0	2	0	15	64	19	36	136
18	0	2	0	20	71	19	39	151
19	0	3	0	25	79	20	43	170
20	1	3	0	31	87	20	47	189
21	1	4	0	37	95	20	51	208
22	1	5	0	44	104	19	56	229
23	1	5	0	51	112	19	61	249
24	1	6	0	59	121	18	65	270
25	1	7	0	68	130	17	71	294

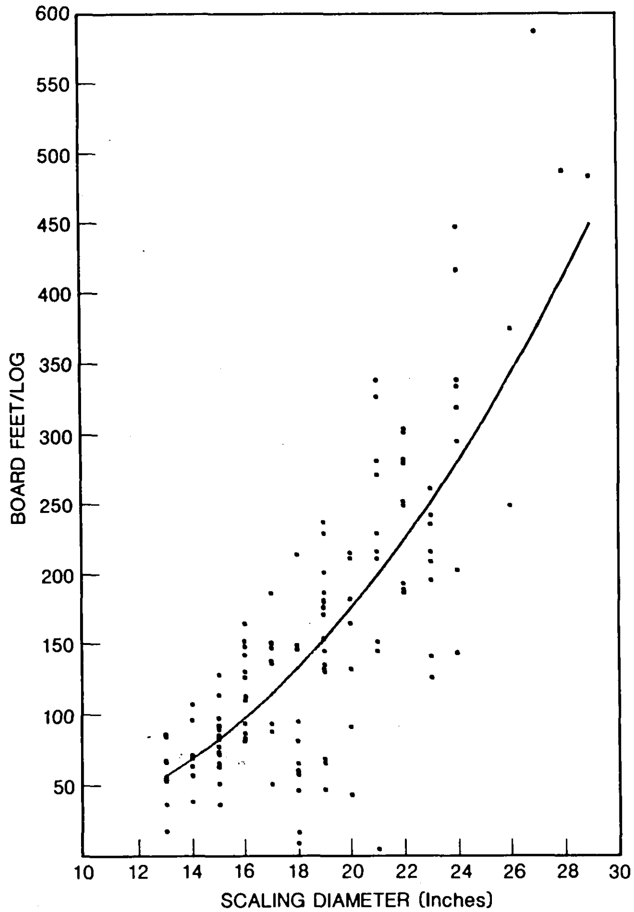

Figure 1. — Predicted volume of 1 Common and Better lumber for grade 1 white oak logs of average length and defect compared to volumes of actual logs.

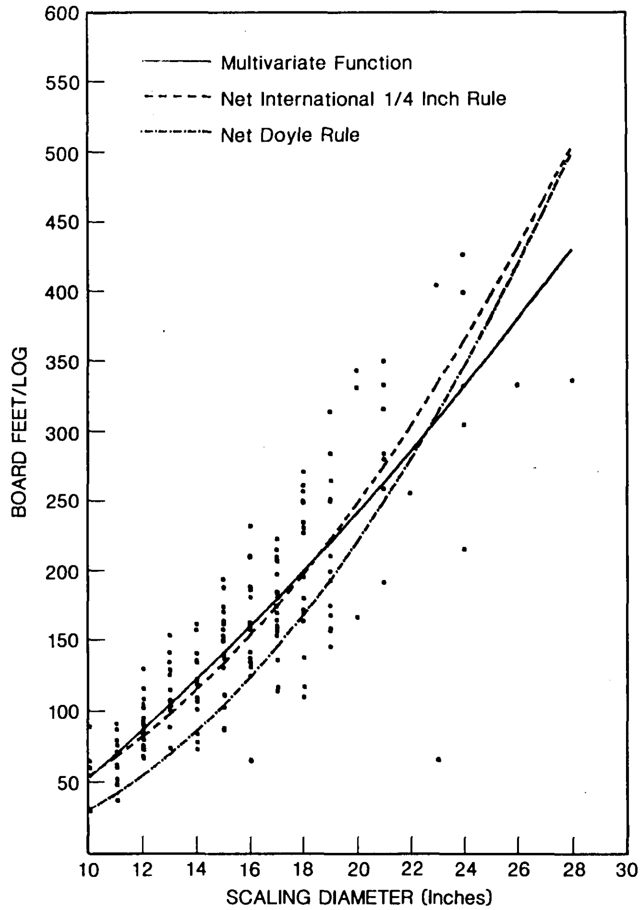

Figure 2. — Comparison of total board foot volume predicted by model and two popular log rules for grade 2 black oak logs of average length and defect with total volumes of actual logs.

A sawmill may not separate all seven lumber grades. They may use the broader class of 1 Common and Better (1C&B) or total board foot volume. The model can be modified to predict these classes by adding certain coefficients:

$$b_{(1C\&B,j)} = b_{(1,j)} + b_{(2,j)} + b_{(3,j)} + b_{(4,j)}$$
$$b_{(total,j)} = b_{(1C\&B,j)} + b_{(5,j)} + b_{(6,j)} + b_{(7,j)}$$
$$\text{for } j = 1,...,10$$

This concept is illustrated in Figures 1 and 2. In Figure 1, the average length and the average defect for a grade 1 white oak log (Table 1) were used in the 1C&B model, while scaling diameter changed from 13 to 29 inches. The resulting line is plotted over the actual 1C&B board foot volumes of grade 1 white oak logs.

Figure 2 uses the same idea for total board foot volumes per log with log grade 2 black oak. Also shown on this graph are the predicted board foot volumes obtained by using the International 1/4-inch and the Doyle log rules for a log 14.4 feet long with 3.5 percent defect. An underrun for grade 2 black oak logs with scaling diameters larger than 18 inches can be seen by comparing the net International line with the line from the multivariate model. This is consistent with the negative overruns reported in Hanks et al. (3).

Conclusions

Lumber grade yields can be estimated from the log measurements that might be taken during a log inventory. The models developed are suitable for use in computer simulators in which estimates of each lumber grade are desired for exacting economic studies. The models also can be used to predict broader classes of lumber grades that might fit into a sawmill's inventory program better than the commonly used log rules.

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