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Butt Log Quality of Trees in Pennsylvania Oak Stands

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Abstract

Describes the distribution of sawtimber trees by diameter at breast height (d.b.h.) and grade for eight hardwood species in upland oak stands of Pennsylvania. The proportion of trees by d.b.h. and grade revealed differences between species. The quality of northern red oak, white oak, and yellow-poplar appeared inherently better than that of red maple, chestnut oak, and a group of other hardwoods. Grade predictions by size and species allow more precise timber appraisals and enable managers to evaluate alternative management strategies more accurately.

Introduction

The dollar value of a hardwood tree depends largely on its suitability for conversion into various types of wood products. Some hardwood trees are converted to high-value products such as face veneer or First and Second and Select grade factory lumber; others are used only for their fiber or as fuelwood.

Hardwood log and tree grading systems have been used since the early 1900's by foresters, timber buyers or sellers, and others to appraise timber values. USDA Forest Service standard grades for hardwood factory lumber logs have not changed since they were first published in 1949 by the Forest Service's Forest Products Laboratory. However, guides for applying the rules have been revised and now provide greater detail and more clarification (Rast et al. 1973). Lumber grade yields associated with the log grades have been tabulated and expanded to include other hardwood species (Hanks et al. 1980).

In addition to the grades for factory lumber logs, specifications have been developed for other major use classes of logs, including veneer, construction, and local use. Grade specifications within each class of logs are designed to separate logs into value groups based on product requirements.

It is possible to determine the precise relative value of a tree if yields in factory lumber grades or other product classes are available by log grade, species, and diameter at breast height (d.b.h.). Tree-value conversion standards reported by (Mendel et al. 1976) measure a tree's relative worth based on the quantity and quality of its expected yield of 4/4 (1-inch) lumber. This approach to tree or stand evaluation is beneficial to foresters and others because it is easy to use, objective, and provides a realistic ranking of relative tree or stand values. The only information needed is d.b.h., merchantable height, tree grade, and species.

Unfortunately, there is little information on tree grades in most forest inventories or growth and yield simulators. Although we can not determine accurately the value of individual trees, it is still possible to evaluate stands. This requires an appropriate distribution of trees for each species that gives the percentage by grade in each d.b.h. class. Such grade distributions have been described mathematically for six hardwood species on the Allegheny Plateau (Ernst and Marquis 1979). Trimble (1965) presented freehand curves that described the grade distribution for factory-grade butt logs for six hardwood species in West Virginia. It was apparent from these findings that there were large differences between species in the d.b.h.-grade relationship and by geographic area.

Our objective in this study was to develop estimates of the d.b.h.-grade relationship for an expanded list of species for upland oak stands of Pennsylvania. These distributions could be used to evaluate typical stands for timber sale appraisals or used in growth simulators to assign a grade to individual trees. Although the specific grade distributions developed in this study apply only to the Pennsylvania oak stands, the methodology is applicable to other timber types or geographic areas.

Methods

Data

Our data on log grades were extracted from 10-point cluster plots used in the USDA Forest Service's 1978 forest survey of Pennsylvania. Original field plots were first screened to select all plots where oak and hickory species constituted a plurality of the stand basal area. From 506 plots representing the oak-hickory type in Pennsylvania, we tabulated the number of trees by species, grade, 1-inch diameter class, and productivity class. Our sample of hardwood sawtimber trees, excluding all conifers, consisted of 15,716 observations by species and grade (Table 1). Sugar maple, hickory, and beech were later pooled with other hardwoods because data were insufficient for analysis.

Grades were assigned by survey field crews using Forest Service standard grades for hardwood factory lumber logs for log grades 1 through 3. If the butt log failed to meet specifications for a factory lumber log but met specifications of Forest Service standard hardwood construction logs (Tie and Timber logs), it was assigned grade 4. The major factors that affect quality for the tie and timber logs are size and condition of log defects, straightness, and soundness of heart (Rast et al. 1973). Culls and other sawtimber-size trees not meeting these specifications were assigned grade 5. Trees generally were graded on the butt 16-foot section rather than on the shorter sections permitted by the grading rules. However, to prevent underestimating log quality, if a 12-or 14-foot section qualified as a higher grade compared to the entire log, then the higher grade was assigned to the entire 16-foot log.

Four productivity classes originally were tabulated on the basis of the ability of the site to produce wood, and were expressed as growth in cubic feet (ft^3) per acre per year. The best sites were those capable of producing a mean annual increment greater than 120 ft^3/acre; the mean annual increment on the poorest site was less than 50 ft^3/acre. Intermediate sites ranged from 50 to 84 and from 85 to 120 ft^3. We later found that productivity class had no significant effect on the distribution of grades by d.b.h. class. As a result, this variable was dropped from our analyses.

Table 1.—Number of trees by grade and species

Species	No. 1	No. 2	No. 3	No. 4	No. 5	Total	Percent by species
White oak	215	448	1021	79	86	1849	12
Chestnut oak	202	739	1851	66	411	3269	21
Northern red oak	690	999	1570	41	181	3481	22
Other oaks	258	477	1034	94	87	1950	12
Red maple	45	190	816	94	204	1349	09
Yellow-poplar	190	211	344	65	32	842	05
Walnut ash	44	133	260	5	100	522	03
Sugar maple	10	32	87	9	30	168	01
Hickory	37	85	278	51	32	483	03
Beech	2	18	47	43	29	139	01
Other hardwoods	73	275	775	77	464	1664	11
Total	1,766	3,587	8,033	624	1,656	15,716	--
Percent	11	23	51	04	11	--	100

Analysis

The proportion of trees in each grade within a diameter class was computed and plotted over the range of diameters for a species (Fig. 1). From these plotted distributions we were able to hypothesize mathematical models to describe the grade distributions. A nonlinear model was developed to fit the distribution of grade 1 trees of the form:

$$Y(i,1) = \beta_0 *(1-EXP(\beta_1 *(D_i-C_o)))**\beta_2 \qquad (1)$$

where:

$Y_{i,1}$ = proportion of trees in the ith diameter class that are grade 1

D_i = midpoint of the ith diameter class

C_o = a constant to be estimated. Interpreted as the minimum d.b.h. that qualifies as a grade 1 tree; hence, C_o = 15.5 inches

$\beta_0, \beta_1, \beta_2$ = model parameters to be estimated: $\beta_0>0; \beta_1<0$

Data analysis indicated that the percentage of grade 1 trees reached a maximum at a d.b.h. of 18 to 20 inches. For most species, the proportion of grade 1 trees declined beyond 20 inches in d.b.h. The coefficient, β_0 in model 1, is the asymptote and represents the maximum percentage of grade 1 trees. We determined the approximate value of β_0 by reading the maximum value from free-hand curves. Values of β_1 and β_2 were then computed by nonlinear regression using data through the 20-inch d.b.h. class.

The shape of the grade 2 frequency distribution was more difficult to describe mathematically, but when grade 1 and grade 2 trees were combined the shape of the curve resembled that for model 1 (Fig. 1). We used the combined grade 1 and 2 data to fit model 1 and then by subtracting the estimate for grade 1 obtained the estimated percentage for grade 2 trees for a specified diameter. The model parameter β_0 was read from the hand-fitted curves as before. Minimum d.b.h. for a grade 2 hardwood log is 13 inches, so C_o was assigned the value 12.5. Estimates of β_1 and β_2 were computed by nonlinear regression for all data through the 20-inch d.b.h. class.

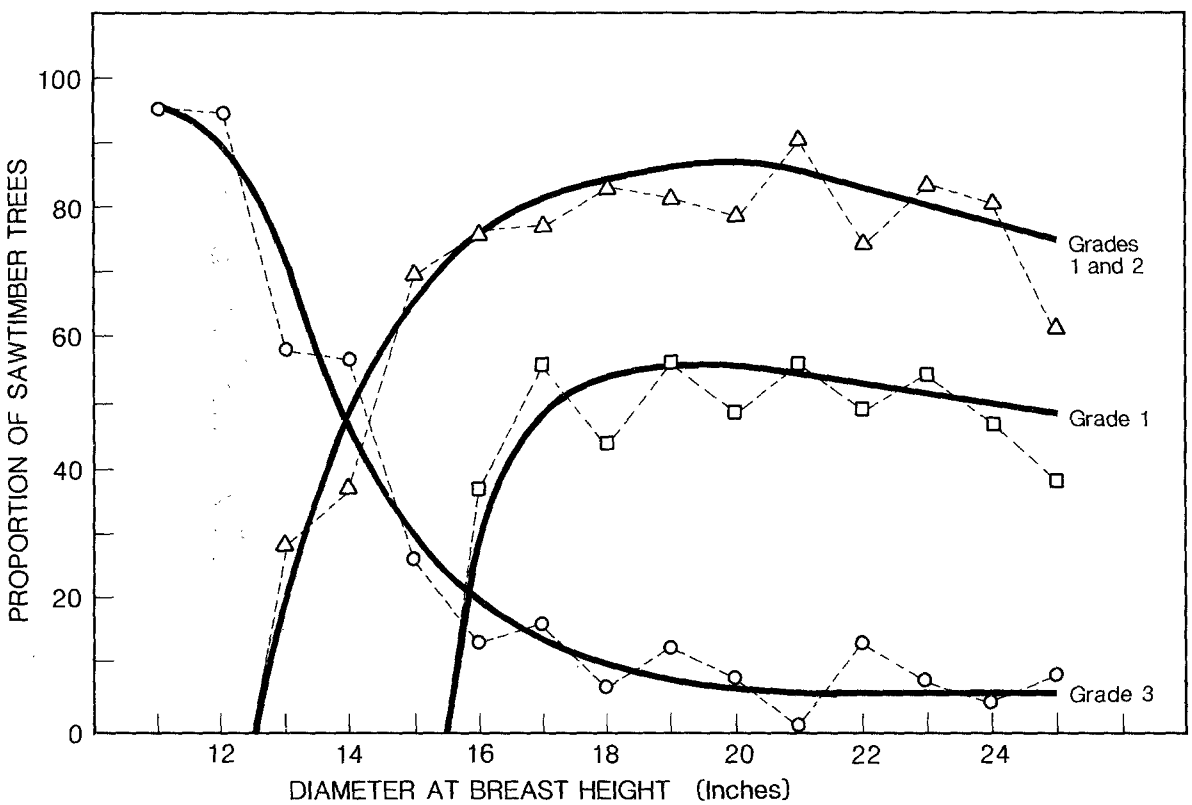

Figure 1.—Distribution of butt-log grade for white oak trees.

For all trees larger than 20 inches in d.b.h., we used a linear regression model to estimate the proportion of trees in grade 1 and the combined log grades 1 and 2. This regression was conditioned so that when the d.b.h. was 20.5 inches, model 1 or 2 provided identical estimates. The intercept term, α_0 in the model:

$$Y = \alpha_0 + \alpha_1 EXP(D_i - 20.5) \quad (2)$$

was set equal to the solution of model 1 using a d.b.h. of 20.5 inches. Linear regression was used to estimate the value of α_1 for each species.

The distribution of grade 3 trees was fitted to a nonlinear model of the form:

$$Y(i,3) = \alpha_0 - \beta_0 * (1 - EXP(\beta_1 * (D_i - C_0))) ** \beta_2 \quad (3)$$

where:

$Y(i,3)$ = proportion of trees in the ith diameter class that are grade 3

C_0 = a constant. The minimum sawtimber size hardwood was 11.0 inches in d.b.h., hence, $C_0 = 11.0$ inches

$\alpha_0, \beta_0, \beta_1, \beta_2$ = model parameters to be estimated. $\alpha_0 > 0; \alpha_0 > \beta_0; \beta_1 < 0$

Approximately 95 percent of white oak trees that are 11.0 inches d.b.h. are grade 3 (Fig. 1). The parameter α_0 was set equal to this value, or 0.95. Figure 1 also shows that the proportion of grade 3 trees seems to have some minimum value which is approached asymptotically with large trees. Therefore, we determined the value of this asymptote as $(\alpha_0 - \beta_0)$ from the free-hand curve value for a 25-inch tree. Data from all diameter classes were used to estimate the parameters β_1 and β_2 as before.

Trees that were grade 4 made up a relatively small percentage of all trees for most species and accounted for only 4 percent of the entire sample (Table 1). We did not attempt to separate grade 4 from grade 5 trees since both grades combined accounted for only 15 percent of the total, and both grades represent low value or unmerchantable material. Plotted data indicated that grade 5 trees, or culls, generally tended to increase with d.b.h. class, particularly for trees more than 20 inches d.b.h. The percentage of grade 4 and 5 trees combined was obtained for any d.b.h. class by substracting the combined percentages of grades 1, 2, and 3 from unity.

Results

We were unable to detect significant differences in grades due to site quality, so this variable was dropped from the final analyses. Also, sample size was too small or poorly distributed across d.b.h. classes to obtain reliable equations for hickory, sugar maple, or beech, so these species were pooled with other hardwoods.

Estimated parameters and statistics are given for predicting the proportion of trees in each grade in Tables 2, 3, and 4. From observed and predicted values we calculated R^2 values for each species and grade and the root mean square residual. For a given species, higher computed R^2 values were obtained for grade 3 trees than grade 1 or grade 1 and 2 combined (Table 4). However, the root mean square residual indicates that data fitted the model for each grade about equally well since there was little difference in the statistic between the models. Some species, generally those with the most observations, provided slightly better estimates of the parameters. The root mean square residual ranged from 0.05 or 0.06 to 0.15 for each of the three models. Overall, the models seemed to fit northern red oak, white oak, and other oaks somewhat better than the other species, particularly red maple and the black walnut/ash group.

Model parameters for white oak were used to predict the proportion of trees by grade for each diameter class (Table 5). As expected, similar calculations for other species revealed considerable differences between species. Table 6 gives the percentage of combined grade 1 and 2 trees; red oak, white oak, and yellow-poplar usually have inherently better quality than chestnut oak, red maple, or the group of other hardwoods.

Discussion

The results of this study indicated large differences among species in the d.b.h.-grade relationship. Similar findings were reported by Trimble (1965), who believed that these differences were due to inherent differences in branching habit and frequency of dormant buds. There are similar inherent differences between Allegheny hardwood species (Ernst and Marquis 1979). The latter found the highest proportion of grade 1 or 2 trees in the black cherry/yellow-poplar group, whereas the beech/birch group consisted of higher proportions of grade 3 or lower quality trees.

Table 2.—Model parameters for predicting the proportion of grade 1 trees

Species	Trees ≤ 20.5 inches d.b.h.			Trees ≥ 20.5 inches d.b.h.		R^2	Root mean square residual
	β_0	β_1	β_2	α_0	α_1		
White oak	.56	-1.1948	0.8908	.5587	-.0144	.14	.064
Chestnut oak	.44	-0.8340	0.9384	.4336	+.0072	.39	.096
Northern red oak	.70	-3.3948	1.8049	.7000	-.0123	.09	.068
Other oak	.62	-1.3828	1.5821	.6190	-.0369	.34	.115
Red maple	.37	-1.6440	1.1589	.3699	-.0158	.19	.134
Yellow-poplar	.75	-0.7511	1.0043	.7324	-.0303	.26	.148
Walnut/ash	.64	-0.8071	1.3390	.6249	-.0526	.70	.107
Other hardwoods	.40	-0.5001	1.0931	.3782	+.0791	.69	.119

Table 3.—Model parameters for predicting the proportion of grade 1 and grade 2 trees combined

Species	Trees ≤ 20.5 inches d.b.h.			Trees ≥ 20.5 inches d.b.h.		R^2	Root mean square residual
	β_0	β_1	β_2	α_0	α_1		
White oak	.88	-0.6316	1.1970	.8733	-.0240	.89	.060
Chestnut oak	.72	-0.6916	1.1076	.7168	-.0433	.53	.109
Northern red oak	.90	-0.8966	0.9596	.8993	-.0422	.66	.082
Other oak	.79	-0.6716	1.1276	.7859	-.0444	.84	.058
Red maple	.59	-0.6477	0.8341	.5872	-.0467	.32	.131
Yellow-poplar	.94	-0.3663	0.7354	.9028	-.0170	.79	.094
Walnut/ash	.76	-0.6362	0.9442	.7556	-.0689	.30	.154
Other hardwoods	.61	-0.4853	1.0606	.5967	-.0382	.30	.122

Table 4.—Model parameters for predicting the proportion of grade 3 trees

Species	All trees ≥11.0 inches d.b.h.				R^2	Root mean square residual
	α_0	β_0	β_1	β_2		
White oak	.95	.89	-0.6596	4.4001	.96	.056
Chestnut oak	.81	.72	-0.7590	6.8966	.80	.110
Northern red oak	.92	.85	-1.1836	10.3264	.94	.061
Other oaks	.90	.80	-0.6081	3.7632	.93	.057
Red maple	.78	.59	-0.6761	3.6106	.53	.159
Yellow-poplar	.96	.91	-0.4939	1.7693	.89	.083
Walnut/ash	.86	.75	-0.3791	1.6353	.65	.126
Other hardwoods	.64	.52	-0.3926	1.7900	.82	.077

Table 5.—Predicted grade distribution of white oak by d.b.h. class.

D.b.h.	Grade 1	Grade 2	Grade 3	Grade 4 and 5
11	--	--	.950	.050
12	--	--	.914	.086
13	--	.184	.724	.092
14	--	.489	.488	.023
15	--	.667	.308	.025
16	.275	.491	.196	.038
17	.476	.343	.132	.049
18	.535	.312	.098	.055
19	.552	.311	.080	.057
20	.558	.313	.070	.059
21	.552	.309	.065	.074
22	.537	.300	.063	.100
23	.523	.290	.061	.126
24	.508	.281	.061	.150
25	.494	.271	.060	.175
26	.480	.261	.060	.199
27	.465	.252	.060	.223

Table 6.—Percentage of sawtimber trees with grade 1 or 2 butt log, by species and d.b.h. class.

D.b.h.	White oak	Chestnut oak	Northern red oak	Other oak	Yellow-poplar	Walnut ash	Red maple	Other hardwoods
13	18	18	34	19	25	22	20	12
14	49	44	67	47	50	48	40	30
15	67	58	81	63	64	61	49	42
16	77	65	86	71	74	68	54	49
17	82	68	88	75	80	72	56	54
18	85	70	89	77	85	74	58	56
19	86	71	90	78	88	75	58	58
20	87	72	90	78	90	76	59	59
21	86	70	88	76	89	72	59	58
22	84	65	84	72	88	65	58	54
23	81	61	79	68	86	58	58	50
24	79	56	75	63	84	51	57	46
25	76	52	71	59	83	45	57	43

Our sample data on tree quality represent a much broader spectrum of various forest conditions than was reported in earlier studies. Because of this diversity in ownerships, management practices, and forest conditions, our sample quality data should represent average stand conditions for the Pennsylvania upland oak type. Although our sample included data on some of the same species discussed in earlier studies, no comparisons were attempted because both geographic areas and forest conditions differed. It should be noted that the quality of trees in individual stands may vary widely from the average values reported here because of the great variation in forest conditions sampled.

Our grade distributions also differ from earlier results in that beyond a d.b.h. of 20 inches all species show a decline in the proportion of grade 1 and 2 trees. Many of our sample stands have been cut indiscriminately over the years, leaving culls or low-value trees to occupy the lands.

The 31-percent drop in grade 1 or 2 walnut or ash trees between 20 and 25 inches may reflect the fact that high-value, high-quality trees that are more than 20 inches in d.b.h. are more likely to be cut.

The computed percentages by grade and d.b.h. class for each of the various species are useful when estimating stand or tree values for typical stands where specific grade information is lacking. In broad regional economic analyses, grade distributions are helpful in determining current and projected timber resources by species, quality class, and value. When grade distributions are used in conjunction with growth simulators, more precise economic evaluations are possible for alternative management strategies.

The equations presented here provide a means of building grade predictions into growth simulators for eight species groups. Thus, as the simulator grows a tree in height, d.b.h., and volume, we can change the grade over time with these equations. For example, if we have a 14-inch grade 3 white oak, what is the probability of it becoming grade 1 or grade 2 when it reaches 16 inches? Using Table 5 or the equations, we can determine that about 29 percent of such grade 3 trees will become grades 1 or 2 by the time they grow to 16 inches (.488-.196=.292).

The grade distributions by d.b.h. class (Table 5) should be an important reminder that quality and, therefore, value are closely linked to size. Less than 50 percent of 14-inch white oak trees are expected to be better than grade 3. If these trees grow 4 more inches, then 85 percent should qualify as grade 1 or 2. Goho and Wysor (1980) showed that most logs more than 17 inches in scaling diameter that were delivered to sawmills were grade 1. However, they added that the most frequent scaling diameter of logs delivered at their sample sawmills in West Virginia was only 12 to 14 inches; thus, these logs were of low quality. Since the stumpage price of grade 1 or 2 trees is several times that of grade 3 trees, managers should look at the economics of growing their small sawtimber trees a few more years so that more would qualify as grade 1 or 2.

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