Accuracy of Tree Grade Projections for Five Appalachian Hardwood Species

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ABSTRACT

The potential value increase of individual trees is an important factor in planning effective forest management strategies. Similar to other investments, trees with high potential value increase are retained and allowed to grow, and those with relatively low potential value increase are harvested so that the proceeds may earn a higher rate of return elsewhere. Tree grade is used to assess the quality and value of wood within a tree; thus, projecting tree grade is an integral part of estimating potential value increase. This study measured the accuracy of projected tree grades over a period of 12–15 years for 588 black cherry, 404 northern red oak, 167 red maple, 191 white and chestnut oaks, and 450 yellow-poplar sawtimber trees in both thinned and unthinned stands. Projected grade was based on surface defects and percent volume deductions for sweep, crook, and rot at the time of the projection with the assumption that the threshold dbh for the highest possible grade would be reached in the future. This approach allows the forest manager to make grade projections based on what is visible and measurable on the tree, even if the tree is currently too small to qualify for higher grades. In general, grade projections were somewhat accurate, with 9% of trees higher than the projected grade, 80% projected correctly, and 11% lower than the projected grade. Trees that had a lower-than-projected grade usually exhibited additional deductions for percent cull volume and/or new epicormic branches. Grade projections were less accurate for larger, higher-quality trees because requirements for the top grade are more constraining and sensitive to changes in butt log characteristics than lower grades. For black cherry and northern red oak, grade projections in thinned stands were less accurate compared with unthinned stands because of resulting logging wounds or new epicormic branches.

Keywords: tree quality, thinning, silviculture, defect, epicormic branches, wood value

Tree quality is an important factor that influences decisions made by landowners, forest managers, and the forest products industry. Tree quality often is measured by assigning tree grades (1, 2, 3, or below grade) using guidelines established by the US Forest Service (Table 1). Tree grades incorporate tree size, visible surface defects, and volume-reducing defects such as sweep, crook, and rot. These factors directly influence the quality and quantity of lumber contained in the tree (Hanks 1976). Data from periodic inventories have been used to estimate tree grade distributions in uncut stands (Ernst and Marquis 1979, Myers et al. 1986, Prestemon 1998) and potential tree grade distributions for economically important hardwoods (Belli et al. 1993, Yaussy 1993). Projected tree grade is a useful estimate of a tree's future quality and market value thus serving to indicate a tree's potential increase in value. For financial objectives, a manager might retain trees that promise higher rates of return and harvest those with lower rates so that the proceeds may be shifted to better investments elsewhere. This approach requires a relatively simple means to project tree grade and an estimate of the accuracy of tree grade projections. Despite the usefulness of projected tree grades, there have been no known studies that quantify the accuracy of projected grades based on rules presented by Hanks (1976) for important Appalachian hardwoods.

The first objective of this study was to determine the accuracy of tree grade projections for five Appalachian hardwood species. The second objective was to determine whether grade projection accuracy was associated with silvicultural treatment, initial size class, projected grade, or species group.

Study Sites

Tree grade data were collected at two sites. The first site is located on the Monongahela National Forest (MNF) within northern Pocahontas County, West Virginia (38°41′N, 79°43′W). Elevation averages 3,500 ft on a southwest aspect. The landforms include mostly convex ridges and hillsides where slopes range from 5 to 20%. The soil series is consistent throughout the study site, described as Mandy channery silt loam (loamy-skeletal, mixed, frigid Typic Dystrochrept; USDA Soil Conservation Service [1994]). Soil depth within the study plots ranged from 22 to 28 in. Site index for black cherry is 75 ft at base age 50 years. These stands originated after heavy timber cutting of the original forests in the 1920s. When this study began, the overstory was predominantly 60-year-old, second-growth black cherry (*Prunus serotina* Ehrh.), with some white ash (*Fraxinus americana* L.) and red maple (*Acer rubrum* L.). In 1982, approximately 30 ac of the study site were commercially thinned to various levels of residual stand density according to Roach (1977), and 12 ac of the site were used as uncut controls. The design and

Received January 25, 2007; accepted May 18, 2007.

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Table 1. General summary of US Forest Service tree grading rules (Hanks 1976).[a]

Tree grade	dbh[b] (in.)	Maximum cull deduction	Defect-free section on grading face: Combined length (ft)	Minimum length per section (ft)	Number of sections
3	≥9.6	50[c]	6	3	Unlimited
2	≥12.6	9[d]	8	5	1 or 2
1	≥15.6	9	10	7	1 or 2

[a] Tree grade is defined by the second worst grading face on the butt 16-ft log. See Hanks (1976) for a complete explanation of the grade rules.
[b] The dbh thresholds of 9.6 , 12.6, and 15.6 in. represent the lower limits of the 10, 13, and 16 in. diameter classes, respectively.
[c] Trees with >50% cull deduction are considered below grade.
[d] Up to 15% deduction for crook and sweep or 40% total cull deduction are allowed in grade 2 if the tree otherwise has the size and grading faces to qualify as grade 1.

results of the thinning trial on wood volume growth were reported by Miller (1997).

The second study site is located on the West Virginia University (WVU) Forest in northern Monongalia and Preston Counties (40°00′N, 79°50′W). Elevation ranges from 1,600 to 2,300 ft with slopes ranging from 5 to 40% on hill slopes and ridgetops. Soils are moderately to extremely well drained, described as Dekalb stony sandy loam (loamy-skeletal, mixed mesic, Typic Dystrochrept; USDA Soil Conservation Service [1982]). Site indices for northern red oak (*Quercus rubra* L.) and yellow-poplar (*Liriodendron tulipifera* L.) averaged 80 and 90 ft, respectively. Similar to most stands in the region, the WVU study site has undergone many disturbances within the past 150 years: periodic partial cuttings, fires, chestnut blight, and gypsy moth defoliation. On mesic lower slopes the current forest consists of yellow-poplar, northern red oak, and black cherry, with lesser amounts of red maple, sweet birch (*Betula lenta* L.), and white oak (*Quercus alba* L.). Drier ridgetops are dominated by chestnut oak (*Quercus montana* L.) and scarlet oak (*Quercus coccinea* Muenchh.), with smaller amounts of red maple. Tree grade data at the WVU site were collected from stands that were part of a larger study established to measure the effect of thinning on gypsy moth defoliation-induced mortality. In 1990, five 60-year-old stands were thinned to 60% relative density according to Gingrich (1967), with an emphasis on removing low vigor oaks that are susceptible to gypsy moth defoliation, with similar adjacent areas observed as uncut controls. Details of the thinning trial and its effect on gypsy moth dynamics were reported by Liebhold et al. (1998).

Field Measurements

Tree grade is based on three major characteristics of the butt log, which is measured from 1 to 17 ft above the ground (Hanks 1976). These characteristics include log diameter, length and number of defect-free sections on the log surface, and percent volume deductions for sweep, crook, and rot within the log. The dbh is used as a surrogate for log diameter in a standing tree, and trees meet the size specifications for better grades as they grow into minimum dbh thresholds for each grade (Table 1). Projected tree grade was determined by considering two of the three major grading factors: the length and number of defect-free sections, and the percent volume deductions for sweep, crook, and rot within the log. It was assumed that all trees would continue to grow and eventually reach the minimum dbh requirements for grade 1. In projecting grade, each tree was evaluated in terms of the following question: "Based on current visible surface defects and current estimates of percent volume deductions, what is the highest grade possible once all dbh thresholds are met?" Such a question is important for forest managers as they make "cut or leave" decisions when planning a harvest operation. Trees destined for higher grades offer competitive earnings if retained, while those with lower expectations are candidates for removal. Earlier studies used a similar approach to projecting tree quality based on visible surface defects and volume deductions while subject trees were still smaller than 16 in. dbh (Sonderman 1979, 1987; Sonderman and Rast 1987, 1988). However, these studies used provisional grade specifications (Boyce and Carpenter 1968), not US Forest Service tree grades (Hanks 1976) as reported here.

Projected tree grades were later reconciled with actual tree grades for 588 black cherry trees on the MNF site and 404 northern red oak, 167 red maple, 191 white and chestnut oak, and 450 yellow-poplar trees on the WVU site. For both projected and actual tree grades, the recorded measurements also included dbh, number of epicormic and dead branches, wounds, and percent volume deductions for sweep, crook, and rot on each tree. Such information provided a basis for explaining discrepancies between projected and actual grades. Data were collected in both thinned and unthinned plots on the study sites. At the WVU site, projected grade was determined before thinning and actual grade was determined 12 years later. At the MNF site, projected grade was determined 3 years after thinning and actual grade was determined 15 years later. All trees in the data set had grown large enough to be eligible for the projected grade; thus, only changes in visible surface defects and/or percent volume deductions could affect the accuracy of projections.

Although tree grades were assessed many years apart, field personnel were trained to apply tree grade rules consistently and to avoid bias in the grading procedures. Training and supervision were provided by experienced personnel who had installed both study sites, determined the initial and projected tree grades, and then conducted quality control checks to assure that the grade rules were applied consistently in the 12- to 15-year remeasurements.

Data Analysis

The comparison of projected versus actual tree grades had three possible outcomes: tree grade was higher than projected (higher), the same as projected (correct), or lower than projected (lower). Tree counts and the observed percent distribution for the three possible grade outcomes were tabulated by species and treatment (Table 2); species, treatment, and initial size class (Table 3); and species, treatment, and projected grade (Table 4). Pearson chi-square tests were performed on tree counts by grade outcome categories to determine if the grade outcomes were independent of treatment for a given species (Table 2), independent of initial size class for a given species and treatment (Table 3), or independent of projected grade for a given species and treatment (Table 4). To simplify the analyses, tree counts with higher or correct outcomes were combined to compute observed and expected values in each cell of the chi-square table. Although a grade outcome that is correct or higher than projected might be acceptable, a grade outcome lower than projected was

Table 2. Accuracy of projected tree grades by treatment for each species.

Species	Treatment	Actual versus projected grade: Higher (%)	Correct[a] (%)	Lower (%)	n	df	Chi-square	P-value[b]
Black cherry	Thinned	11	72	17*	445	1	11.3	<0.01
	Control	7	87	6*	143			
Northern red oak	Thinned	10	79	11*	174	1	7.5	<0.01
	Control	10	86	4*	230			
Red maple	Thinned	12	83	5	82	1	1.9	0.17
	Control	11	78	11	85			
White oak group	Thinned	10	80	10	81	1	0.2	0.67
	Control	4	84	12	110			
Yellow-poplar	Thinned	9	80	11	203	1	0.3	0.57
	Control	5	82	13	247			

[a] Grade projection outcomes were grouped for testing: correct and higher versus lower.
[b] When the value of $P < 0.05$, asterisks denote values contributing most to the chi-square statistic.
df, Degrees of freedom.

Table 3. Accuracy of projected tree grades by initial size class for each species and treatment.

Species	Treatment	Initial dbh (in.)[a]	Actual versus projected grade: Higher (%)	Correct[b] (%)	Lower (%)	n	df	Chi-square	P-value[c]
Black cherry	Thinned	≥15.6	24	66	10	68	3	2.9	0.41
		12.6–15.5	14	67	19	209			
		9.6–12.5	4	79	17	156			
		<9.6	0	83	17	12			
	Control	≥15.6	13	79	8	24	—	—	—[d]
		12.6–15.5	10	87	3	68			
		9.6–12.5	0	92	8	49			
Northern red oak	Thinned	≥15.6	0	84	16	49	3	4.7	0.20
		12.6–15.5	6	81	13	63			
		9.6–12.5	16	77	7	43			
		<9.6	32	68	0	19			
	Control	≥15.6	8	87	5	62	—	—	—[d]
		12.6–15.5	10	84	6	67			
		9.6–12.5	7	91	2	60			
		<9.6	17	81	2	41			
Red maple	All	12.6–15.5	13	87	0	30	—	—	—[d]
		9.6–12.5	6	79	15	76			
		<9.6	19	79	2	61			
White oak group	All	≥15.6	3	73	24*	34	3	12.5	<0.01
		12.6–15.5	0	80	20*	30			
		9.6–12.5	6	87	7	84			
		<9.6	16	82	2*	43			
Yellow-poplar	All	≥15.6	6	79	15*	218	3	8.0	0.04
		12.6–15.5	8	80	12	156			
		9.6–12.5	10	87	3*	62			
		<9.6	7	93	0*	14			

[a] The dbh categories represent the minimum dbh to qualify for grade 1, 2, 3, and below grade, respectively. Percentages not presented are caused by small sample sizes: black cherry control, < 9.6 dbh (n = 2); red maple, >15.6 dbh (n = 11).
[b] Grade projection outcomes were grouped for testing: correct and higher versus lower.
[c] When the value of $P < 0.05$, asterisks denote values contributing most to the chi-square statistic.
[d] These categories did not meet the requirements for chi-square testing.
df, Degrees of freedom.

considered a more serious concern because it might represent an unforeseen loss of value to the landowner. A chi-square test was performed only if the data met each of the following requirements: (1) no expected values were less than 1; (2) no more than one expected value was less than 2; (3) greater than 50% of expected values were greater than or equal to 5 (Snedecor and Cochran 1989). When chi-square tests were significant ($P < 0.05$), asterisks were placed on values in the tables that contributed most to the chi-square statistic, based on examination of standardized deviates (SYSTAT 1992). When the combined higher and correct count was statistically significant, asterisks were placed on both categories in the accompanying table for added clarity. Tree counts in some cells of the chi-square tables were not suitable for statistical testing, as indicated by footnotes, but they were included for completeness.

Results and Discussion

Tree grade projections using the method described here were somewhat accurate. When all 1,800 trees were considered together, 9% of trees were higher than the projected grade, 80% were projected correctly, and 11% were lower than the projected grade (Table 2). For black cherry and northern red oak, thinning led to a greater percentage of trees with lower-than-projected grade outcomes compared with controls. The accuracy of tree grade projections did not differ by treatment for red maple, white and chestnut oak, or yellow-poplar. The dbh growth in thinned stands exceeded

Table 4. Accuracy of projected tree grades by projected grade for each species and treatment.

Species	Treatment	Projected grade[a]	Actual versus projected grade: Higher (%)	Correct[b] (%)	Lower (%)	n	df	Chi-square	P-value[c]
Black Cherry	Thinned	1	NA	84	16	55	2	3.7	0.16
		2	12	70	18	345			
		3	23	70	7	44			
	Control	1[d]	NA	100	0	12	1	0.2	0.69
		2	9	84	7	107			
		3	0	96	4	23			
Northern red oak	Thinned	1	NA	77	23*	56	2	15.9	<0.01
		2	0	83	17	36			
		3	14*	86*	0*	64			
		below grade[d]	44	56	NA	18			
	Control	1	NA	81	19*	32	2	18.9	<0.01
		2	5	91	4	56			
		3	6	93	1*	114			
		below grade[d]	46	54	NA	28			
Red maple	All	2	0	85	15	26	1	0.5	0.46
		3	6	84	10	82			
		below grade[d]	24	76	NA	59			
White oak group	All	1	NA	79	21	14	2	17.8	<0.01
		2	0*	68*	32*	38			
		3	3	92	5*	109			
		below grade[d]	33	67	NA	30			
Yellow-poplar	All	1	NA	81	19*	173	2	21.1	<0.01
		2	5	79	16	108			
		3	15	83	2*	138			
		below grade[d]	19	81	NA	31			

[a] Percentages were not presented for the following groups because of small sample sizes: black cherry below grade, thinned ($n = 1$) and control ($n = 1$); red maple grade 1 ($n = 3$).
[b] Grade projection outcomes were grouped for testing: correct and higher versus lower.
[c] When the value of $P < 0.05$, asterisks denote values contributing most to the chi-square statistic.
[d] These categories were not included in statistical tests.
df, Degrees of freedom; NA, not applicable. The outcomes marked are not possible.

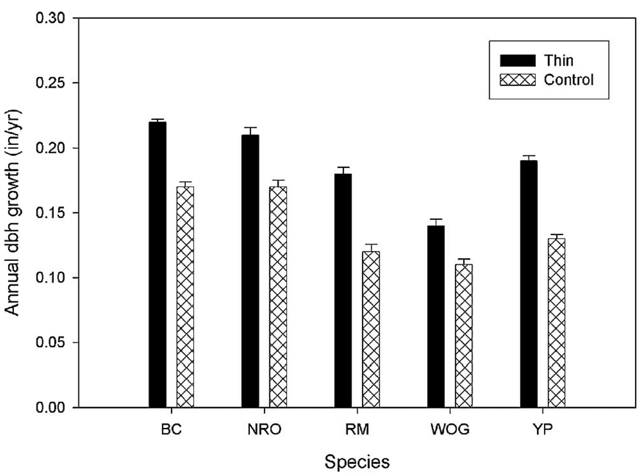

Figure 1. Annual dbh growth with standard error shown above each bar for graded trees in thinned and unthinned stands. Initial dbh averaged 12.7 in. for black cherry (BC), 13.9 in. for northern red oak (NRO), 11.3 in. for red maple (RM), 12.8 for the white oak group (WOG), and 15.6 in. for yellow-poplar (YP).

that observed in unthinned stands for all species (Figure 1). However, the data set was limited to trees in which their dbh had reached the required threshold dbh for all projected grades. Although the subject trees had various growth rates, the accuracy of grade projections reported here was affected only by unforeseen changes in surface defects and precent volume deductions for sweep, crook, and rot. Thinning was the only major disturbance on the study sites during the study period; no additional natural disturbances such as windthrow, ice storms, or insect defoliations were observed. The changes in tree characteristics that affected tree grade were caused by changes in stand density or logging activities in the thinned stands, overcrowding in the unthinned stands, or inherent variability within or among the species groups.

Black Cherry

A closer look at black cherry indicated that thinning nearly tripled the occurrence of lower-than-projected tree grades, 17% in thinned stands compared with only 6% in unthinned stands (Table 2). In a related analysis, 11% of trees exhibited reduced grade in thinned stands, compared with only 3% in unthinned stands over a 15-year period (Miller et al. 2003). New epicormic branches accounted for 83% of the lower-than-projected grades in the unthinned stands as relatively high stand density caused low vigor trees with weak crowns to develop branches on the butt log. About 70% of grade shortfalls for black cherry in thinned stands also developed new epicormic branches because of exposure, and 30% of lower-than-predicted grades resulted from increased volume deduction for rot because of decaying logging wounds. The accuracy of grade predictions for black cherry was not significantly associated with initial size class in thinned stands (Table 3) or projected grade for either treatment (Table 4).

Northern Red Oak

Grade projections for northern red oak also were significantly associated with treatment. Again, thinning nearly tripled the occurrence of trees with lower-than-projected grades, 11% in thinned stands compared with only 4% in unthinned stands (Table 2). In thinned stands, increased volume deduction for rot accounted for 60% of cases with lower-than-projected grade, and 40% was caused by new epicormic branches. Average volume deduction for cull in thinned stands increased by 2% for trees with correct or higher-than-projected grades compared with 9% for trees with lower-than-projected grade. In unthinned stands, new epicormic branches accounted for 70% of grade shortfalls. The accuracy of grade projections for northern red oak was not significantly associated with initial size class (Table 3), but accuracy differed by projected grade in both thinned and unthinned stands. In both treatments, about 20% of trees projected to be grade 1 failed to reach grade 1 after 12 years, and accuracy for lower-than-projected grades was much greater (Table 4). About two-thirds of the grade shortfalls in this category for northern red oak were caused by increased volume deduction for rot, and one-third was caused by new epicormic branches. In either case, the rules for grade 1 are relatively strict compared with lower grades, so even a few new epicormic branches or a slight increase in volume deductions can preclude advancement to grade 1, while lower grades would not be affected.

Red Maple

The accuracy of grade projections for red maple was not significantly associated with thinning treatment (Table 2), initial size class (Table 3), or projected grade (Table 4). Data on initial size class and projected grade indicated that red maple was relatively small and exhibited lower quality compared with other canopy trees on the WVU site. In fact, few red maples were good candidates as residual trees in the applied thinning prescriptions (Miller et al. 2003). Of the 167 red maples observed in this study, about 15% were projected to reach grade 2, and none were projected to reach grade 1. The main reason for poor quality was the presence of branches and surface defects that are common on red maple (Walters and Yawney 1990). In general, less than 10% of red maples had lower-than-projected grades after 12 years (Table 2). Only 12 red maples in the data set failed to reach their projected grade, with nearly all of those caused by new epicormic branches. The grade rules for lower grade trees are relatively lenient, so a few additional defects can be tolerated without further lowering the grade.

White and Chestnut Oak

Tree grade projections for the white oak group were not significantly associated with thinning treatment (Table 2), but they did differ by initial size class (Table 3) and projected grade (Table 4). Differences associated with initial size class and projected grade were consistent, showing less accurate projections for larger diameter and higher grade trees, compared with smaller and lower grade trees. A greater percentage of trees 12.6 in. dbh or more had a lower-than-projected grade (20–24%), compared with trees less than 12.6 dbh (2–7%; Table 3). Similarly, trees projected to reach grades 1 and 2 were more likely to fall short of expectations (21–32%) compared with trees projected to reach grade 3 (5%; Table 4). Again, the rules for higher grades are relatively strict, so larger, higher-quality trees can fail to reach their projected grade with only modest changes in tree characteristics compared with low grade trees. In both thinned and unthinned stands, over 70% of trees that failed to reach their projected grade had developed new epicormic branches during the study period. Trimble (1975) ranked white oaks as the most susceptible species among central Appalachian hardwoods to develop epicormic branches.

Yellow-Poplar

The trends for yellow-poplar were similar to those observed for white and chestnut oaks. The accuracy of grade projections was not significantly associated with thinning treatment (Table 2), but grade projections were less reliable for trees in larger initial sized classes and higher projected grade. For yellow-poplar 12.6 in. dbh or more, about 14% of trees had lower-than-projected grade, compared with only 2% of trees in which initial dbh was less than 12.6 in. dbh (Table 3). Similarly, 18% of trees projected to reach grade 2 or better had lower-than-projected grade, and only 3% of trees projected to reach grade 3 fell short of expectations (Table 4). Overall, however, nearly 90% of yellow-poplar trees reached their projected grade. Of the few trees that had lower-than-projected grades, two-thirds were caused by new epicormic branches and one-third was caused by increased volume deduction for rot. Artist's fungus (*Ganoderma applanatum*) had developed on many trees in both treatments during the study period, thus indicating that cull deductions on affected trees were increasing. The rules for grade 1 allow 9% or less volume deduction for sweep, crook, and rot, whereas the rules for grades 2 and 3 allow a much greater deduction (Table 1). Even a relatively small increase in percent volume deduction for rot during the 12-year study period grade prevented some trees from reaching their projected grade 1, but the same change would not affect trees projected to be grades 2 or 3.

Comparisons among Species

The results presented in Tables 2–4 focused on the accuracy of grade projections within species groups, and comparisons among species groups by treatment, initial size classes, and projected grade are presented in Table 5. Each row compares the accuracy of grade projection among all species using the variable listed in the first column. For example, the first row illustrates the Pearson chi-square test of association between grade projection outcomes (higher and correct versus lower) and species (black cherry, northern red oak, red maple, white oak group, and yellow-poplar) in thinned stands. Note that the degrees of freedom for this statistic are defined by $(r - 1) \times (c - 1)$, where r is the number of rows (two outcomes) and c is the number of columns (five species) in the chi-square table. This comparison poses the question, "Is there a difference in accuracy of grade projection among the five species in thinned stands?" The chi-square statistic indicates that there is a significant association between projection accuracy and species ($P = 0.01$), and the asterisks indicate that black cherry and red maple contribute most to the chi-square statistic. Referring back to Table 2, 17% of black cherry had lower-than-projected grades compared with only 5% for red maple in thinned stands. The data on black cherry and red maple in this analysis were acquired from different growing sites, so their response to thinning is not directly comparable. However, the results provide a useful insight for forest managers who are concerned about the effects of thinning on tree quality. On one extreme, the projected grade of high-quality black cherry was very sensitive to thinning. In this study, one of every six black cherry in thinned stands failed to reach its projected grade because of logging wounds and new epicormic branches (Table 2). Black cherry is relatively susceptible to epicormic branching after a logging disturbance (Trimble 1975), and relatively strict grading rules for grade 1 do not allow for many additional defects. On the other extreme, the red maple began with much lower grade expectations and lower risk of new epicormic branches (Trimble 1975). Only 1 of every 20 red maple in thinned stands failed to achieve its projected grade (Table 2).

Table 5. Accuracy of projected tree grade by species for each treatment, initial dbh, and projected grade.

					Species and treatment						
					BC		NRO		RM	WOG	YP
Test[a]	n	df	Chi-square	P-value[b]	Thinned	Control	Thinned	Control	All	All	All
Thinned	985	4	12.8	0.01	*		—		*	—	—
Control	815	4	14.9	<0.01	—		*		—	—	*
≥15.6 in. dbh	455	5	8.8	0.12	—	—	—	—	NT[c]	—	—
12.6–15.5	623	6	22.3	<0.01	*	—	*	—	*	*	—
9.6–12.5	521	6	18.7	<0.01	*	—	—	*	*	—	*
<9.6[c]	190	—	—	—	—	—	—	—	—	—	—
Grade 1	342	5	3.8	0.58	—	—	—	—	NT	—	—
Grade 2	716	6	22.2	<0.01	—	*	—	*	—	*	—
Grade 3	548	5	16.7	<0.01	—	NT	*	*	*	—	—
Below grade[c]	168	—	—	—	—	—	—	—	—	—	—

[a] Grade projection outcomes were grouped for testing: correct and higher versus lower.
[b] When the value of $P < 0.05$, asterisks denote values contributing most to the chi-square statistic.
[c] NT, not tested. These species/test categories did not meet the requirements for chi-square testing: red maple ≥15.6 dbh (n = 11), red maple grade 1 (n = 3), black cherry grade 3 control (n = 23), dbh < 9.6 dbh, and below grade.
df, Degrees of freedom; BC, black cherry; NRO, northern red oak; RM, red maple; WOG, white oak group; YP, yellow-poplar.

The accuracy of grade projections was also associated with species in control stands (Table 5), with 13% of yellow-poplar with lower-than-projected grades compared with only 4% of northern red oak (Table 2). Both species were found on the WVU site, but they exhibited different responses to full stocking in unthinned stands during the study period. Bole characteristics of northern red oak in unthinned stands were relatively stable during the study period, so nearly all trees (96%) reached their projected grade. For yellow-poplar, however, several trees developed new epicormic branches on the upper butt log and/or rot-inducing fungal infections near stump height, probably because of increased stress from overcrowding.

The analyses also indicated a significant association between accuracy of grade projections and species for certain initial size classes (Table 5). The most notable association with initial size class occurred for trees 12.6–15.5 in. dbh. Red maple seemed to differ from all other species, probably because of its poor initial quality and not necessarily because of real differences in its subsequent response over time. In fact, no red maples in any size class were projected to exceed grade 2. With relatively lenient grade rules governing the lower grades associated with red maple, all red maples in this size class met or exceeded their projected grades (Table 3). All other species exhibited some grade shortfalls, thus resulting in significantly lower projection accuracy compared with red maple. In a related result, grade projection accuracy was not associated with species for trees projected to reach grade 1 (P = 0.58; Table 5), thus excluding red maple from this comparison. Finally, there was a significant association between prediction accuracy and species for projected grades 2 and 3. For trees projected to be grade 2, 32% of the white oak group had lower-than-projected grades, with much greater accuracy for all other species (Table 4). Lower-quality white oaks with numerous epicormic branches have a tendency to develop many additional branches as the stand ages, particularly after thinning (Sonderman 1984, Sonderman and Rast 1988). Such trees are prone to develop new branches because stress from overcrowding or increased exposure to sunlight after thinning interferes with the distribution of auxins that inhibit epicormic branch emergence (Ward 1966, Bowersox and Ward 1968). Forest managers should exercise caution in projecting grades of white oaks, particularly those with evidence of epicormic branching in the past.

Conclusions

Any system of projecting the future quality of standing trees has some inherent variability. Although some bole characteristics such as current surface defects are readily apparent or can easily be measured, current trends can change over time, depending on the species and its response to disturbance. Even in the absence of any major disturbance, up to 13% of trees monitored in this study failed to reach their projected grade (Table 2). In addition, underestimating internal volume deductions for rot or the advent of logging wounds or new epicormic branches as result of thinning can complicate matters in projecting tree grade over 10 years or more. This report sheds some light on the accuracy of those projections based on empirical observations of projected and actual tree grade on 1,800 trees over 12–15 years.

Grade projections for black cherry and northern red oak were less accurate in thinned stands, but this difference was not apparent in other species. A related study found that grade distributions of black cherry and northern red oak varied by both initial grade and thinning treatment (Miller et al. 2003). Grade projections for large diameter and higher-quality trees generally were less accurate than those for smaller or lower grade trees. In most cases, an unforeseen increase in percent volume deduction for rot or the development of a few epicormic branches led to a lower-than-projected grade. Maximum cull deduction for grade 1 is relatively limiting (9% or less), so even a slight increase in rot can lead to lower-than-projected grade. Similarly, even one or two unforeseen surface defects can lead to a reduction in grade if they reduce the length of defect-free surfaces on the bole. In light of these conditions, the following findings may be helpful to forest managers who use projected tree grade in management decisions.

- Considering all 1,800 trees observed over 12–15 years, 9% were higher than projected grade, 80% were correctly projected, and 11% were lower than projected.
- Grade projections were less accurate for black cherry and northern red oak in thinned stands compared with controls (Table 2).
- Grade projections were less accurate for larger diameter white and chestnut oaks and yellow-poplar compared with smaller diameter trees (Table 3).

- Grade projections were less accurate for northern red oak (thinned and control), white and chestnut oaks, and yellow-poplar projected to reach grade 2 or higher (Table 4).
- The main reason why trees failed to reach their projected grade was the unforeseen development of new epicormic branches.
- Another important reason for grade shortfalls was unforeseen increases in percent volume deduction for rot on existing wounds or new wounds caused by logging. Careful logging practices around residual trees could reduce such damage and improve the accuracy of grade projections in thinned stands.

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