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Quality Response of 29-Year-Old, Even-Aged Central Hardwoods After Thinning

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Abstract

Describes the quality response of a 29-year-old upland hardwood stand grown for 6 years under different levels of residual stand density. Both the number of defects per square foot of surface area and the number of epicormic branches changed under different stocking levels. The results suggest that the effect of stocking on potential stem quality of certain species may be substantial even after a few years of treatment.

Introduction

In the last decade, much research has been done on diameter and height growth responses associated with various silvicultural treatments designed to regulate density of even-aged upland hardwood stands (Hilt 1979). But there has been little research on comparing the response of quality-related tree characteristics to those treatments. Stem quality of trees can be changed, sometimes adversely, by regulating the stand density. Recent studies (Dale and Sonderman 1983) have shown that live and dead branches on young white oak trees grown under different density levels increased the most on the lowest density plots. Sonderman (1983) found that the number of defects per square foot of surface area for 80-year-old white oaks increased significantly at the heaviest thinning level. Godman (1968) showed that after 16 years, heavy stem release of sugar maple shortened the average clear bole length. Godman and Books (1971) also showed that stem quality improvement in northern hardwoods was related to residual stand density.

In this study, 6-year changes in individual limb-related characteristics for several species have been summarized in relation to different levels of residual stand density. Limb-related defects are the greatest deterrent to stem quality and the most important consideration in managing a stand for maximum quality development. Hardwood quality research has shown that potential stem quality also is affected by species, age, crown class, and crown ratio. However, limb-related defects and epicormic branches still are the bole characteristics that are affected most by thinning treatments, and they should be considered simultaneously when interpreting results.

The Stand

The trees selected for this study are located on the Vinton Furnace Experimental Forest in southern Ohio. The stand originated on an 8-acre demonstration plot after a clearcut in 1954. The area was originally a mature, even-aged, fully stocked, mixed oak stand with an average site index of 64. The stand was divided into twenty-two 1/10 acre-plots with ½-chain isolation strips around each treatment area. In 1976, the basal area of the young stand was 93 square feet before thinning. Thinning treatments of 30, 50, and 70 percent stocking were applied to groups of plots. Five plots were used as a control. After treatment, the stand was composed of aspen, red maple, mixed oaks, yellow-poplar, black cherry, and hickory. A total of 338 trees are included in the study. Four species groups were used in the analyses (Table 1). A miscellaneous group, which included black cherry and hickory, accounted for only a few trees and was not included in the analyses.

Table 1.—Number of trees used in study, by species group and stocking level

Species group	Stocking level (%)			
	30	50	70	Control
Oak	19	22	24	16
Yellow-poplar	15	3	19	8
Red maple	29	9	21	46
Aspen	7	34	42	24

Methods

A quality classification system (Sonderman and Brisbin 1978) was used to systematically measure the external characteristics of all trees 3.6 inches or larger in diameter at breast height (d.b.h.). All measurements, including limb-related measurements taken on the first and second 8-foot section of each tree, were made before thinning in the spring of 1976 and in 1982. Limb size had to be at least 0.3 inch in diameter to be measured.

Tree quality characteristics (Sonderman 1979) recorded were:

- d.b.h.
- total height
- crown ratio
- number of live limbs on the 1st and 2nd 8-foot section
- number of dead limbs on the 1st and 2nd 8-foot section
- diameter of the largest live limb on the 1st and 2nd 8-foot section
- diameter of the largest dead limb on the 1st and 2nd 8-foot section
- number of epicormic branches on the 1st and 2nd 8-foot section

These characteristics were summarized by species, plot, and treatments; limb-related variables were analyzed by covariance analysis. The value of the variable at initial time was used as the covariate.

Results and Discussion

Diameter Growth

The effect of stocking on diameter growth over the 6-year period is evident. Mean diameter growth of sample trees in the 30 percent stocking plots was almost twice as much as on the controls (Table 2). Hilt (1979) reported similar trends in diameter growth in relation to stocking from a much larger data base representing the largest trees. Aspen and yellow-poplar had the highest diameter growth in all treatments. Red maple was next and the oaks had the slowest growth. In the control, the oaks had the least diameter growth of all species compared.

Height Growth

The effect of stocking on height growth (Table 2) follows a different pattern than diameter growth. Trees grown at levels of stocking where crowding of stems occurs tend to have greater height growth than diameter growth (Toumey and Korstian 1947). Maximum height growth of all species combined occurred between 50 and 70 percent stocking and averaged slightly more than 2 feet a year from 1976 to 1982. The trend was similar for individual species. The 30 percent plots and the control plots had the least overall change except for aspen. In the control, aspen grew 3 times faster than other species.

Crown Ratio

Crown ratio is the ratio of live crown length to total tree height. Changes in crown ratio after 6 years of thinning treatments are shown in Table 2. For all species combined there was a reduction of crown ratio in all treatments except for the 30 percent treatment. The increase in crown ratio was caused by the open conditions created by heavy thinning. Opening a stand provides additional growing space and light needed to develop epicormic branches and promote the development of live branches. This contributes to a downward extension of the crown and results in an increase in crown ratio.

Looking at the species individually, crown ratios for yellow-poplar increased nearly twice as much as other species in the 30 percent plots. Most species increased in crown ratio in the 30 percent plots and decreased in the control. In the control after 6 years, aspen changed in crown ratio only by 0.3 percent. Red maple, which had the most uniform change in crown ratios, was affected the least by treatment.

The 30 percent treatment, regardless of species, showed significantly greater crown ratio than the other treatments ($P < .005$). However, within the same treatment there was no significant difference in crown ratio between oaks and all species combined.

Table 2.—Summary of average tree characteristics in 1976 and 1982, by species group and stocking level

Species group	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	D.b.h. (Inches)							
Oak	6.1	8.0	5.2	6.6	5.4	6.5	6.0	6.7
Yellow-poplar	6.5	9.6	4.8	7.9	6.1	8.3	6.5	8.1
Red maple	5.5	8.0	4.9	7.2	5.5	7.2	5.2	6.4
Aspen	7.2	10.2	6.6	9.4	6.9	9.1	6.9	8.9
	Height (Feet)							
Oak	48.9	53.2	41.9	53.4	41.5	51.2	48.9	52.6
Yellow-poplar	54.2	59.4	42.0	63.3	46.5	58.3	59.5	62.4
Red maple	48.6	56.4	42.1	53.0	42.3	56.7	51.5	54.6
Aspen	60.1	66.8	51.8	68.8	52.3	68.4	63.3	72.9
	Crown Ratio (Percent)							
Oak	33.2	39.9	30.9	24.0	28.6	22.5	25.8	27.5
Yellow-poplar	26.6	41.9	43.7	35.6	34.9	25.0	25.0	19.4
Red maple	37.2	45.8	36.7	37.5	38.4	35.2	28.3	25.9
Aspen	41.7	49.3	38.7	31.1	41.3	28.9	29.1	28.8
	Defects/ft² Surface Area (Number)[a]							
Oak	0.235	0.157	0.165	0.091	0.188	0.064	0.094	0.045
Yellow-poplar	.029	.060	.316	.052	.048	.015	.029	—
Red maple	.143	.120	.320	.191	.221	.082	.222	.074
Aspen	.402	.084	.369	.152	.427	.185	.308	.171

[a]Live and dead limbs, butt 16-foot section.

Live and Dead Limb Defects Per Square Foot of Surface Area

Both volume and total surface area of the bole increase as the tree grows. Expansion of the surface area expressed in square feet may show an increasing or decreasing number of defects per square foot of surface area, depending on how many existing and new defects come and go. This is apparent in Table 2, which shows an overall reduction in the number of live and dead limb defects per square foot of surface area in the butt 16-foot section after 6 years.

Aspen showed by far the greatest reduction in number of live and dead limb defects per square foot of surface area over all treatments. Yellow-poplar and red maple showed the least change of live and dead limbs in the 30 percent plots. The oaks displayed a low but uniform reduction in live and dead limb defects per square foot of surface area throughout all treatments.

When combining all species, the number of live and dead limb defects per square foot of surface area in both the 70 percent and control plots each decreased by about 61 percent from 1976 to 1982. However, there was no significant difference among treatments and species.

Comparing limb defects per square foot of surface area for oaks after 6 years, the 30 percent treatment was significantly greater than the other treatments ($P < .13$).

Epicormic Branches

When a tree stem changes, as in sudden full exposure to sunlight,

dormant buds on the stem begin to grow and develop into epicormic branches. These epicormic branches can develop into small live limbs if allowed to grow in sunlight under conditions of open stocking.

In this study, epicormic branches were grouped to facilitate counting on each tree section. The groups are:

0 = No epicormic branches
1 = 1 to 6 epicormic branches
2 = 7+ epicormic branches

Silviculturists attempt to regulate the development of epicormic branches by maintaining different levels of stocking and favoring species that are not prolific epicormic sprouters. Some of the species included (Table 3) are considered prolific epicormic sprouters. For example, red maple showed an increase in the number of epicormic branches in both the butt and the second 8-foot section as the stocking level decreased. Both sections increased the most at the 50 percent level.

At all stocking levels, the oaks increased in the percentage of trees with epicormic branches; the largest increases were in the 50 and 70 percent plots. The oak trees had a somewhat uniform distribution of epicormic branches in both the butt 8-foot section and the second 8-foot section. This was not the case for many of the other species groups.

In the second 8-foot section, the percentage of yellow-poplar trees with epicormic branches increased at all treatment levels. Percentages were 3 times greater than the original figure for the 30, 50, and 70 percent levels. Percentages in the control increased only by one-third.

Table 3.—Percentage of trees with epicormic branches in butt 8-foot and second 8-foot sections 1976–82, by species

Number of epicormic branches	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	70.0	15.8	86.4	4.5	96.0	20.8	73.7	6.3
1-6	20.0	42.1	9.1	27.3	4.0	41.7	21.0	62.5
7+	10.0	42.1	4.5	68.2	—	37.5	5.3	31.2
Second 8-Foot Section								
0	65.0	5.3	86.4	—	92.0	12.5	57.9	—
1-6	15.0	15.8	9.1	9.1	8.0	25.0	31.6	37.5
7+	20.0	78.9	4.5	90.9	—	62.5	10.5	62.5
YELLOW-POPLAR								
Butt 8-Foot Section								
0	75.0	53.3	100.0	—	90.0	52.6	100.0	37.5
1-6	25.0	46.7	—	100.0	10.0	42.1	—	62.5
7+	—	—	—	—	—	5.3	—	—
Second 8-Foot Section								
0	68.7	13.3	100.0	33.3	75.0	26.3	62.5	50.0
1-6	25.0	66.7	—	33.4	25.0	63.2	37.5	37.5
7+	6.3	20.0	—	33.3	—	10.5	—	12.5
RED MAPLE								
Butt 8-Foot Section								
0	90.0	10.4	100.0	11.1	100.0	38.1	82.6	37.0
1-6	10.0	44.8	—	44.4	—	47.6	15.2	56.5
7+	—	44.8	—	44.5	—	14.3	2.2	6.5
Second 8-Foot Section								
0	83.3	6.9	100.0	11.1	100.0	38.1	76.1	23.0
1-6	16.7	37.9	—	33.3	—	33.3	23.9	52.2
7+	—	55.2	—	55.6	—	28.6	—	23.9
ASPEN								
Butt 8-Foot Section								
0	100.0	71.4	76.5	50.0	97.7	69.0	100.0	75.0
1-6	—	28.6	20.6	50.0	2.3	31.0	—	25.0
7+	—	—	2.9	—	—	—	—	—
Second 8-Foot Section								
0	100.0	85.7	88.2	73.5	100.0	69.0	100.0	45.8
1-6	—	14.3	11.8	26.5	—	31.0	—	54.2
7+	—	—	—	—	—	—	—	—

Aspen showed little change in the percentage of trees with epicormic branches in the butt 8-foot section. In the second 8-foot section, the proportion of aspen trees with epicormic branches increased the most in the control plots. On all plots, the number of epicormic branches on the second 8-foot section never exceeded six branches.

Live Limbs

Limbs were classified by number, size, and condition (live or dead). Limb size had to be at least 0.3 inch in diameter to be considered; anything smaller was classified as an epicormic branch. Red maple showed the greatest reaction to treatment (Table 4). In 1982, the percentage of red maple trees with live limbs in the butt 8-foot section was 45 at 30 percent stocking level and 22 at 50 percent stocking. The 70 percent and control plots showed no live limb development in the butt 8-foot section.

In the second 8-foot section, the percentage of red maple trees with live limbs at 30 percent stocking was 10 in 1976 and 86 in 1982. At 50 percent stocking, the percentages were 11 in 1976 and 56 in 1982, the percentage of trees with live limbs decreasing as stocking increased. The number of live limbs ranged from 1 to 16 limbs on the 30 percent plots to only 1 to 2 limbs on the control plots.

In comparing the butt and second 8-foot sections of the tree, the percentage of yellow-poplar trees with live limbs in 1982 was 13 for the butt 8-foot section and 60 for the second 8-foot section. The second 8-foot section usually contains more live limbs.

The oaks responded to the lowest stocking treatment—52 percent of the trees had live limbs in the second 8-foot section in 1982. In 1976, the oaks were free of live limbs in the 30 percent plots. In the 50 and 70 percent plots, the oaks accounted for 32 and 17 percent of the trees with live limbs. The control plots showed little change.

Table 4.—Percentage of trees with live limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Number of live limbs	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	100.0	57.9	100.0	86.4	100.0	95.8	100.0	100.0
1-2	—	42.1	—	13.6	—	4.2	—	—
Second 8-Foot Section								
0	100.0	47.4	100.0	68.2	100.0	83.3	94.7	100.0
1-2	—	36.8	—	27.3	—	16.7	5.3	—
3-4	—	5.3	—	4.3	—	—	—	—
5-8	—	10.5	—	—	—	—	—	—
YELLOW-POPLAR								
Butt 8-Foot Section								
0	100.0	87.7	100.0	100.0	100.0	100.0	100.0	100.0
1-2	—	13.3	—	—	—	—	—	—
Second 8-Foot Section								
0	100.0	40.0	33.3	100.0	85.0	84.2	100.0	100.0
1-2	—	40.0	33.3	—	10.0	10.6	—	—
3-4	—	20.0	33.4	—	—	5.2	—	—
5-8	—	—	—	—	5.0	—	—	—
RED MAPLE								
Butt 8-Foot Section								
0	100.0	55.2	100.0	77.8	100.0	100.0	100.0	100.0
1-2	—	31.0	—	11.1	—	—	—	—
3-4	—	10.4	—	—	—	—	—	—
5-8	—	3.4	—	11.1	—	—	—	—
Second 8-Foot Section								
0	90.0	13.8	88.9	44.5	76.2	42.9	89.1	87.0
1-2	6.7	51.7	—	33.3	14.3	47.6	10.9	13.0
3-4	3.3	20.6	—	—	9.5	9.5	—	—
5-8	—	10.5	11.1	11.1	—	—	—	—
9-16	—	3.4	—	11.1	—	—	—	—
ASPEN								
Butt 8-Foot Section								
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Second 8-Foot Section								
0	100.0	100.0	97.1	100.0	100.0	100.0	100.0	100.0
1-2	—	—	2.9	—	—	—	—	—

One reason for the increase in the percentage and number of trees with live limbs is that many of the small shoots and twigs that were less than 0.3 inch in diameter in 1976 and classified as epicormics grew larger in diameter by 1982 and, therefore were classified as measurable live limbs. Under heavy thinning, most trees with epicormic branches will feather out and develop more epicormic branches. Some of these epicormic branches will become live limbs in a short time.

When comparing all species, treatment differences for live limbs were significant ($P < .001$). In the 30 percent treatment alone, there was an increase of 1.8 live limbs over the control. When separating out only the oak species, treatment differences for live limbs were significant ($P < .089$).

Diameter of Live Limbs

The average diameter of the largest live limbs in 1976 and 1982 is shown in Table 5. The diameter of live limbs was larger on the second 8-foot section than the butt 8-foot section. On the butt 8-foot section, the oaks, yellow-poplars, and red maples increased in live limb size at both the 30 and 50 percent stocking. The 70 percent and control plots showed little change.

In the second 8-foot section, the average size of the largest live limbs appeared somewhat uniform for the 6-year period. Red maple had the greatest change, with limb size decreasing in all treatments except the control. Because the second 8-foot section usually encompasses part of the living crown in the younger trees, it receives more light than the lower bole section. Consequently, the development of live limbs on the second 8-foot section is not at the same rate as on the butt 8-foot section.

Table 5.—Average diameter of the largest live limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Species	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	Inches							
	Butt 8-Foot Section							
Oak	—	0.68	—	0.50	—	—	—	—
Yellow-poplar	—	.50	—	—	—	—	—	—
Red maple	—	.53	—	.50	—	—	—	—
Aspen	—	—	—	—	—	—	—	—
	Second 8-Foot Section							
Oak	—	.94	—	1.03	—	1.12	—	—
Yellow-poplar	—	1.16	1.20	—	.91	1.08	—	—
Red maple	1.08	.84	2.00	.84	1.75	1.41	1.15	1.95
Aspen	—	—	1.25	—	—	4.00	—	—

Dead Limbs

Two important factors that affect the presence of dead limbs in trees are species and stand density. Species is important because of inherent differences caused by growth, vigor, shade tolerance, and natural pruning. Stand density is important because of its effect on the factors just cited.

Aspen had the largest percentage of trees with dead limbs and the largest number of dead limbs in the butt 8-foot section (Table 6). In all treatments, aspen showed a reduction in the percentage of trees with dead limbs in the butt 8-foot section over the 6-year period. The 70 percent plots had the greatest reduction in the percentage of trees with dead limbs, and the 30 percent plots had the least reduction. Other species showed similar trends for dead limbs in the butt 8-foot section.

Analysis of the data for the upper 8-foot section shows aspen with both the largest percentage of trees with dead limbs and the largest number of dead limbs. For red maple, the percentage of trees with dead limbs in the second 8-foot section decreased from 83 percent in 1976 to 38 percent in 1982 in the 30 percent plots, and from 96 to 44 percent in the control plots. Trends were similar for many other species.

Table 6.—Percentage of trees with dead limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Number of dead limbs	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	50.0	57.9	59.1	81.8	60.0	83.3	73.7	93.7
1-2	35.0	36.8	40.9	13.6	24.0	8.3	26.3	6.3
3-4	15.0	5.3	—	4.6	4.0	8.4	—	—
5-8	—	—	—	—	12.0	—	—	—
Second 8-Foot Section								
0	15.0	36.8	9.1	31.8	16.0	50.0	31.6	43.8
1-2	25.0	42.1	31.8	40.9	44.0	41.7	52.6	43.7
3-4	40.0	10.5	45.5	22.7	8.0	—	5.3	12.5
5-8	15.0	—	13.6	4.6	24.0	8.3	10.5	—
9-16	5.0	10.6	—	—	8.0	—	—	—
YELLOW-POPLAR								
Butt 8-Foot Section								
0	81.3	86.7	66.7	100.0	75.0	94.7	100.0	100.0
1-2	18.7	13.3	—	—	20.0	5.3	—	—
3-4	—	—	33.3	—	5.0	—	—	—
Second 8-Foot Section								
0	62.5	80.0	33.3	66.7	65.0	68.4	62.5	100.0
1-2	37.5	13.3	—	—	25.0	31.6	37.5	—
3-4	—	6.7	66.7	33.3	10.0	—	—	—
RED MAPLE								
Butt 8-Foot Section								
0	76.7	89.7	44.4	88.9	47.6	80.9	65.2	80.4
1-2	20.0	10.3	44.4	11.1	47.6	19.1	30.4	17.4
3-4	3.3	—	11.2	—	4.8	—	4.4	2.2
Second 8-Foot Section								
0	16.6	62.1	—	22.2	4.8	28.6	4.3	56.5
1-2	53.4	37.9	22.2	55.6	28.6	61.9	39.1	34.8
3-4	20.0	—	33.4	22.2	28.5	9.5	45.6	6.5
5-8	10.0	—	44.4	—	38.1	—	11.0	2.2
ASPEN								
Butt 8-Foot Section								
0	28.6	42.8	5.9	38.2	14.0	59.5	29.6	58.3
1-2	14.2	42.9	32.3	41.2	44.2	30.9	29.6	33.3
3-4	28.6	14.3	38.3	17.7	20.9	7.2	29.6	8.4
5-8	28.6	—	20.6	2.9	16.3	2.4	11.2	—
9-16	—	—	2.9	—	4.6	—	—	—
Second 8-Foot Section								
0	—	28.6	—	5.9	—	11.9	3.7	—
1-2	—	28.6	5.9	29.4	11.6	28.6	—	20.9
3-4	—	28.6	8.8	23.5	21.0	16.6	22.3	20.8
5-8	71.4	14.2	67.7	38.3	53.3	33.3	48.1	50.0
9-16	28.6	—	17.6	2.9	13.9	9.6	—	8.3

Summary and Conclusions

The response of the oaks to treatment showed a reduction in the percentage of trees with dead limbs as the stocking increased. However, there was no significant difference among treatments in the number of dead limbs for the oak group.

Diameter of Dead Limbs

The average diameter of the largest dead limbs on the butt 8-foot section (Table 7) was smaller than the average diameter of the dead limbs on the second 8-foot section. Analyzing all species for both 8-foot sections, the size of dead limbs in 1982 decreased in all treatments except for the control. One reason for the larger dead limbs in the dense control plots is that the smaller dead limbs naturally pruned off over the 6-year period, leaving only the larger remaining limbs to be counted during the second measurement period.

Results of this research are not intended as guidelines for applying cultural treatments to forest stands. Instead, they allow the woodland manager to look at what might happen to a forest stand in a short time at different levels of stocking. The results have limited application because only one site class and one age group was used. The comparisons and quantifications in this paper are the beginning of a long-term research study to determine the effects of different cultural practices on tree quality.

In 6 years, there have been numerous changes due to treatment in both the rate of growth and the bole quality of certain species groups. The defect characteristics covered in this study are not independent of each other. There is a sequence of events that occurs simultaneously. For example, epicormic branches that develop will grow into live limbs, live limbs die and become dead limbs, and dead limbs fall off and become overgrowths. It is equally important to note that growth and quality sometimes develop naturally even when nothing is done to the forest stand. As evidence of this, some of the control plots had better quality than some of the treated plots. Drastic cutting schemes sometimes are applied to stimulate the growth rate; this adversely affects bole quality. Therefore, there is a trade-off between growth and quality when both are objectives.

Table 7.—Average diameter of the largest dead limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Species	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	Inches							
	Butt 8-Foot Section							
Oak	1.06	0.56	0.77	0.81	1.32	1.30	1.40	1.75
Yellow-poplar	1.49	.50	.75	—	.80	.75	—	—
Red maple	1.42	1.10	.55	.50	1.06	.75	.85	1.08
Aspen	.60	.56	.58	.55	.56	.54	.53	.52
	Second 8-Foot Section							
Oak	1.51	1.54	1.29	1.17	1.59	1.55	1.24	2.08
Yellow-poplar	1.29	.50	1.12	1.00	1.25	.95	.92	—
Red maple	1.08	1.03	.77	.85	1.44	1.11	.83	1.13
Aspen	1.07	1.14	1.00	.93	.97	.88	.77	.76

Some of the findings in this study indicate that:

- Diameter (d.b.h.) growth increased with an increase in growing space.
- Average crown ratio of all trees combined increased only at the lowest stocking level.
- Live and dead limb defects per square foot of surface area decreased as stocking increased.
- The number of live limbs and the percentage of trees with live limbs decreased as stocking increased.
- There were more dead branches than live branches on the butt 16-foot log regardless of stocking level.
- The second 8-foot section of the butt 16-foot log of the tree had more and larger live and dead limbs than the bottom 8-foot section.
- The number of epicormic branches and the percentages of trees with epicormic branches increased as the stocking level declined for all species combined.
- Aspen and yellow-poplar increased the most in diameter growth after 6 years.
- Red maple outperformed all other species in height growth in the 30 percent plots.
- Aspen had fewer limb defects per square foot of surface area than any other species.
- At 30 percent stocking, yellow-poplar was the only species to show an increase in limb defects per square foot of surface area.

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Toumey, James W.; Korstian, Clarence F. **Foundations of silviculture.** New York: John Wiley and Sons; 1947. 468 p.

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Describes the quality response of a 29-year-old upland hardwood stand grown for 6 years under different levels of residual stand density. Both the number of defects per square foot of surface area and the number of epicormic branches changed under different stocking levels. The results suggest that the effect of stocking on potential stem quality of certain species may be substantial even after a few years of treatment.

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