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Stand Development and Yields of Appalachian Hardwood Stands Managed with Single-Tree Selection for at Least 30 Years

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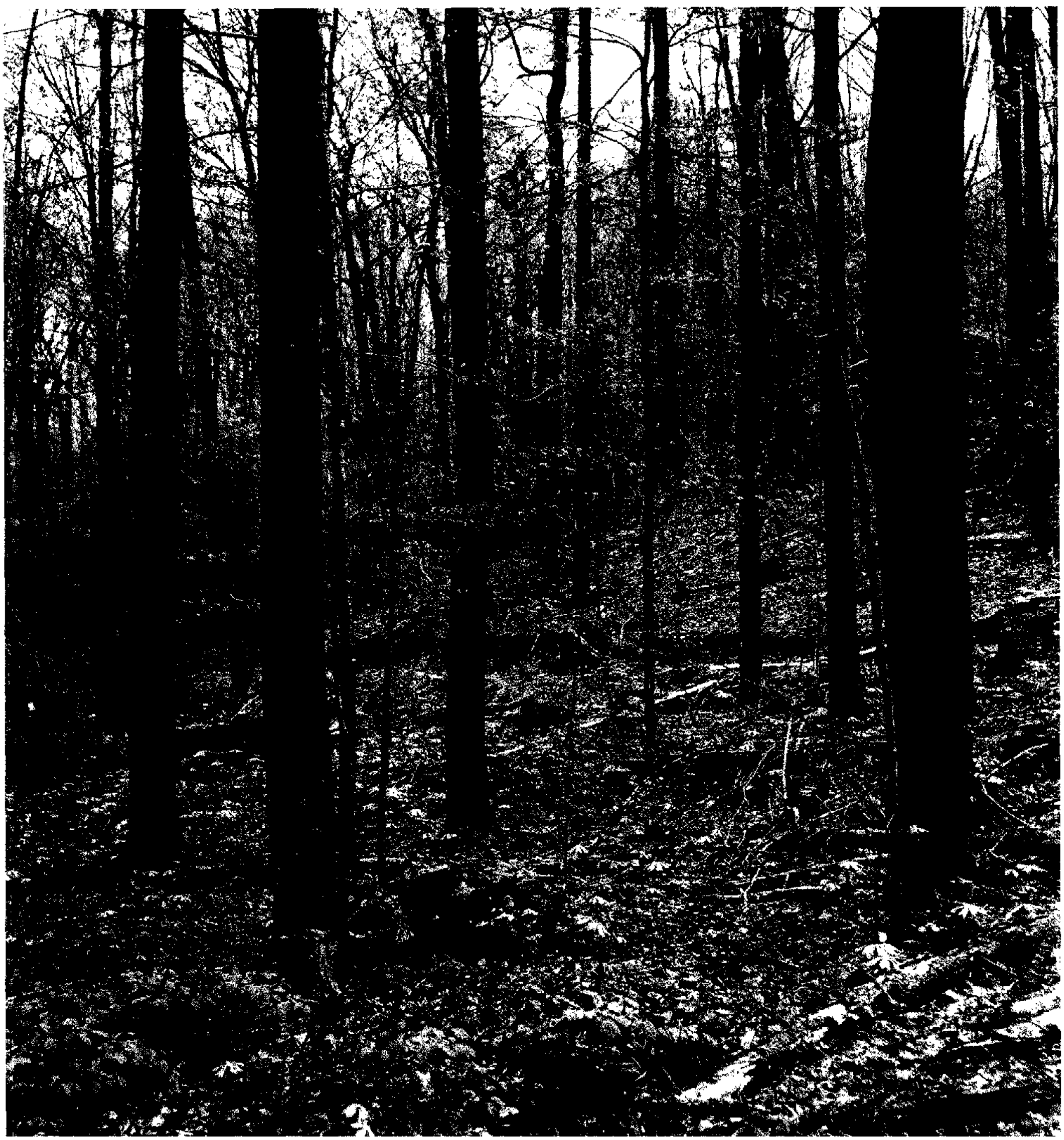

Abstract

Appalachian hardwood stands in West Virginia were managed for 30 or more years using single-tree selection regeneration practices. Stand yield data suggest that current stand growth will provide economical harvest cuts for several future cutting cycles. This case study indicates that single-tree selection has potential for landowners who want to maintain continuous overstory cover and are willing to accept the gradual species shift to more shade-tolerant species.

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Background

Single-tree selection is an uneven-age regeneration cutting practice in which stand regulation is achieved by maintaining a specific number of trees in each diameter class. Continuous overstory tree cover is retained and periodically individual trees are removed throughout all merchantable diameter classes. Regeneration, primarily tolerant tree species, is established after each cut and residual-tree development (stand structure) is expected throughout a range of diameter classes.

An ideal tree diameter distribution in uneven-aged stands usually takes the form of a reverse J-shaped curve when number of trees is plotted over d.b.h. (age) classes. A practical means of attaining such a distribution is through the use of a "q" factor (the ratio of number of trees in a d.b.h. class to the number in the next smaller class). In addition to the q factor, residual basal area and largest diameter tree to grow must be determined in order to mark stands for periodic harvests using single-tree selection cutting.

Although guidelines are available on managing stands using single-tree selection (Smith and Lamson 1982; Leak and Gottsacker 1985; Nyland 1987; Smith and Miller 1987), little information is available on yields of stands managed with the selection cutting practice. In this publication, we describe the yield of six stands that have been managed for 30 years or more using single-tree selection. Although this is a case study, it does provide growth information on the potential for using an uneven-age management in eastern hardwood forests. However, these growth data are from second-growth stands that were established using even-age practices. Thus, the yields were from a species mixture that included a significant number of intolerant species. In these stands we expect intolerant species to become increasingly rare unless some catastrophic event occurs.

Figure 1.—Stand managed with single-tree selection for at least 30 years—excellent growing site.

The Study and Methods

During the period 1952-58, six compartments were established as single-tree selection areas on the Fernow Experimental Forest, in north-central West Virginia near Parsons (Fig. 1). Precipitation averages 58 inches annually and the growing season is 120 to 140 frost-free days. Compartment size ranges from 11 to 78 acres. Two compartments each were established on northern red oak site index (SI) 60, 70, and 80 areas. At the time of study establishment, stands were primarily 50- to 55-year-old second-growth hardwoods and contained some large trees left from earlier logging between 1905 and 1910. Also, scattered saplings and poletimber trees were present that replaced American chestnut trees that died during the 1930's. After more than 30 years of management, principal overstory species were: SI 80 areas — black cherry, red oak, yellow-poplar, sugar maple; SI 70 areas — red oak, black cherry, sugar maple, basswood; SI 60 areas — red oak, chestnut oak, red maple.

Since establishment, the six compartments have been managed using residual number of trees guidelines (Smith and Lamson 1982). These guidelines include a q value of 1.3, largest diameter tree to grow (LDT) of 20, 26, and 32 inches, and residual basal area (RBA) of 50, 65, and 80 ft^2 per acre in trees 5.0 inches d.b.h. and larger for SI 60, 70, and 80, respectively (Table 1). The SI 70 and SI 80 areas are managed on a 10-year cutting cycle, while the SI 60 areas are on a 15-year cutting cycle. Three of the compartments have been cut three times and three have been cut four times, with periodic harvests averaging 3,000 to 4,000 board feet per acre. Immediately before each cut, a 100-percent inventory was conducted of trees with more than 5.0 inches d.b.h. These inventories, by 2-inch d.b.h. classes, were used to determine the mark cut. Marking was accomplished using cut-ratios by diameter class (Smith and Lamson 1982). The compartments were managed for sawlog products only, so no trees less than 11.0 inches d.b.h. (12-inch d.b.h. class) were marked for cutting. Logging was done by a 3- or 4-man crew using a crawler tractor and/or rubber-tired skidder.

The stands, essentially even-aged at the time the study was initiated, had a surplus (more than the established goal) of 12- and 14-inch d.b.h. trees and a deficit (less than the established goal) or trees more than 18 inches d.b.h. It was not possible to initially cut all the surplus trees because this would have reduced the stand below the desired RBA and influenced periodic sustained yield goals. In the beginning, highest priority was given to removing poor-quality and high-risk trees. In later markings, after most of the poor-quality and high-risk trees had been removed, potential butt-log tree grade and spacing among residual trees were the primary criteria used to select trees for removal.

To monitor individual tree growth, four or five growth plots were established in each compartment from 1981 to 1983. All trees 1.0 inch d.b.h. and larger were permanently identified on these 0.5-acre growth plots. Observation on the identified trees included d.b.h., crown class, and other stem characteristics. All trees on the growth plots were remeasured at 5-year intervals.

Results

Stand Structure

Table 1 shows initial and current stand data for trees more than 5.0 inches d.b.h. for each of the three site-index classes. When number of stems is plotted over d.b.h. (tree size, not age), these stands exhibited the typical uneven-age reverse J-shaped curve even though the stands were more or less even-aged. Most natural hardwood stands have more smaller than larger stems due to different growth rates in mixed species stands. After 30 or more years of stand management (stems 12 inches d.b.h. and larger), there are still surplus pole and sawtimber trees in nearly all d.b.h. classes. Stand structure residual tree goals (Table 1) for sawtimber-size trees (11.0 inches d.b.h. and larger) range from 28 to 36 trees per acre for all areas. The SI 80 areas are nearest to the stand structure goal for 12- to 18-inch d.b.h. trees, though these areas still have deficits (less than the established goal) for trees more than 26 inches d.b.h. For the SI 70 areas, there are surplus trees in the 12- to 22-inch d.b.h. classes, while the SI 60 areas have a large number of surplus trees in the 12- to 26-inch d.b.h. classes. Both the SI 60 and SI 70 areas still have a few trees in d.b.h. classes above the largest diameter tree (LDT) goal, even though the stands have been cut three or four times. Most of these large trees, residuals from the early logging, will be removed in the next scheduled cut (Table 1).

Changes in species composition and number of poles and sawtimber trees before treatment and in the current residual stand were compared (Table 2). Important changes in species composition can be seen in the pole-size trees. Generally, the maples and beech have made a major increase in number of trees during the study period. After 30 years, these managed areas are not uneven-aged stands where tree size indicates age. However, shade-tolerant reproduction in the sapling and pole stands is well established and developing. Also, stand structure is beginning to develop and within the next two to four cutting periods, the diameter of sapling, pole, and perhaps small sawlog-size stems should reflect tree age. Likewise, the number of shade-tolerant trees should increase in the sawlog-size class.

Stand Growth

Per-acre stand growth for merchantable trees larger than 5.0 inches d.b.h. of the six compartments is shown in Table 3. These data are based on the periodic growth before the last cut in each compartment and also include ingrowth from saplings to pole stems and from poles to sawtimber trees. Residual stand volumes following the

Table 1.—Initial, current, and desired number of trees per acre for stands managed with single-tree selection

D.b.h.	SI 60 [a]			SI 70 [b]			SI 80 [c]		
(inches)	Initial[d]	Current[e]	Goal	Initial[d]	Current[e]	Goal	Initial[d]	Current[e]	Goal
	Number of trees/acre								
6	76.9	57.1	19.2	63.3	51.8	18.6	41.5	29.6	19.4
8	45.7	21.3	14.7	38.9	32.1	14.3	33.8	21.2	14.9
10	21.8	15.7	11.3	27.3	22.3	11.0	27.3	17.2	11.5
Subtotal	144.4	94.1	45.2	129.5	106.2	43.9	102.6	68.0	45.8
12	13.8	9.1	8.7	16.6	9.7	8.5	20.2	9.3	8.8
14	8.4	7.0	6.7	9.4	7.6	6.5	13.9	6.8	6.8
16	6.1	7.0	5.2	6.2	7.1	5.0	9.3	5.3	5.2
18	4.0	5.2	4.0	3.6	5.3	3.9	4.9	4.4	4.0
20	2.4	4.2	3.1	3.1	4.3	3.0	3.1	4.0	3.1
22	1.7	2.8		2.2	2.6	2.3	2.0	4.3	2.4
24	0.6	1.9		1.4	1.4	1.8	1.3	2.3	1.8
26	0.4	1.1		1.1	0.7	1.3	0.7	1.4	1.4
28	0.2	0.1		0.8	0.1		0.6	0.7	1.1
30	0.1			0.3	0.1		0.3	0.3	0.8
32	0.1			0.1			0.1	0.2	0.6
34				0.2			0.1		
Subtotal	37.8	38.4	27.7	45.0	38.9	32.3	56.5	39.0	36.0
Total	182.2	132.5	72.9	174.5	145.1	76.2	159.1	107.0	81.8

[a]q = 1.3; RBA = 50 ft^2/acre; LDT = 20 inches d.b.h.
[b]q = 1.3; RBA = 65 ft^2/acre; LDT = 26 inches d.b.h.
[c]q = 1.3; RBA = 80 ft^2/acre; LDT = 32 inches d.b.h.
[d]Average of two compartments based on 100-percent inventories.
[e]Average of two compartments based on 100-percent inventories after 30 years.

next to last cut were subtracted from the inventory completed immediately before last cut. Growth periods were 10 years on the SI 70 and SI 80 areas and 14 years on the SI 60 areas. Residual number of stems per acre 5.0 inches d.b.h. and larger ranged from 124 to 174, while residual basal area ranged from 86 to 95 ft^2 per acre. Residual board-feet volume per acre ranged from 5,540 on SI 60 areas to 11,763 on SI 80 areas, reflecting increased RBA and LDT for the higher quality sites.

Annual average basal area growth ranged from 2.1 to 2.7 ft^2 per acre. There was no clear trend of increasing basal-area growth with increasing site quality. Annual per-acre board-foot volume growth showed a similar trend with lowest growth on SI 60 areas (329 board feet per acre): on SI 70 and SI 80 areas, annual growth averaged 505 and 476 board feet per acre, respectively.

Individual Tree Growth

Data on individual tree growth were obtained on the 0.5-acre growth plots. Five-year individual tree growth of all stems 1.0 inch d.b.h. and larger was essentially the same in all areas—0.5 inch d.b.h. (Table 4). This was due to the large number of small, overtopped stems in all areas which grew 0.1 inch or less during the 5 years. Diameter growth of dominant/codominant trees was highest on the SI 80 areas, 1.2 inches, and lowest on the SI 60 areas, 1.0 inch. Five-year diameter growth of the 50 largest trees per acre was about equal to the diameter growth of the dominant/codominant trees on a given site.

Prediction Equations

Regressions were used to predict 10-year d.b.h. growth of individual trees for each site-index class. The prediction equations and coefficients for each red oak site-index classes are of the form:

$$y = a + b(X) + c(X)^2$$

where y = 5-year basal area growth, a = intercept, b,c = coefficients, and X = diameter breast height.

SI	a	b	c	R^2
60	–0.00849	0.00722	0.00035	0.74
70	–0.00546	0.00497	0.00058	0.84
80	–0.00274	0.00233	0.00065	0.85

Table 2.—Pole and sawtimber trees per acre before logging compared with similar trees in the current residual stand

Species	Poles[a]			Sawtimber[b]		
	Initial[c]	Current[d]	Percent change	Initial[c]	Current[d]	Percent change
	------*Number of trees* -----			------*Number of trees* -----		
			SITE INDEX 60			
N. red oak	18.1	14.5	− 20	8.4	12.4	+ 46
Red maple	16.2	26.8	+ 65	2.7	5.1	+ 89
Black birch	7.3	14.9	+ 104	1.5	0.6	− 60
Chestnut oak	13.9	9.0	− 31	7.3	4.0	− 45
Beech	6.6	9.4	+ 42	5.3	1.5	− 72
Sassafras	33.4	6.0	− 82	0.4	0	0
Other species	52.1	43.0	− 18	13.0	9.2	− 29
Total	147.6	123.6	− 16	38.7	32.8	− 15
			SITE INDEX 70			
N. red oak	38.4	14.8	− 62	12.8	20.5	+ 60
Sugar maple	10.7	35.8	+ 235	6.8	3.4	− 50
Red maple	9.1	12.2	+ 34	1.3	1.8	+ 39
Basswood	16.0	11.8	− 26	4.9	2.2	− 55
Black cherry	9.8	2.5	− 75	5.1	3.9	− 24
Black birch	8.2	5.4	− 34	2.4	0.3	− 88
White ash	4.5	3.1	− 31	0.6	1.6	+ 167
Yellow-poplar	3.3	0.9	− 73	2.8	1.8	− 36
Other species	29.4	22.0	− 25	8.1	1.8	− 78
Total	129.4	108.5	− 16	44.8	37.3	− 17
			SITE INDEX 80			
N. red oak	16.6	3.1	− 81	8.7	9.7	+ 12
Sugar maple	11.7	27.9	+ 139	4.9	5.6	+ 14
Black cherry	13.9	1.5	− 89	14.5	6.0	− 59
Yellow-poplar	4.8	1.6	+ 67	6.2	4.2	− 32
Hickory	3.2	1.5	− 53	1.7	0.9	− 47
Beech	5.1	8.5	+ 67	5.9	2.6	− 56
Red maple	5.7	7.0	+ 23	1.1	2.0	+ 82
Black birch	10.8	4.9	− 55	1.8	2.0	+ 11
White ash	1.5	0.2	− 87	0.8	0.5	− 38
Other species	29.4	10.8	− 64	11.0	0.5	− 38
Total	102.7	67.0	− 35	56.6	37.6	− 34

[a]5.0 to 10.9 inches d.b.h.
[b]11.0 inches d.b.h. and larger.
[c]Average of two compartments based on 100-percent inventories.
[d]Average of two compartments based on 100-percent inventories after 30 years.

Coefficients were derived by least-square fit using actual data.

These equations for a given site were used to compute 5-year basal-area growth. This 5-year basal-area value was converted to 5-year d.b.h. to develop the 10-year diameter growth information in Table 5. For example, 10-year d.b.h. growth for a tree 16 inches d.b.h. on an oak SI 80 area was calculated as:

$y = -0.00274 + .00233(16) + .00065(16^2)$
5-year basal area growth = 0.2009 ft^2

Basal area 16.0-inch tree = 1.3963 ft^2
5-year tree basal area = 1.3963 + 0.2009 = 1.5972 ft^2
5-year tree d.b.h. = 17.1
5-year d.b.h. − initial d.b.h. = 5-year d.b.h. growth
17.1−16.0 = 1.1 inches
10-year d.b.h. growth = 2.2 inches (Table 5)

Table 3.—Per-acre stand growth data for Appalachian hardwood stands managed with single-tree selection trees 5.0 inches d.b.h. and larger[a]

Residual inventory[b]			Periodic inventory[c]				Stand net growth			
							Periodic		Ave. annual	
No. of trees	Basal area	Board-foot volume[d]	No. of trees	Basal area	Board-foot volume[d]	No. of years	Basal area	Board-foot volume[d]	Basal area	Board-foot volume[d]
	ft^2			ft^2			ft^2		ft^2	
				SITE INDEX 60						
174	86	5,540	182	116	10,140	14	30	4,600	2.1	329
				SITE INDEX 70						
156	90	8,336	166	117	13,387	10	27	5,051	2.7	505
				SITE INDEX 80						
124	95	11,763	126	120	16,525	10	25	4,762	2.5	476

[a]Inventories and stand growth data include ingrowth but exclude mortality; no trees were cut during the measurement intervals.
[b]Stand data immediately after cut at beginning of last cycle.
[c]Stand data at end of cutting cycle prior to cut.
[d]International 1/4-inch board-foot volume.

Table 4.—Average 5-year individual-tree diameter growth in stands managed with single-tree selection

Item	All trees[a]	Dominant/ codominant trees	50 largest trees/acre
		SITE INDEX 60	
No./acre	566	52	50
D.b.h. (inches)	4.2	12.1	12.6
5-year growth (inches)	0.5	1.0	1.0
		SITE INDEX 70	
No./acre	475	57	50
D.b.h. (inches)	4.8	14.0	14.8
Growth (inches)	0.5	1.2	1.2
		SITE INDEX 80	
No./acre	369	49	50
D.b.h. (inches)	5.7	17.0	16.9
Growth (inches)	0.5	1.2	1.2

[a]1.0 inch d.b.h. and larger.

Prediction equations for all three site-index classes accounted for a significant amount of the variability, coefficients of determinations (R^2) ranged from 0.74 to 0.85.

Table 5 shows the estimated 10-year diameter growth of individual trees for these stands managed with single-tree selection. Diameter growth was lowest on SI 60 areas and about equal on SI 70 and SI 80 areas.

Table 5.—Average predicted 10-year diameter growth by d.b.h. class of individual trees for stands managed with single-tree selection

D.b.h. (inches)	SI 60	SI 70	SI 80
		Inches	
6	1.4	1.3	1.0
8	1.6	1.6	1.3
10	1.7	1.8	1.5
12	1.9	2.0	1.8
14	2.0	2.2	2.0
16	2.2	2.5	2.2
18	2.3	2.7	2.5
20	2.5	2.9	2.7
22	2.6	3.1	2.9
24	2.7	3.3	3.2

Ten-year diameter growth ranged from 1.0 inch to 3.3 inches. The 10-year diameter growth of sawlog-size trees ranged from about 2 inches for the 12-inch class to more than 3 inches for the 24-inch d.b.h. class (limit of data) on SI 70 and 80 areas.

Discussion

Appalachian hardwood stands in West Virginia were managed for 30 or more years using the single-tree selection practice. Stand yield data suggest that current stand growth will provide economical harvest cuts for several future cutting periods. Based on this information, current mature Appalachian stands with northern red oak site indexes from 60 to 80 are expected to yield 300 to 500 board feet per acre per year or 3,000 to 5,000 board feet per acre at 10- to 15-year intervals until the shade tolerant species begin to dominate the sawlog-size trees. Although this is a case history and all data were collected in the same general area, similar growth response can be expected with similar species composition, sites, and management practices. With skid and haul roads previously established, the expected volume yield is more than a marginal economic harvest.

When applying single-tree selection, an important objective is to attain the desired number of residual trees by d.b.h. class as soon as possible while satisfying periodic sustained yield objectives. In this study, the decision was made to gradually approach the established goals over several cutting periods. It is possible to remove all surplus trees during the initial cut, but in most instances, the residual stand would be cut below the desired RBA because of deficits in some diameter classes. This would delay future harvests and create large openings in the crown canopy. This latter approach will jeopardize an important objective of single-tree selection: providing a periodic even flow of products while maintaining continuous overstory tree cover.

Individual-tree diameter growth of sawlog-size trees should be at least 2 inches in 10 years for Appalachian hardwood stands managed with single-tree selection — oak site index 60 to 80. Thus, all merchantable trees are expected to grow into the next 2-inch diameter class during any 10-year period.

A common objection to single-tree selection is that marking is difficult compared to thinning even-aged stands. Basic data required before marking stands using single-tree selection is a stand table by 2-inch d.b.h. classes. Similar data are required for thinning stands. The selection cut is determined by using residual number of trees guidelines (Smith and Lamson 1982). With some training, foresters can mark stands in a single pass using single-tree selection. Foresters who can thin hardwood stands using stocking guides can apply the single-tree selection practice.

Another objection to single-tree selection has been potential damage to residual trees. In this study of stands managed with single-tree selection, most of the trees damaged during logging were saplings. Few sawlog trees were damaged (Lamson and others 1985). After each harvest, all stands contained a surplus of undamaged, high-quality saplings and poles.

Managing current second-growth, even-aged hardwood stands in the central Appalachians using single-tree selection results in a change of species composition. Stands will eventually be dominated by shade-tolerant species. We expect the periodic growth to be reduced by this change in species composition. Total board-foot volume for an 8.0-inch top d.i.b. sugar maple is about 10 percent less than that of intolerant species such as black cherry or yellow-poplar. In mixed hardwood stands, intolerants usually account for about half of the stand volume, and this percent volume continues to decline with each periodic cut using single-tree selection. Therefore, it seems likely that converting mixed Appalachian hardwood stands to tolerant species would reduce periodic growth by at least 10 percent.

This case study indicates that single-tree selection has potential in the Appalachians. It is useful for landowners who want to maintain continuous overstory cover and are willing to accept the gradual species shift to the more shade-tolerant species. Experience has shown that marking stands using single-tree selection is not difficult; in most cases it can be accomplished in one pass through the stand. Foresters who use stocking guides to thin stands can use also single-tree selection residual-tree guidelines as a regeneration practice.

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