Silvicultural Systems

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TWO-AGED SILVICULTURAL SYSTEMS: DIAMETER DISTRIBUTION AND PREDICTIVE MODELS FOR DETERMINING MINIMUM RESERVE TREE DIAMETERS

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Abstract—Two-aged silvicultural systems are currently being studied for implementation in Eastern hardwood forests. However, implementation of these systems can be constrained by the reduction in harvesting receipts due to the value left standing in reserve trees. This study developed best-fit equations for predicting the minimum diameter at breast height for reserve trees occupying approximately 20 feet^2 of basal area per acre. The mean stumpage value averaged $312.12 per acre for reserve trees selected using standard silvicultural criteria of codominant trees of average diameter and $229.48 per acre for reserve trees selected from the trees having the smallest diameters of those meeting minimum reserve requirements. These values represented 24.8 and 17.1 percent of the total timber receipts. Prediction equations developed in this study can be used as marking guidelines, providing the forest owner with the maximum timber harvesting receipts possible while maintaining a reasonable timber production potential in the reserve trees.

INTRODUCTION

The two-aged system is currently being evaluated for use in Eastern hardwood forests (Beck 1986, Miller and others 1995, Sims 1992). Types of the two-aged system, including deferment cutting and irregular shelterwoods, when initiated in sawtimber-sized stands, involves the retention of 15 to 40 feet (ft)^2 of basal area per acre of overstory trees, termed reserves or standards (Nyland 1996). This provides, at least initially, for the rapid growth of the understory and the development of two age classes (Miller and Schuller 1995). These two-aged types have the ability to deliver several important biologic and managerial advantages compared to other regeneration cuts commonly employed in the region, such as clearcutting (Smith and others 1989). Specifically they can provide stands capable of simultaneously providing roundwood and highly valued sawtimber or veneer, maintenance of visual or esthetic standards, and an uninterrupted production of propagules for the development of advanced regeneration throughout a rotation. The latter may be critical in maintaining our ability to regenerate stands, particularly those composed of intermediate and shade intolerant species.

Selection of reserve trees and use of the two-age system should reflect the following concerns:

(1) Availability of appropriate reserve species. Species must be commercially valuable and posses the necessary lifespan to sustain themselves for a second rotation length. In many instances stands will not contain overstory species meeting this criteria; therefore, cuts to develop two-age stands would not be appropriate.
(2) Individual trees must maintain their vigor and bole quality after the initial cut (Brinkman 1955, Miller 1996, Smith 1965). This requires that individual tree selection criteria be developed and adhered to during marking.
(3) Individual trees must be able to survive harvest and postharvest environments. This requires that topographic position, soil characteristics, and the relative size of reserve versus cut trees be taken into account when selecting reserve trees.
(4) Timber harvesting operators must be able to successfully implement harvests.
(5) Impacts of leaving a limited number of mating individuals on the mating systems and potential loss of heterozygosity in progeny, may be of concern in developing two-age stands with extremely low densities. Investigation of this potential problem is currently underway.
(6) The ability to generate reasonable monetary return in the initial cut.

The latter is an important concern if the two-aged system is to be used on private lands. Forest owners, particularity nonindustrial private forest owners, are sensitive to reductions in timber harvesting receipts. Maintaining large stumpage values in reserve trees may limit the use of this system on nonindustrial private forest lands. Therefore, if the two-aged system is to be widely deployed, reserve trees must be selected based on their ability to meet silvicultural objectives as well as to minimally impact harvesting receipts. In the majority of cases, this means selecting reserve trees of the smallest diameter possible that will still meet two-aged timber production objectives. The need for selecting relatively small reserve trees is exacerbated when low stocking levels are encountered. This often precludes the selection of the best trees as reserves. Thus, it is critical to develop individual tree marking guides which will provide for silvicultural objectives in the reserves and allow for implementation of commercial harvests if the two-aged system is to be established as viable options in silvicultural operations on nonindustrial private forest lands.

This study was designed to provide the following:

(1) the diameter at breast height (d.b.h.) distribution of potential reserve trees in sawtimber stands in eastern Kentucky;
(2) useful models for predicting the minimum d.b.h. requirements for reserve tree candidates in stands maintaining <20 ft^2 per acre in reserve basal area; and

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(3) the stumpage value of reserve trees and the percentage of total harvesting receipts contained in the reserves.

The predictive equations can be used to determine minimum d.b.h. requirements for reserve trees, as well as to determine the volume contained in reserve trees. This information can be used by forest managers to determine volume and value reductions in harvest receipts, and by silviculturists and marking crews for determining target diameters for reserve trees.

METHODS

Six .10-acre circular plots were randomly established in each of seven timber sale tracts on the Daniel Boone National Forest in eastern Kentucky. These tracts were part of standard sales packages and each tract contained a number of different stands (represented by the plots) growing over a wide range of site indexes (black oak site index 62 to 95, base age = 50). Each of the 42 plots was assumed to represent the stand in which it was contained. Individual measures for trees $\geq$ 5 inches d.b.h. in each plot included species, d.b.h., crown class, live crown ratio, and USFS tree grade (Stringer and others 1989) or potential tree grade (Yaussy 1991). Two sets of potential reserve trees were selected in each plot. Each reserve tree selected was a relatively long-lived species, having a live crown ratio of >40 percent, and a USFS tree grade or potential tree grade of $\leq$2. Set I trees were selected from codominant trees of average d.b.h. Set II trees were selected from trees having the smallest d.b.h. that met the criteria mentioned above. The average d.b.h. of both Set I and Set II trees was determined for each plot. Both linear and curvilinear equations were used to generate best-fit models for Set II means (i.e., the dependent variable was the minimum d.b.h. of the reserve tree candidates) for the primary species groups. Independent variables tested included those that could easily be generated from common timber harvesting or silvicultural data sets, including: total stand basal area per acre, average stand d.b.h., average d.b.h. of the codominant trees, and total stand volume per acre. Graphs were generated for each species or species group. Each graph included the plotting of each mean plot d.b.h. for Set II trees and the best-fit equation.

The International 1/4-inch volume was determined for each tree (Hahn and Hansen 1991). Stumpage value was also determined for each tree using average regional values for the appropriate species groups. Total volume and value per acre were determined for each tract as well as for each set of potential reserve trees. The percentage of the total timber volume and value that was contained in reserve trees of both Set I and Set II was determined.

RESULTS AND DISCUSSION

Descriptive tract data are presented in table 1. All tracts contained sawtimber volumes that were readily merchandisable and were representative of timber harvests in the region. The tract sizes were also common to eastern Kentucky and reflected the dissected nature of the topography. Both reserve tree sets were relatively close to meeting their target basal area objective of 20 ft^2 per acre.

Best-Fit Equations

Best-fit equations for predicting the minimum d.b.h. of reserve trees was obtained using the mean d.b.h. of the codominant trees in the stand as the independent variable. The three most numerous species or species groups contained in both Set I and Set II included: *Quercus alba*, *Q. prinus, Acer* spp. (*A. saccharum* and *A. rubrum*). Best- fit equations were for all species and species groups combined as well as for individual groups. A best-fit equation was also developed for the minor species group, which included *Liriodendron tulipifera, Carya* spp., *Q. rubra, and Fraxinus americana.* Significant differences were found among species or

Table 1—Descriptive statistics and potential reserve basal area by tract

Tract	Area	Diameter at breast height	Board feet	Total BA	Reserve BA Set I[a]	Set II[b]
	Acres	*Inches*	*Int. 1/4"*	*Ft^2/acre*		*Ft^2a^{-1}*
1	23	14.3	16,270	124	21.9	19.6
2	33	14.9	14,880	112	22.4	17.8
3	9	14.3	15,930	116	20.0	21.1
4	15	13.5	16,380	118	20.5	19.7
5	19	10.8	15,390	114	19.2	18.1
6	13	13.5	16,910	124	20.7	20.9
7	15	14.6	15,600	116	21.3	16.5
Mean	18	13.7	15,908	118	20.7	19.1

[a] Set I is composed of codominant trees of average d.b.h. that met the following reserve tree criteria: relatively long-lived species, live crown ratio of >40 percent, USFS tree grade or potential tree grade of $\leq$2.
[b] Set II is composed of trees having the minimum d.b.h. that still meet the minimum criteria for reserve trees as listed above.

species groups. Figure 1 shows the minimum diameter of Set II reserve trees for each plot, and the best-fit equation,

$$y = 2.035041 + .669431 * \text{d.b.h.} \ (r^2 = 0.30). \qquad (1)$$

While this equation can be useful in determining overall predictions for entire forests, the high degree of variability precludes its use as a tool for developing criteria for individual stands or tracts. Variation is decreased when plotting individual species and species groups and the coefficient of variation increases substantially at this level of analysis (fig. 2). Figure 2(a) shows the plot for *Q. alba* with the best-fit equation,

$$y = \text{sqrt}(-2.119e{+}02 + 2.779e{+}01 * x) \ (r^2 = 0.44). \qquad (2)$$

This indicates that the minimum diameter of reserve trees for this species was only 1 to 2 inches below the average diameter of the codominants in the stand. In contrast, the minimum diameters for *Q. prinus* reserve trees produced a best-fit equation,

$$\ln y = .755 + .112 * x \ (r^2 = 0.43) \qquad (3)$$

which indicates that reserve trees can be selected from individuals having a d.b.h. of 2 to 4 inches less than the average codominates in the stand [fig. 2(b)]. Figure 2(c) shows the plot for *Acer* spp. with the best-fit equation,

$$y^2 = 51.621 + 4960.533/x^2 \ (r^2 = 0.13). \qquad (4)$$

The results of this study indicate that reserve tree selection for *A. rubrum* and *A. saccharum* would be independent of codominant d.b.h., with the average minimum d.b.h. of acceptable reserve trees approximately 8 inches. However, the large differential in size between the potential reserve trees and the codominants might increase harvest damage to an unacceptable level (Hesterberg 1957). Selection of reserve trees in this species group would be driven primarily by their position relative to cut trees, rather than by concern over their meeting minimum diameter requirements. The remaining species, primarily *Liriodendron tulipifera, Carya* spp., *Q. rubra, and F. americana,* were not present in great enough numbers to warrant individual analysis and were grouped together for analysis [fig. 2(d)] with a best-fit equation,

$$y^2 = -209.529 + 24.085 * x, \ (r^2 = 0.64)) \qquad (5)$$

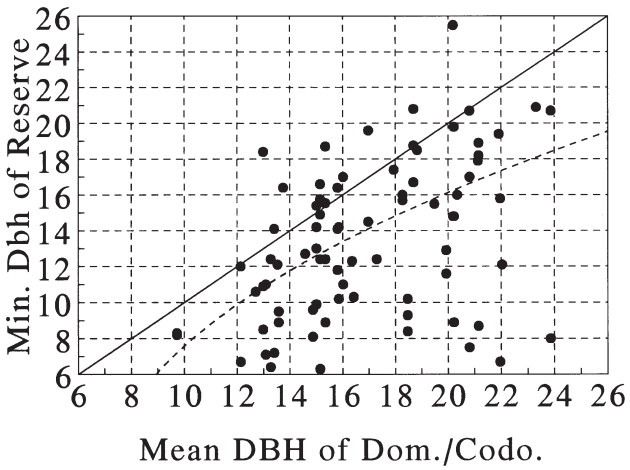

Figure 1—Mean minimum d.b.h. requirements of two-age reserve trees. Points represent the average minimum d.b.h. of 20 ft^2 per acre of reserve trees relative to the average d.b.h. of codominant stems in each stand. Dotted line represents the plot of the best-fit equation for these points ($y = 2.035041 + .669431 * \text{d.b.h.} \ (r^2 = 0.30)$).

Effect of Reserve Tree Selection Criteria on Stumpage Values

The stumpage values of Set I reserve trees averaged $312.12 per acre and Set II reserve trees averaged $229.48 per acre (table 2). These values represented 24.8 and 17.1 percent of the timber receipts of the tracts. The difference of approximately $82 per acre would pay for the site preparation costs normally associated with natural regeneration of the commercial species found in the study. The stumpage value determined for the reserve trees is highly conservative and was obtained using the regional average price for stumpage of average grade. As the grade of the codominant trees increases so will the discrepancy in stumpage value between Set I and Set II trees. Regardless, selecting reserve trees with diameters greater than that necessary may decrease the ability of foresters to implement this practice in nonindustrial private forests and will decrease the revenues for site preparation activities.

Table 2—Value per acre of reserve trees left as 20 ft^2 basal area per acre

Tract	Set I Average d.b.h.		Set II Minimum d.b.h.	
	$/acre	*Percent*	*$/acre*	*Percent*
1	301.50	23.0	238.59	18.4
2	334.09	32.1	186.85	16.9
3	289.03	22.6	245.00	20.2
4	322.82	22.5	223.97	22.5
5	328.41	17.9	273.72	14.6
6	281.36	23.3	248.41	20.7
7	327.63	32.5	189.79	13.9
Mean	312.12	24.8	229.48	17.1

Two sets of criteria were used to select reserve trees. Set I: reserves selected from trees of average d.b.h. of the codominates, and Set II: reserves selected from trees having the smallest d.b.h. of trees meeting minimum reserve requirements (USFS tree grade or potential tree grade $\leq$2, live crown ratio >40 percent, long-lived, commercial species).

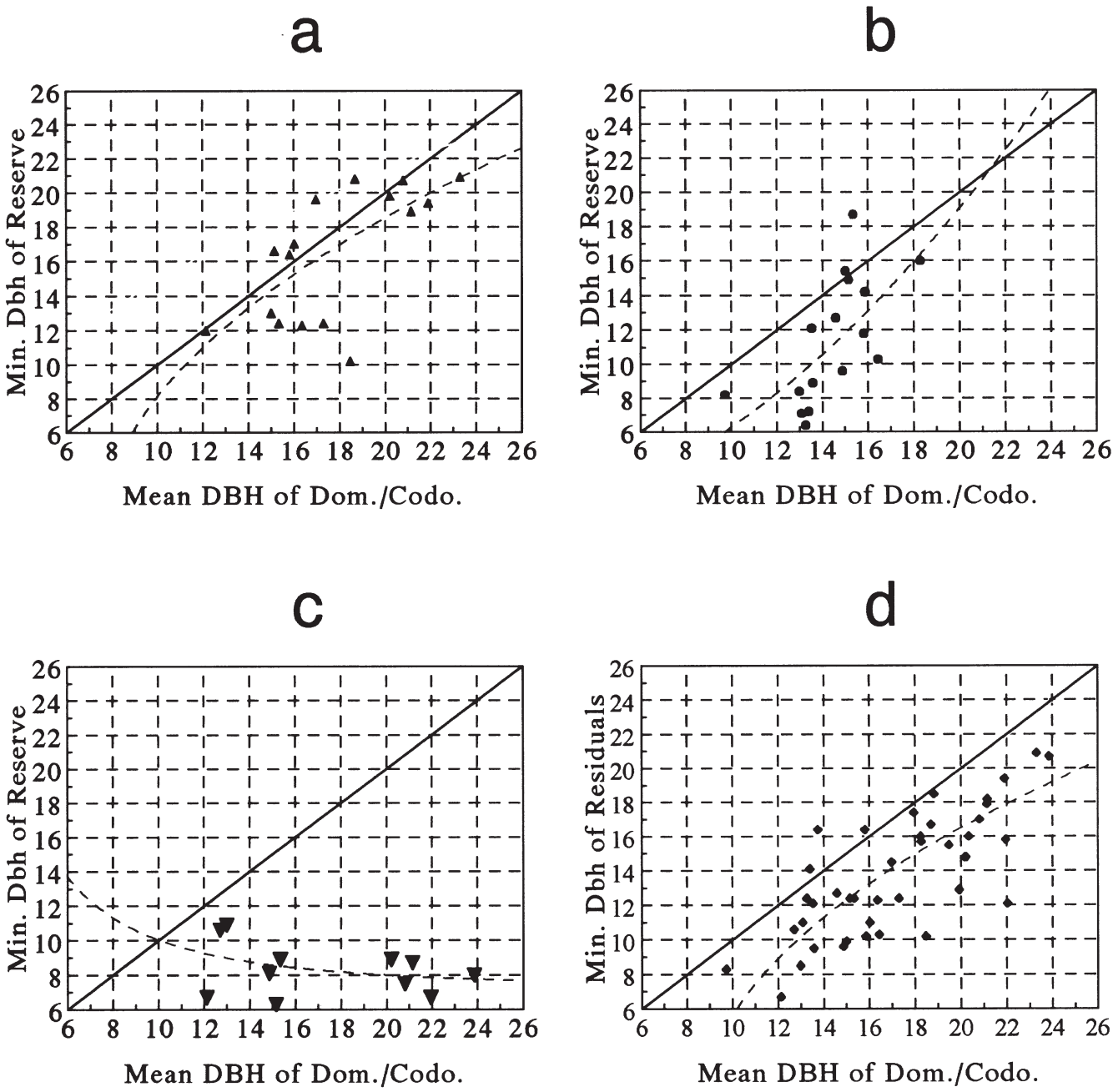

Figure 2—Mean minimum d.b.h. requirements of two-age reserve trees by species and/or species groups. Points represent the average minimum d.b.h. of 20 ft^2 per acre of reserve trees relative to the average d.b.h. of codominant stems in each stand. Dotted line represents the plot of the best-fit equation for these points. (a) *Q. alba*, y = sqrt (-2.119e +02 + 2.779e +01*x) (r^2 = 0.44); (b) *Q. prinus*, lny = .755 + .112*x (r^2 = 0.43); (c) *Acer* spp., y^2= 51.621 + 4960.533/x^2 (r^2 = 0.13); (d) other species including *Liriodendron tulipifera, Carya* spp., *Q. rubra, and Fraxinus americana* y^2 = -209.529 + 24.085*x, (r^2 = 0.64).

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GROWTH AND EPICORMIC BRANCHING OF RESIDUAL TREES FOLLOWING DEFERMENT CUTTING IN RED OAK-SWEETGUM STANDS

James S. Meadows[1]

Abstract—Growth and epicormic branching of residual trees were evaluated following deferment cutting in three red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stands on minor streambottom sites in west-central Georgia. Deferment cutting consisted of complete removal of all stems except previously selected residual trees, to a target basal area of 10 to 15 square feet per acre. Diameter growth of residual trees during the 3-year period following deferment cutting averaged 0.83 inches across all species on all three sites. However, 3-year diameter growth response of oaks was much higher, and averaged 2.10, 1.25, and 1.38 inches for willow oak (*Q. phellos* L.), water oak (*Q. nigra* L.), and overcup oak (*Q. lyrata* Walt.), respectively. In contrast, 3-year diameter growth of green ash (*Fraxinus pennsylvanica* Marsh.) and sweetgum averaged only 0.68 and 0.64 inches, respectively. Production of new epicormic branches on the butt logs of residual trees averaged 7.9 sprouts over the 3-year period, but varied considerably by species. In general, oaks (especially water oak) produced many new epicormic branches, whereas green ash and water tupelo (*Nyssa aquatica* L.) produced very few. However, much variation was found within a species; production of new epicormic branches was highly dependent upon initial vigor of individual trees.

INTRODUCTION

Deferment cutting, also known as the irregular shelterwood method (Smith 1986), is a possible regeneration alternative to clearcutting. In this technique, a stand near rotation age is cut heavily and an underwood of either natural or artificial regeneration is allowed to develop. The two stories, the older residual trees from the previous stand and the younger regeneration from the new stand, are then allowed to develop together as a two-aged stand (Beck 1987). This technique is designed to create a new even-aged stand while leaving 10 to 25 square feet of basal area per acre from the previous stand, primarily for aesthetics.

This alternative regeneration method may be attractive to landowners because it maintains at least some high forest cover continuously on the site, while allowing the development of even-aged stands. Most commercially important hardwood species are best suited to even-aged management (Clatterbuck and Meadows 1993). Continuous maintenance of some forest cover not only improves the aesthetic appearance of the new stand, but also maintains continuous mast production for wildlife. Deferment cutting to produce a two-aged stand provides the benefits of clearcutting (nearly full sunlight to the forest floor to encourage the even-aged development of shade-intolerant species), but reduces the negative attributes associated with clearcutting (unsightly appearance and the loss of mast production from the site for 20 to 30 years).

Beck (1987) observed the development of a two-aged stand 20 years after a deferment cutting in a northern red oak (*Q. rubra* L.) stand in the Southern Appalachian Mountains. The residual overstory responded well, in terms of both diameter and volume growth, to the nearly unlimited growing space provided by the deferment cutting, with little or no loss in bole quality due to excessive epicormic branching. Regeneration in the new stand was similar in both species composition and size to that in an adjacent clearcut of the same age. Consequently, deferment cutting appears to be a viable regeneration alternative to clearcutting, at least in Appalachian hardwood stands, but the technique has not been tested in southern bottom-land hardwood forests.

To address the feasibility of deferment cutting in southern bottom-land hardwood forests, this study evaluated the growth and bole quality development of residual trees following deferment cutting in three red oak-sweetgum stands on minor streambottom sites in west-central Georgia. Specific objectives addressed in the study were (1) to determine the effects of deferment cutting on diameter growth and epicormic branching of residual trees, and (2) to assess the extent of logging damage to residual trees and its effects on tree vigor, epicormic branching, and bole quality.

METHODS

Study Area

The study area consists of three sites within the floodplain of the Flint River in west-central Georgia, on land owned by the Georgia-Pacific Corporation. Two of the three sites are high flats that support small sawtimber stands composed primarily of red oak and sweetgum. The third site is a low flat that supports a small sawtimber stand composed predominantly of water tupelo, green ash, and overcup oak, but with some red oaks and sweetgum on the higher areas. All three stands were about 55 to 70 years old.

Treatments

Two treatments were applied in this study: (1) deferment cutting, and (2) control. Deferment cutting consisted of complete removal of all stems except previously selected residual trees. Target basal area was 10 to 15 square feet per acre. Increment cores from residual trees served as the control treatment, and were used to compare pre- and posttreatment diameter growth.

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Sims (1992) emphasized the importance of selecting vigorous trees of desirable species to be left as residuals following deferment cutting. In general, residual trees should be capable of growing in both volume and value for an extended period of time under very open stand conditions without excessive loss through windthrow, other mortality, or degrade.

Consequently, trees selected as residual trees in this study were classified as preferred growing stock trees, as described by Putnam and others (1960). They were generally the most vigorous and most desirable trees in the stand, and were selected on the basis of the following desirable characteristics: (1) must be in good condition and show no evidence of disease or previous damage; (2) must be of a desirable species for the site and for management objectives; (3) must be in the dominant or codominant crown class; (4) must be capable of being left indefinitely; and (5) must currently meet, or be capable of eventually meeting, the requirements for at least a 16-foot Grade 1 saw log, as defined by Rast and others (1973).

Residual trees were spaced at least 2 chains (132 feet) apart, so that they experienced essentially open-grown conditions after treatment. If possible, residual trees will be left for the duration of the next rotation, or at least until the time of the first thinning in the new stand.

The deferment cutting operation was performed by contract logging crews in September 1993. All trees were directionally felled with a mechanized feller. Rubber-tired skidders were used to remove the merchantable products, in the form of longwood, from the woods.

Plot Design

One square, 20-acre treatment plot was established at each of the three sites. Deferment cutting to a target basal area of 10 to 15 square feet per acre was applied across the entire 20-acre plot.

One square, 4.9-acre measurement plot was established in the center of each 20-acre treatment plot at each site. Each measurement plot is 7 by 7 chains (462 by 462 feet). Corners were permanently marked with PVC pipe driven into the ground. All residual trees within the measurement plots were permanently identified with a numbered aluminum tag.

Measurements and Statistical Analysis

Variables measured on all residual trees included species, diameter at breast height (d.b.h.), merchantable height, height to the base of the live crown, total height, crown class, tree class, length and grade of all saw logs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section. At the end of each growing season after treatment, d.b.h. and the number of epicormic branches on each 16-foot log section were remeasured.

As described by Meadows (1993), logging damage to individual residual trees, in the form of root, bole, or crown injuries, was assessed on the basis of three factors: (1) type of damage, (2) severity of damage, and (3) location of damage.

Data were subjected to analysis of variance for a randomized complete block design with three replications (sites) of two treatments, for a total of six experimental units. All effects were considered fixed. *Alpha* was set at 0.05. Plot- level variables represented the mean for all residual trees on each measurement plot. Means were separated through the use of Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

Stand Conditions

Based on a pre-harvest inventory conducted during August 1993,[2] stand density across the three sites ranged from 94 to 104 square feet of basal area per acre. Average d.b.h. of upper-canopy trees ranged from about 14 to 18 inches on the two high flat sites, and from 14 to 15 inches on the low flat site. Most of the larger trees in all three stands were oaks (average d.b.h. of oaks was 18.2 inches). Red oaks (primarily willow and water oaks) and sweetgum accounted for 60 to 70 percent of the basal area on the two high flat sites. Other species scattered throughout these two stands included elm (*Ulmus* spp.), sugarberry (*Celtis laevigata* Willd.), overcup oak, maple (*Acer* spp.), green ash, and water tupelo. On the low flat site, water tupelo accounted for 76 percent of the basal area. Other species found in the stand included green ash, overcup oak, sweetgum, red oaks, elm, and maple.

Deferment cutting removed approximately 87 percent of the basal area at each of the three sites, creating essentially open-grown conditions for the residual trees scattered across the areas. Residual stand density ranged from 7.5 to 10.4 trees and 11.5 to 14.9 square feet of basal area per acre. Average d.b.h. of residual trees ranged from 15 to 16 inches across the three sites. Oaks were the largest residual trees, with an average d.b.h. of 18.0 inches. Residual trees on the two high flat sites were primarily sweetgum, red oak (principally water and willow oaks), elm, green ash, and overcup oak, with lesser amounts of water hickory [*Carya aquatica* (Michx. f.) Nutt.], water tupelo, common persimmon (*Diospyros virginiana* L.), and swamp chestnut oak (*Q. michauxii* Nutt.). Residual trees on the low flat site were predominantly water tupelo and green ash, with lesser amounts of sweetgum, overcup oak, red oak, and sugarberry.

Diameter Growth

Average cumulative diameter growth of residual trees over the 3-year period following deferment cutting is compared to average cumulative diameter growth of residual trees over the 3-year period prior to treatment in table 1. There were no significant differences between posttreatment

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[2] Personal communication. 1993. Robin G. Clawson, School of Forestry, Auburn University, 108 M.W. Smith Hall, Auburn, AL 36849.

Table 1—Average cumulative diameter growth of residual trees for the 3-year period before and the 3-year period after deferment cutting

Treatment	Cumulative diameter growth		
	Year 1	Year 2	Year 3
	- - - - - - - - - - -	*Inches*	- - - - - - - -
Pre-treatment	0.25[a]	0.53	0.83
Posttreatment	0.22	0.49	0.83

[a] Differences between treatment means within each year are not statistically significant.

diameter growth and pre-treatment diameter growth during any of the 3 years of the study period. In fact, residual trees across all three sites grew an average of 0.83 inches in diameter in 3 years, exactly the same rate of growth observed prior to treatment. Consequently, deferment cutting had no effect on diameter growth of residual trees after 3 years, a result both unexpected and unexplained.

Individual species groups varied in their diameter growth response to deferment cutting (fig. 1). As a group, red oaks responded well to release and grew an average of 1.5 inches in d.b.h. during the 3 years following deferment cutting, as compared to an average growth rate of 1.1 inches during the 3 years prior to treatment. In contrast, essentially no diameter growth response was observed in green ash, sweetgum, or the white oak group (primarily overcup oak with a few swamp chestnut oaks).

Diameter growth response of individual oak species is presented in fig. 2. Willow oak responded very well to

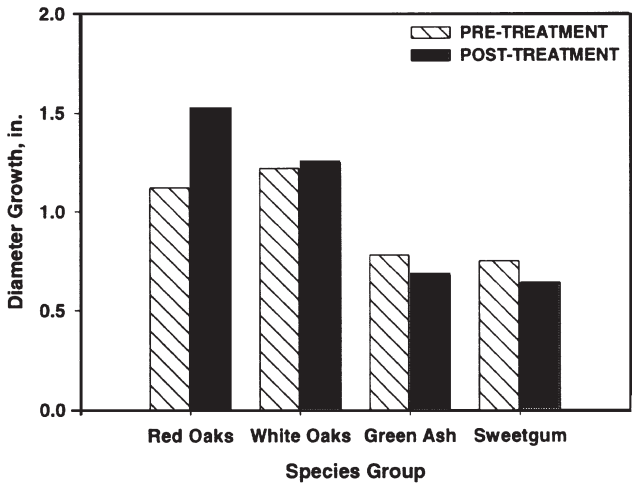

Figure 1—Cumulative diameter growth of residual trees, by species group, during the 3-year period following deferment cutting.

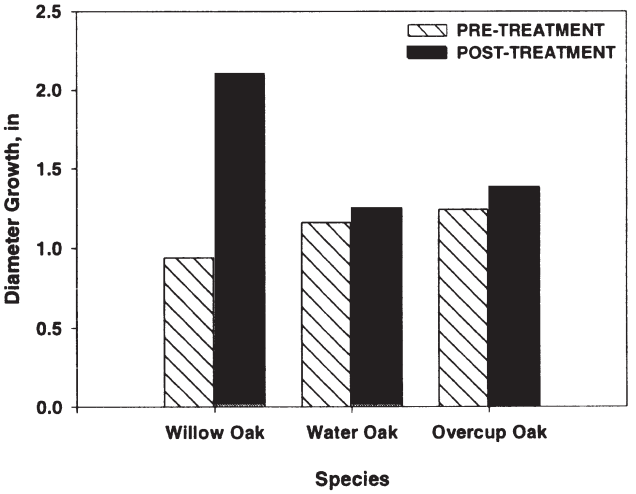

Figure 2—Cumulative diameter growth of residual trees of three oak species during the 3-year period following deferment cutting.

deferment cutting and grew an average of 2.1 inches in d.b.h. over the 3-year period, more than double its average pre-treatment growth rate of 0.9 inches. Both water and overcup oaks produced only small increases in diameter growth 3 years after deferment cutting.

Although deferment cutting had no statistically significant effect on diameter growth of residual trees, when averaged across all species, it does appear that diameter growth of willow oak, and, to a lesser extent, water and overcup oaks, will be increased by deferment cutting. These increases will likely become more pronounced as the study progresses.

Epicormic Branching

The cumulative production of new epicormic branches on both butt logs and upper logs of residual trees during the 3-year period following deferment cutting is summarized in table 2. Across all species and across all three sites, deferment cutting resulted in the production of 7.9 new epicormic branches on the butt logs and 10.6 new epicormic branches on the upper logs of residual trees. In

Table 2—Number of new epicormic branches produced on both butt logs and upper logs of residual trees during the 3-year period following deferment cutting

Log position	Cumulative total of new epicormic branches		
	Year 1	Year 2	Year 3
Butt log	3.7	6.6	7.9
Upper logs	3.2	7.8	10.6
Total	6.9	14.4	18.5

general, as few as five epicormic branches are enough to cause a reduction in grade of butt logs of hardwood trees (Meadows and Burkhardt, in press). In this study, nearly eight new epicormic branches were produced on the butt logs of residual trees. Although log grade has not been reevaluated since the deferment cutting was conducted, it is likely that many of the butt logs of residual trees have experienced a one-grade reduction in log grade as a result of new epicormic branches produced in response to deferment cutting. This probable reduction in log grade may also result in a significant loss of value of the standing timber.

Differences in epicormic branching among species—Species varied greatly in the number of new epicormic branches produced in response to deferment cutting (fig. 3). These observations support the contention that hardwood species vary considerably in their propensity to produce epicormic branches following some type of disturbance (Meadows 1995). For example, red oaks, classified by Meadows (1995) as highly susceptible to epicormic branching, averaged 20.6 new epicormic branches on the butt log 3 years after deferment cutting, whereas green ash, classified as a much more resistant species by Meadows (1995), averaged only 2.5 new epicormic branches on the butt log. White oaks and sweetgum, both classified as highly susceptible by Meadows (1995), actually ranked intermediate between the red oaks and green ash in the production of new epicormic branches in this study.

On average, the three primary species of oaks found in this study produced numerous epicormic branches in the 3-year period following deferment cutting (fig. 4). Generally, more new epicormic branches were produced on upper logs than on butt logs. All three oak species produced at least 14 new epicormic branches on the butt log; water oak, with an average of 23.5 new epicormic branches, was the most prolific sprouter. Meadows (1995) classified all three of these oak species as highly susceptible to epicormic branching, an assessment certainly supported by these data.

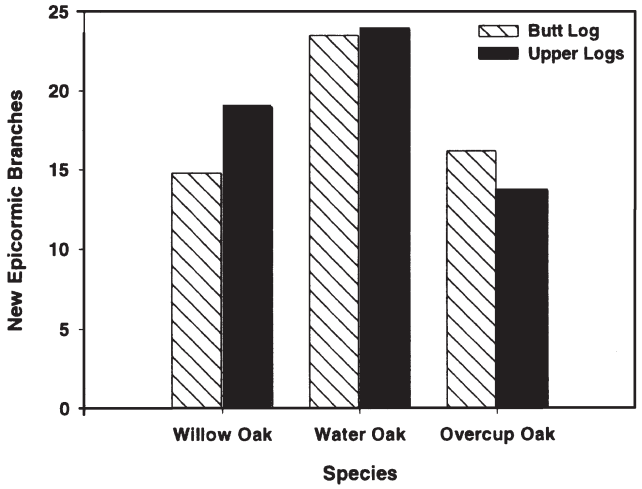

Figure 4—Number of new epicormic branches produced on both butt logs and upper logs of residual trees of three oak species during the 3-year period following deferment cutting.

Differences in epicormic branching among crown classes—Production of new epicormic branches also varied greatly among crown classes (fig. 5). The data form an orderly progression of increasing production of new epicormic branches from the dominant crown class through the codominant class to the intermediate class. Meadows (1995) proposed that tree vigor greatly affects the propensity of an individual hardwood tree to produce epicormic branches following some type of disturbance. Under this hypothesis, high-vigor trees are much less likely to produce epicormic branches than are low-vigor trees. Given that crown class is a reasonably adequate indicator

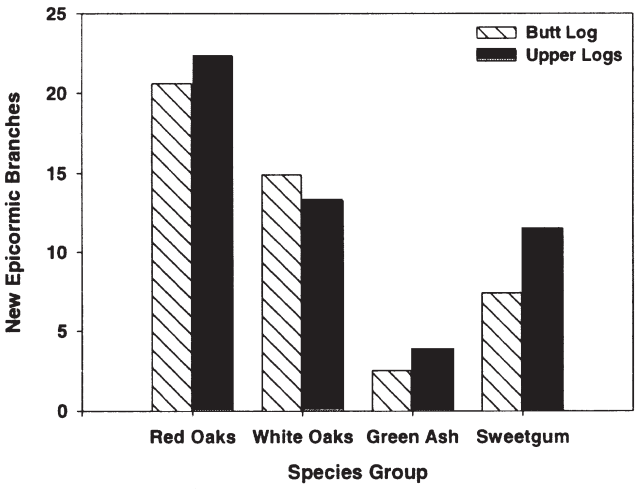

Figure 3—Number of new epicormic branches produced on both butt logs and upper logs of residual trees, by species group, during the 3-year period following deferment cutting.

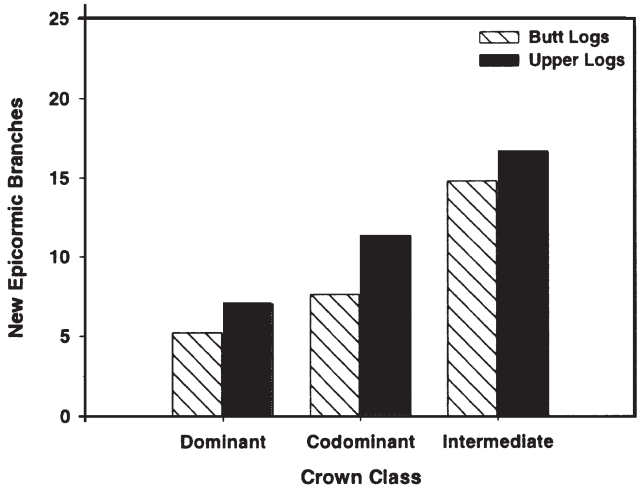

Figure 5—Number of new epicormic branches produced on both butt logs and upper logs of residual trees, by crown class, during the 3-year period following deferment cutting.

of tree vigor, the results obtained in this study tend to support the hypothesis that the production of new epicormic branches increases as initial tree vigor declines.

The apparent relationship between tree vigor and production of new epicormic branches was also observed across red oak crown classes (fig. 6). Dominant and codominant red oaks averaged 12.8 and 16.2 new epicormic branches on the butt log, respectively, whereas less-vigorous, intermediate red oaks averaged 52.3 new epicormic branches 3 years following deferment cutting. Even though red oaks are classified as highly susceptible to epicormic branching (Meadows 1995), the data from this study indicate that this inherent propensity to produce epicormic branches is diminished in high-vigor trees, even of highly susceptible species. However, intermediate red oaks, which represent a combination of highly susceptible species and low-vigor trees, were very prolific sprouters because they were unable to suppress their inherent propensity to produce epicormic branches.

Epicormic branching varied greatly not only among species but also among crown classes, especially within the red oak group. These observations support the hypothesis proposed by Meadows (1995) that the propensity of an individual hardwood tree to produce epicormic branches following some type of disturbance is inherently controlled at the species level, but is greatly modified by tree vigor, such that high-vigor trees, even of a highly susceptible species, are much less likely to produce epicormic branches than are low-vigor trees of the same species.

Logging Damage

A survey of logging damage across all three sites revealed that an average of 47 percent of the residual trees were damaged at least to some extent. This proportion of damaged trees is unacceptably high, particularly for stands in which residual trees are so widely scattered that skidder operators have ample space to maneuver. However, most of the logging damage found in this study was minor and probably will not result in a permanent loss of tree vigor.

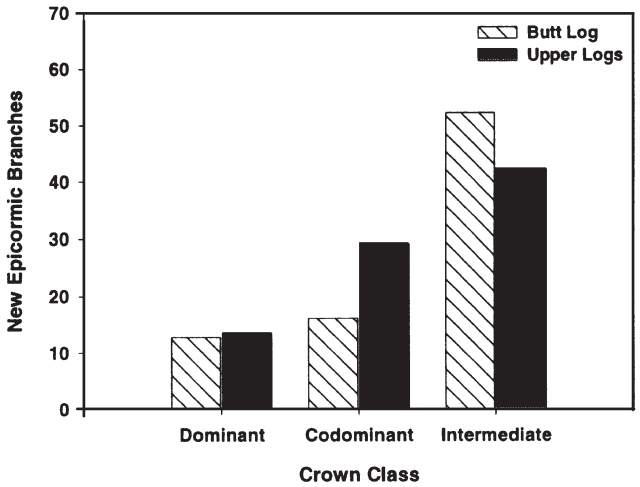

Figure 6—Number of new epicormic branches produced on both butt logs and upper logs of residual trees, by red oak crown class, during the 3-year period following deferment cutting.

The extent of the logging damage varied widely among the three sites, and ranged from 24 percent on one of the high flats to 65 percent on the other high flat. Logging damage on the more difficult terrain encountered on the low flat was 45 percent. Because different logging crews were contracted to cut each of the three sites, it is apparent that much of the differences in logging damage observed among the sites was due to differences among the logging crews in proper harvest planning and skidder operation.

Most of the damage occurred as logs pulled by the skidder scraped the lower boles and/or exposed lateral roots of residual trees. Although some degree of logging damage must be expected during any partial cutting operation, the extent of damage can be minimized through better planning of the logging operation and through more careful skidder operation.

CONCLUSIONS

Surprisingly, deferment cutting had no significant effect on average diameter growth of residual trees, except in willow oak, where diameter growth more than doubled during the 3-year period following treatment.

Deferment cutting also resulted in the production of numerous new epicormic branches along the boles of residual trees. However, the extent of epicormic branching varied widely among species and among crown classes. High-vigor, upper-crown-class trees produced considerably fewer new epicormic branches than did low-vigor, lower-crown-class trees, especially among red oaks.

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LEAVE-TREE MARKING VERSUS MARKING TO CUT—A COMPARISON OF SILVICULTURAL TACTICS

James M. Guldin, Fernando Carrillo, Miguel Acosta, and Raymond P. Guries[1]

Abstract—Leave-tree marking, or marking trees for retention, is commonly used in uneven-aged silviculture in western States but not in southern pines. We compared marking accuracy in one study (six 4-hectare stands) in which leave trees were marked, with that from a second study (sixteen 40-acre stands) in which trees were marked for cutting. Each study included similar shelterwood and single-tree selection treatments. Acceptable marking accuracy was defined as marking a stand to within ± 10 percent of the residual basal area target. Accuracy of leave-tree marking was acceptable in most tests, as was accuracy of cut-tree marking. With leave-tree marking, the tendency to undermark a stand leads to more, not less, overstory removal; this is important in uneven-aged silviculture, in which regeneration can be suppressed if too many leave trees are retained. Leave-tree marking might also be helpful in stands for which pre-harvest inventory information is limited, because it permits a direct tally of residual trees and basal area.

INTRODUCTION

Reproduction cutting methods in which a residual stand is retained after cutting, such as the even-aged shelterwood and uneven-aged single-tree selection methods, challenge the technical ability of both the silviculturist and the marking crew. If too few trees are retained, seed production and shelter may be foregone; if too many trees are retained, regeneration may become suppressed. The best silvicultural prescription is of little value if the marking crew is unable to mark the stand to achieve the prescribed stocking and stand structure.

When marking a reproduction cutting in a stand, a marking crew must distinguish between trees that are to be cut and those to be retained. This is usually done by marking and tallying the trees that are to be cut. This method has the advantage of generating a precise tally of volume being harvested. But if done carelessly, cut-tree marking can make crew members more concerned about the timber volume being harvested rather than about the desirable attributes of the trees being retained.

The main criterion for successful reproduction cutting is whether the stand successfully regenerates, not how much volume is removed. A properly marked stand is one that retains the best phenotypes at prescribed levels of stocking. But as the target stand structure becomes more complicated, so does accurate marking. For example, uneven-aged reproduction cutting requires leaving both the target residual basal area (RBA) and the proper distribution of trees across diameter classes. This is difficult for marking crews that lack experience with the method.

In Western States, silviculturists in uneven-aged stands have often used leave-tree marking, or marking trees for retention, instead of cut-tree marking (Becker 1995). Leave-tree marking provides a direct tally of the residual stand rather than of the trees being cut; crews that use cut-tree marking typically do not tally the residual stand. In addition, leave-tree marking allows experienced markers to compensate for diameter classes that have a deficit of trees by marking a comparable basal area in classes that have surplus trees. These advantages are especially useful when uneven-aged stands with complicated residual stand structures are being marked.

But leave-tree marking for reproduction cutting is uncommon in southern silviculture. Foresters sometimes mark leave trees in dense plantations or natural stands at the time of the first thinning, but use of a “logger-select” method, or no marking at all, is more common. Leave-tree marking has been used increasingly to mark residual trees in shelterwood and seed-tree stands on national forest land, but cut-tree marking is almost always used concurrently to meet other administrative requirements.

The objectives of this study were to compare the accuracy of leave-tree marking with that of cut-tree marking, and to briefly examine the advantages and disadvantages of leave-tree marking applied to southern pine stands.

METHODS

Comparisons were based on data from two separate studies in which the method of marking was carefully monitored, but in which the marking was otherwise done much as it is in operational practice. In one study, trees were marked for retention; in the other, trees were marked for cutting.

First Study—Leave-Tree Marking

Study area—Leave-tree marking data were obtained from a study of Montezuma pine (*Pinus montezumae* Lamb.) in Mexico. Montezuma pine, Mexico’s most important commercial conifer, is a yellow pine that attains a diameter of 1 meter (m) and a height of 35 m (Perry 1991). The study was located approximately 100 kilometers east of Mexico City at Campo Experimental San Juan Tetla (CE

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SJT), which is administered by Region Centro of the Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP), the national forestry research organization of Mexico. The stand lies at an elevation of 3300 m and has a southeasterly aspect. Topography is gentle to moderately steep (10 to 30 percent). Soils are deep, fertile, and of volcanic origin; the litter layer is over 0.5 m deep at some locations within the stand.

The 40-hectare (ha) stand used in this study was dominated by Montezuma pine, with minor proportions of three other conifers—a white pine (*P. ayacahuite* var. *veitchii* Shaw), a yellow pine (*P. teocote* Schl. & Cham.), and a fir (*Abies religiosa* Mart.). Hardwoods in the stand included an alder (*Alnus firmifolia* Fernald), willows (*Salix oxylepis* C.K. Schneid. and other *Salix* spp.), and an oak (*Quercus laurina* H.& B.). The understory is dominated by small *Alnus* spp., *Quercus* spp., *Salix* spp., and *Senecio* spp. The understory is dense (~20,000 stems per ha); walking through the stand is difficult.

Before treatment, stand basal area was 37.6 m^2 per ha, of which 32.8 m^2 per ha was Montezuma pine. Montezuma pine composed 70 percent of the stems and 87 percent of the basal area per ha. The quadratic mean diameter of Montezuma pine was 61.3 centimeters (cm), and 3.5 percent of the Montezuma pine trees in the study had diameters greater than 90 cm. Dominant Montezuma pines were approximately 35 m tall and 90 years old. Mature white pines were of similar size, and the largest tree measured was a fir with a diameter exceeding 1.4 m.

Installation of study plots—Eight square 4-ha treatment plots were located in January 1995. Each of these contained one square, concentrically located, 1-ha measurement plot. In January 1996, two replications of four treatments were installed, with one replication x treatment combination per 4-ha plot. The four treatments included two different shelterwood prescriptions, a single-tree selection prescription, and an uncut control (table 1). A 25 percent cruise of each 4-ha plot was used to develop a plot-specific marking tally for the reproduction cutting treatment in each plot. Marking tallies listed the number of trees to be retained by species and 5-cm diameter classes.

The shelterwood treatments were developed using spreadsheet software. For each treatment, the target number of trees within each diameter class was identified, and adjustments were made as marking proceeded to ensure that the tally matched the target RBA.

For the single-tree selection treatments, desired stand structure was obtained by applying the “BDq” approach (Leak 1964, Marquis 1978) using spreadsheet software. Several diameter classes had deficits of trees when compared to the target q. Since meeting the RBA target was thought to be more important than meeting the target q, the basal area deficit was distributed among the diameter classes that had surplus trees. This was done by developing a second q curve just for the surplus classes, such that the cumulative difference in basal area between the first and second q curves was equal to the deficit. Thus, six separate marking tallies—four shelterwood and

Table 1—Target stand structure for the Montezuma pine study and the shortleaf pine study

Treatment	Target RBA[a]	Dmax[b]	Dmin[c]	Keep[d]	q[e]
Montezuma pine study					
	m^2/ha	*cm*	*cm*	*Pct*	
Shelterwood, heavy	20	87.5	52.5	80	n/a
Shelterwood, moderate	15	87.5	62.5	75	n/a
Single-tree selection	21	87.5	n/a	n/a	1.21
Shortleaf pine study					
	ft^2/ac	*In*	*In*	*Pct*	
Shelterwood					
a. Pine	40	n/a	14-18	80	n/a
b. Pine-hardwood	30	n/a	14-18	80	n/a
Single-tree selection					
a. Pine	60	20	n/a	n/a	1.44
b. Pine-hardwood	50	20	n/a	n/a	1.44

[a] RBA is the residual basal area (m^2/ha) in the pine component.
[b] Dmax is the maximum diameter class retained.
[c] Dmin is the minimum diameter class retained.
[d] Keep is the percentage of trees retained in diameter classes between Dmax and Dmin to improve residual tree quality.
[e] q is the ratio between the number of stems in adjacent diameter classes.

two single-tree selection tallies—were prepared for the six 4-ha plots being marked.

Marking trees for retention—Three two-person marking crews did the marking, and a seventh person supervised the marking tally. One 4-ha treatment typically required three passes by the marking crews, and took 3 to 4 hours to mark. When a candidate residual tree was found, its diameter at breast height (d.b.h.) was measured and called out to the tally person. If the tally person indicated that the tree was acceptable for retention, the south face of the tree's bole was marked by blazing a smooth area on the bark surface (not to the cambium) with a machete (traditional Mexican technique), and spraying it with paint.

The tally person kept a cumulative tally of marked trees in all diameter classes, and compared this with the target residual stand based on the pre-harvest inventory. The marking tally typically deviated from the target, because of sampling error and silvicultural considerations such as size and spacing of residual trees. The challenge for the tally person was to balance the deviations in the tally by basal area. This was done by calculating the unmarked target basal area in the diameter classes where the target was not obtained, and by marking an equivalent basal area of trees in the diameter classes where the target was exceeded. With experience, this balance was obtained in the woods as the markers worked their way through the stand. All trees in the stand that were not marked with paint were subject to be cut.

Second Study—Marking Trees to Cut

Study area—Data on marking trees to cut were obtained from a replicated operational research study in 52 mature shortleaf pine (*P. echinata* Mill.) and pine-hardwood stands on south- and southwest-facing slopes in the Ouachita and Ozark National Forests (Baker 1994, Guldin and others 1994). Methods for stand selection and random assignment of treatments have been described elsewhere (Baker 1994, Guldin and others 1994).

Four treatments (16 stands) from the larger study were used in this comparison (table 1). In two of the treatments, pine shelterwood and pine single-tree selection, retention of hardwoods in the residual overstory was minimized; RBA targets were almost entirely pine. In the remaining two treatments, pine-hardwood shelterwood and pine-hardwood single-tree selection, retention of 10 feet $(ft)^2$ per acre of hardwoods was required. In the present study, however, only the accuracy of marking in the pine component of the stands is considered.

Installation of study plots—In 1991, a pre-harvest inventory (10 percent, using 0.2-acre fixed-radius plots) was conducted in each stand by national forest personnel. A reproduction cutting treatment was randomly assigned to each stand. Research team silviculturists then used the pre-harvest inventory data to develop marking guidelines unique to each stand based on each stand's randomly assigned prescription.

Twelve research plots were installed within the harvested area of each 40-acre stand (Baker 1994, Guldin and others 1994). Each plot consisted of a variable-radius (basal area factor 5.0) overstory plot, a fixed-radius (0.1-acre) midstory plot, and nested shrub and herbaceous plots. In this comparison, residual stand conditions are based on only the merchantable-sized trees (trees 3.6 inches in d.b.h. and larger) on overstory and midstory subplots. Marking accuracy for each treatment was based on the observed after-cut condition of each plot, relative to the target RBA, across 48 plots.

Marking trees for cutting—Trees to be cut were identified directly. For even-aged treatments, instructions were to leave the target pine RBA (30 or 40 ft^2 per acre, depending on the treatment) primarily from the upper crown classes by marking primarily from below. For uneven-aged treatments, the pre-harvest stand structure was compared with a BDq target structure with a specified RBA (50 or 60 ft^2 per acre, depending on the treatment). A marking tally was generated from the difference between the pre-harvest inventory and the BDq target, after adjusting for deficit diameter classes by adding equivalent basal area in surplus classes according to the q (Leak 1964, Marquis 1978), as described previously.

Marking was done by national forest marking crews in summer and fall of 1992, in conformity with standard practice in the USDA Forest Service, Southern Region. Trees were marked for cutting based on the marking tally provided by the research team. Marking guidelines included a tally of the number of trees per acre and per stand to cut by 2-inch diameter classes.

Calculation of Marking Accuracy

For each study, marking accuracy was calculated as the deviation in residual basal area (dRBA):

$$\text{dRBA} = (\text{observed RBA after cut}) - (\text{target stand RBA}).$$

Because the Montezuma pine study is in metric units and the shortleaf pine study is in English units, dRBA was standardized as a percentage deviation (percent dRBA) from the target RBA as follows:

$$\text{percent dRBA} = \text{dRBA}/(\text{target stand RBA}).$$

This allows direct study-to-study comparisons of marking accuracy. Positive values for dRBA and percent dRBA indicate that the observed RBA is greater than the target RBA, or that too many trees were retained. Negative values of dRBA and percent dRBA indicate that too few trees were retained.

RESULTS

Leave-Tree Marking

Marking accuracy was acceptable in two of the three reproduction cutting methods with Montezuma pine at CE SJT (table 2). In both the moderate shelterwood and the single-tree selection treatments, marked RBA was within 1

Table 2—Mean marking accuracy data for the treatments in the study

Treatment	Target RBA	Marked RBA	dRBA	Percent dRBA
Montezuma pine study				
	- - - - - - - - - -	m^2/ha	- - - - - - - - - -	
Heavy shelterwood	20.03	16.02	-4.01	-20.0
Moderate shelterwood	15.02	15.26	0.24	1.6
Both shelterwoods	17.52	15.64	-1.88	-9.2
Single-tree selection	20.98	20.12	-0.86	-4.1
All treatments	18.67	17.13	-1.54	-7.5
Shortleaf pine study				
	- - - - - - - - - -	ft^2/ac	- - - - - - - - - -	
SW, pine[a]	40.0	39.04	-0.96	-2.4
SW, pine-hardwood	30.0	32.26	2.26	7.5
Both shelterwoods	35.0	35.65	0.65	2.6
STS, pine[b]	60.0	64.92	4.92	8.2
STS, pine-hardwood	50.0	55.35	5.35	10.7
Both STS treatments	55.0	60.14	5.14	9.5
All treatments	45.0	47.89	2.89	6.0

[a] SW: shelterwood.
[b] STS: single-tree selection.

m^2 per ha (5 percent) of the target. However, the heavy shelterwood method was marked too heavily, with RBA 4 m^2 per ha (20 percent) under target. When marking, crews found it difficult to justify retaining trees of poor form in the smaller diameter classes simply to meet the target RBA.

When both shelterwood treatments were combined, the overall marking accuracy was acceptable (table 2), within 2 m^2 per ha (9.2 percent) under the target. Again, this RBA was slightly lower than intended.

Marking accuracy for all three treatments combined was also within acceptable limits. The marked RBA was 1.54 m^2 per ha (7.5 percent) under the target. Therefore, we judged marking trees for retention to be an acceptably accurate method of marking; deviations were in the direction of retaining slightly less RBA than the prescribed target.

Cut-Tree Marking

Marking accuracy was acceptable in both the pine and pine-hardwood shelterwood treatments in the Ouachita shortleaf pine study (table 2). The pine shelterwood treatment was overmarked slightly, with RBA averaging ~1 ft^2 per acre (2.4 percent) below the target. In the pine-hardwood shelterwood, the pine component was undermarked slightly; RBA was a little more than 2 ft^2 per acre (7.5 percent) greater than the target. For the shelterwood treatments combined, marking accuracy was within 1 ft^2 per acre (2.6 percent) of the target.

In the single-tree selection stands, cut-tree marking was slightly less accurate but still acceptable (table 2). The pine component was slightly undermarked in the pine single-tree selection stands; RBA was about 5 ft^2 per acre (8.2 percent) greater than the target. The pine-hardwood treatments were of marginally unacceptable accuracy—mean RBA was just over 5 ft^2 per acre (10.7 percent) greater than the target RBA. For the two single-tree selection treatments combined, actual RBA exceeded target RBA by 5.1 ft^2 per acre (9.5 percent)—just within the 10 percent margin of acceptable accuracy.

Marking accuracy was also well within the pre-established standard for all cut-tree marking treatments combined. The marked RBA was just less than 3 ft^2 per acre (6 percent) higher than target RBA. All of these data indicate that cut-tree marking was acceptably accurate, though marginally so in some treatments.

Comparison of Methods

Percent dRBA figures for both studies show that marking accuracy was generally acceptable—within 10 percent (table 3). Overall, cut-tree marking was the more accurate method in the pine shelterwood treatments. However, leave-tree marking was slightly more accurate than cut-tree marking in the single-tree selection stands. Marking accuracy was unacceptable (percent dRBA greater than 10 percent) in only one of the six treatment and marking combinations.

In both treatments with leave-tree marking, after-cut stands had negative deviations from the target, indicating the

Table 3—Marking accuracy (percent dRBA), leave-tree marking versus cut-tree marking in shelterwood and single-tree selection treatments

Treatment	Percent dRBA leave-tree marking	Percent dRBA cut-tree marking pine	Percent dRBA cut-tree marking pine-hardwood
Shelterwood	-9.2	-2.4	7.5
Single-tree selection	-4.1	8.2	10.7
All treatments	-7.5	2.9	9.1

stands were overcut slightly (table 3). Conversely, three of the four cut-tree marking treatments had after-cut stands with positive deviations from the target (table 3), indicating a slightly undercut stand (more overstory residual basal area than the target). Undercutting was more likely in the single-tree selection than in the shelterwood treatments, and more likely in the pine-hardwood treatments than in the pine treatments.

DISCUSSION

These data suggest that leave-tree marking can be a feasible alternative to cut-tree marking; both were generally similar in marking accuracy. Overall, leave-tree marking generally resulted in accuracy within 10 percent of the RBA target. Leave-tree marking was slightly less accurate than cut-tree marking where the shelterwood method was employed, but slightly more accurate than cut-tree marking when the single-tree selection method was used. Generally, as the residual stand structure was increasingly complicated (higher RBA or an increasing hardwood component), cut-tree marking became less accurate.

This comparison is not extremely robust statistically. The two studies were established in different forest types in different countries, by different marking crews. Edaphic, climatic, and physiographic conditions differed between studies, and different experimental designs and units of measurement were used. But key elements of the comparison are robust—all marking plans in both studies were developed in very much the same way by the same investigator. Comparable silvicultural systems were analyzed, and the percent dRBA marking accuracy statistic was designed to equalize data based on different measurement units.

Leave-tree marking has several attributes that justify its consideration as an alternative to cut-tree marking. First, the method allows timber markers to concentrate directly, rather than indirectly, on the trees to leave. If too much attention is paid to marking the trees to cut, the residual stand becomes a byproduct of the harvest—especially in the valuable larger size classes. Leave-tree marking results in a marking job more in line with the silvicultural rationale by which the decision to retain a residual stand was initially made.

Second, the tendency of markers to undermark—to put paint on fewer trees than is specified on the marking tally—leads to different results under the two methods. When marking trees to cut, undermarking results in RBAs that exceed target levels. For example, pines in the single-tree selection stands in the Ouachita study were undermarked by 5 ft^2 per acre, and pines in the pine-hardwood treatment were undermarked by over 10 ft^2 per acre. These RBAs may be sufficiently high to preclude adequate development of regeneration through the cutting cycle. Conversely, when marking trees to leave, undermarking results in RBA that is lower than the target level, as in the heavy shelterwood treatment in the Mexico study. This results in a less dense residual overstory than intended—and such an overstory is more favorable for establishment and development of regeneration than one that is too dense.

Leave-tree marking has another advantage when applied to the single-tree selection method. Existing practice in uneven-aged silviculture requires a pre-harvest stand inventory to prepare the marking tally. This inventory has a sampling error associated with it. Under cut-tree marking, all trees marked to cut are tallied—essentially a 100 percent tally of trees being cut. Thus, that original pre-harvest sampling error will be carried into the residual stand, since the 100 percent marking tally has, by definition, no error. The result is that the target RBA may be missed by a factor directly related to the sampling error in the pre-harvest inventory.

On the other hand, if leave-tree marking is used, all trees marked to leave are tallied. This gives a direct calculation of the target RBA. The pre-harvest sampling error is placed “on the logging deck” in the trees being cut. This is a more desirable silvicultural situation especially if accurate retention of the residual stand is critical, as it can be for uneven-aged reproduction cutting.

From this, it follows that leave-tree marking may provide a way to mark uneven-aged stands accurately without a pre-harvest inventory. If a reasonable target residual BDq structure for average stand conditions can be developed for typical stands in a given ecological land type, then one could mark directly to that target. The requirement of a pre-harvest inventory has hindered the use of uneven-aged silviculture in certain situations, such as national forest land in which district technical support is becoming increasingly limited. However, this would work only if the stand was fairly typical. Otherwise, extreme care would be needed to avoid potentially serious deviations from the target.

Certainly, leave-tree marking has disadvantages. Foremost among them is the considerable effort and time that goes into determining the volume to be harvested. For example, Region 8 of the USDA Forest Service has developed detailed procedures for estimating the volume of timber being harvested based on a subsample of trees marked for cutting. Such procedures would require extensive modification to enable them to generate accurate volumes under leave-tree marking. On the other hand, Region 8 has occasionally conducted area-estimation sales for even-aged stands, and this could be done for uneven-aged stands as well.

Second, new procedures for monitoring harvests will be needed when leave trees are marked because the trees being cut are unmarked. It would be important to clearly identify stand boundaries to prevent cutting of unmarked trees in stream protection zones or beyond project boundaries. Procedures for preventing cutting of unmarked trees (tracer paint, for example) would have to be replaced by procedures for preventing cutting of marked trees (stump inspections for marks that have been removed or obscured).

Third, leave-tree marking can be more labor-intensive than cut-tree marking. In a shelterwood where RBA is being reduced from 90 to 30 ft^2 per acre, there are relatively few leave trees to be marked. However, in a well-balanced

uneven-aged stand where RBA is being reduced from 75 to 60 ft^2 per acre, leave-tree marking will be much more labor-intensive than cut-tree marking because the bulk of the basal area must be marked. Thus, if leave-tree marking has a role in southern silviculture, it may well be as a method applied in converting even-aged stands to uneven-aged structure, where stand basal area is taken from 100 to 120 ft^2 per acre to 50 to 60 ft^2 per acre, and where the quality of residual trees must be considered.

Finally, paint on residual trees after the cut may be visually unattractive. One modification might be to mark trees inconspicuously, such as with a vertical stripe from groundline to 3 feet on the side that faces away from roads. Another might be to use colors that blend into the forest. A third might be to change colors from one harvest to the next, especially where short cutting cycles (3 to 5 years) are employed.

In summary, leave-tree marking may be a useful alternative to cut-tree marking in certain silvicultural applications. Our data suggest that crews can mark with similar accuracy by both methods. A broader operational test would be needed to identify the practical modifications required for administration of timber sales. Given its practical advantages, especially relative to uneven-aged reproduction cutting, leave-tree marking might have a place in the repertoire of the silviculturist.

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