GROWTH AND BOLE QUALITY RESPONSES TO THINNING IN A RED OAK-SWEETGUM STAND IN SOUTHEASTERN ARKANSAS: NINE-YEAR RESULTS

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ABSTRACT

Science-based guidelines for thinning in southern bottomland hardwood stands are inadequate. To address this need, we established a series of thinning studies based on stand density management in hardwood stands on minor streambottom sites across the South. In the third study in this series, four thinning treatments were applied to a poletimber-sized, red oak-sweetgum (Quercus spp.-Liquidambar styraciflua) stand in southeastern Arkansas in September 1999: (1) unthinned control; (2) light thinning to 70 to75 percent residual stocking; (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to the recommended residual stocking for bottomland hardwoods. By the end of the ninth year after treatment, thinning had improved stand-level basal area growth but with no differences among the three levels of thinning in the rate of growth. Thinning also had increased diameter growth of residual trees, especially red oaks, but the magnitude of diameter growth response by red oaks did not differ among the three levels of thinning. The increased diameter growth of residual trees accelerated the rate of stand development through rapid increases in the number of red oak sawtimber trees per acre and rapid increases in quadratic mean diameter. The number of epicormic branches on the butt log was high and did not differ statistically among treatments.

INTRODUCTION

Management of hardwood stands for the production of high-quality sawtimber requires the capability to develop and sustain satisfactory growth rates and high-grade logs in trees of commercially valuable species. To achieve this goal, thinning often is used in mixed-species hardwood stands to increase growth of residual trees, to maintain and possibly enhance bole quality of residual trees, and to improve species composition of the residual stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees. In general, diameter growth increases as thinning intensity increases. Goelz (1995) proposed that desirable residual stocking after thinning in even-aged, sawtimber stands of southern hardwoods ranges from 65 to 80 percent. However, very heavy thinning may reduce stand density to such an extent that stand growth is diminished even though growth of individual trees may be enhanced. Goelz (1997) estimated that the minimum stocking level necessary to maintain acceptable stand-level growth in southern hardwood stands ranges from 40 to 60 percent.

Even though thinnings are designed to maintain and possibly enhance bole quality of residual trees, they sometimes have adverse effects on bole quality. New epicormic branches may develop along the boles of residual hardwood trees during the first few years after thinning. Epicormic branches are adventitious twigs that develop from dormant buds along the bole. Standard grading rules for hardwood factory logs stipulate that epicormic branches greater than 3/8 inches in diameter at the bark surface are defects on logs of all sizes, grades, and species (Rast and others 1973). Consequently, the presence of a sufficient number of well-distributed epicormic branches may reduce log grade and both lumber grade and value (Meadows and Burkhardt 2001).

Meadows (1995) hypothesized that species and tree health control the release of those dormant buds that develop into epicormic branches, such that healthy, upper-crown-class trees are much less likely to produce epicormic branches after thinning than are unhealthy, lower-crown-class trees. Because well-designed hardwood thinnings retain healthy, high-quality trees of desirable species and remove unhealthy, low-quality trees, production of epicormic branches across the residual stand actually may decrease after thinning (Sonderman and Rast 1988). Conversely, thinnings that fail to retain healthy, high-quality trees often result in the development of numerous epicormic branches along the boles of residual trees.

Thinning also improves both species composition and stand quality in mixed-species hardwood stands (Meadows 1996). Thinning prescriptions that emphasize quality and value of individual trees tend to decrease the proportion of low-quality, low-value trees and to increase the proportion of high-quality, high-value trees in the residual stand. Trees that are damaged or diseased, that have low-quality boles, or that are undesirable species should be removed from the stand; trees that are healthy, that have high-quality boles, and that are desirable species should be retained.

Science-based information on thinning in southern bottomland hardwood stands is inadequate. Published guidelines, such as those proposed by McKnight (1958),

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Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience than on actual research results. To address this need, we established a series of thinning studies based on the concept of stand density management in red oak-sweetgum (Quercus spp.-Liquidambar styraciflua) stands on minor streambottom sites across the South. The underlying presumption of stand density management is that hardwood stands are managed best through regulation of stand density. The stand to be thinned is marked to some pre-determined level of residual density spread uniformly across the stand.

All studies in this series use the same design, treatments, and methods. Each study will determine the effects of several levels of thinning on: stand growth and development; and growth and bole quality of individual trees. Results from the entire series of studies will be combined to develop practical thinning guidelines for managing existing stands of southern bottomland hardwoods. The study reported here is the third in the series. Early results from other studies in the series were reported by Meadows and Goelz (1998, 1999, and 2002) and by Meadows and Skojac (2006).

METHODS

STUDY AREA

The study area is located within the floodplain of the Saline River in Cleveland County, north of the city of Warren, in southeastern Arkansas. The site is nearly flat and is subject to periodic flooding in winter and spring. Ochlockonee silt loam (coarse-loamy, siliceous, active, acid, thermic Typic Udifluvent) is the predominant soil series, with average site indices of 90 feet at 50 years for willow oak (*Q. phellos*) and 112 feet at 50 years for sweetgum (Broadfoot 1976).

The study area lies in a 138-acre, even-aged stand composed primarily of red oak and sweetgum. Principal red oak species are willow oak and water oak (*Q. nigra*), with scattered cherrybark oak (*Q. pagoda*) and Nuttall oak (*Q. texana*). In addition to sweetgum, other common species in the overstory include overcup oak (*Q. lyrata*), green ash (*Fraxinus pennsylvanica*), and baldcypress (*Taxodium distichum*). The primary understory species is American hornbeam (*Carpinus caroliniana*). The stand was about 35 years old at the time of study installation. We classified the stand as a poletimber stand on a medium-quality site, with high initial stocking.

PLOT DESIGN

Plot design followed a standard format for silvicultural research plots.[1] Each treatment was applied uniformly across a 2.0-acre rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One 0.6-acre rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), which provided a buffer strip 1 chain (66 feet) wide around each measurement plot. The entire study covered an area of 24 acres.

TREATMENTS

Treatments were defined as different levels of residual stocking, based on the stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (1) an unthinned control, (2) light thinning to 70 to 75 percent residual stocking, (3) heavy thinning to 50 to 55 percent residual stocking, and (4) B-line thinning to the desirable residual stocking recommended by Putnam and others (1960).

All thinning treatments removed most of the smaller poletimber trees as well as sawtimber trees that were damaged or diseased, had poor bole quality, or were undesirable species. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), formed the cutting priority for each treatment. Cutting stock and cull stock trees were removed first, followed by reserve growing stock trees, when necessary, until the target residual stocking for each treatment was met. Three replications of the four treatments were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1999.

STATISTICAL ANALYSIS

Data were subjected to a one-way analysis of variance for a randomized complete block design with three replications of four treatments, for a total of 12 experimental units. Treatment effects were considered fixed, while block effects were considered random. Alpha was set at 0.05 for all statistical tests. Plot-level variables represented the mean for all residual trees on each measurement plot. Treatment means were separated through the use of Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

STAND CONDITIONS PRIOR TO THINNING

Prior to thinning, the study area averaged 343 trees and 123 square feet of basal area per acre, with a quadratic mean diameter of 8.2 inches, among trees ≥ 3.5 inches d.b.h. Average stocking across the study area was 117 percent, which greatly exceeded maximum full stocking (100 percent), the point at which thinning is recommended in even-aged stands of southern bottomland hardwoods (Goelz 1995). There were no significant differences among treatments in any preharvest characteristics (table 1). Many codominant trees exhibited symptoms of poor health, such as crown deterioration, loss of apical dominance, and the

[1]Marquis, D.; Smith, C.; Lamson, N. [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. 55 p. Unpublished report. On file with: James S. Meadows, Southern Research Station, P.O. Box 227, Stoneville, MS 38776

presence of numerous epicormic branches along the boles. Most of these trees were removed during the thinning operation. Thinning the stand a few years earlier, however, would have prevented overstocking and would have minimized the proportion of trees in poor health.

Red oak and sweetgum clearly dominated this poletimber stand. Prior to thinning, these species together accounted for 83 percent of stand basal area. Red oak comprised 56 percent of stand basal area and dominated the upper canopy of the stand, whereas sweetgum accounted for 27 percent of the basal area and was found in both the upper and middle canopies. Other species, such as overcup oak, green ash, and baldcypress, made up 13 percent of stand basal area and occurred as scattered individuals throughout the upper canopy. American hornbeam in the lower canopy accounted for the remaining 4 percent of stand basal area.

STAND DEVELOPMENT AFTER THINNING

Stand conditions immediately after thinning—Light thinning reduced stand density to 125 trees and 80 square feet of basal area per acre, increased quadratic mean diameter to 10.9 inches, and reduced stocking to 70 percent (table 2). Compared to the overall stand averages prior to thinning, it removed 64 percent of the trees and 35 percent of the basal area. Heavy thinning reduced stand density to 106 trees and 58 square feet of basal area per acre, increased quadratic mean diameter to 10.0 inches, and reduced stocking to 52 percent. It removed 69 percent of the trees and 53 percent of the basal area. B-line thinning reduced stand density to 118 trees and 70 square feet of basal area per acre, increased quadratic mean diameter to 10.4 inches, and reduced stocking to 62 percent. It removed 66 percent of the trees and 43 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control, with one exception: quadratic mean diameter of the residual stand after heavy thinning was not significantly different from quadratic mean diameter of the unthinned control.

Stand conditions 9 years after thinning—Stand-level growth in the unthinned control plots over the past 9 years has been slow (table 3). Basal area increased 11 square feet per acre (from 132 to 143 square feet per acre), an average of only 1.2 square feet per acre per year. Cumulative mortality was 25 percent, an average rate of 2.8 percent per year. Most of the trees that died were small, overtopped trees that were in poor health at the time of study establishment. Quadratic mean diameter of the unthinned control plots increased 1.7 inches, from 8.9 to 10.6 inches. However, much of the increase in quadratic mean diameter is the result of the deaths of many small trees rather than the result of actual diameter growth by surviving trees. With a current quadratic mean diameter of 10.6 inches, the unthinned stand remains in the poletimber size class. Stocking 9 years after study establishment averaged 126 percent, a level that well exceeds maximum full stocking (100 percent). The unthinned control plots are greatly overstocked and stagnant, a condition that has led to slow stand-level growth and moderately high mortality.

By the end of the ninth year after treatment, all three levels of thinning exhibited stand-level characteristics that were significantly different from the unthinned control, but no significant differences in cumulative basal area growth and quadratic mean diameter were found among the three levels of thinning (table 3). Cumulative basal area growth rates ranged from 2.7 to 3.1 square feet per acre per year across the three levels of thinning, as compared to only 1.2 square feet per acre per year in the unthinned control. Because the rates of basal area growth were so similar among the three levels of thinning, significant differences in stand basal area that were created immediately after thinning (table 2) still persist 9 years later (table 3). Similarly, increases in quadratic mean diameter among the three levels of thinning ranged from 4.7 to 5.1 inches, as compared to only 1.7 inches in the unthinned control. The current quadratic mean diameters of the thinned plots indicate that all three levels of thinning accelerated the rate of stand development to the extent that all thinned plots presently are classified as small-sawtimber stands. The unthinned control, with a current quadratic mean diameter of 10.6 inches, remains classified as a poletimber stand. Because hardwood sawtimber is much more valuable than hardwood poletimber, all three levels of thinning increased stand value dramatically in just 9 years.

Clearly, thinning greatly improved stand basal area growth and development, with no differences found among the three levels of thinning in the rate of stand growth. Relative to the unthinned control plots, the thinned plots are growing more rapidly, are developing at a more accelerated pace, are healthier, and contain more valuable timber. These desirable responses to thinning will help achieve the management goal of high-quality, hardwood sawtimber production.

DIAMETER GROWTH

Relative to the unthinned control, all three levels of thinning significantly increased cumulative diameter growth of residual trees, averaged across all trees of all species, throughout the 9 years since thinning (table 4). Significant differences among treatments observed after the first year continued to widen over time. In fact, by the end of the third year after thinning, cumulative diameter growth of residual trees after both heavy thinning and B-line thinning was significantly greater than cumulative diameter growth of residual trees after light thinning. This pattern continued through the end of the ninth year after thinning. By that time, both heavy thinning and B-line thinning had nearly tripled individual-tree diameter growth relative to the unthinned control.

Diameter growth response data were separated into two species groups: red oak and sweetgum. Relative to the unthinned control, all three levels of thinning significantly increased diameter growth of residual red oaks, through the ninth year after thinning (fig. 1). Cumulative diameter growth in the thinned plots ranged from 2.2 inches after light thinning to 2.7 inches after heavy thinning, as compared to 1.7 inches in the unthinned control plots. All three levels of thinning also significantly improved cumulative diameter growth of sweetgum, but response was less than that observed among red oaks. In contrast to the red oaks, diameter growth response of sweetgum was significantly greater after both heavy thinning and B-line thinning than after light thinning.

Even though all three levels of thinning significantly increased cumulative diameter growth of residual red oaks relative to the unthinned control, there were no significant differences among those three levels of thinning (fig. 1). In other words, diameter growth response of residual red oaks 9 years after thinning was statistically the same for light thinning, heavy thinning, and B-line thinning. Diameter growth response of residual red oaks to thinning was independent of residual stand density, at least within the range of residual densities evaluated in this study: 58 square feet of basal area per acre after heavy thinning to 80 square feet of basal area per acre after light thinning. The same result was observed in other studies within our series of thinning studies based on stand density management (Meadows and Goelz 2002, Meadows and Skojac 2006).

Clearly, all three levels of thinning successfully increased diameter growth of residual trees during the first 9 years after treatment. The largest increases were observed among red oaks. In fact, when the three levels of thinning are averaged together, thinning increased diameter growth of residual red oaks by 47 percent relative to the unthinned control. Because the magnitude of the diameter growth response by red oaks did not differ within the fairly broad range of residual densities evaluated in this study, thinning prescriptions that strictly adhere to stand density management may not be appropriate in bottomland hardwood stands with a large component of red oak. Rather, thinning prescriptions that focus on development and maintenance of high-quality, high-value trees may be more suitable for those stands.

PRODUCTION OF EPICORMIC BRANCHES

When averaged across all trees of all species, thinning had no significant effect on the number of epicormic branches on the butt logs of residual trees throughout the 9 years since thinning (table 5). Means after all three levels of thinning increased steadily for the first 3 years after thinning, remained relatively stable through the sixth year, then appeared to decline somewhat over the last 3 years. This same pattern was observed in other studies within this series of thinning studies based on stand density management (Meadows and Goelz 2002, Meadows and Skojac 2006). In contrast, the number of epicormic branches on the butt logs of trees in the unthinned control remained relatively constant through the first 9 years of the study.

The number of epicormic branches on the butt log varied widely among individual trees. Most trees that appeared to be healthy, with large, well-shaped crowns and dense foliage, had either no epicormic branches or only a few. Conversely, most trees that appeared to be unhealthy, with small crowns and sparse foliage, generally had many epicormic branches. These general observations tend to support the hypothesis advanced by Meadows (1995) that tree health is the primary factor that controls the production of new epicormic branches in response to disturbance.

Because hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995), data were partitioned by the species groups red oak and sweetgum (fig. 2). None of the three levels of thinning had a significant effect on the number of epicormic branches on the butt logs of residual red oak or sweetgum, 9 years after thinning. However, wide variation in the data may have prevented detection of significant differences among treatments within each species group. The number of epicormic branches on the butt logs of residual red oaks ranged from 8.7 after B-line thinning to 11.4 after heavy thinning, as compared to 8.3 branches on the butt logs of red oaks in the unthinned control. Much broader variation was found among sweetgum trees, where means ranged from 5.3 branches after B-line thinning to 11.8 branches after heavy thinning, as compared to 6.4 branches in the unthinned control. All of these means are sufficiently high to likely cause reductions in log grade and value.

The presence of numerous epicormic branches on trees in the unthinned control plots likely was due to two factors: (1) overall poor stand health throughout the study, and (2) a large proportion of red oak and sweetgum in the stand. The original stand was overstocked and stagnant at the time of study establishment and remained so in the unthinned control plots throughout the study. Many trees in the stand exhibited symptoms of poor health. Meadows (1995) hypothesized that trees in poor health are more susceptible to the production of epicormic branches than are trees in good health. Meadows (1995) further observed that hardwood species vary greatly in the likelihood that they will produce epicormic branches and classified willow oak, water oak, and sweetgum as highly susceptible to the production of epicormic branches. Therefore, it is likely that the large proportions of these species in the stand contributed to the large number of epicormic branches found on trees throughout the study.

These two factors, combined with the use of thinning prescriptions based on stand density management, led to the presence of large numbers of epicormic branches on the butt logs of residual trees after all three levels of thinning. When the stand was marked, there were insufficient numbers of trees in good health to meet the target residual densities specified by the three thinning prescriptions. To maintain the target residual densities uniformly across the treatment plots, it was necessary to retain relatively large numbers of trees in poor to moderate health in all thinned plots. These trees usually already have several epicormic branches and are very susceptible to the production of additional epicormic branches. Consequently, strict adherence to stand density management forced the retention of many less-than-desirable trees, which resulted in a large number of epicormic branches on residual red oak and sweetgum trees across all three levels of thinning.

ACCELERATED DEVELOPMENT OF RED OAK SAWTIMBER

Because red oak is more valuable than sweetgum and because sawtimber is more valuable than poletimber, the most valuable component of the stand is red oak sawtimber. If the basic goal of thinning is to increase the value of the stand, one way to evaluate the success of the thinning treatments is to monitor the number of red oak sawtimber (d.b.h. ≥ 12.0 inches) trees per acre over time. Because means for this variable were similar across the three levels of thinning during each year of the study, the data for the thinned plots were combined into a single mean for each year, which then was compared to the unthinned control (fig. 3).

The number of red oak sawtimber trees per acre in the unthinned control increased slowly during the past 9 years (fig. 3). There were 17 red oak sawtimber trees per acre in the unthinned control at the time of study establishment. Red oak sawtimber accounted for 14 percent of all living red oaks and 5 percent of all living trees at that time. By the end of the ninth year after study establishment, there were 28 red oak sawtimber trees per acre, which represented 33 percent of all living red oaks and only 12 percent of all living trees.

Similarly, there were 17 red oak sawtimber trees per acre, averaged across the three levels of thinning, just prior to thinning (fig. 3). Red oak sawtimber comprised 9 percent of all living red oaks and 5 percent of all living trees at that time. The average rate of increase in the number of red oak sawtimber trees per acre in the thinned plots was similar to the rate of increase in the unthinned control plots through the first 2 years after thinning. However, during the third year after thinning, the rate of increase accelerated substantially in the thinned plots. The gap between the thinned plots and the unthinned control plots in the number of red oak sawtimber trees per acre continued to widen from the third through the ninth years after thinning. By the end of the ninth year, there were 46 red oak sawtimber trees per acre in the thinned plots, which accounted for 57 percent of all living red oaks and 44 percent of all living trees.

Currently, in the unthinned control plots, red oak sawtimber accounts for one out of every three red oak trees and only one out of every eight trees of all species and sizes. With a current quadratic mean diameter of 10.6 inches and such a small component of red oak sawtimber, the unthinned control is classified as a poletimber stand. At the current stage of stand development, the primary timber product available for harvest in the unthinned control is pulpwood. Conversely, red oak sawtimber in the thinned plots accounts for over half of all red oak trees and nearly half of all trees. With quadratic mean diameters ranging from 12.8 to 13.0 inches and relatively large components of red oak sawtimber, the thinned plots for all three levels of thinning are classified as small-sawtimber stands. At this accelerated stage of stand development, both sawtimber and pulpwood are available for harvest in the thinned plots.

All three levels of thinning accelerated the rate of stand development, relative to the unthinned control. Because they contain both sawtimber and pulpwood rather than just pulpwood, the thinned plots are now more valuable than the unthinned control plots and likely will remain so for many years. Furthermore, this accelerated rate of stand development likely will reduce the length of the rotation in the thinned plots, as residual trees reach the desired size classes more rapidly. All in all, the three thinning prescriptions evaluated in this study provide acceptable pathways to achieve the management goal of high-quality sawtimber production in red oak-sweetgum stands.

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Table 1—Treatment means (± SE) for stand conditions prior to application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.22 for number of trees, p = 0.27 for basal area, p = 0.06 for quadratic mean diameter, p = 0.51 for stocking)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned	310 ± 16 a	132 ± 3 a	8.9 ± 0.3 a	122 ± 1 a
Light Thinning	323 ± 10 a	122 ± 7 a	8.3 ± 0.2 a	115 ± 6 a
Heavy Thinning	365 ± 38 a	116 ± 8 a	7.7 ± 0.1 a	112 ± 8 a
B-Line Thinning	373 ± 20 a	123 ± 3 a	7.8 ± 0.3 a	118 ± 1 a

Table 2—Treatment means (± SE) for stand conditions immediately after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for number of trees, p < 0.01 for basal area, p = 0.04 for quadratic mean diameter, p < 0.01 for stocking)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned	310 ± 16 a	132 ± 3 a	8.9 ± 0.3 b	122 ± 1 a
Light Thinning	125 ± 10 b	80 ± 1 b	10.9 ± 0.4 a	70 ± 1 b
Heavy Thinning	106 ± 3 b	58 ± 1 d	10.0 ± 0.2 ab	52 ± 1 d
B-Line Thinning	118 ± 7 b	70 ± 2 c	10.4 ± 0.5 a	62 ± 1 c

Table 3—Treatment means (± SE) for stand conditions 9 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for number of trees, p < 0.01 for cumulative mortality, p < 0.01 for basal area, p < 0.01 for cumulative basal area growth, p = 0.01 for quadratic mean diameter, p < 0.01 for stocking)

Treatment	Trees	Cumulative mortality	Basal area	Cumulative basal area growth	Quadratic mean diameter	Stocking
	no./ac	%	ft^2/ac	ft^2/ac	inches	%
Unthinned	232 ± 8 a	25 ± 2 a	143 ± 6 a	11 ± 2 b	10.6 ± 0.4 b	126 ± 4 a
Light Thinning	116 ± 8 b	7 ± 1 c	107 ± 5 b	27 ± 3 a	13.0 ± 0.5 a	90 ± 4 b
Heavy Thinning	92 ± 1 c	13 ± 1 b	82 ± 1 c	24 ± 1 a	12.8 ± 0.1 a	70 ± 1 c
B-Line Thinning	109 ± 5 bc	8 ± 1 c	98 ± 3 b	28 ± 2 a	12.9 ± 0.5 a	83 ± 2 b

Table 4—Cumulative diameter growth (± SE) of residual trees 1, 2, 3, 4, 6, and 9 years after application of four thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for all years)

Treatment	Years after thinning					
	1	2	3	4	6	9
	inches					
Unthinned	0.11 ± 0.02 b	0.18 ± 0.02 c	0.28 ± 0.03 c	0.37 ± 0.04 c	0.56 ± 0.04 c	0.84 ± 0.07 c
Light Thinning	0.26 ± 0.05 a	0.42 ± 0.05 b	0.70 ± 0.09 b	0.94 ± 0.12 b	1.36 ± 0.15 b	1.91 ± 0.20 b
Heavy Thinning	0.28 ± 0.02 a	0.51 ± 0.03 a	0.91 ± 0.06 a	1.29 ± 0.08 a	1.84 ± 0.09 a	2.51 ± 0.12 a
B-Line Thinning	0.29 ± 0.03 a	0.49 ± 0.02 ab	0.83 ± 0.04 a	1.15 ± 0.04 a	1.66 ± 0.08 a	2.32 ± 0.09 a

Table 5—Number (± SE) of epicormic branches found on the butt logs of residual trees immediately after thinning (year 0) and 1, 2, 3, 4, 6, and 9 years after application of four thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.09 for year 0, p = 0.52 for year 1, p = 0.22 for year 2, p = 0.18 for year 3, p = 0.20 for year 4, p = 0.13 for year 6, p = 0.28 for year 9)

Treatment	Years after thinning						
	0	1	2	3	4	6	9
Unthinned	8.6 ± 2.0 a	7.9 ± 1.9 a	8.8 ± 1.8 a	9.4 ± 1.9 a	9.7 ± 1.9 a	9.3 ± 1.5 a	8.5 ± 1.6 a
Light Thinning	5.0 ± 1.7 a	6.8 ± 2.2 a	9.1 ± 2.4 a	10.0 ± 2.2 a	10.3 ± 2.4 a	10.4 ± 2.1 a	9.6 ± 2.0 a
Heavy Thinning	4.7 ± 1.0 a	7.8 ± 1.6 a	12.4 ± 1.7 a	13.5 ± 1.6 a	13.7 ± 1.6 a	13.4 ± 1.5 a	11.4 ± 1.9 a
B-Line Thinning	3.4 ± 0.4 a	5.2 ± 1.4 a	7.9 ± 1.1 a	8.8 ± 0.9 a	8.8 ± 0.8 a	8.7 ± 1.0 a	7.6 ± 1.1 a

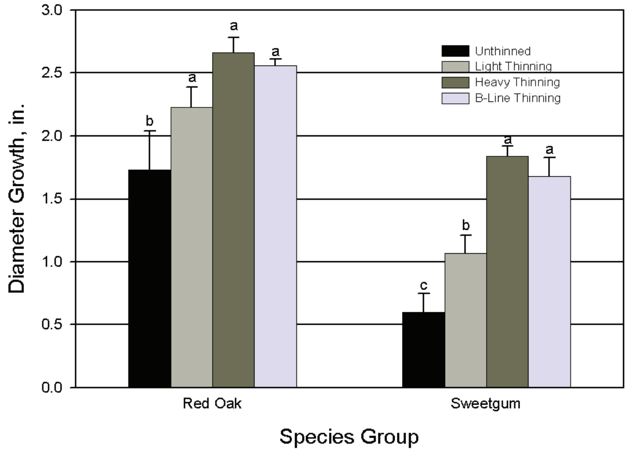

Figure 1—Cumulative diameter growth (± SE) of residual trees, by species group, 9 years after application of four thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.01 for red oak, p < 0.01 for sweetgum).

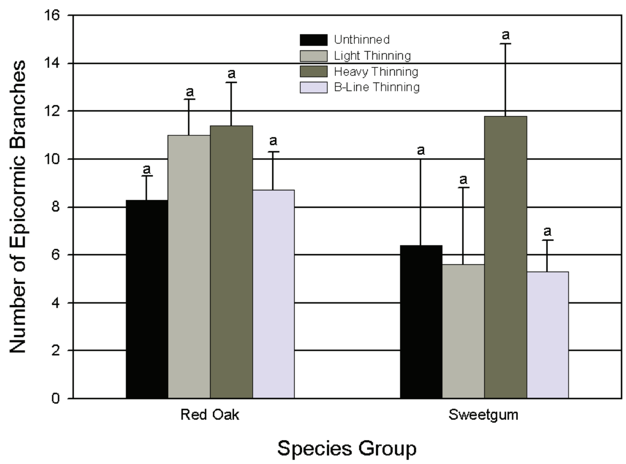

Figure 2—Number (± SE) of epicormic branches found on the butt logs of residual trees, by species group, 9 years after application of four thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.09 for red oak, p = 0.35 for sweetgum).

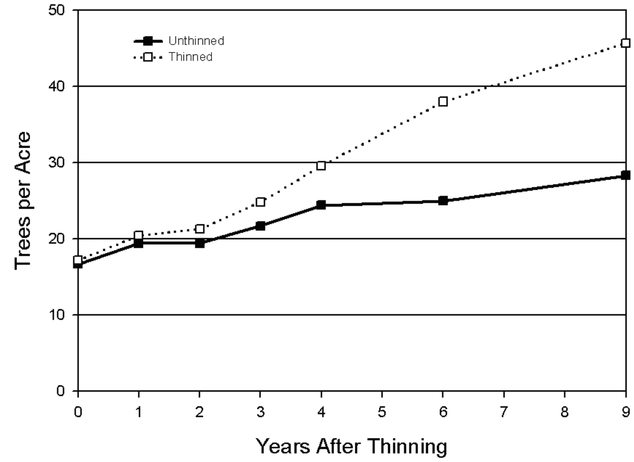

Figure 3—Number of red oak sawtimber trees per acre, through the 9 years since treatment application, in the unthinned control and averaged across the three levels of thinning.