THIRD-YEAR GROWTH AND BOLE-QUALITY RESPONSES TO THINNING IN A LATE-ROTATION RED OAK-SWEETGUM STAND IN EAST TEXAS

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Abstract—Three thinning treatments were applied to an 80- to 90-year-old stand dominated by red oaks (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.) along the Neches River in East Texas: (1) unthinned control, (2) light thinning (70 to 75 percent residual stocking), and (3) heavy thinning (50 to 55 percent residual stocking). Three years after treatment, both thinning regimes had significantly increased diameter growth of individual trees, especially the red oaks. Thinning had little effect on the production of epicormic branches on butt logs of residual trees, even among red oaks. Within the range of residual stand density evaluated in this study, we found no differences between light thinning and heavy thinning in either diameter growth or production of epicormic branches by residual red oaks. Residual stand density, at least within fairly broad limits, had little effect on the initial response of individual red oaks to thinning.

INTRODUCTION

Successful management of hardwood stands for sawtimber production requires satisfactory growth rates, as well as the development and maintenance of high-quality logs. A combination of thinning and improvement cutting often is used in mixed-species bottomland hardwood stands to (1) enhance growth of residual trees, (2) maintain and improve bole quality of residual trees, and (3) improve species composition of the stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees. Generally, diameter growth response increases as thinning intensity increases. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished, even though diameter growth and volume growth of individual residual trees are greatly enhanced. In heavily thinned stands, density may be so low that the stand is unable to fully occupy the site and therefore cannot achieve its optimum level of production. Earlier research suggests that minimum residual stocking levels necessary to maintain satisfactory stand-level growth after thinning are 46 to 65 percent of maximum full stocking for upland oak stands (Hilt 1979) and 45 to 60 percent of maximum full stocking for Allegheny hardwood stands (Lamson and Smith 1988). No recommended minimum residual stocking levels have been reported for southern bottomland hardwood stands. However, Meadows and Goelz (2001) observed that residual stand density equivalent to 52 percent stocking in a young water oak (*Quercus nigra* L.) plantation appeared to be sufficient to promote adequate stand-level basal area growth following thinning, but that a residual stocking level of 33 percent created such a severely understocked condition that stand-level basal area growth will likely be depressed for many years.

Degradation of bole quality, as a result of increased production of epicormic branches along the boles of residual trees, sometimes may be associated with increased thinning intensity. For example, Sonderman (1984) found that the number and size of both living and dead limbs on the boles of residual upland oak trees increased significantly as residual stocking decreased. However, this adverse effect of thinning on bole quality most often is related to poorly planned thinning operations. In fact, well-designed hardwood thinning operations tend to favor healthy, sawtimber-sized trees, so that the proportion of dominant and codominant trees in the residual stand typically increases as thinning intensity increases. Vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, in well-designed thinnings, the production of epicormic branches on residual trees may actually decrease as thinning intensity increases (Sonderman and Rast 1988). In fact, carefully planned thinnings should improve average bole quality throughout the residual stand. In some stands, however, as thinning intensity increases and residual stand density decreases, there may be a trade-off between markedly improved diameter growth and the increased potential for adverse effects on bole quality of residual trees.

This combination of thinning and improvement cutting in mixed-species hardwood stands also is used to improve both species composition and quality of the residual stand (Meadows 1996). Generally, by emphasizing the value or quality of individual trees rather than the density of the residual stand, it is possible to increase the proportion of high-value trees and to decrease the proportion of low-value trees. Trees that are damaged or diseased, have low-quality boles, or are undesirable species are removed; trees that are healthy, have high-quality boles, and are desirable species are retained. Although more important at the time of the first thinning, improvement of both species composition and residual bole quality should be major considerations whenever partial cuttings are performed in mixed-species hardwood stands.

These three components of a well-designed hardwood thinning operation—increased diameter and volume growth of individual trees, enhanced bole quality, and improved species composition—are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, thinning regimes should be designed to optimize the value of the stand through synthesis of these

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three components. However, because maximization of all three components is generally not likely, some compromises in expected benefits are often necessary.

Science-based information on thinning in southern bottomland hardwood stands is lacking. Existing guidelines, such as those published by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience and observation than on specific research results. Effective management of such stands for high-quality sawtimber production requires thinning guidelines that include recommendations for (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) marking rules designed to optimize stand value throughout the rotation.

To address this need for science-based thinning guidelines, we established a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. All of the individual studies within the series use the same study design, treatments, and methods. This study is the fourth in that series. Early results for one of the other studies were reported by Meadows and Goelz (1998, 1999, and 2002). All individual studies within the series are designed to determine how several levels of thinning affect (1) stand-level growth, development, and yield; and (2) growth and bole quality of individual trees. Results from the entire series of studies will be combined to (1) develop practical guidelines for managing stands of southern bottomland hardwoods, (2) evaluate the suitability of various levels of residual stocking across a variety of site and stand conditions, and (3) develop a growth-and-yield model for managed stands of southern bottomland hardwoods.

METHODS

Study Area

The study is located near the Neches River in southern Angelina County, near the community of Beulah, in east Texas. The land is owned by Temple-Inland Forest Products Corporation. The site is subject to periodic flooding during the winter and spring, but floodwaters generally recede within a few days.

The study site supports a bottomland hardwood forest dominated by red oaks and sweetgum. Principal red oak species are water oak, cherrybark oak (*Q. pagoda* Raf.), and willow oak (*Q. phellos* L.). The stand was about 80 to 90 years old at the time of study installation. There was no evidence of previous harvesting activity in the stand. We classified the study area as a medium to large sawtimber stand on a medium-quality site, with high initial stocking.

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station (Marquis and others 1990). We applied each treatment 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), providing a 1-chain-wide (66 feet) buffer strip around each measurement plot. The entire study area is 18 acres.

Treatments

Treatments included three levels of residual stocking, based on a stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (1) an unthinned control, (2) light thinning (70 to 75 percent residual stocking), and (3) heavy thinning (50 to 55 percent residual stocking). Space limitations at this particular study site did not allow us to install a fourth treatment, which was evaluated in all other studies within this series.

A combination of low thinning and improvement cutting removed most of the pulpwood-sized trees, as well as sawtimber-sized trees that were damaged or diseased, had low-quality boles, 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. Trees were removed from the cutting stock and the cull stock classes first and then from the reserve growing stock class, when necessary, until the target residual stocking level for each treatment was met.

Three replications of the three treatments were applied in a randomized complete block design to the nine treatment plots (experimental units) in October 2000. A contract logging crew directionally felled all marked trees with a mechanized feller using a continuously running cutting head. Felled trees were topped and delimbed in the woods. Tree-length logs were removed from the woods with rubber-tired skidders.

Measurements

A preharvest survey to determine species composition and initial stand density was conducted on each 0.6-acre measurement plot prior to assignment of treatments. Species, diameter at breast height (d.b.h.), crown class, and tree class (Meadows 1996, Putnam and others 1960) were recorded for all trees ≥ 3.5 inches d.b.h. Treatment plots were marked for thinning to the target residual stocking prescribed for each treatment. Hardwood tree classes were used to set the cutting priority on each plot. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section (below the base of the live crown) were recorded on all "leave" trees. Merchantable height, height to the base of the live crown, and total height were measured on a subsample of "leave" trees. Crown class, d.b.h., and the number of epicormic branches on each 16-foot log section were measured annually for the first 3 years after thinning.

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

The pretreatment stand averaged 147 trees and 118 square feet of basal area per acre, with a quadratic mean diameter of 12.3 inches, among trees ≥ 3.5 inches d.b.h. The average stocking of 101 percent exceeded the level of maximum full stocking (100 percent), the point at which thinning is recommended in even-aged southern bottomland hardwood stands (Goelz 1995). There were no significant differences among treatment plots in any of the preharvest characteristics. Although the stand was dense, most of the dominant and codominant trees were healthy and exhibited few symptoms of poor vigor, such as crown deterioration, loss of dominance, or the presence of numerous epicormic branches along the boles. In short, the stand was too dense and needed to be thinned, but the overstocked conditions were not so severe that overall stand health had begun to deteriorate.

Red oaks and sweetgum together comprised 66 percent of the basal area of the stand prior to thinning. Red oaks (primarily water, cherrybark, and willow oaks) accounted for 39 percent of the basal area, while sweetgum accounted for 27 percent. Red oaks and sweetgum clearly dominated the upper canopy of the stand and had quadratic mean diameters of 16.3 and 16.5 inches, respectively. Nearly all of the very large trees (> 30 inches d.b.h.) scattered throughout the stand were red oaks.

Other species commonly found throughout the stand were mockernut hickory [*Carya tomentosa* (Poir.) Nutt.], shagbark hickory [*C. ovata* (Mill.) K. Koch], American elm (*Ulmus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and black tupelo (*Nyssa sylvatica* Marsh.). Scattered individuals of a wide variety of species, such as sugarberry (*Celtis laevigata* Willd.), water hickory [*Carya aquatica* (Michx. f.) Nutt.], honeylocust (*Gleditsia triacanthos* L.), swamp chestnut oak (*Q. michauxii* Nutt.), and overcup oak (*Q. lyrata* Walt.), also occurred. Collectively, these species accounted for 31 percent of the basal area prior to thinning. Most of these trees were found in the very dense, midcanopy layer of the stand.

Shade-tolerant species, such as American hornbeam (*Carpinus caroliniana* Walt.), American holly (*Ilex opaca* Ait.), dogwood (*Cornus* spp.), eastern hophornbeam [*Ostrya virginiana* (Mill.) K. Koch], hawthorn (*Crataegus* spp.), and red mulberry (*Morus rubra* L.), dominated the lower canopy and understory and accounted for the remaining 3 percent of the basal area prior to thinning. Giant cane [*Arundinaria gigantea* (Walt.) Muhl.] formed a very dense component of the understory throughout the study site.

Stand Development Following Thinning

Light thinning reduced stand density to 43 trees and 86 square feet of basal area per acre, increased quadratic mean diameter to 19.1 inches, and reduced stocking to 68 percent. It removed 71 percent of the trees and 27 percent of the basal area. Heavy thinning reduced density to 31 trees and 64 square feet of basal area per acre, increased quadratic mean diameter to 19.6 inches, and reduced stocking to 50 percent. It removed 79 percent of the trees and 46 percent of the basal area. Both thinning treatments produced stand characteristics significantly different from the unthinned control. The light thinning and heavy thinning treatments were not significantly different from each other in terms of residual trees per acre or quadratic mean diameter but were significantly different from each other in terms of residual basal area per acre and residual stocking percent.

Mortality during the 3-year period after thinning did not differ significantly among the three treatments (table 1). A few trees died in both the unthinned control plots and in the heavily thinned plots, but none died in the lightly thinned plots. A few trees were destroyed during the logging operation, but most of the mortality occurred as a result of windthrow.

There has been little stand-level growth in any of the treatment plots during the first 3 years following thinning (table 1). Although stand-level basal area growth and an increase in stocking percent may indicate the stand is recovering faster from light thinning than from heavy thinning, these results may be misleading. Failure of the stand to achieve a net increase in basal area following heavy thinning is most likely due to mortality in the heavily thinned plots, resulting in no net basal area growth.

All treatments produced increases in quadratic mean diameter (table 1). In the heavily thinned stand, it increased 1.2 inches during the 3 years following thinning, from 19.6 to 20.8 inches. By contrast, in the unthinned control and the lightly thinned plots, it increased only 0.4 and 0.5 inches, respectively. Again, this relatively large increase in quadratic mean diameter following heavy thinning may be due to mortality in the heavily thinned plots. The trees that died following heavy thinning were smaller than the initial quadratic mean diameter of the stand. Consequently, the calculated increase in quadratic mean diameter of the heavily thinned stand is primarily a reflection of the larger diameters of the surviving trees. Taking all variables into account, changes in stand conditions during the 3 years following thinning are inconclusive.

Diameter Growth

Heavy thinning significantly increased cumulative diameter growth of residual trees, averaged across all species, during each of the first 3 years following thinning (fig. 1). A significant difference between the heavy thinning treatment and the unthinned control was detected even after the first year. Significant diameter growth responses were not detected until the third year in one of the other thinning studies within the larger series of studies (Meadows and Goelz 1999). By the end of the third year in this study, cumulative diameter growth of residual trees in the heavily thinned plots was 2.5 times greater than the cumulative diameter growth of trees in the unthinned control—0.64 inches and 0.26 inches for the two treatments, respectively. By contrast, cumulative diameter growth of residual trees in the lightly thinned plots was 1.8 times that of trees in the unthinned control, but this difference was not statistically significant. Light thinning also did not differ significantly from heavy thinning in cumulative diameter growth at the end of the third year. The cumulative

Table 1—Stand conditions 3 years after application of three thinning treatments

Treatment	Trees	Cumulative mortality	Basal area	Cumulative basal area growth	Stocking	Quadratic mean diameter
	no./ac	*%*	- - - - - *ft²/acre*	- - - - -	*%*	*inches*
Unthinned control	144 a	5.9 a	121 a	1 a	103 a	12.5 b
Light thinning	43 b	0.0 a	90 b	4 a	71 b	19.6 a
Heavy thinning	28 b	9.7 a	64 c	0 a	50 c	20.8 a

Means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

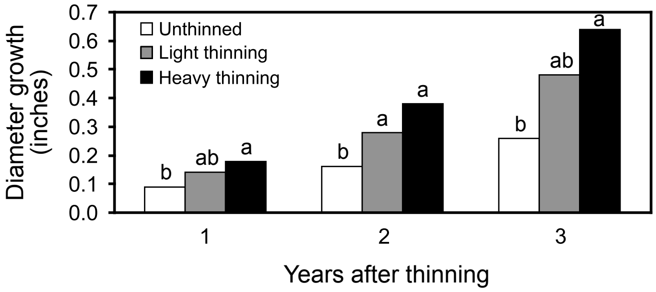

Figure 1—Cumulative diameter growth of residual trees at the end of each of the first 3 years after application of three thinning treatments. Bars within a year followed by the same letter are not significantly different at the 0.05 level of probability.

diameter growth data represent trees of all species and all crown classes within each of the three treatments.

When separating data by species groups, we found that, by the end of the third year, light thinning had increased cumulative diameter growth of red oaks (primarily water, cherrybark, and willow oaks) by 61 percent; heavy thinning had increased cumulative diameter growth of red oaks by 47 percent, relative to the unthinned control (fig. 2). Residual red oaks in the lightly thinned plots grew 0.95 inches in the 3 years following thinning, while residual red oaks in the heavily thinned plots grew 0.87 inches. By contrast, red oaks in the unthinned control plots grew 0.59 inches. Both thinning regimes significantly improved the cumulative diameter growth of sweetgum and other merchantable species (primarily hickory, American elm, green ash, and black tupelo) but not nearly to the same extent as they did in the red oaks.

It is very important to note that, while both thinning regimes significantly improved cumulative diameter growth of residual red oaks relative to the unthinned control, there were no significant differences between the two regimes. In other words, the diameter growth response of residual red oaks was about the same for both light thinning and heavy thinning. Diameter growth response of residual red oaks appeared to be independent of residual stand density, at least within the range of residual densities we evaluated—64 square feet of basal area per acre following heavy thinning to 86 square feet of basal area per acre following light thinning. We found the same trend in other studies in the series (Meadows and Goelz 2002).

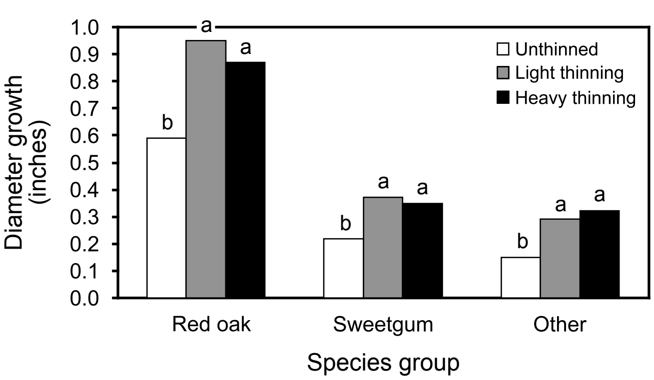

Figure 2—Cumulative diameter growth of residual trees, by species group, 3 years after application of three thinning treatments. Bars within a species group followed by the same letter are not significantly different at the 0.05 level of probability.

When averaged across trees of all species, there appeared to be a favorable cumulative diameter growth response by both dominant and codominant trees to the two thinning regimes (fig. 3). However, the only statistically significant result was that codominant trees in the heavily thinned plots grew more than codominant trees in the unthinned control plots. The cumulative diameter growth rate of codominant trees following heavy thinning was 31 percent greater than it was for codominant trees in the unthinned control plots. Heavy thinning also significantly increased cumulative diameter growth of residual trees in the intermediate crown class by 77 percent. This rapid increase in diameter growth indicates that there may be good growth potential for the smaller trees eventually to develop into valuable sawtimber trees.

Both thinning regimes successfully increased the cumulative diameter growth of residual trees during the first 3 years following treatment. Excellent diameter growth responses were observed for red oaks, particularly in the codominant crown class. Most of the stand's red oaks were classified as crop trees, the most desirable trees in the stand for high-quality sawtimber production. For that reason, both levels of thinning greatly enhanced the value of the stand.

Epicormic Branching

Thinning operations in hardwood stands, while producing positive effects on diameter growth, also may have negative impacts on bole quality of residual trees, particularly in the form of epicormic branches. The production of epicormic branches along the merchantable boles of residual trees can become a serious problem in thinned hardwood stands. Epicormic branches cause defects in the underlying wood and can reduce both log grade and lumber value. However, well-designed thinning prescriptions with proper marking rules can minimize the production of new epicormic branches in most hardwood stands.

When averaged across all species, thinning had no significant effects on the total number of epicormic branches on butt logs of the residual trees after each of the first 3 years following thinning (fig. 4). It is important to note that, immediately after thinning (year zero), residual trees in the two thinning treatments averaged fewer than two epicormic branches on the butt log, whereas trees in the unthinned control plots averaged four epicormic branches on the butt log, even though these differences among treatments were not statistically significant. Both thinning treatments discriminated against trees

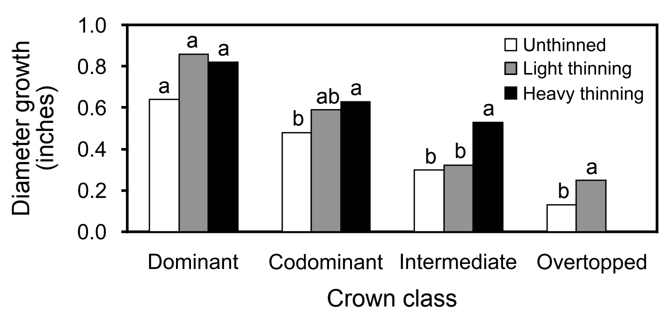

Figure 3—Cumulative diameter growth of residual trees, by crown class, 3 years after application of three thinning treatments. Bars within a crown class followed by the same letter are not significantly different at the 0.05 level of probability.

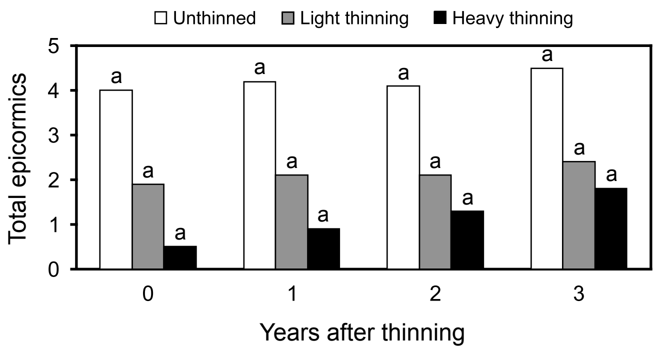

Figure 4—Total number of epicormic branches on the butt logs of residual trees initially and at the end of each of the first 3 years after application of three thinning treatments. Bars within a year followed by the same letter are not significantly different at the 0.05 level of probability.

that had numerous epicormic branches; those trees were removed from the stand during thinning. In the first 3 years following thinning, few changes occurred in the total number of epicormic branches found on the butt logs of residual trees across the three treatments. Because none of the treatment means represented in figure 4 was significantly different in any given year, the two levels of thinning did not negatively affect bole quality, at least when data were averaged across trees of all species. However, production of new epicormic branches on the butt log varied among individual trees. Some trees produced no new branches, while others produced only a few. Most of those trees were highly vigorous and had large, well-shaped crowns with dense foliage. By contrast, some trees produced many new epicormic branches. Those trees expressed relatively low vigor and had small crowns with sparse foliage.

Because hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995), data were partitioned by species groups (fig. 5). Neither thinning regime affected the production of epicormic branches in residual sweetgum trees or in residual trees of the Other species group. On the other hand, by the end of the third year following thinning, residual red oaks in the lightly thinned plots averaged 1.1 more epicormic branches on the butt log than did red oaks in the unthinned control plots. By contrast, residual red oaks in the heavily thinned plots averaged 1.2 fewer epicormic branches on the butt log than did red oaks in the unthinned control plots. These treatment differences were not statistically significant, but it is interesting to note that red oaks in the heavily thinned plots averaged 2.3 fewer epicormic branches on the butt log than did red oaks in the lightly thinned plots.

To maintain the target residual density in the lightly thinned plots, we had to leave some low-vigor trees, which are generally highly susceptible to the production of epicormic branches, especially the red oaks (Meadows 1995). Consequently, strict adherence to residual density targets forced the retention of some less than desirable trees, which resulted in a greater average number of epicormic branches on residual red oaks in the lightly thinned plots than in the heavily thinned plots, although these treatment differences were not statistically significant. At least to some extent, enhancement of overall stand quality in the lightly thinned plots may have suffered.

Production of epicormic branches on the butt logs of residual trees also varied among crown classes, when averaged across trees of all species (fig. 6). Generally, epicormic branches were more numerous on lower-crown-class trees than on upper-crown-class trees, especially those within the unthinned control plots. This observation indicates that epicormic branches often are produced in response to increased stress and reduced vigor, even in undisturbed stands. It is interesting to note that upper-crown-class trees, even though they produced a few new epicormic branches in response to thinning, still averaged fewer than two epicormic branches on the butt log, regardless of treatment.

These results support the hypothesis advanced by Meadows (1995) that the tendency for an individual hardwood tree to produce epicormic branches in response to some type of disturbance or stress is controlled by both the species and the tree's initial vigor. Meadows (1995) observed that hardwood species vary greatly in the likelihood that they will produce epicormic branches; he proposed a classification scheme to categorize the susceptibility of most commercially important bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the primary factor controlling production of epicormic branches when a tree is subjected to a disturbance or stress. This hypothesis further proposes that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Observations in this study that the production of epicormic branches varied not

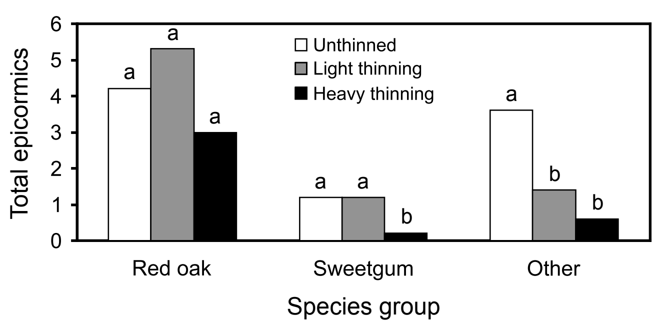

Figure 5—Total number of epicormic branches on the butt logs of residual trees, by species group, 3 years after application of three thinning treatments. Bars within a species group followed by the same letter are not significantly different at the 0.05 level of probability.

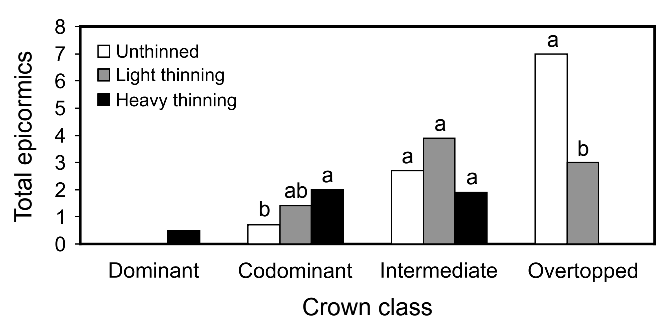

Figure 6—Total number of epicormic branches on the butt logs of residual trees, by crown class, 3 years after application of three thinning treatments. Bars within a crown class followed by the same letter are not significantly different at the 0.05 level of probability.

only by species but also among crown classes strongly support these hypotheses.

When assessing the effects of thinning on the production of epicormic branches, the most important consideration, however, is the total number of epicormic branches found on the butt logs of crop trees, particularly sawtimber-sized red oaks. These trees are favored during the thinning operation because they produce high-quality, high-value sawtimber. Our study showed that neither level of thinning had a significant effect on the total number of epicormic branches found on the butt logs of sawtimber-sized red oaks 3 years after thinning (fig. 7). In fact, sawtimber-sized red oaks in both the lightly thinned plots and the heavily thinned plots averaged < 3.5 epicormic branches on the butt log.

Based on a general rule of thumb that five epicormic branches are sufficient to cause a reduction in the grade of the butt log (Meadows and Burkhardt 2001), it is likely that most of the sawtimber-sized red oaks in our study did not experience a negative impact on overall bole quality due to the production of epicormic branches on the butt log following thinning. Sawtimber-sized red oaks with healthy dominant or codominant crowns are fairly resistant to the production of epicormic branches even after heavy thinning.

Production of epicormic branches on the boles of pulpwood-sized red oaks increased significantly during the 3 years following light thinning (fig. 7). To maintain the target residual stocking of 70 to 75 percent associated with the light thinning treatment, we had to leave numerous pulpwood-sized red oaks with small, sparse crowns. Most of these low-vigor, lower-crown-class red oaks retained in the lightly thinned plots produced many new epicormic branches during the 3 years following thinning. By contrast, because the target residual stocking associated with the heavy thinning treatment was much lower (50 to 55 percent), we were able to retain only the healthiest pulpwood-sized red oaks. These relatively high-vigor trees had dense, well-shaped crowns and produced few new epicormic branches during the 3 years following thinning.

CONCLUSIONS

Stand-level growth has been negligible, but increases in quadratic mean diameter have been observed through the first 3 years of the study, particularly following the heavy thinning treatment.

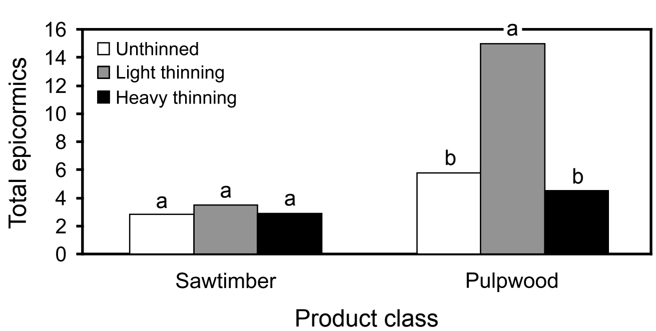

Figure 7—Total number of epicormic branches on the butt logs of residual red oak trees, by product class, 3 years after application of three thinning treatments. Bars within a product class followed by the same letter are not significantly different at the 0.05 level of probability.

Thinning increased cumulative diameter growth of residual trees, when averaged across all species. Diameter growth response varied among species groups, but the most pronounced response was by red oaks. Both levels of thinning increased cumulative diameter growth of residual red oaks by at least 47 percent, but there were no significant differences in diameter growth response between residual red oaks in the lightly thinned plots and in the heavily thinned plots. Heavy thinning also significantly increased diameter growth of codominant trees (by 31 percent), when averaged across all species.

Neither light nor heavy thinning significantly affected the production of epicormic branches on the butt logs of residual trees, even among red oaks, which generally are considered to be highly susceptible to the production of epicormic branches. In fact, across both levels of thinning, sawtimber-sized red oaks averaged a total of < 3.5 epicormic branches on the butt log at the end of the third year. The number of epicormic branches on the butt logs of residual, sawtimber-sized red oaks generally was not enough to cause a reduction in the grade of the butt log.

Most important, within the range of residual stand density evaluated (64 square feet of basal area per acre following heavy thinning to 86 square feet of basal area per acre following light thinning), we found no differences between light and heavy thinning in either cumulative diameter growth or production of epicormic branches by residual red oaks. Residual stand density, at least within fairly broad limits, had little effect on the initial response of individual red oaks to thinning.

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