THINNING TO IMPROVE GROWTH AND BOLE QUALITY IN AN *INONOTUS HISPIDUS*-INFECTED, RED OAK-SWEETGUM STAND IN THE MISSISSIPPI DELTA: SIXTH-YEAR RESULTS

James S. Meadows, Theodor D. Leininger, and T. Evan Nebeker[1]

Abstract—Thinning was applied to a 55-year-old red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand in the Delta region of western Mississippi in 1997. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus* (Bull.) P. Karst, a canker decay fungus that causes serious degrade and cull. Little stand-level growth occurred during the first 6 years after thinning. Thinning significantly increased diameter growth of residual trees, especially among red oaks, but to date, the treatment has not significantly increased quadratic mean diameter. Thinning had no significant effect on the production of new epicormic branches on the butt logs of residual red oaks, but it greatly increased the number of epicormic branches on the butt logs of residual sweetgum trees. Increased numbers of epicormic branches on sweetgum sawtimber trees caused the degradation of many sweetgum logs from grade 2 to grade 3. These reductions increased the proportion of sweetgum volume in grade 3 logs. Because thinning did not increase the number of epicormic branches on red oak sawtimber, the proportion of volume in grade 1 logs increased, and the proportion of red oak volume in grade 3 logs decreased.

INTRODUCTION

A combination of thinning and improvement cutting often is used in mixed-species forests, not only to enhance the growth of residual trees but also to improve species composition and residual stand quality (Meadows 1996). These three characteristics—growth rate, species composition, and quality—are critically important when managing southern bottomland hardwood stands for high-quality sawtimber production.

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 stand density to such an extent that stand growth is greatly diminished even though individual tree growth is enhanced. Stocking may become so low that potential site productivity is not fully realized. In fact, Meadows and Goelz (2001) showed that thinning to a 33 percent residual stocking level in a relatively young water oak (*Quercus nigra* L.) plantation created such a severely understocked condition that stand-level growth is likely to be depressed for many years. Recommended minimum stocking levels necessary to maintain satisfactory rates of stand-level growth are 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in Allegheny hardwoods (Lamson and Smith 1988).

Thinning also may have adverse effects on the bole quality of residual hardwood trees. Production of epicormic branches along the boles of residual trees often is associated with poorly designed thinning operations. However, well-designed hardwood thinning operations tend to favor healthy, sawtimber-sized trees, so that the proportion of dominant and codominant trees in the stand typically increases after thinning. These vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, the production of epicormic branches may actually decrease after well-designed thinnings (Sonderman and Rast 1988).

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. Improvement cuttings often are used to curtail disease-causing fungi in stands that have a high proportion of diseased trees.

Bottomland hardwood stands in the Mississippi Delta region often are infected with *Inonotus hispidus* (Bull.) P. Karst, a canker decay fungus that causes the disease commonly known as hispidus canker. The fungus often is found on willow oak (*Q. phellos* L.) and water oak but also occurs on Nuttall oak (*Q. nuttallii* Palmer) and white oak (*Q. alba* L.). Hispidus canker causes severe degrade and cull in infected trees. The fungus results in formation of a large, spindle-shaped canker usually at the site of an old branch stub 12 to 15 feet or more up the bole of the infected tree (McCracken 1978). The central part of the canker is concave and covered with bark. Damage occurs in the form of heartwood decay, in which the wood behind the canker becomes soft and delignified. In addition to the degrade caused by the heart rot, the hispidus canker greatly increases the possibility of stem breakage at the site of the canker. Improvement cuttings to remove trees with hispidus canker have reduced spore production and dissemination within infested stands, thus minimizing spread of the disease to adjacent trees (McCracken and Toole 1974).

Our study is part of a larger research project investigating relationships between silvicultural practices and insect and disease populations in southern hardwood forests. Specifically, the larger project's goals are (1) to better understand

[1] Principal Silviculturist and Principal Plant Pathologist, respectively, USDA Forest Service, Southern Research Station, P.O. Box 227, Stoneville, MS 38776; and Professor of Entomology, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

and quantify the effects that stand modification has on insect and disease populations, and (2) to use this knowledge to develop pest management recommendations for use in silvicultural prescriptions.

This paper considers only one study site and addresses only the silvicultural component of the larger project. Our objectives were (1) to determine the effects of thinning on stand growth, development, and yield; and (2) to determine the effects of thinning on tree growth and bole quality.

METHODS

Study Area

The study site is on the Delta National Forest in the Delta region of western Mississippi. The study area is adjacent to Ten Mile Bayou, within the floodplain of the Big Sunflower River, in southeastern Sharkey County. The site is nearly flat and is subject to frequent periodic flooding during the winter and spring months. Floodwaters may remain on the site for several weeks.

Soils across most of the area are in the Sharkey series, but smaller areas are interspersed with Alligator soils. Dowling soils also occur in small depressions. All three soils are poorly drained clays that shrink and form wide cracks when dry and expand when wet. These soils formed in fine-textured Mississippi River sediments deposited in slackwater areas of the floodplain. Broadfoot (1976) reported that average site indices of the Sharkey soils are 92 feet at 50 years for willow oak and 91 feet at 50 years for Nuttall oak. Average site index of the Alligator soils is 88 feet at 50 years for both species.

The study site supports an even-aged red oak-sweetgum stand, in which the principal red oak species are willow and Nuttall oaks. In addition to sweetgum, other common species include sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), common persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and honeylocust (*Gleditsia triacanthos* L.). The stand was 55 years old when we installed the study.

Plot Design

Plot design was modified from the format for standard silvicultural research plots, as originally recommended by Marquis and others (1990). Each treatment was uniformly applied across a 4.8-acre rectangular treatment plot that measured 6 by 8 chains (396 by 528 feet). We established four 0.6-acre rectangular measurement plots in the center of each treatment plot; each measurement plot was 2 by 3 chains (132 by 198 feet), thus establishing a 1-chain buffer strip around the group of four measurement plots. The entire study site is 9.6 acres.

Treatments

Only two treatments were applied: (1) an unthinned control, and (2) an operational thinning marked by Delta National Forest personnel. The operation combined low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as those sawtimber-sized trees that were damaged, diseased, had poor bole quality, or were undesirable species. We emphasized removing all red oaks infected with hispidus canker.

Four replications of the two treatments were applied in a randomized complete block design to the eight plots (experimental units) in August 1997. A mechanized feller with a continuously running cutting head was used to directionally fell all marked trees. Felled trees were topped and delimbed in the woods. Rubber-tired skidders were used to remove merchantable products in the form of longwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. Species, diameter at breast height (d.b.h.), crown class, and tree class, as defined by Meadows (1996), were recorded on all trees ≥ 5.5 inches d.b.h. The number of epicormic branches on the 16-foot butt log of all “leave” trees was also tallied. Log grade, as defined by Rast and others (1973), of the 16-foot butt log and sawtimber merchantable height were also recorded on “leave” trees ≥ 13.5 inches d.b.h. For each of the first 3 years following thinning, we measured crown class, d.b.h., and number of epicormic branches on each 16-foot butt log. These 3-year results were reported by Meadows and others (2002). We measured all variables again at the end of the sixth year after thinning.

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

The pretreatment study area averaged 98 trees and 125 square feet of basal area per acre, with a quadratic mean diameter of 15.4 inches. The average stocking of 102 percent exceeded the level (100 percent) at which thinning is recommended in even-aged, southern bottomland hardwood stands (Goelz 1995). There were no significant differences among plots in any of these preharvest characteristics. Although the stand was fairly dense, most of the dominant and codominant trees were healthy and exhibited few signs of poor vigor. Hispidus canker was found on about 24 percent of red oaks in the study area; however, many of the infected red oaks were in the intermediate crown class.

The stand was clearly dominated by red oak and sweetgum. Prior to thinning, those species together comprised 91 percent of the stand’s basal area. Red oaks (primarily willow and Nuttall oaks) accounted for about 43 percent of the basal area and dominated the upper canopy. Quadratic mean diameter of red oaks before thinning was 16.7 inches. Most of the stand’s large trees were red oaks. Sweetgum comprised about 48 percent of the basal area and occurred in both the upper and middle canopies. Quadratic mean diameter of sweetgum was 15.1 inches. Other species, mainly sugarberry and American elm, comprised the remaining 9 percent of basal area. Those species were found almost exclusively in the lower canopy.

Stand Development Following Thinning

Thinning reduced stand density to 33 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 17.9 inches, and reduced stocking to 47 percent. It removed 66 percent of the trees and 53 percent of the basal area. Average d.b.h. of trees removed was 13.5 inches. Across the study site as a whole, thinning removed about 3,500 board feet per acre (Doyle scale) of sawtimber and about 11 cords per acre of pulpwood. Following thinning, residual sawtimber volume contained in the butt logs only averaged 3,326 board feet per acre. Thinning produced stand density characteristics significantly different from the unthinned control.

The thinning operation reduced stand density to a level approaching the minimum residual stocking level necessary to maintain satisfactory stand-level growth, as recommended for other hardwood forest types (Hilt 1979, Lamson and Smith 1988). Thinning was unusually heavy because we emphasized the removal of all red oaks infected with hispidus canker. However, even with the additional removals of diseased red oaks, thinning improved species composition of the residual stand. It increased the red oak component of the stand from 43 percent to 56 percent of the basal area, and it reduced the sweetgum component from 48 percent to 41 percent of the basal area.

There has been little stand-level growth in either the thinned plots or in the unthinned control during the 6 years following thinning (table 1). In fact, basal area growth averaged about 1 square foot per acre per year under both treatments. Mortality has been negligible, averaging 1.5 percent or less per year for both treatments. Cumulative sawtimber volume growth (in butt logs only) in the unthinned control averaged about 750 board feet per acre over the 6-year period but only about 400 board feet per acre in the thinned plots. However, this difference in cumulative sawtimber volume growth was not statistically significant.

Quadratic mean diameter in the thinned stand increased 1.9 inches during the 6 years since thinning, from 17.9 to 19.8 inches (table 1). By contrast, quadratic mean diameter of the unthinned control increased only 1.0 inch, from 15.4 to 16.4 inches. However, quadratic mean diameter 6 years after thinning was not significantly different between the two stands.

Diameter Growth

Thinning significantly increased cumulative diameter growth of individual trees, averaged across all species, during the first, third, and sixth years after thinning (fig. 1). A significant difference between the thinning treatment and the unthinned control was detected even after the first year; this difference between treatments widened over time. By the end of the sixth year, cumulative diameter growth of residual trees in the thinned plots was 2.5 times greater than the cumulative diameter growth of trees in the unthinned control—1.46 inches as compared to only 0.59 inches, respectively. These diameter growth averages represent trees of all species and all crown classes within each of the two treatments.

When we separated the data by species groups, we found that, by the end of year six, the red oaks (primarily willow and Nuttall oaks) and sweetgum had similar cumulative diameter growth responses to the operational thinning (fig. 2). Thinning more than doubled the diameter growth of both species groups, relative to the unthinned control. Residual red oaks in the thinned plots grew 1.55 inches in diameter; residual sweetgum in the thinned plots grew 1.36 inches. Both of these values were significantly greater than the corresponding values in the unthinned control. Cumulative diameter growth of red oaks and sweetgum in the unthinned control averaged 0.71 and 0.57 inches, respectively.

Of particular importance is the observation that thinning significantly increased diameter growth of codominant trees (by about 75 percent over the unthinned control), when averaged across all species (fig. 3). Further, diameter growth of dominant trees in the thinned plots was about 28 percent greater than diameter growth of dominant trees in the unthinned control plots; however, this growth difference was not statistically

Table 1—Stand conditions 6 years after application of two thinning treatments

Treatment	Trees	Cumulative mortality	Basal area	Cumulative basal area growth	Sawtimber volume	Quadratic mean diameter
	no./ac	*%*	- - - - - - *ft²/ac*	- - - - - -	*bd ft/ac*	*inches*
Unthinned	92 a	8.0 a	135 a	6 a	6,724 a	16.4 a
Thinned	30 b	9.1 a	66 b	7 a	3,726 a	19.8 a

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

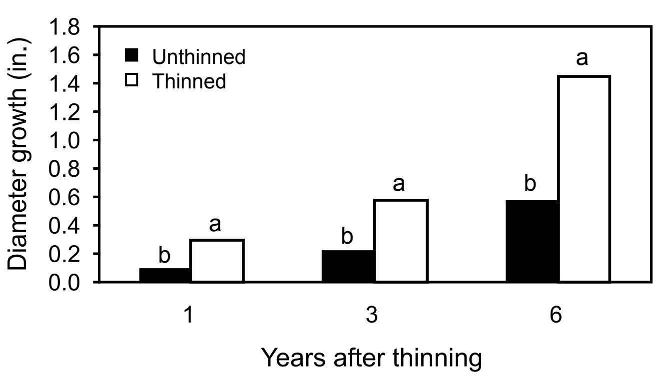

Figure 1—Cumulative diameter growth of residual trees 1, 3, and 6 years after application of two thinning treatments.

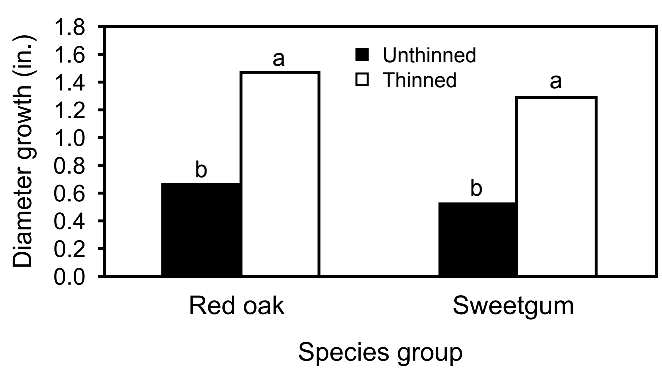

Figure 2—Cumulative diameter growth of residual trees, by species group, 6 years after application of two thinning treatments.

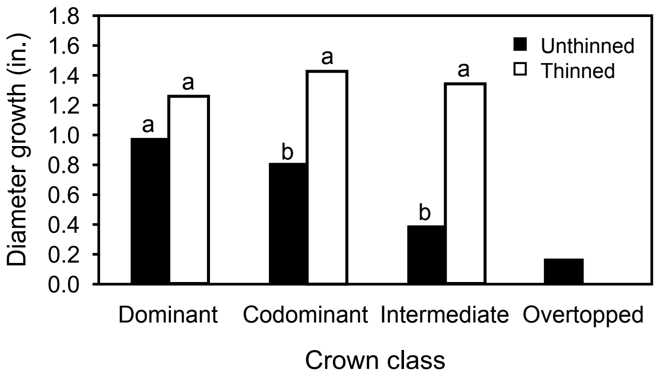

Figure 3—Cumulative diameter growth of residual trees, by crown class, 6 years after application of two thinning treatments.

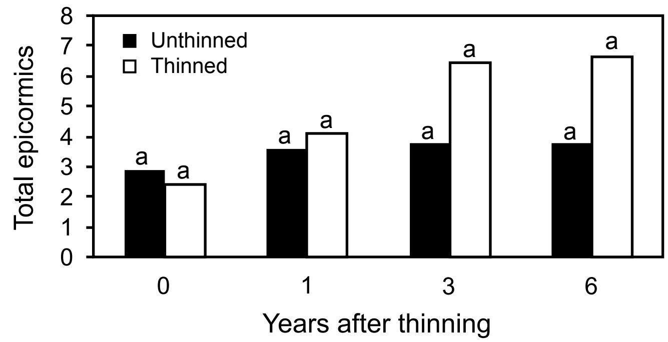

Figure 4—Total number of epicormic branches found on the butt logs of residual trees initially and 1, 3, and 6 years after application of two thinning treatments.

significant. Thinning also more than tripled the diameter growth of trees in the intermediate crown class. This rapid increase in diameter growth of trees in the intermediate crown class is important because many of these smaller trees exhibited good potential to eventually develop into valuable sawtimber trees. We could make no comparisons for trees in the overtopped crown class because thinning removed all overtopped trees.

It is clear that thinning successfully increased cumulative diameter growth of residual trees during the first 6 years after treatment. Excellent diameter growth responses were observed for both red oak and sweetgum in the dominant and codominant crown classes. Those trees, but especially the red oaks, are classified as crop trees and, as such, are the most desirable trees in the stand for high-quality sawtimber production. From a timber production perspective, thinning greatly enhanced diameter growth of the stand's most valuable trees.

Epicormic Branching

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

We recorded no significant effects of thinning on either the number of new epicormic branches or the total number of epicormic branches found on the butt logs of residual trees at the end of the first, third, or sixth years after thinning, when averaged across all trees and all species (fig. 4). There was little change in the total number of epicormic branches at the end of the first year. However, by the end of the third year, we found a fairly large increase in the total number of epicormic branches on the butt logs of residual trees in thinned plots, from an average of 4.1 branches at the end of the first year to an average of 6.4 branches at the end of the third year. The total number of epicormic branches on the butt logs of trees in both the thinned and the unthinned plots remained relatively stable from year three through year six.

Even though residual trees in the thinned plots averaged more total epicormic branches on the butt log than trees in the unthinned control, those differences were not statistically different in any given year. Consequently, when epicormic branch data were averaged across all trees and all species, the thinning operation did not negatively affect bole quality. We did observe, however, that production of new epicormic branches on the butt log varied widely among individual trees. Most high-vigor trees, characterized by large, well-shaped crowns with dense foliage, produced either no new branches or only a few. Conversely, most of the low-vigor trees, characterized by small crowns with sparse foliage, generally produced many new epicormic branches.

To diagnose the source of this broad variation in epicormic branch production by individual trees following thinning, we partitioned the data by species groups. Previous research indicates that hardwood species, in general, vary widely in their susceptibility to the production of epicormic branches (Meadows 1995). In our study, thinning had no effect on the production of epicormic branches in red oak but caused a very large, significant increase in the total number of epicormic branches on the butt logs of residual sweetgum trees 6 years after thinning (fig. 5). In fact, residual red oaks in the thinned plots averaged only 3.4 epicormic branches on the butt log, whereas residual sweetgum trees averaged 10.9 branches.

Because both red oak and sweetgum are generally considered to be highly susceptible to the production of epicormic branches (Meadows 1995), further diagnosis was required to

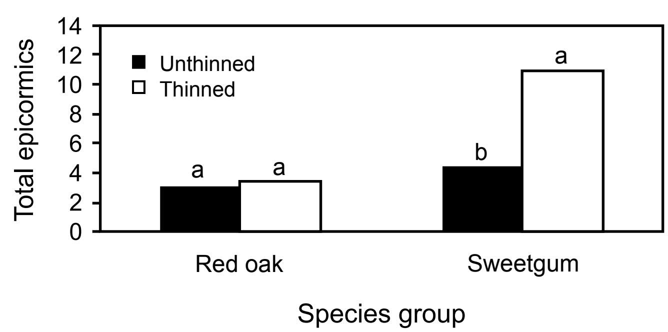

Figure 5—Total number of epicormic branches found on the butt logs of residual trees, by species group, 6 years after application of two thinning treatments.

explain the large difference between the species groups in the total number of epicormic branches found on the butt logs of residual trees 6 years after thinning. We observed that most residual red oaks in the thinned stand were high-vigor, dominant or codominant trees that are generally less likely to produce epicormic branches than are less healthy trees.

On the other hand, many of the residual sweetgum trees in the thinned stand were low to medium vigor, intermediate or weak codominant trees that are generally more likely to produce epicormic branches than are healthy trees. Consequently, we found very few new epicormic branches on the butt logs of residual red oaks and many new epicormic branches on the butt logs of residual sweetgum trees, even though Meadows (1995) categorized both species groups as highly susceptible to the production of epicormic branches following some type of disturbance, such as thinning. These observations strongly support the hypothesis proposed by Meadows (1995) that healthy, vigorous trees, even of highly susceptible species, are much less likely to produce epicormic branches than are trees in poor health.

When evaluating the effects of thinning on the production of epicormic branches, the most important consideration remains the total number of epicormic branches found on the butt logs of the crop trees, particularly sawtimber-sized red oaks and, to a lesser extent, sawtimber-sized sweetgum trees. Such trees are favored during the thinning operation and are most likely to produce high-quality, high-value sawtimber. In our study, thinning had no effect on the total number of epicormic branches found on the butt logs of sawtimber-sized red oaks 6 years after thinning (fig. 6). In fact, sawtimber-sized red oaks in both the unthinned control and in the thinned plots averaged fewer than three epicormic branches on the butt log, generally not enough to have a negative impact on bole quality.

Conversely, thinning greatly increased the total number of epicormic branches found on the butt logs of sawtimber-sized sweetgum trees. These trees averaged 10.5 epicormic branches on the butt log. Based on a very general rule of thumb that five epicormic branches are sufficient to cause a reduction in log grade (Meadows and Burkhardt 2001), it is likely that the bole quality of many sawtimber-sized sweetgum trees in our study was adversely affected by the excessive production of epicormic branches on the butt log following thinning. Production of epicormic branches on the boles of pulpwood-sized trees of both species groups was uniformly high 6 years after thinning. Most of the pulpwood-sized trees in the residual stand were relatively low-vigor, lower-crown-class trees that produced many new epicormic branches following thinning.

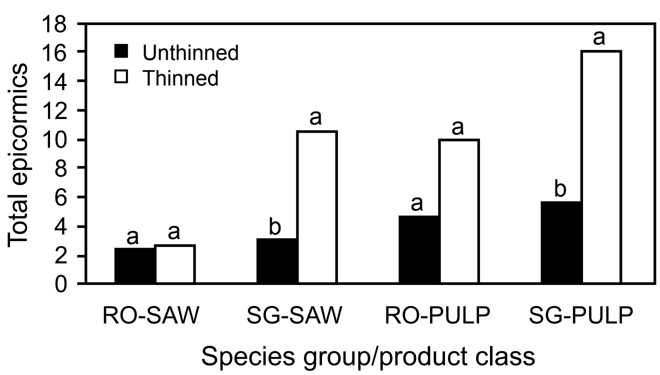

Figure 6—Total number of epicormic branches found on the butt logs of residual trees, by species group and product class, 6 years after application of two thinning treatments (RO-SAW = red oak sawtimber, SG-SAW = sweetgum sawtimber, RO-PULP = red oak pulpwood, SG-PULP = sweetgum pulpwood).

Log Grade Distribution

Although it is clear that thinning had no effect on the production of epicormic branches in red oak sawtimber and greatly increased the number of epicormic branches on sweetgum sawtimber, it is not clear whether these results affect log grade and, therefore, stand value. In most hardwood species, there is a huge difference in value between grade 1 logs (the most valuable) and grade 3 logs (the least valuable). Any factor that reduces log grade in individual trees has a potentially large effect on stand value.

The log grade distributions for all sawtimber trees, regardless of species, in the unthinned control plots and in the thinned plots at both year zero and at year six are depicted in figure 7. These distributions are presented as the proportion of total sawtimber volume (butt log only) in each of the three log grades.

There was little change in log grade distribution from year zero to year six in the unthinned control plots, when trees of all species were combined (fig. 7). The proportion of total

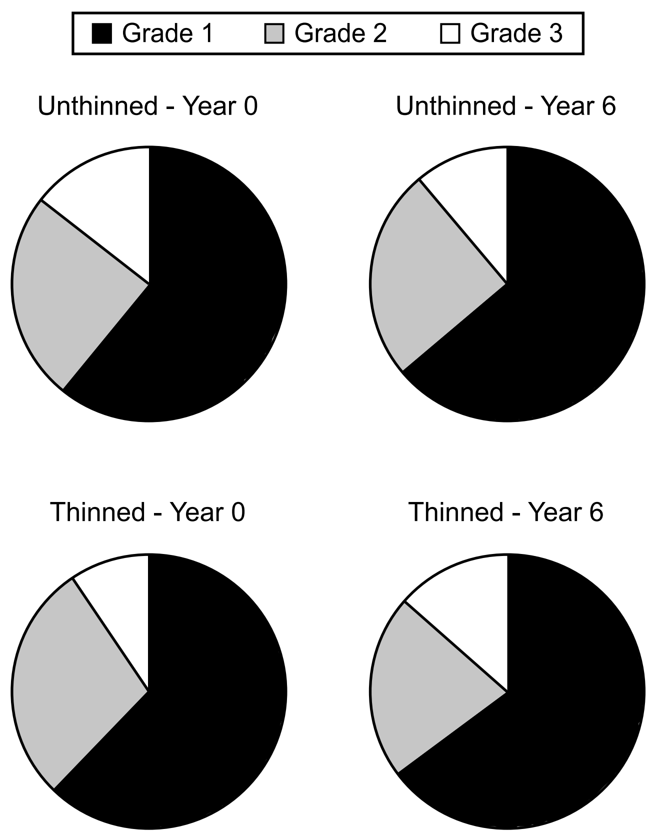

Figure 7—Log grade distributions for all sawtimber trees, regardless of species, at both year zero and at year six for both the unthinned control plots and the thinned plots.

volume in high-value grade 1 logs increased slightly (from 61 percent to 64 percent), and the proportion of total volume in low-value grade 3 logs decreased slightly (from 15 percent to 11 percent). This trend, observed in the unthinned control plots, is typical for undisturbed, midrotation hardwood stands. Generally, in these types of stands, there is a gradual upward movement of log grades over time, as trees get large enough to meet minimum size requirements for the higher grades. The end result of this process is a gradual upward shift in the proportion of total volume found in the higher grades.

The negative impact of the increased production of epicormic branches on sweetgum sawtimber trees is reflected in the log grade distributions in the thinned plots (fig. 7). At first glance, the log grade distributions for the thinned plots appear to be similar to the log grade distributions for the unthinned control plots. There was a slight increase in the proportion of total volume in grade 1 logs (from 62 percent to 65 percent), as was found in the unthinned control plots. However, in contrast to the trend observed in the unthinned control plots, there was a slight increase in the proportion of total volume in low-value grade 3 logs (from 10 percent to 13 percent) in the thinned plots. This increase in the proportion of total volume in grade 3 logs in the thinned plots is the manifestation of the negative impact on bole quality associated with the increased production of epicormic branches on sweetgum sawtimber trees. Many of the grade 2 sweetgum butt logs were downgraded to grade 3 logs because of the abundance of epicormic branches. A few grade 1 sweetgum logs were degraded to grade 3, but the most common situation was a one-grade reduction from grade 2 to grade 3. Although sweetgum is not as valuable as red oak, these reductions in log grade of sweetgum sawtimber trees will likely have at least a slight negative impact on stand value.

When analysis of the change in log grade distributions from year zero to year six was limited to only red oak sawtimber in the unthinned control plots (fig. 8), we observed a very similar trend to the one observed in the unthinned control plots, for all species combined (fig. 7). The proportion of red oak volume in high-value grade 1 logs increased slightly (from 67 percent to 71 percent), and the proportion of red oak volume in low-value grade 3 logs decreased slightly (from 12 percent to 9 percent). As in the analysis combining trees of all species, the trend observed for red oak sawtimber in the unthinned control plots is typical for undisturbed, midrotation hardwood stands: a gradual, upward change in log grades over time.

However, because thinning had no effect on the production of epicormic branches in red oak sawtimber, we did not observe the same patterns of change in log grade distributions of red oak sawtimber in the thinned plots (fig. 8) as was observed in the thinned plots when trees of all species were combined (fig. 7). The proportion of red oak volume in grade 1 logs in the thinned plots increased considerably (from 58 percent to 70 percent) and, in contrast to the trend observed in the thinned plots when trees of all species were combined, the proportion of red oak volume in grade 3 logs decreased slightly (from 9 percent to 7 percent).

A closer examination of the log grade distributions for red oak sawtimber in figure 8 reveals that the increased proportion of volume in grade 1 logs came from the grade 2 class. About one-third of the red oak volume classified as grade 2 in year zero moved up to the grade 1 class by year six. In other words, instead of a gradual upward movement of log grades over time, which is typical in undisturbed stands, our thinning operation produced a fairly rapid acceleration of that process within red oak sawtimber, the most valuable component of the stand. This acceleration occurred because thinning greatly increased the diameter growth rate of individual red oak sawtimber trees without any negative impacts on bole quality. The increased diameter growth rate allowed trees to reach minimum size requirements for the higher log grades more quickly. The absence of negative impacts on bole quality allowed trees to move into the higher log grades and, thus, to fulfill their maximum potential in a shorter period of time. From a timber production perspective, the thinning operation conducted in this study was a notable success.

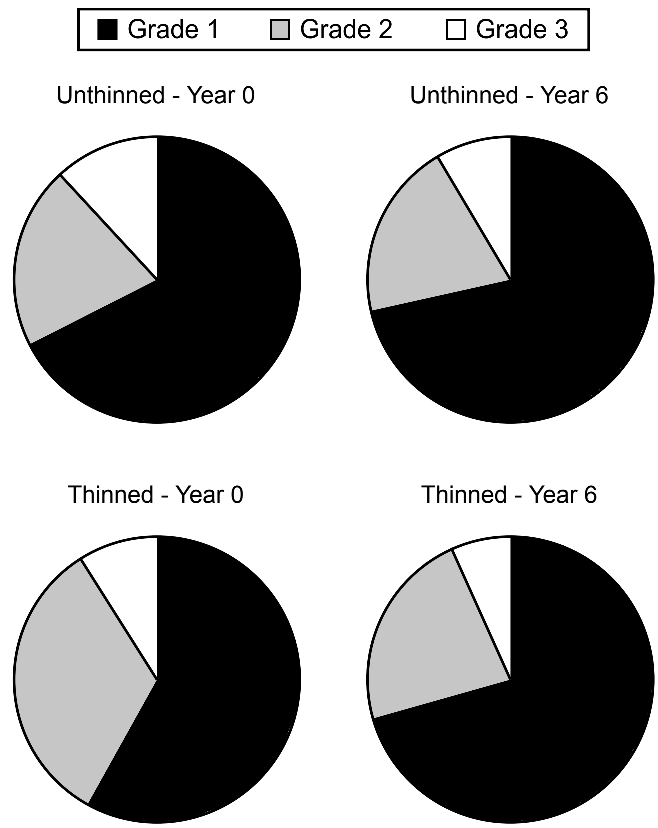

Figure 8—Log grade distributions for red oak sawtimber trees at both year zero and at year six for both the unthinned control plots and the thinned plots.

ACKNOWLEDGMENTS

We express appreciation to Delta National Forest for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Larry Moore and Ralph Pearce of Delta National Forest for their continuing assistance in this study. We also thank Luben Dimov and Dan Wilson for providing helpful suggestions on earlier drafts of this manuscript.

LITERATURE CITED

Broadfoot, W.M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3): 103-104.

Hilt, D.E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Lamson, N.I.; Smith, H.C. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

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. Warren, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

McCracken, F.I. 1978. Canker-rots in southern hardwoods. Forest Insect & Disease Leaflet 33. Washington, DC: U.S. Department of Agriculture, Forest Service. 4 p.

McCracken, F.I.; Toole, E.R. 1974. Felling infected oaks in natural stands reduces dissemination of *Polyporus hispidus* spores. Phytopathology. 64(2): 265-266.

Meadows, J.S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, G.; Meyer, D., eds. Advances in hardwood utilization: following profitability from the woods through rough dimension. Proceedings of the 23rd annual hardwood symposium. Memphis, TN: National Hardwood Lumber Association: 19-25.

Meadows, J.S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, K.M., ed. Proceedings of the southern forested wetlands ecology and management conference. Clemson, SC: Clemson University, Consortium for Research on Southern Forested Wetlands: 98-101.

Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. Southern Journal of Applied Forestry. 25(3): 136-141.

Meadows, J.S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1): 31-39.

Meadows, J.S.; Leininger, T.D.; Nebeker, T.E. 2002. Thinning to improve growth and control the canker decay fungus *Inonotus hispidus* in a red oak-sweetgum stand in the Mississippi Delta. In: Outcalt, K.W., ed. Proceedings of the 11th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 183-188.

Rast, E.D.; Sonderman, D.L.; Gammon, G.L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

Sonderman, D.L.; Rast, E.D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.