THINNING TO IMPROVE GROWTH, BOLE QUALITY, AND FOREST HEALTH IN AN *INONOTUS HISPIDUS*-INFECTED, RED OAK-SWEETGUM STAND IN THE MISSISSIPPI DELTA: 10-YEAR RESULTS

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Abstract—A 55-year-old red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua*) stand on the Delta National Forest in western Mississippi was subjected to a combination of low thinning and improvement cutting in 1997. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus*, a canker decay fungus that causes severe degradation and cull. Stand-level growth during the 10 years since thinning has been minimal. Thinning significantly increased diameter growth of residual trees, especially red oaks, but has not yet produced a significant increase in stand-level quadratic mean diameter. Thinning had little influence on the production of new epicormic branches on residual red oaks, but it greatly increased the number of epicormic branches on residual sweetgum trees. Because it removed all red oaks infected with *Inonotus hispidus*, thinning improved overall forest health. During the 10 years since the thinning operation, thinning has had no adverse effects on the incidence of new infections by a variety of pathogens.

INTRODUCTION

Thinnings and improvement cuttings often are used in mixed-species forests to enhance growth of residual trees and to improve both species composition and quality of the residual stand (Meadows 1996). These three goals—increased growth, improved species composition, and enhanced quality—are critically important for profitable management of southern bottomland hardwood stands for the production of high-quality sawtimber.

Thinning regulates stand density and increases diameter growth of residual trees. In general, diameter growth of residual trees increases as thinning intensity increases. However, very heavy thinning may reduce stand density to such an extent that stand growth declines to an unsatisfactory level even though growth of individual trees may be greatly enhanced. Residual stocking of very heavily thinned stands simply becomes so low that the stand is unable to utilize fully the potential productivity of the site. For example, thinning to a residual stocking level of 33 percent in a relatively young water oak (*Quercus nigra*) plantation created a severely understocked condition that likely will depress stand growth for many years (Meadows and Goelz 2001). Based on data and recommendations from Putnam and others (1960), Goelz (1995) estimated that desirable residual stocking after thinning in even-aged, sawtimber stands of southern hardwoods ranges from 65 to 80 percent. Goelz (1997) further estimated that the minimum stocking level necessary to maintain satisfactory stand-level growth in these same stands ranges from 40 to 60 percent, depending on tree size. Similar ranges for minimum acceptable stocking have been reported in upland oak forests (Hilt 1979) and Allegheny hardwood forests (Lamson and Smith 1988).

The combination of thinning and improvement cutting used in mixed-species hardwood stands also improves both species composition and quality of the residual stand (Meadows 1996). Marking rules and prescriptions that emphasize both quality and value of individual trees, rather than uniform spacing and residual stand density, tend to increase the proportion of high-quality, high-value trees and to decrease the proportion of low-quality, low-value trees in the residual stand. Trees that are damaged or diseased, have low-quality boles, or are undesirable species are removed from the stand under these marking rules; trees that are healthy, have high-quality boles, and are desirable species are retained. Improvement cuttings also may reduce the populations of disease-causing fungi in stands with a high proportion of diseased trees.

Thinnings may have adverse effects on bole quality, specifically in the form of new epicormic branches that may develop along the boles of residual hardwood trees. Epicormic branches are adventitious twigs that develop from dormant buds along the bole. If present in sufficient numbers, epicormic branches may reduce log grade and both lumber grade and value. Species and tree health appear to control the release of these dormant buds when the tree is exposed to some type of disturbance, such as thinning (Meadows 1995). Well-designed hardwood thinnings tend to retain healthy, sawtimber trees and to remove most poletimber trees and low-quality sawtimber trees. As a result, the proportion of dominant and codominant trees typically increases after thinning. These healthy, upper crown-class trees are much less likely to produce epicormic branches than are unhealthy, lower crown-class trees (Meadows 1995). Consequently, the production of epicormic branches across the residual stand actually may decrease after a well-designed thinning (Sonderman and Rast 1988). In contrast, poorly designed thinnings, in which marking guidelines fail to focus on retention of healthy, high-quality trees, typically result in the production of numerous epicormic branches along the boles of residual trees.

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Bottomland hardwood stands in the Delta region of western Mississippi often are infected with *Inonotus hispidus*, a canker decay fungus that causes the disease commonly known as hispidus canker. The fungus occurs most frequently on willow oak (*Q. phellos*), water oak, and Nuttall oak (*Q. texana*) in the Delta region, but also may be found on other red oaks, white oak (*Q. alba*), hickory (*Carya* spp.), and other hardwoods. Hispidus canker causes severe degradation 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. Damage occurs in the form of heartwood decay, in which the wood behind the canker becomes soft and delignified. Presence of hispidus canker greatly increases the likelihood of stem breakage at the site of the canker. Improvement cuttings to remove trees with hispidus canker may reduce spore production and dissemination within infested stands and thus may minimize 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. The goals of this larger project are (1) to understand and quantify the effects of stand modification 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; (2) to determine the effects of thinning on tree growth and bole quality; and (3) to determine the effects of thinning on insect and disease populations, with emphasis on those pests that lead to degradation and/or mortality.

METHODS

Study Area

The study is located on the Delta National Forest in the Delta region of western Mississippi. Specifically, the study area is adjacent to Ten Mile Bayou, within the flood plain 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 study area are classified in the Sharkey series (very-fine, smectitic, thermic Chromic Epiaquerts), but small portions of the area are interspersed with Alligator soils (very-fine, smectitic, thermic Chromic Dystraquerts). Dowling soils (very-fine, smectitic, nonacid, thermic Vertic Endoaquepts) also occur in small depressions. All three soils are poorly to very poorly drained, very slowly permeable clays that shrink and form wide, deep cracks when dry and expand when wet. They formed in fine-textured, Mississippi River alluvium deposited in slackwater areas of the flood plain. 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, whereas average site index of the Alligator soils is 88 feet at 50 years for both species (Broadfoot 1976).

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

Plot Design

Plot design was modified from the standard format for silvicultural research plots, as described by Marquis and others (1990). Each treatment was applied uniformly 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), which allowed a buffer strip 1 chain (66 feet) wide around each group of four measurement plots. The entire study area is 9.6 acres.

Treatments

Two levels of treatment were applied to the study area: (1) an unthinned control, and (2) an operational thinning marked by personnel from Delta National Forest. The harvest operation combined low thinning and improvement cutting to remove most of the poletimber trees and those sawtimber trees that were damaged, diseased, had poor bole quality, or were undesirable species. Special emphasis was placed on removal of all red oaks infected with *Inonotus hispidus*.

The operational thinning was applied in August 1997. A mechanized feller buncher 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 removed merchantable products in the form of longwood.

Measurements and Statistical Analysis

We conducted a preharvest survey to determine initial stand density and species composition 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-long butt log of all “leave” trees was also tallied. Log grade, as defined by Rast and others (1973), of the 16-foot-long butt log and sawtimber merchantable height were recorded on all “leave” trees ≥13.5 inches d.b.h. We measured d.b.h., crown class, and the number of epicormic branches on the butt log at the end of each of the first 3 years after thinning. We measured these variables, as well as tree class, log grade, and sawtimber merchantable height, again at the end of the sixth year after thinning. Meadows and others (2002) reported 3-year results, and Meadows and others (2006) reported 6-year results. At the end of the 10th year after thinning, we measured d.b.h., crown class, and the number of epicormic branches, and surveyed all plots for damage and infection by insects and diseases.

Data were subjected to a one-way analysis of variance for a randomized complete block design with four replications of two treatments, for a total of eight experimental units. All effects were considered fixed. Alpha was set at 0.05. Plot-level variables represented the mean for all residual trees on each measurement plot. Means were separated through the use of Duncan's multiple range test.

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the study area as a whole averaged 98 trees and 125 square feet of basal area per acre, with a quadratic mean diameter of 15.4 inches. These means represent data averaged across all eight plots. Quadratic mean diameter is a stand-level variable calculated from stand basal area per acre and the number of trees per acre. It is defined as the diameter of a tree whose basal area equals the average basal area per tree within the stand. Average stocking across the entire study area was 102 percent, which exceeded the level (100 percent) at which thinning is recommended in even-aged stands of southern bottomland hardwoods (Goelz 1995). We found no significant differences between treatments in any preharvest characteristics (table 1). Although the stand was overstocked, most dominant and codominant trees appeared vigorous and exhibited few signs of poor health. Hispidus canker was found on about 24 percent of red oaks in the study area, but most infected red oaks were in the intermediate and overtopped crown classes.

Red oaks and sweetgum clearly dominated the stand. Prior to thinning, these species together accounted for 91 percent of the basal area of the stand. Red oaks (primarily willow and Nuttall oaks) comprised 43 percent of the basal area and dominated the upper canopy of the stand. Quadratic mean diameter of red oaks before thinning was 16.7 inches. Nearly all of the largest trees in the stand were red oaks. Sweetgum accounted for 48 percent of the basal area and was found in both the upper and middle canopies. Quadratic mean diameter of sweetgum before thinning was 15.1 inches. Other species, such as sugarberry and American elm, made up the remaining 9 percent of the basal area. These species were found almost exclusively in the lower canopy.

Stand Development After Thinning

Stand conditions immediately after thinning—The thinning operation reduced stand density to 32 trees and 59 square feet of basal area per acre, produced a quadratic mean diameter of 18.4 inches, and reduced stocking to 47 percent (table 2). It removed 66 percent of the trees and 52 percent of

Table 1—Treatment means (±SE) for stand conditions prior to application of two thinning treatments

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	number per acre	*square feet per acre*	*inches*	*percent*
Unthinned	100±4 a	127±6 a	15.2±0.4 a	104±5 a
Thinned	95±9 a	123±6 a	15.5±0.4 a	101±6 a

Means followed by the same letter are not significantly different at the 0.05 level of probability ($n = 4$ per treatment; $P = 0.70$ for number of trees, $P = 0.74$ for basal area, $P = 0.74$ for quadratic mean diameter, $P = 0.72$ for stocking).

Table 2—Treatment means (±SE) for stand conditions immediately after application of two thinning treatments

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	number per acre	*square feet per acre*	*inches*	*percent*
Unthinned	100±4 a	129±6 a	15.4±0.4 a	105±5 a
Thinned	32±1 b	59±6 b	18.4±0.8 a	47±4 b

Means followed by the same letter are not significantly different at the 0.05 level of probability ($n = 4$ per treatment; $P < 0.01$ for number of trees, $P = 0.01$ for basal area, $P = 0.09$ for quadratic mean diameter, $P = 0.01$ for stocking).

the basal area. Average d.b.h. of trees removed was 13.5 inches. Across the study site, thinning removed about 3,500 board feet (Doyle scale) of sawtimber and about 11 cords of pulpwood, per acre. Thinning produced stand density characteristics significantly different from the unthinned control plots (table 2), but quadratic mean diameter of the thinned plots, 18.4 inches, was not significantly different ($P = 0.09$) from quadratic mean diameter of the unthinned control plots, 15.4 inches.

The thinning operation reduced stocking to 47 percent, a level approaching the minimum residual stocking level necessary to maintain satisfactory stand-level growth, as recommended for southern hardwoods (Goelz 1997) and for other hardwood forest types (Hilt 1979, Lamson and Smith 1988). Removal of all red oaks infected with hispidus canker resulted in an unusually heavy thinning. However, even with the additional removal of diseased red oaks, thinning improved species composition of the residual stand. It increased the red oak component from 43 to 56 percent of stand basal area, and reduced the sweetgum component from 48 to 41 percent of stand basal area.

Stand conditions 10 years after thinning—There has been little stand-level growth in the unthinned control plots over the past 10 years (table 3). Stand basal area in the unthinned control plots increased from 129 to 135 square feet per acre, an average of only 0.6 square feet per acre per year during the 10-year period, with no net basal area growth over the past 4 years. The number of trees per acre decreased from 100 to 83, an average mortality of 1.7 percent per year, a somewhat higher than normal rate for unmanaged stands of southern bottomland hardwoods. The losses from mortality in the unthinned control plots negated most of the gross growth in basal area, such that there has been very little net gain in stand basal area over the past 10 years. Stocking across the unthinned control plots 10 years after study inception averaged 108 percent (table 3), a level that exceeds maximum full stocking (100 percent). The unthinned control plots are clearly overstocked and stagnant, a condition that has led to very slow stand-level growth and moderately high mortality.

Ten-year stand basal area growth was not significantly greater ($P = 0.18$) in the thinned plots than in the unthinned control plots (table 3). Stand basal area in the thinned plots increased from 59 to 69 square feet per acre, an average of 1.0 square feet per acre per year during the 10-year period, well below the rate that might be expected in a fully stocked stand of southern bottomland hardwoods. According to the stocking chart published by Goelz (1997), average stocking across the thinned plots 10 years after thinning (54 percent) falls on the C-10 line of stocking, indicating that it will take 10 more years of growth for the thinned plots to reach minimum full stocking (B-line). The thinning operation in our study reduced stocking to a level well below the B-line, creating an understocked residual stand that is still understocked 10 years after thinning. The thinned plots have not been able to utilize fully the potential productivity of the site over the past 10 years and are not expected to do so during the next 10 years. Consequently, stand-level growth in the thinned plots may be depressed for as much as 10 more years before full site occupancy is recovered.

We were unable to detect significant differences ($P = 0.06$) between treatments in quadratic mean diameter 10 years after thinning (table 3). Quadratic mean diameter of the unthinned control plots increased 1.8 inches over the past 10 years, from 15.4 to 17.2 inches, whereas quadratic mean diameter of the thinned plots increased 2.3 inches, from 18.4 to 20.7 inches (table 3). However, the similarity between the two treatments in the magnitude of the 10-year increase in quadratic mean diameter is misleading. Much of the 10-year increase in quadratic mean diameter of the unthinned control plots is the direct result of the deaths of numerous small trees rather than the result of actual diameter growth by surviving trees. Because quadratic mean diameter is calculated directly from stand basal area per acre and the number of trees per acre, deaths of trees smaller than the current quadratic mean diameter produce an immediate increase in the quadratic mean diameter of the surviving trees in the stand. In contrast, because mortality in the thinned plots was relatively low, most of the 10-year increase in quadratic mean diameter of the thinned plots is due to actual diameter growth of residual trees. Therefore, even though the magnitude of the 10-year increase in quadratic mean diameter is similar between the two treatments, the basis for the increase is clearly different.

Table 3—Treatment means (±SE) for stand conditions 10 years after application of two thinning treatments

Treatment	Trees	Cumulative mortality	Basal area	Cumulative basal area growth	Quadratic mean diameter	Stocking
	number per acre	*percent*	*-------- square feet per acre --------*		*inches*	*percent*
Unthinned	83±3 a	16±2 a	135±8 a	6±3 a	17.2±0.5 a	108±6 a
Thinned	30±2 b	7±4 a	69±6 b	10±2 a	20.7±0.7 a	54±5 b

Means followed by the same letter are not significantly different at the 0.05 level of probability ($n = 4$ per treatment; $P < 0.01$ for number of trees, $P = 0.0502$ for cumulative mortality, $P = 0.02$ for basal area, $P = 0.18$ for cumulative basal area growth, $P = 0.06$ for quadratic mean diameter, $P = 0.01$ for stocking).

Diameter Growth

Diameter growth is a tree-level variable defined, in this study, as the average diameter growth of all trees across a plot or across some specified group within a plot. Diameter growth, a tree-level variable, and the increase in quadratic mean diameter, a stand-level variable, are not synonymous terms. Diameter growth is an indication of the average rate of growth of individual trees within a stand, whereas the increase in quadratic mean diameter is an indication of the change in size of the average tree in a stand.

Thinning significantly increased cumulative diameter growth of residual trees ($P = 0.01$ for year 1, $P < 0.01$ for years 3, 6, and 10), averaged across all species, throughout the 10 years since thinning (fig. 1). A significant difference in average diameter growth between the thinned plots and the unthinned control plots was detected even after the first year, which is somewhat unusual. The difference between treatments widened over time. By the end of the 10th year after thinning, cumulative diameter growth of residual trees in the thinned plots was about 2.3 times greater than cumulative diameter growth of surviving trees in the unthinned control plots—2.5 inches as compared to only 1.1 inches, respectively.

When we separated the data by species groups, we found that red oaks and sweetgum in the thinned plots had similar cumulative diameter growth responses 10 years after the operational thinning (fig. 2). Thinning roughly doubled diameter growth of both species groups, relative to the unthinned control. Residual red oaks in the thinned plots grew 2.8 inches in diameter; residual sweetgum in the thinned plots grew 2.2 inches. Both values were significantly greater ($P = 0.01$ for red oak, $P < 0.01$ for sweetgum) than the corresponding values in the unthinned control. Ten-year cumulative diameter growth of red oaks and sweetgum in the unthinned control plots averaged 1.5 and 0.9 inches, respectively.

Of special importance in this study is that thinning significantly increased ($P = 0.01$) 10-year cumulative diameter growth of codominant trees by 73 percent over the unthinned control, when averaged across all species (fig. 3). Residual codominant trees in the thinned plots grew 2.6 inches in diameter, whereas codominant trees in the unthinned control plots grew 1.5 inches. Codominant trees comprise the bulk of sawtimber crop trees in most hardwood stands and are generally the most valuable trees in the stand. However, we were unable to detect statistically significant differences ($P = 0.34$) between treatments in 10-year cumulative diameter growth of dominant trees. Thinning also nearly tripled 10-year cumulative diameter growth of residual trees in the intermediate crown class, relative to the unthinned control. This significant increase ($P = 0.03$) in diameter growth by residual trees in the intermediate crown class is important because many of these poletimber trees exhibited good potential to develop into valuable sawtimber trees in the near future. We made no comparisons for trees in the overtopped crown class because thinning removed all overtopped trees.

The operational thinning successfully increased diameter growth of residual trees during the first 10 years after treatment. We observed excellent diameter growth responses by both red oak and sweetgum trees in the codominant crown

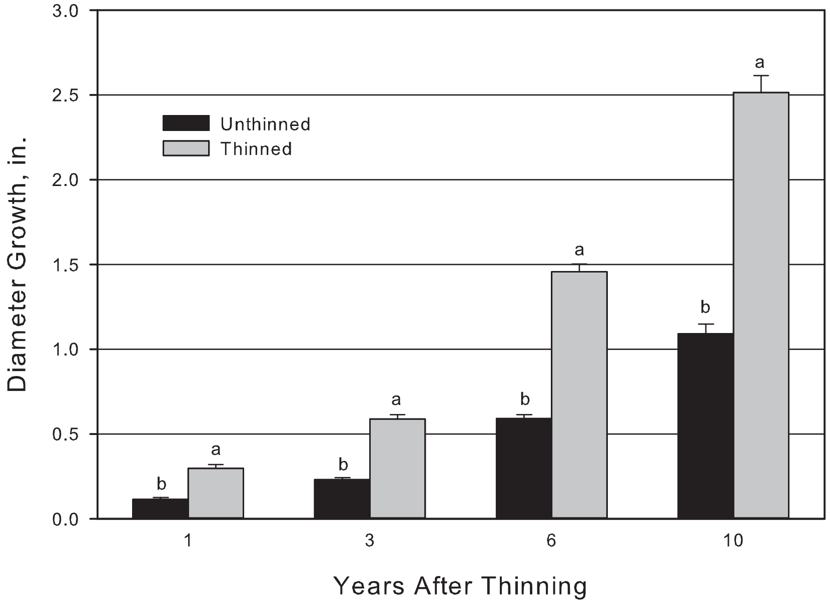

Figure 1—Cumulative diameter growth (±SE) of residual trees 1, 3, 6, and 10 years after application of two thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability ($n = 4$ per treatment; $P = 0.01$ for year 1, $P < 0.01$ for years 3, 6, and 10).

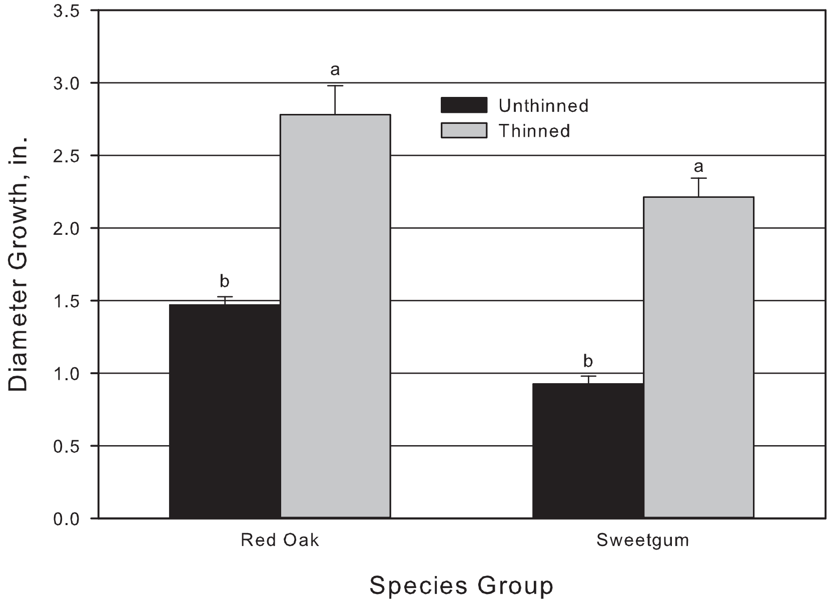

Figure 2—Cumulative diameter growth (±SE) of residual trees, by species group, 10 years after application of two thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (*n* = 4 per treatment; *P* = 0.01 for red oak, *P* < 0.01 for sweetgum).

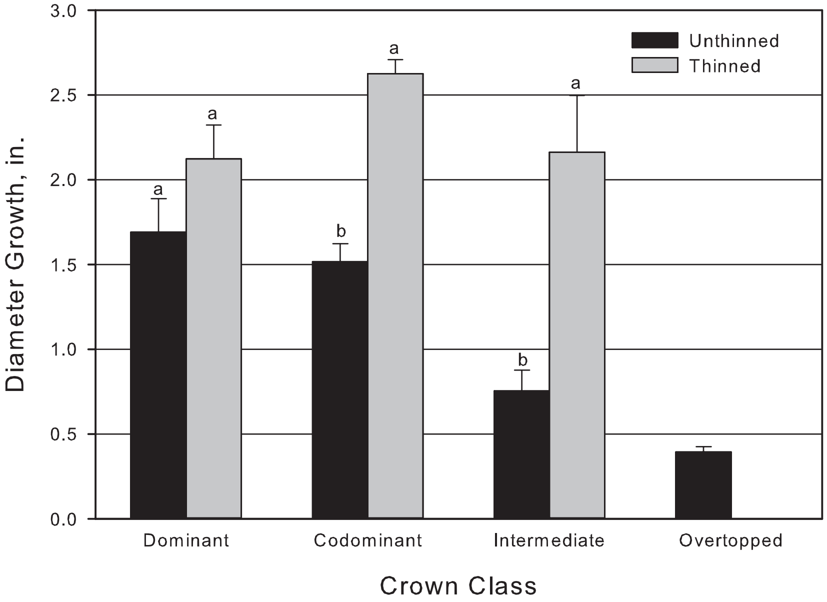

Figure 3—Cumulative diameter growth (±SE) of residual trees, by crown class, 10 years after application of two thinning treatments. Means within each crown class followed by the same letter are not significantly different at the 0.05 level of probability (*n* = 4 per treatment; *P* = 0.34 for dominant, *P* = 0.01 for codominant, *P* = 0.03 for intermediate).

class. Most of those trees, but particularly the red oaks, are classified as crop trees and are the most desirable and most valuable trees in the stand for production of high-quality sawtimber. From a timber production perspective, thinning greatly enhanced diameter growth of the most valuable trees in the stand.

Production of Epicormic Branches

Thinning operations in hardwood stands, while producing positive impacts on diameter growth of residual trees, also may have negative effects on bole quality. Thinning may stimulate production of new epicormic branches along the merchantable boles of residual trees. Because they cause defects in the underlying wood and can reduce both log grade and subsequent lumber value, the possible production of epicormic branches on residual trees can be a serious problem when thinning hardwood stands. However, well-designed thinning prescriptions with marking rules that emphasize retention of healthy, high-quality trees can minimize production of new epicormic branches in most hardwood stands.

When averaged across all trees and all species, the mean number of epicormic branches on the butt logs of residual trees in the thinned plots increased steadily through the end of the third year after thinning, but thereafter remained relatively stable through the end of the 10th year (fig. 4). In contrast, the mean number of epicormic branches on the butt logs of trees in the unthinned control plots remained fairly constant through the first 10 years of the study. Through the first 6 years, means for the two treatments did not differ significantly from each other (P = 0.38 for year 1, P = 0.10 for year 3, P = 0.07 for year 6). However, the relatively large standard errors associated with the thinned plots at the end of the third and sixth years (SE = 1.0 for the thinned plots in both years, SE = 0.6 for the unthinned plots in both years) may indicate that there was too much variation within the thinned plots to allow detection of statistically significant differences in both years. We did detect a statistical difference between treatments (P = 0.04) at the end of the 10th year after thinning. At that time, residual trees in the thinned plots averaged 6.1±0.8 epicormic branches on the butt log, whereas surviving trees in the unthinned control plots averaged 3.1±0.5 branches.

Based on the 10-year means presented in figure 4, thinning had a detrimental effect on bole quality, as evidenced by a significant increase in the number of epicormic branches on the butt logs of residual trees in the thinned plots. However, treatment means in figure 4 were calculated across all trees and all species and reflect only a broad analysis of the data. In fact, we observed that the number of epicormic branches on the butt log varied widely among individual trees. Most healthy trees, with large, well-shaped crowns and dense foliage, had either no epicormic branches or only a few. Conversely, most unhealthy trees, with small crowns and sparse foliage, generally had many epicormic branches.

To diagnose the source of the broad variation in epicormic branch production across individual trees, we partitioned the data by species groups. Hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995). In our study, thinning had no effect (P = 0.56) on production of epicormic branches on residual red oaks, but caused a large, significant increase (P = 0.01) in the number of epicormic branches on the butt logs of residual sweetgum trees 10 years after thinning (fig. 5). In fact, residual red oaks in the thinned plots averaged only 3.2 epicormic branches on the butt log, whereas residual sweetgum trees averaged 9.7 branches, more than three times as many. Surviving red oaks in the unthinned control plots averaged 2.5 branches on the butt log, whereas surviving sweetgum trees averaged 3.8 branches.

Because most red oaks and sweetgum are classified as highly susceptible to the production of epicormic branches (Meadows 1995), further diagnosis was required to explain

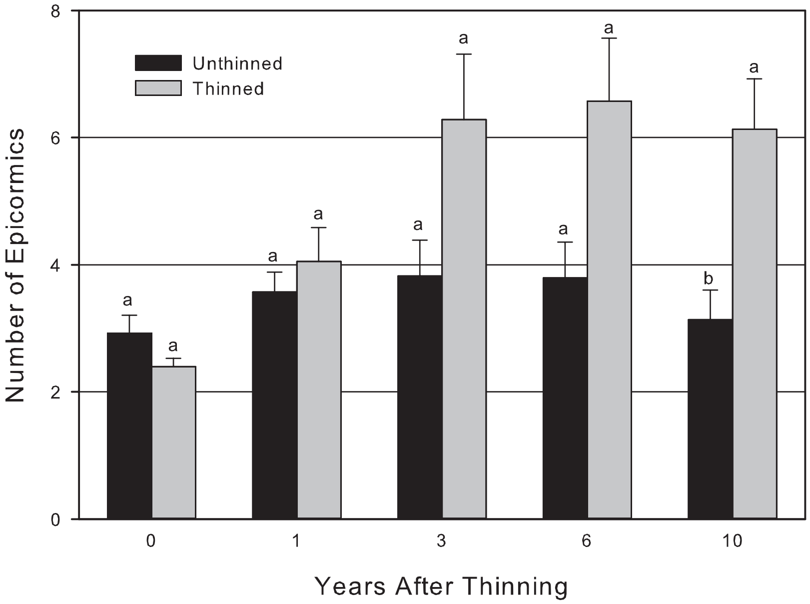

Figure 4—Mean number (±SE) of epicormic branches found on the butt logs of residual trees initially and 1, 3, 6, and 10 years after application of two thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 4 per treatment; P = 0.15 for year 0, P = 0.38 for year 1, P = 0.10 for year 3, P = 0.07 for year 6, P = 0.04 for year 10).

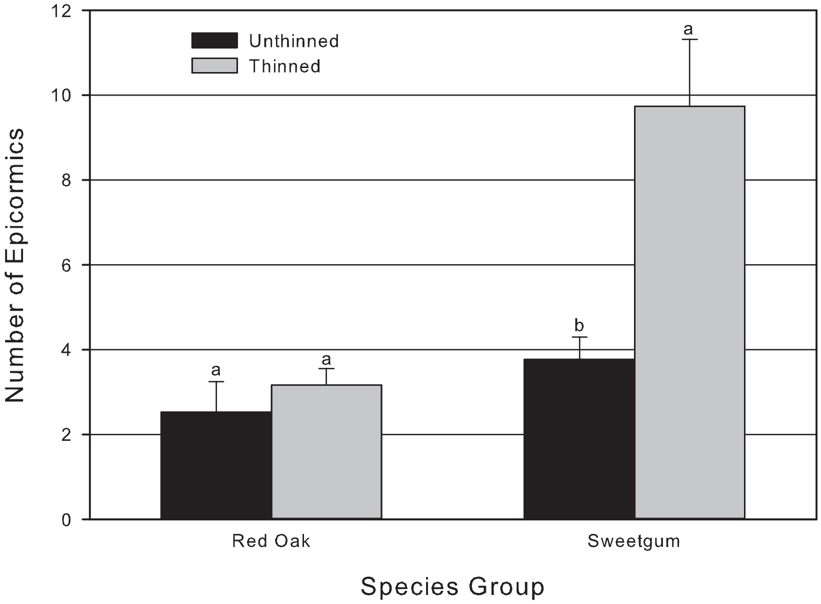

Figure 5—Mean number (±SE) of epicormic branches found on the butt logs of residual trees, by species group, 10 years after application of two thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (*n* = 4 per treatment; *P* = 0.56 for red oak, *P* = 0.01 for sweetgum).

the large difference between these species groups in the number of epicormic branches found on the butt logs of residual trees in the thinned plots 10 years after thinning. We observed that most residual red oaks in the thinned plots were healthy, dominant, or strongly codominant trees that produced very few new epicormic branches after thinning. On the other hand, most residual sweetgum trees in the thinned plots exhibited poor-to-moderate health and were classified as intermediate or weakly codominant trees that produced many new epicormic branches after thinning. These observations strongly support the hypothesis proposed by Meadows (1995) that healthy, vigorous trees, even of highly susceptible species like most bottomland red oaks, 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 in hardwoods, the most important consideration is the number of epicormic branches on the butt logs of crop trees, particularly red oak sawtimber trees and, to a much lesser extent, sweetgum sawtimber trees. Crop trees are favored during the thinning operation and are most likely to produce high-quality, high-value sawtimber. Because they are the most valuable trees in the stand, any significant increase in the production of epicormic branches along the boles of crop trees will reduce the overall value of the stand and will prove to be costly to the landowner. In our study, thinning had no effect (*P* = 0.96) on the number of epicormic branches on the butt logs of red oak sawtimber trees 10 years after thinning (fig. 6). In fact, red oak sawtimber trees in both the thinned plots and the unthinned control plots averaged fewer than three epicormic branches on the butt log, generally not sufficient to cause a negative impact on log grade. Conversely, thinning significantly increased (*P* = 0.01) the number of epicormic branches on the butt logs of sweetgum sawtimber trees. These trees averaged 9.5 epicormic branches on the butt log alone. Based on a general rule of thumb that as few as five epicormic branches may be sufficient to cause a reduction in log grade (Meadows and Burkhardt 2001), it is likely that log grade of many sweetgum sawtimber trees in the thinned plots was affected adversely by the increased production of epicormic branches following thinning. The boles of red oak poletimber trees in the thinned plots supported 10.2±5.2 epicormic branches 10 years after thinning. Due to this large standard error, we were unable to detect significant differences (*P* = 0.13) between treatments, even though red oak poletimber in the unthinned control plots averaged only 3.2±1.8 epicormic branches. Many of the poletimber trees in the thinned plots were relatively unhealthy, lower crown-class trees that produced many new epicormic branches after thinning. We made no comparisons among sweetgum poletimber trees because they have little or no potential to develop into high-value crop trees.

Pathogen Infections Since Thinning

Our third objective in this study was to determine the effects of thinning on insect and disease incidence. The thinning operation removed all red oaks infected with *Inonotus hispidus* in an effort to minimize the likelihood of new hispidus infections and thereby improve forest health.

We surveyed all treatment plots to determine the incidence of new infections of various pathogens by the end of the 10th

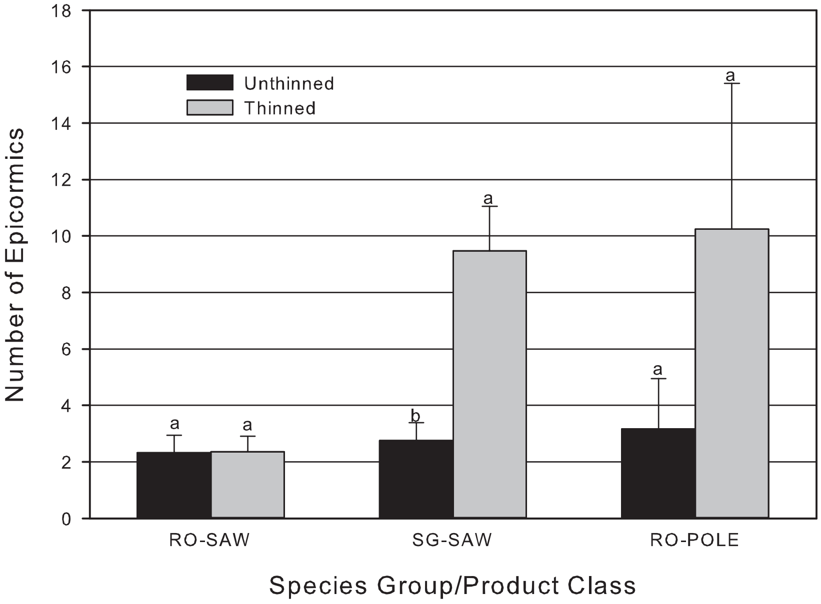

Figure 6—Mean number (±SE) of epicormic branches found on the butt logs of residual trees, by species group and product class, 10 years after application of two thinning treatments (RO-SAW = red oak sawtimber, SG-SAW = sweetgum sawtimber, RO-POLE = red oak poletimber). Means within each species group/product class combination followed by the same letter are not significantly different at the 0.05 level of probability (*n* = 4 per treatment; *P* = 0.96 for red oak sawtimber, *P* = 0.01 for sweetgum sawtimber, *P* = 0.13 for red oak poletimber).

Table 4—Percentage (±SE) of trees with new infections of various pathogens 10 years after application of two thinning treatments

	Pathogens				
Treatment	Deadwood insects	Hispidus canker	Spiculosa canker	Hypoxylon canker	Bacterial wetwood
Unthinned	6.6±1.6 a	1.0±0.6 a	0.0±0.0 a	3.5±0.5 a	2.0±0.1 a
Thinned	10.7±3.8 a	1.4±1.4 a	2.9±1.7 a	1.4±1.4 a	5.7±2.3 a

Means followed by the same letter are not significantly different at the 0.05 level of probability (*n* = 4 per treatment; *P* = 0.46 for deadwood insects, *P* = 0.85 for hispidus canker, *P* = 0.19 for spiculosa canker, *P* = 0.34 for hypoxylon canker, *P* = 0.21 for bacterial wetwood).

year after thinning (table 4). Incidence of deadwood insects (termites, carpenter ants, ambrosia beetles, and powderpost beetles) did not differ significantly between treatments (*P* = 0.46). In addition to hispidus canker, caused by *Inonotus hispidus*, we surveyed for new infections of spiculosa canker, a white rot disease caused by *Phellinus spiculosus*, and hypoxylon canker, a decay disease caused by *Hypoxylon atropunctatum* common on drought-stressed and suppressed trees. Incidence of new disease infections was uniformly low across both treatments and did not differ significantly between treatments (*P* = 0.85 for hispidus, *P* = 0.19 for spiculosa, *P* = 0.34 for hypoxylon). Incidence of bacterial wetwood, a common disease condition that causes “honeycombing” and “shake” in oak lumber, was not significantly different between treatments (*P* = 0.21). Our 10-year survey of new pathogen infections indicates that thinning had no detrimental effects on overall forest health.

CONCLUSIONS

1. Thinning severely reduced stocking and created an understocked residual stand that has not been able to utilize fully the potential productivity of the site during the 10 years since thinning and is not expected to do so during the next 10 years.
2. Thinning significantly increased diameter growth of residual trees, especially red oak sawtimber trees.

3. Thinning had no effect on production of epicormic branches on the butt logs of red oak sawtimber trees, but greatly increased production of epicormic branches on the butt logs of sweetgum sawtimber trees.
4. Thinning improved overall forest health by creating tree and stand conditions not conducive to new infections by a variety of pathogens. Through the targeted removal of all red oaks infected with hispidus canker, thinning reduced *Inonotus hispidus* inoculum, but did not reduce the number of new hispidus infections relative to the unthinned control plots.

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LITERATURE CITED

Broadfoot, W.M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans: 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.

Goelz, J.C.G. 1997. C-lines of stocking for southern bottomland hardwoods: a guide to identifying insufficient stocking. Res. Note SO-385. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 3 p.

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. For. Insect & Dis. Leaf. 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 twenty-third 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.

Meadows, J.S.; Leininger, T.D.; Nebeker, T.E. 2006. Thinning to improve growth and bole quality in an *Inonotus hispidus*-infected, red oak-sweetgum stand in the Mississippi Delta: sixth-year results. In: Connor, K.F., ed. 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: 623–629.

Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

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.