

Intermediate Management

Moderators:

EDWARD R. BUCKNER

University of Tennessee

DAVID L. LOFTIS

Southern Research Station

TEN-YEAR GROWTH RESPONSE OF RED AND WHITE OAK CROP TREES TO INTENSITY OF CROWN RELEASE

David L. Graney¹

Abstract—A thinning study of 60-year-old northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), and white oak (*Q. alba* L.) was superimposed on an existing crown-release study in the Boston Mountains of Arkansas during the summer of 1985. In the new study, individual crop trees were released to achieve relative stocking densities of 40 percent, 60 percent, or 80 percent, and control. The rule thinning method, which defines a thinning radius based on d.b.h., was employed. Ten-year diameter-growth response was influenced by the previous crown release treatment, species, and relative stocking density. Rule thinning can be used to effectively release potential red and white oak crop trees in intermediate-aged mixed oak stands. However, some competing trees—such as leaning trees, and large-diameter trees up-slope from the crop tree—may reduce growth benefits. These situations have to be considered for successful application of rule thinning.

INTRODUCTION

Several hundred thousand acres of forest land in northern Arkansas support overstocked, even-aged stands of pole- to small sawtimber-size oaks. Although many stands are on medium to good sites (site index of 60 to 70 feet at 50 years), diameter growth averages only about 1 inch in 10 years. Growth in these stands can be increased by areawide thinning to target stocking densities (Dale and Hilt 1986, Graney and Murphy 1994), which reallocates site resources to fewer trees, shortens time required to grow products to a given size, and allows utilization of low-vigor and poor-quality stems that would ordinarily die. However, this type of thinning does not guarantee effective release of all high-quality, potentially high-value stems (Lamson and others 1990, Smith and others 1994). Although there are markets for small hardwood roundwood in northern Arkansas, the value of the product is often too low to make these thinnings profitable.

Crop-tree release could provide an alternative means of increasing or maintaining growth of high-quality stems. The crown-touching method of crop-tree release (Smith and Lamson 1986, Lamson and others 1990) is a simple, straightforward, and effective method of releasing selected crop trees by removing the competing trees whose crowns touch the crown of the selected crop tree. Rogers and Johnson (1985) have suggested a crop-tree release technique they call rule thinning. In this method, diameter at breast height (d.b.h.) and a specified relative stocking are used to determine the thinning radius around the crop tree.

This paper summarizes 10-year diameter-growth response of red oaks [northern red (*Quercus rubra* L.) and black (*Q. velutina* Lam.)] and white oak (*Q. alba* L.) to crown release achieved by rule thinning. It describes the effects of first and second crown-release treatments on diameter growth of red and white oak crop trees and describes the effect of relative stocking density on crop-tree growth.

METHODS

Study Region

The Boston Mountains are the highest and most southern member of the Ozark Plateau's physiographic province. They form a band 30 to 40 miles wide and 200 miles long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected, and most ridges are flat to gently rolling and are generally less than 0.5 mile wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Annual precipitation averages 46 to 48 inches, and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

Original study treatments—This study utilized 272 individual red and white oak crop trees that had been part of the crown-release and fertilization study established on Ozark National Forest land in 1974 (Graney 1987). The study was installed in three overstocked 50-year-old mixed oak poletimber stands on south- or west-facing mountain benches. In each stand, 40 to 48 red oak and 40 to 48 white oak crop trees were selected for the crown-release and fertilization treatments. All study trees were tightly grown, small-crowned codominants that required release. For each species group, one-half of the trees were randomly assigned crown release or no release, and each tree was randomly assigned one of three N-P fertilizer treatments. Crowns were released by removing two major competitors and only remaining smaller trees until the basal area based on a 10-factor prism count around each crop tree was reduced to about 70 ft² to approximate B-level stocking. Before treatment, mean d.b.h. for red oak sample trees was 8.33 inches, mean d.b.h. for white oak sample trees was 8.08 inches, and stand basal area averaged 122 ft² per acre. Sample-tree d.b.h. was

¹ Principal Silviculturist, USDA Forest Service, Southern Research Station, 726 West Maple, Fayetteville, AR 72701.

measured to the nearest 0.01 inch annually from 1974 through 1985. The diameter measurement point for each tree was identified by a painted band.

Present study treatments and analysis—For each species, there were two sequences of thinning (one-release and two-release) and four relative stocking densities (40 percent, 60 percent, 80 percent, and no control of density), for a total of eight treatments (table 1).

Sample trees were released using the rule thinning method (Rogers and Johnson 1985). It is a two-step procedure:

1. Find the thinning radius in feet for a given stocking target and crop-tree d.b.h. Remove all trees within the boundary defined by the thinning radius.
2. Survey the area outside the thinning radius of the crop tree to determine if a tree larger than the crop tree is nearby. If such a tree is present, determine its d.b.h. and thinning radius. If the crop tree falls within the thinning radius of the larger tree, then the larger tree is removed.

Thinning-radius values for a range of tree diameters are presented in Rogers and Johnson (1985) (table 2). Thinning-radius values representative of those employed in the present study are:

Crop-tree d.b.h.	Relative stocking (%)		
	40	60	80
<i>Inches</i>	-----Thinning radius (ft)-----		
8	11.8	8.1	5.3
10	14.2	9.7	6.4
12	16.6	11.4	7.5
14	18.9	13.0	8.5

Crop trees receiving the 40 percent treatment were released from crown-touching competition on at least three sides but usually on four sides, while the 60 percent treatment resulted in release on three sides but

Table 1—Mean stand and tree characteristics after treatment and 10 years of growth by species (n=17 for each species x treatment combination)

Treatments		After treatment		10-year change	
Release	Stocking	D.b.h.	Basal area	D.b.h.	Basal area
		Mean (range)	Mean (range)	Mean (range)	Mean (range)
<i>Percent</i>		<i>---Inches---</i>	<i>---Ft²/acre---</i>	<i>---Inches---</i>	<i>---Ft²/acre---</i>
Red oaks (age = 61; site index = 62)					
First	40	10.3 (8.4-13.2)	40 (30-50)	12.3 (9.7-16.0)	47 (40-60)
	60	10.5 (9.9-14.7)	57 (50-70)	12.4 (10.6-16.7)	66 (50-80)
	80	10.3 (8.2-14.6)	80 (70-90)	11.7 (9.2-16.3)	89 (70-100)
Second	Control ^a	10.4 (8.0-15.1)	126 (100-150)	11.4 (8.9-16.3)	121 (110-140)
	40	10.9 (8.1-13.3)	42 (30-50)	13.1 (9.5-15.5)	55 (30-70)
	60	10.9 (8.2-13.3)	56 (50-70)	12.9 (10.3-15.5)	66 (50-80)
	80	10.8 (8.0-14.0)	75 (60-90)	12.4 (9.4-15.4)	84 (70-100)
	Control ^b	10.5 (7.9-14.6)	92 (80-110)	11.9 (8.5-16.7)	97 (70-120)
White oak (age = 63; site index = 59)					
First	40	9.5 (8.0-14.5)	43 (30-50)	11.4 (9.5-16.0)	52 (40-70)
	60	9.3 (7.6-11.6)	56 (40-70)	11.1 (9.6-14.4)	61 (50-70)
	80	9.4 (7.4-12.1)	84 (80-100)	10.6 (7.9-13.8)	95 (80-110)
Second	Control ^a	9.3 (7.2-11.0)	131 (80-170)	10.4 (8.3-12.3)	128 (100-150)
	40	10.8 (8.2-13.4)	43 (40-50)	13.2 (9.8-15.4)	54 (40-70)
	60	10.9 (7.4-13.4)	56 (50-60)	12.9 (8.9-15.8)	66 (50-90)
	80	10.9 (7.9-13.1)	75 (70-80)	12.5 (9.2-14.6)	84 (70-100)
	Control ^b	10.7 (8.0-12.2)	90 (80-110)	12.1 (9.3-13.6)	99 (90-120)

^aControl trees not released in 1974 or 1985.

^bControl trees partially released in 1974 but not released in 1985.

Table 2—Analysis of variance probabilities of greater F-value and Error II Mean Squares for red and white oak periodic annual diameter growth for 1986-1990, 1991-1995, and 1986-1995

Source of variation	DF	Red oaks			White oak		
		Periodic annual growth			Periodic annual growth		
		1986-90	1991-95	1986-95	1986-90	1991-95	1986-95
-----Pr > F-----							
Rep	16	0.8502	0.2019	0.5257	0.4668	0.2044	0.3010
Release	1	0.0001	0.1071	0.0002	0.0001	0.0143	0.0001
Release x rep [Error I]	16	0.3612	0.2917	0.3933	0.7521	0.6786	0.6630
Stocking	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Release x stocking	3	0.3273	0.4318	0.5968	0.1380	0.5733	0.3396
-----Mean square x 100 (inches ²)-----							
Error II	96	0.1434	0.1915	0.1633	0.1087	0.1561	0.1216
Total	135						

occasionally in release on two sides. The 80 percent treatment released trees on one side at best and often effected no release from crown-touching competition. Control trees that were not released either in 1974 or in 1985 had crown-touching competitors on four sides, while controls released only in 1974 were often still free of crown competition on one side.

Crown-release and stocking-density treatments were applied in June and July 1985. Sample-tree d.b.h. was measured in the fall of 1985 following treatment and annually thereafter through 1995. Average tree and stand characteristics following treatment in 1985 and 10-year change in d.b.h. and basal area values are shown in table 1.

The study had a completely randomized split-plot design with one-release or two-release representing the whole plot, and relative stocking densities (40 percent, 60 percent, 80 percent, and no control of density) representing the subplots. Data were analyzed by analysis of variance with treatment effects tested at the 0.01 level of significance. Differences among treatment means were tested using the LSMEANS option of the General Linear Model procedure in SAS (SAS Institute 1989).

RESULTS

Over the 10-year measurement period, red and white oak crop trees receiving two release treatments produced significantly greater diameter growth than trees receiving the single crown release. However, this response was pronounced for only the first 5 years following treatment. While response to a second release was slightly greater over the second 5-year period, the difference in diameter growth was not significant at the 0.01 level (table 2).

Response to intensity of crown release (stocking level) was highly significant for each 5-year period. There was no significant interaction between number of release and stocking level for either species group (table 2).

Response to a First or Second Crown Release

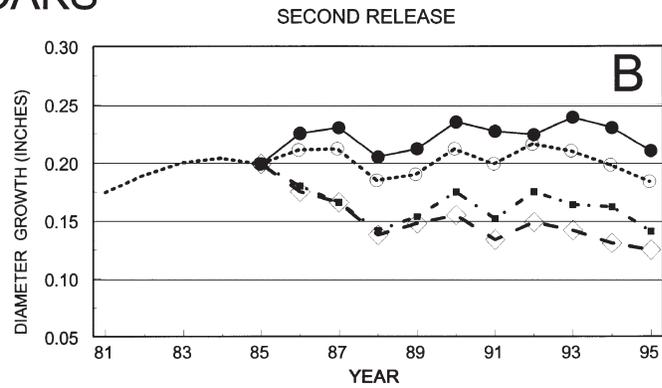
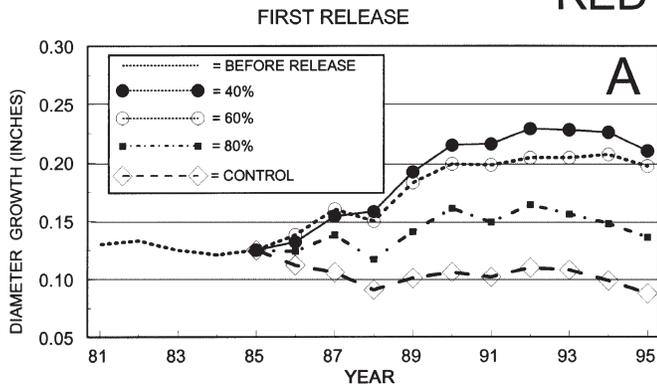
When red and white oak crop trees received a second crown release, the second release treatment usually enabled the trees to maintain their previous rate of diameter growth. However, trees that had received no previous crown release responded to the release with increased diameter growth, and by the sixth through tenth years after release these trees were growing at about the same rate as the previously released trees (fig. 1).

Diameter growth of red and white oak trees that received only a single crown release generally declined throughout the 10-year measurement period but was still greater than diameter growth of the controls that received no release (0.15 in. vs. 0.10 for red oaks and 0.14 in. vs. 0.11 for white oak). Thus, some response to a single crown release can be expected to persist for about 20 years following release. This finding is consistent with the 20-year response reported for white oak poles in southern Illinois (Schlesinger 1978), but overall response in the present study is less than reported by Schlesinger (1978). To maintain growth rates observed for red and white oak crop trees at the end of the previous study, another effective crown release would be required within 10 years after the first release (fig. 1).

Response to Stocking Density

Response of red and white oak crop trees to stocking density varied somewhat by species and the previous

RED OAKS



WHITE OAK

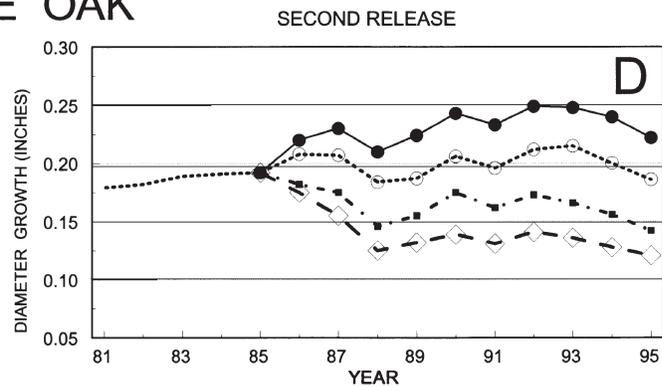
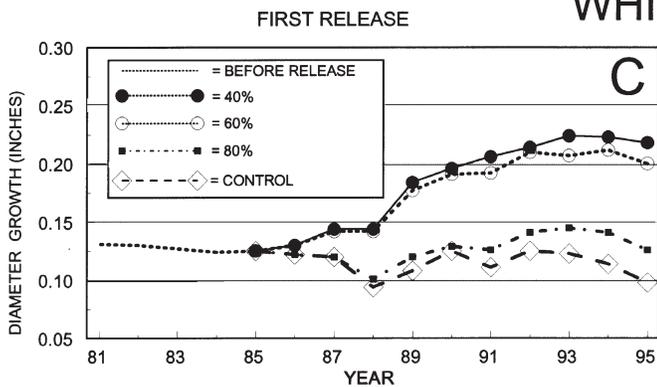


Figure 1—Mean annual growth of red and white oaks following first or second crown release treatments and at four relative stocking densities.

release treatment. However, the 60 percent and 40 percent relative stocking treatments produced the greatest responses in both red oaks and white oak.

Red oaks receiving the first crown release in 1985 did not have a significant growth response the first year after treatment, although growth of the released trees was greater than that of the nonreleased controls. After the first year, all red oaks that received only one release grew significantly better than the controls. Diameter growth of the once-released red oaks that were released to 40 percent and 60 percent increased rapidly by the fourth year and reached a maximum at 7 to 9 years after treatment. Once-released red oaks released to 40 percent stocking exhibited the greatest overall growth, the difference was not significantly greater than red oaks released to 60 percent stocking. Trees released to 80 percent stocking grew better than controls but significantly less than trees that received the 40 or 60 percent stocking treatments (table 3).

Red oaks that had received a previous crown release exhibited an immediate and significant diameter-growth response to a second crown release to 40 percent or 60 percent relative stocking density. Diameter growth of trees released to 80 percent stocking density was about the

same as that of the control trees over the 10-year period. Although annual diameter growth of red oaks released to 40 percent stocking was consistently greater than that of those related to 60 percent stocking over the 10-year measurement period, differences between growth for the 40 percent treatment and growth for the 60 percent treatment were not significant. Diameter growth of red oaks receiving the control and 80 percent treatments generally declined over the 10-year period, but growth of the trees released to 80 percent stocking declined at a slower rate (table 3).

Diameter growth of white oak sample trees that received only one crown release did not respond to that release immediately. In white oaks, significant response to crown release began the third year after treatment. Response was significant only for the 40 percent and 60 percent stocking treatments. Unlike once-released red oaks that were released to an 80 percent stocking density, once-released white oaks receiving the 80 percent stocking treatment did not grow significantly more than controls. Once-released white oaks, like once-released red oaks, responded similarly to the 40 percent and 60 percent density treatments, and maximum diameter growth occurred about 7 to 9 years after release (table 3).

Table 3—Least square means comparisons for mean annual diameter growth response of red and white oaks to a first or second crown release and four relative stocking densities

Species/year	First release				Second release			
	Relative stocking (percent)				Relative stocking (percent)			
	Control ^a	80	60	40	Control ^b	80	60	40
Red oak								
1986	.112a	.124a	.138a	.132a ^c	.175a	.180a	.211b	.225b ^c
1987	.106a	.138b	.160b	.154b	.166a	.166a	.212b	.230b
1988	.091a	.117b	.150b	.158b	.128a	.142a	.185b	.205b
1989	.101a	.141b	.183c	.192c	.138a	.154a	.190b	.212b
1990	.106a	.161b	.199bc	.215bc	.155a	.175a	.212b	.235b
1991	.102a	.149b	.198c	.216c	.134a	.152a	.199b	.227b
1992	.110a	.164b	.204c	.229c	.149a	.175a	.216b	.244b
1993	.108a	.156b	.204c	.228c	.142a	.164a	.210b	.239b
1994	.099a	.148b	.207c	.226c	.131a	.162a	.198b	.230b
1995	.088a	.136b	.197c	.210c	.125a	.141a	.184b	.210b
Mean	.102a	.143b	.184c	.196c	.144a	.161a	.202b	.226b
White oak								
1986	.122a	.122a	.130a	.130a ^c	.175a	.182a	.208b	.220b ^c
1987	.120a	.120a	.142a	.144a	.155a	.175a	.207b	.230b
1988	.094a	.101a	.142b	.144b	.125a	.146a	.184b	.210b
1989	.108a	.120a	.177b	.184b	.132a	.155a	.187b	.224c
1990	.125a	.129a	.191b	.196b	.139a	.175b	.206c	.243d
1991	.111a	.126a	.192b	.206c	.131a	.162a	.196c	.233d
1992	.125a	.141a	.210b	.214b	.141a	.173a	.212b	.249c
1993	.123a	.145a	.207b	.224b	.136a	.166a	.215b	.248c
1994	.114a	.141a	.212b	.223b	.128a	.156a	.200b	.240c
1995	.098a	.126b	.200c	.218c	.121a	.142a	.186b	.222c
Mean	.114a	.127a	.180b	.188b	.138a	.163a	.200b	.232c

^a Control trees not released in 1974 or 1985.

^b Control trees partially released in 1974 but not released in 1985.

^c Values in rows followed by the same letter are not significantly different at the 0.01 level.

White oak crop trees also responded immediately and significantly to a second crown release, but only for the more intensive release treatments. Diameter-growth responses to the 40 percent and 60 percent treatments were about the same for the first 3 years after release, but diameter growth of trees released to 40 percent stocking was significantly greater than that of trees released to 60 percent stocking for the remainder of the study. White oaks released to 80 percent stocking generally grew better than controls, but differences were not significant over the 10- year period. Diameter growth for both control and 80 percent stocking treatments generally declined over the 10- year period (table 3).

DISCUSSION

If applied as recommended, rule thinning gives a selected crop tree the growing space at a prescribed target stocking density. However, the method does require measurement of

crop-tree diameter and corresponding thinning radius to identify competing trees to be removed. The method also requires consideration of noncrop trees larger than the crop tree that are outside of the crop tree's thinning radius but large enough to compete with the crop tree. This requirement could confuse marking crews initially. Strict application of the rule thinning method does not provide for removal of competing trees that are not within the crop tree's thinning radius or the larger noncrop trees' thinning radius but lean toward the crop tree and touch or even overtop the crop tree's crown. This situation occurred in each stand and usually involved large-diameter residual stems located on steep interbench slopes above the crop trees. Although our Boston Mountain oak stands are essentially even-aged, they usually include five or more trees per acre that were not removed in the previous harvest because of their quality, species, or size. These

stems are usually cull or very low quality with large crowns and often have significant lean. When located on steep interbench slopes, these large-crowned, leaning stems often influence a much larger area than their diameter would suggest. Such trees must be considered when the rule thinning method is applied. In the present study, leaning trees that were in competition with the crop tree but that were not designated for removal by application of the method were removed in most instances.

Response to partial crown release may persist for as long as 20 years, but to produce acceptable rates of diameter growth and to maintain these growth rates, release treatments will have to be more intensive than the partial release applied in the previous study and may have to be repeated on a 10- or 15-year cycle.

The rule thinning crown release to 40 percent residual stocking density would be roughly equivalent to the crown-touching release procedure recommended for stands of pole- and small sawtimber-sized mixed hardwoods in the Appalachians (Lamson and others 1990, Smith and others 1994).

CONCLUSIONS

Crown release can be an effective method for increasing growth of red and white oaks in heavily stocked stands of intermediate-aged, pole- and small sawtimber-size mixed oaks in the Boston Mountains. Annual diameter growth of tightly grown codominant red and white oak crop trees can be increased from current levels of about 0.1 inch to 0.2 to 0.25 inch with effective crown release. However, to maintain the higher rates of diameter growth, additional crown release would be required after a 10- to 15-year interval.

The rule thinning method has important advantages. It is based on established and accepted oak stocking guides which define growing space requirements, and it was developed for upland mixed oak stands in the Missouri Ozarks. The method is straightforward and provides a system for providing consistent release of oak crop trees to a prescribed stocking. However, the method does require measurement of crop-tree diameter and thinning radius, and the evaluation of competing trees that are not within the defined thinning radius of the designated crop tree. The method also does not make provision for leaning trees that compete with the sample tree's crown but are not within thinning radii.

LITERATURE CITED

- Dale, Martin E.; Hilt, Donald E.** 1986. Thinning pole and small sawtimber mixed oak stands. In: Smith, H. Clay; Eye, Maxine C., eds. Proceedings, guidelines for managing immature Appalachian hardwood stands; 1986 May 28-30; Morgantown, WV. SAF Publ. 86-02. Morgantown, WV: West Virginia University Books: 99-117.
- Graney, D.L.** 1987. Ten-year growth of red and white oak crop trees following thinning and fertilization in the Boston Mountains of Arkansas. In: Phillips, Douglas R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 445-450.
- Graney, David L.; Murphy, Paul A.** 1994. Growth and yield of thinned upland oak stands in the Boston Mountains of Arkansas. *Southern Journal of Applied Forestry*. 18(1): 10-14.
- Lamson, Neil I.; Smith, H. Clay; Parkey, Arlyn W; Brock, Samuel M.** 1990. Crown release increases growth of crop trees. Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.
- Rogers, Robert; Johnson, Paul S.** 1985. Rule thinning: a field method for meeting stocking goals in oak stands. In: Dawson, Jeffrey O.; Majerus, Kimberly A., eds. Proceedings, fifth central hardwood forest conference; 1985 April 15-17; Urbana-Champaign, IL. SAF Publ. 85-05. Urbana-Champaign, IL: University of Illinois, Department of Forestry: 106-110.
- SAS Institute, Inc.** 1989. SAS/STAT user's guide, version 6, 4th ed., vol. 2. Cary, NC: SAS Institute, Inc. 846 p.
- Schlesinger, Richard C.** 1978. Increased growth of released white oak poles continues through two decades. *Journal of Forestry*. 76(11): 726-727.
- Smith, H. Clay; Lamson, Neil I.** 1986. Cultural practices in Appalachian hardwood sapling stands—if done, how to do them. In: Smith, H. Clay; Eye, Maxine C., eds. Proceedings, guidelines for managing immature Appalachian hardwood stands; 1986 May 28-30; Morgantown, WV. SAF Publ. 86-02. Morgantown: West Virginia University Books: 46-61.
- Smith, H. Clay; Miller, Gary W.; Lamson, Neil I.** 1994. Crop-tree release thinning in 65-year old commercial cherry-maple stands (5- year results). Res. Pap. NE-694. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 11 p.

CAMBIAL INCREMENT OF 43-YEAR-OLD WHITE OAK (*QUERCUS ALBA* L.) CROP TREE RESPONSES TO FERTILIZER AND CROWN RELEASE ON A TENNESSEE UPLAND SITE

G. Richard Schaertl, Allen E. Houston, Edward R. Buckner, and James S. Meadows¹

Abstract—Cambial responses to fertilization, crown release, and fertilization × release treatments with untreated controls, and treatment-by-year interactions were studied in pole-sized (approximately 43 years old) white oak (*Quercus alba* L.) crop trees. In the main study, fertilizer was applied by broadcast to plots at a rate of 150 lbs. N and 35 lbs. P₂O₅ per acre, and crown release removed competing trees around crop trees (dominate or codominate trees selected for favorable timber characteristics) in randomly selected plots during spring 1993. Another fertilizer application was applied during spring 1995 at the same rate and method as the first application. Bole diameter, measured at 4.5 ft aboveground line (d.b.h.); scaling diameter inside-bark (d.i.b.) and radial increment, both variables measured at 17.3 ft aboveground; form class; and stem taper were examined. D.b.h., d.i.b., increment, and form class were measured for 4 years beginning with 1992 pretreatment data; stem taper was measured for 1995 only. Stem taper and form class did not differ significantly among treatments. Although annual d.b.h. and d.i.b. differences among treatments were not significant, pooled mean annual d.b.h. and d.i.b. increased significantly each year at compound annual rates of 2.9 percent (9.44 in. in 1992 to 10.29 in. in 1995) and 3.1 percent (7.28 in. in 1992 to 7.97 in. in 1995), respectively. Radial increments for release (0.12 in.) and fertilization × release (0.12 in.) treatments were significantly greater than the control (0.09 in.) in 1993. The fertilization × release treatment continued to significantly increase increment (0.14 in.) more than fertilization and control treatments (0.11 in both treatments) in 1994. By 1995, increment for fertilization × release (0.16 in.) was significantly greater than release, fertilization, and control (0.12, 0.11, and 0.10 in., respectively). Fertilization × release treatment provided greater cambial increment for the first 3 years on mid-rotation white oak crop trees. Should trends continue, the fertilization × release treatment will improve volume in the first log and may improve log form more than release, fertilization, and the control treatments.

¹ The University of Tennessee, Jackson, TN, 38301-3201; Ames Plantation Experiment Station, The University of Tennessee, Grand Junction, TN; Department of Forestry, Wildlife, and Fisheries, The University of Tennessee, Knoxville, TN; and USDA Forest Service, Southern Research Station, Stoneville, MS (respectively).

EARLY THINNINGS IN A YOUNG, SPROUT-ORIGIN, BOTTOM-LAND HARDWOOD STAND IN SOUTH CAROLINA

Mark B. Tinsley and Lawrence E. Nix¹

Abstract—A 23-year-old, sprout-origin, bottom-land hardwood stand along the Congaree River in South Carolina was commercially thinned using three different methods: “corridor,” “leave-tree,” and “trainer-tree.” The stand consisted of 260 to 320 trees per acre of typical, mixed bottom-land species, with 28 to 31 cords per acre, including about 40 percent commercial oaks, and 100 to 140 crop trees per acre. Thinnings were marked to produce a 10 to 12 cords-per-acre harvest and to leave at least 90 crop trees per acre. After one growing season, impact of thinning methods on quality of residual stand, especially the crop trees, was determined by measuring logging damage to lower boles, epicormic sprouting along first 16-foot log, and grape vine severance. All thinning methods produced a commercial level of product and left 80+ crop trees per acre, which were 30 to 40 percent commercial oaks. The crop trees in the “trainer-tree” method averaged 1.1 epicormic sprouts on first 16-foot log, while those in the “corridor” and “leave-tree” methods averaged 3.4 sprouts. Vine severance, which was considered a stand quality enhancement, was greatest in the “trainer-tree” method.

INTRODUCTION

Early thinnings in bottom-land hardwood stands provide much needed income for forest landowners. Many hardwood silviculturists such as Gingrich (1971), Carvell (1971), and Kennedy and Johnson (1984) were recommending early thinning in hardwood stands 20 or 30 years ago. The main objective of thinning is the improvement of the residual stand by favoring or concentrating growth on vigorous, high-quality crop trees (Carvell 1971). Simultaneously generating an intermediate income which might otherwise be lost to imminent natural mortality is highly desirable (Gingrich 1971). Kellison and others (1988) present the benefits of early thinning in terms of cumulative board foot gains. They give examples of the greater cumulative yields that result from beginning a planned thinning schedule at early stand ages. Gingrich (1971) states that yield data clearly indicates the potential for reducing the rotation length in hardwood stands by early thinning. Gingrich (1971) and Carvell (1971) report increases from 30 to 40 percent in individual tree diameter growth on thinned hardwood sites.

Many silviculturists feel that the first thinning should take place as soon as a practical commercial thinning can be made (Carvell 1971, Gingrich 1971, Kennedy and Johnson 1984). Kellison and others (1988) indicate that early manipulation of stocking levels at age 20 to 25 years can increase the productivity and value of bottom-land hardwoods significantly. In fact, they suggest that the thinning of pole-sized trees at about 25 years offers considerably more promise in improving stand development than cleaning or thinning at younger ages.

The beneficial results from hardwood thinning also depend on species composition, tree vigor, and potential stem quality (Clatterbuck and Hodges 1988, Kennedy and Johnson 1984). Ideally, the forester would like to keep the better-quality stems growing steadily by removing the less desirable trees before their competition retards the growth of the more desirable trees.

When thinning in bottom lands, the more valuable, high-quality species are favored, such as cherrybark (*Quercus pagoda*) and shumard oaks (*Q. Shumardii*) (Kennedy and Johnson 1984). Also favored in bottom lands are good sweetgum (*Liquidambar styraciflua*), sycamore (*Platanus occidentalis*), and green ash (*Fraxinus pennsylvanica*). However, it is more important to favor a high-quality stem of a species of lower value, than it is to favor a poorly formed, low-quality stem of a highly valued species (Kennedy and Johnson 1984). Therefore, the selection of crop trees should take into account each individual tree in relation to the quality and growth potential of others nearby in the stand (Clatterbuck and others 1987). The wide range in quality among and within the different bottom-land species presents some real silvicultural challenges. Multiple stump sprouts and other defective stems should be harvested to allow better-quality single stems to use the growing space. Yet all poor-quality trees cannot be removed in a single thinning without leaving the stand understocked (Gingrich 1971).

Historically, the first commercial thinning in bottom-land hardwoods begins when trees reach small sawtimber size (Kennedy and Johnson 1984). However, increasing markets for hardwood pulpwood make it possible to commercially thin young (20 to 25 year old), sprout-origin, pole-size stands on productive sites in the first bottoms of major rivers in the Southern United States (Kellison and others 1988). The primary objective of the present study is to demonstrate that this early thinning can be accomplished without reducing future stand quality in such valuable stands.

METHODS

The study area is a first bottom, 23-year-old, sprout-origin, bottom-land hardwood stand along the Congaree River near Columbia, SC. After several decades of being selectively cut over, the stand was KG blade sheared in 1971 and now consists of 260 to 325 trees per acre of typical, mixed bottom-land species with 28 to 31 cords per

¹ Former Graduate Assistant and Associate Professor, respectively, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003.

acre. From 30 to 40 percent of the basal area per acre is in commercial oaks with about 90 to 140 potential crop trees per acre of different species, e.g., miscellaneous oaks, sycamore, sweetgum, elm (*Ulmus* spp.), green ash, and maple (*Acer* spp.). Two parts of the stand used in the study are reasonably good oak sites with a site index (base age 50) of 85 to 95 for cherrybark oak and are moderately to well-drained silty clay loams. Thinning treatments were applied in a randomized complete block design with 4-acre plots, 1-chain buffer areas, four blocks or replications of a control, and three thinning methods, on about 75 acres. Twenty-foot-wide skidding corridors delimit all plots and blocks for treatment monumentation and future tree measurements.

In order to be practical all treatments were to be commercial, removing at least 10 cords per acre of trees 6 inches in diameter at 4.5 feet height (d.b.h.). Based on the average d.b.h. of the stand (9.2 inches), this corresponded to removing about 100 trees per acre. The “trainer tree” treatment was to leave a few trainer stems as residuals around each of the crop trees. Only enough volume to be commercial was to be removed, so only 100 trees per acre were marked. Since there were at most about 320 trees per acre, if the 100 crop trees per acre with two trainers for each were needed, then not enough could be cut. So it was determined to harvest merchantable trees on about a 20 by 20-foot spacing (100 per acre). But trees had to be marked so that the logger's production was maintained and the harvesting scheme was readily apparent. This meant marking trees of marginal diameter that would aid in finding the merchantable trees to be cut.

The second treatment was the “leave tree,” where theoretically all lower-crown-class trees are harvested and only crop trees remain. To accomplish this goal, the marking was reversed to leave 100 trees per acre, so the minimum number of crop trees per acre was determined by the 20 by 20-foot spacing. Sometimes, crop trees were closer than 20 feet apart; in those cases, they were left. The 20 by 20-foot spacing was a maximum distance as long as 10 cords per acre were harvested.

The third treatment was to be an “efficient” corridor method. Again, at least 100 trees per acre were to be removed, or about one-third of the volume. So one-third of the area of each acre was harvested by cutting 20-foot corridors, leaving 40-foot strips uncut. Since the corridor method is indiscriminant as to which tree it harvests, as many good trees as poor trees were cut. The corridors were marked in a herringbone pattern at no more than 60° angles to the main skid trails, in order to minimize turning damage caused by the full-length trees.

Vines

As in most bottom-land stands, vines (*Vitus* spp.) in this area were very prevalent. On the very fertile, bottom-land sites, lush vine growth is common and can be a major problem in management of high quality hardwoods; in some areas it may completely eliminate high-quality crop

trees. During harvesting the thinning treatments cut or pulled vines out of the residual crowns; therefore, vine presence and condition were monitored before and after thinning. For each residual crop tree vines were classified as follows: (1) cut—if the vine was completely severed, (2) live—if the vine was unharmed by harvesting and growing in the canopy of the crop tree, (3) both—if a crop tree had at least one vine live and one cut, (4) no vines—trees that had vines pulled completely out of their canopy or never had vines, (5) present—meaning vines simply grew on the bole of the crop tree, and (6) overtop—meaning vines had overtopped the crop tree, with the potential for causing increased epicormic sprouting.

Logging Damage

The success of the thinning operation depended upon the proper execution of the harvesting operation. Thus, it was important to design a harvesting scheme that maximized efficient tree removal and minimized residual damage from machinery movement, felling, and skidding. Because loggers usually have no immediate economic interest in the residual stand, incentives were offered to curtail the residual damage caused by reckless or careless harvesting. The thinning objective of each treatment was explained, and the forest manager adjusted the stumpage for the loggers proportionally to production. However, some damage was inevitable as in any logging operation. The damage to residual crop trees was classed as “back,” “fell,” “skid,” and “turn,” which are self explanatory. Only damage to crop trees was reported.

Epicormic Sprouts

The grade of hardwood logs largely determines their value. Log grade reflects the size and number of clear lumber cuttings which can be made from a specific log; thus, any silvicultural practice which causes reductions in grade, subsequently decreases the financial returns from timber management. For this reason, along with harvesting damage, the response of crop trees in epicormic sprouting was monitored. Epicormic sprouts in the first and second log of all crop trees were counted.

In view of the predisposition of some stems to have epicormic sprouts (Smith 1966), this characteristic was included in the criteria for choosing crop trees. Designated “crop trees” were based on the following criteria: (1) dominant or codominant, (2) good form and vigor, (3) no vines or damage, (4) no signs of being prone to epicormic branching, and (5) at least one clear 16-foot log.

Experimental Design

Analysis of variance with a randomized complete block design was used to determine whether treatments differed in their effects on residual stand quality. Response variables were number of crop trees per acre, epicormic sprouting, logging damage, and vine severance, which was considered a positive response for future quality of crop trees.

RESULTS

Number of Crop Trees

There was no difference in the number of crop trees per acre in the corridor, leave, and trainer thinning treatments after thinning (fig. 1). The control plots consistently had more crop trees, however (140 versus 90 per acre). The trainer tree thinning had a significantly higher percentage of oak crop trees than did any other treatment (fig. 2), perhaps because, often, potential crop trees were left as "trainers." No significant differences were found among other thinning treatments.

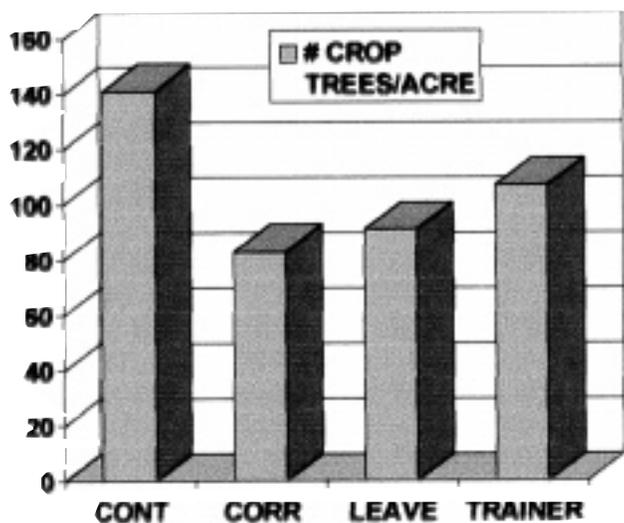


Figure 1—The number of crop trees per acre before and after thinning by three methods in a young, sprout-origin, red river bottom land in South Carolina.

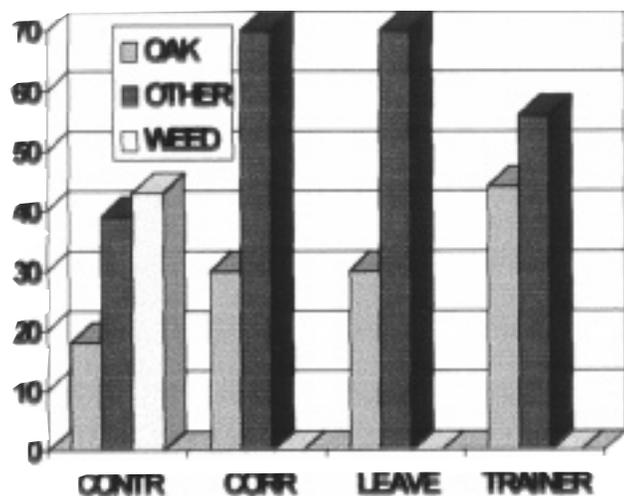


Figure 2—The proportion in percentage of oak and other crop trees after thinning by three methods in a young, sprout-origin, red river bottom land in South Carolina.

Effects on Vine Condition

How thinning methods affected vine composition in the residual stand is shown in figure 3. There were significant differences between the control and the other treatments, i.e., any thinning reduced vines; and this was a positive effect on future stand quality. In the corridor thin, machinery did not get among residuals; thus, there was little difference in vines between the control and the corridor thin. However, there was a significant difference between the corridor and the trainer and leave thins (fig. 3), probably because more bigger trees were cut in these thinnings than in the others. The cut vine difference between the corridor and trainer thins resulted because there were more codominant trees cut in the trainer thin and vines were mainly in codominants. Wide differences occurred in the study area because of present vine position in the canopies, i.e., they started with the sprouts and often suppressed dominant stems causing them to become subordinate. With vines present, there was no difference between corridor and leave thins, but there was a difference between corridor and trainer thins, probably because of vine positioning, i.e., an adjacent tree had to be harvested to remove a vine and there were more adjacent removals in the trainer than in the corridor thin (fig. 3). No difference occurred between the leave and trainer thins for this variable. The overtop vine condition occurred mainly in dominants and codominants and thus was not thinned out. This condition was hard to see in the summer prior to thinning and arises when a vine has no place else to grow. However, this condition can be in any crown class, especially in a sprout origin stand, and may cause a tree to regress to a lower crown class and to epicormically sprout, reducing grade.

Logging Damage

Logging damage was reduced by the following factors: (1) good harvest design, (2) excellent communication with the loggers, and (3) cash incentives for loggers. Although overall damage was slight, the trainer and leave treatments

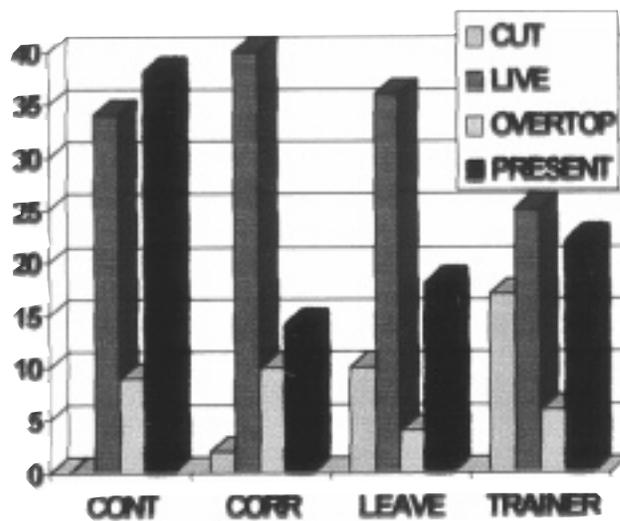


Figure 3—The distribution in percentage of vine types on crop trees after thinning by three methods in a young, sprout-origin, red river bottom-land in South Carolina.

were significantly greater than the corridor, with 5 to 6 percent incidence, while the corridor treatment had only 2 percent incidence (fig. 4). However, damage in excess of 2 to 3 percent could be considered critical when crop trees are in short supply as they were in this stand.

The use of a small feller/buncher helped in maneuvering through the residuals, but occasionally there was trunk wounding or "back damage," especially in the trainer thin, where the feller or skidder often backed into a residual crop tree. When the small feller was not productive enough to suit the loggers, they used a large, full-production feller/buncher, especially in the corridor thin. Some residual trees were used by loggers as pivot points in turning whole-length trees, but frequently trees used as turn trees were later harvested. In the corridor thin, trees were felled in a herringbone pattern in relation to main skid trails and to the road, and were pulled out with a minimum amount of turning. Also the existence of trainer stems appeared to be vital for protecting residual crop trees. Stems left to protect or buffer crop trees from mechanical or skidding damage are very beneficial, but there were many more crop tree residuals in the trainer tree thin plots. Thus, more damage occurred to potential crop trees in this treatment.

The distribution of logging damage among types reported can be summarized as follows (fig. 5): (1) "Back" damage—although least damaged overall, the corridor thin crop trees incurred this type of damage more than any other, where there was less room to maneuver. Actual backing damage occurred most in the leave-tree thin because more trees were cut, leaving fewer residuals to protect crop trees. Damage in the corridor thin occurred only when the feller turned perpendicular to corridor. (2) "Fell" and "turn" damage—this was negligible in all thinning treatments (<1 percent). No fell damage occurred to crop trees in the corridor thin. (3) "Skid" damage—it was difficult to distinguish this damage from the turn type, but all thinnings

had the same distribution with least actual damage in the corridor thin simply because overall damage was least there (fig. 4). Overall, damage was low because trees were felled, held upright, then the feller backed up and set trees down on the just-cut stump to bunch them, i.e., the operator cleared bunching area as he moved forward.

Epicormic Sprouting

The epicormic sprouting was monitored prior to thinning treatments; and although it was prevalent (25 percent of crop trees), no difference was found among crop trees in any of the treatment areas. However, a significant difference in epicormic sprouts was found between the trainer-tree thin and the other treatment areas a year after thinning (fig. 6). The trainer thin had fewest sprouts in either log or total, whereas there was no difference in the others.

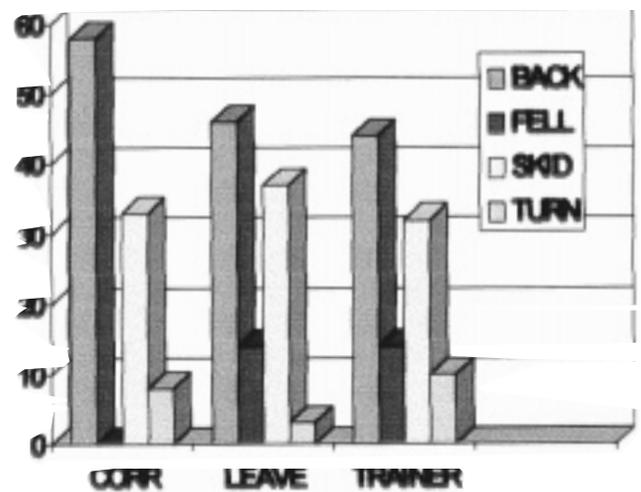


Figure 5—The distribution in percentage of types of logging damage to crop trees after thinning by three methods in a young, sprout-origin red river bottom land in South Carolina.

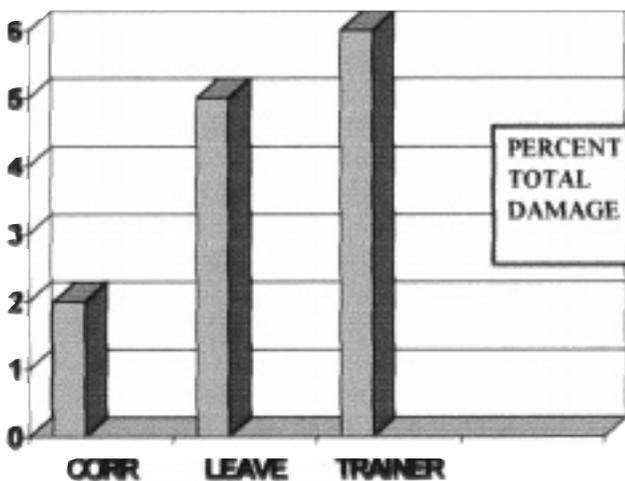


Figure 4—Total logging damage in percentage to crop trees after thinning by three methods in a young, sprout-origin red river bottom land in South Carolina.

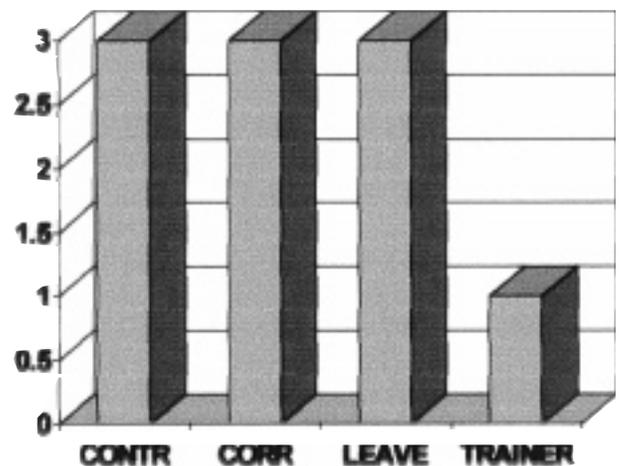


Figure 6—The number of epicormic sprouts in the first log of crop trees after thinning by three methods in a young, sprout-origin, red river bottom land in South Carolina.

Although unexpected, the sprouting in the corridor thin may be because many crop trees were deliberately left along the 20-foot-wide corridors in full sunlight and subsequently developed epicormic branches on one side. In the leave tree treatment, number of stems per acre was drastically reduced (from 300+ to 90+) and the increase in epicormic sprouts was expected. The relatively high number of sprouts in the control, which remained undisturbed, is an enigma. Perhaps it is due to the continued vine infestation in otherwise desirable crop trees. Initially, there was 25 percent vine infestation in crop trees and at least 25 percent of all potential crop trees had epicormic sprouts.

In the early fall when the last measurements were made, vines in the overtopping position were difficult to see among the crop tree crowns, especially in the denser control plots. Perhaps with the low incidence of logging damage, the greatest benefit of these early thinnings might have been the vine removal from residual crop trees, both through actual cutting of vine stems during logging and from tearing vines from the crowns of crop trees during removal of subordinate trees acting as "vine ladders."

CONCLUSIONS

All thinning objectives in this study were met by the three methods tried. Any of the three methods may prove useful in accomplishing various early thinning objectives in similar young bottom-land stands. With proper planning and cooperation, thinning can be done on a commercial basis with a minimal amount of damage to potential crop trees. Although the corridor thin seemed more efficient, the loggers preferred and produced more wood per acre in the leave tree thinning, where nearly 14 cords per acre were cut. In the trainer thin, more potential crop trees were left with fewer epicormic sprouts and vines and a higher percentage of oaks than in the other methods. However, this thinning was the most difficult to mark and the least productive for the loggers to implement. The effects of these logging methods on future stand quality will be monitored closely in the next several years and over the next decade.

ACKNOWLEDGMENT

The authors would like to express their greatest appreciation to Frank McCleod, Consulting Forester of Shaw, McLeod, Belser, and Hurlbutt of Sumter, SC, for his

invaluable technical assistance and encouragement during the course of the study. Appreciation is also extended to the owners of the study tract, Robert Boardman, and the Boardman Carton Trusts, for their willingness to provide a substantial area of valuable young bottom-land hardwoods for the wide range of thinning treatments employed in the study.

LITERATURE CITED

- Carvell, Kenneth L.** 1971. Silvicultural aspects of intermediate cuttings. In: Proceedings, oak symposium; 1971 August 16-20. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 60-64.
- Clatterbuck, W.K.; Olliver, C.D.; Burkhardt, E.C.** 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: spacing is the key. *Southern Journal of Applied Forestry*. 11(3): 158-161.
- Clatterbuck, Wayne K.; Hodges, John D.** 1988. Development of cherrybark oak and sweet gum in mixed, even-aged bottomlands in central Mississippi, U.S.A. *Canadian Journal Forest Research*. 18: 12-18.
- Gingrich, S.F.** 1971. Stocking, growth, and yield of oak stands. In: Proceedings, oak symposium; 1971 August 16-20; Morgantown, WV. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 65-73.
- Kellison, R.C.; Martin, J.P.; Hansen, G.D.; Lea, R.** 1988. Regenerating and managing natural stands of bottomland hardwoods. APA 88-A-6. Bottomland Hardwood Management Taskforce, Southeastern Technical Division, American Pulpwood Association, Inc. 26 p.
- Kennedy, H.E.; Johnson, R.L.** 1984. Silvicultural alternatives in bottomland hardwoods and their impact on stand quality. In: Proceedings, 14th annual Southern Forest Economics Workshop; 1984 March 13-15; Memphis, TN. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 6-18.
- Smith, H.C.** 1966. Epicormic branching on eight species of Appalachian hardwoods. Res. Note NE-53. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 17.

IMPACT OF INTERMEDIATE HARVEST TREATMENTS ON THE DISTRIBUTION AND THE DEVELOPMENT OF BOTTOM LAND OAK REGENERATION

Lawrence E. Nix, Damien Bonal, and Jon E. Barry¹

Abstract—Establishing desirable oak seedlings with properly timed intermediate harvest of midstory and defective overstory trees was examined after fall harvest treatments were applied to a nearly mature bottom-land hardwood stand. Three harvest treatments were assigned to twenty-five 2-acre plots by random drawing. The treatments were: no harvest, low basal area removal (20 square feet per acre), and high basal area removal (40 square feet per acre). Two years after the harvests, the number of established oak seedlings was significantly higher (1,300 per acre) in the harvested areas than in the control (150 per acre) with no difference between the two harvests. Survival of seedlings was much greater in the high removal plots than in the low removal plots. More new red oak seedlings grew in the high removals in 1993 than died during the winter. Distribution of seedlings was positively correlated with the absence of herbaceous or midstory competition, the presence of skidder activity, and a mature oak seed-tree nearby. This last factor seemed to strongly affect the distribution of the seedlings. Since many seedlings were broken by the logging equipment, the height of the seedlings was greater in the control plots than in the treatment plots. Seedlings were also taller in the high removals than in the low removals. Presence of skidder activity improved growth of new seedlings, perhaps due to the impact of the equipment on the understory, and the midstory competition.

INTRODUCTION

Natural regeneration of hardwood stands is most often accomplished by commercial clearcutting and felling of the residual stems (Hannah 1987, Kellison and others 1981). Reproduction of hardwood species comes from either stump sprouts, seedling sprouts, or true seedlings. Successful oak (*Quercus* spp.) regeneration usually results from hardy sprouts of stumps less than 30 centimeters (cm) (12 inches) d.b.h. (diameter at 4.5 feet) or advanced oak reproduction, i.e., seedlings greater than 5 feet tall (Sander 1971).

In bottom-land hardwood forests, site conditions differ significantly from those of upland stands, and silvicultural treatments have been adapted to obtain regeneration (Aust and others 1985, Tolliver and Jackson 1988). In order to reproduce, bottom-land oak seedlings frequently must survive early seasonal soil saturation or flooding (Pezeshki and Chambers 1985), acorn consumption (Goodrum and others 1971), browsing by wildlife during the growing season (Hill 1986), and competition with more shade-tolerant species for light, moisture, and available nutrients (Carvell and Tryon 1961, Chambers and Henkel 1988, Sander 1971).

An experiment was designed in 1991 in a Congaree River bottom in South Carolina (Barry and Nix 1993) to test whether a properly timed intermediate harvest (an improvement cut) of midstory and defective overstory trees could be used to increase the establishment of oak seedlings after a good acorn crop.

The objective of the current study was to determine whether the stand disturbance in 1991 had improved the establishment, distribution, and continued development of the oak seedlings 2 years after cuttings were applied. Site

conditions in the disturbed stands were characterized as to hog rooting activity, presence of thick grass, skidder activity, canopy cover, debris, presence of nearby oak seed-trees, and diameter and species of these seed-trees. It was hypothesized that these factors could have a significant influence on oak regeneration survival and development.

The importance of logging activity in the distribution and development of oak reproduction had been previously observed. Nix and Lafaye (1993) found that the red oak seedling distribution in a nearby clearcut red river bottom-land hardwood stand was concentrated along skid trails and turnaround areas. Relatively wet conditions during logging operations resulted in appreciable scarification of the soil. The heavy traffic of the logging machines dispersed the acorns and buried them in the ground where they were in contact with the mineral soil, hidden from animals, and less likely to be displaced by floodings. These types of activities in 1991 resulted in initial oak seedling establishment from 1 to 2,000 seedlings per acre (Barry and Nix 1993).

MATERIALS AND METHODS

The study area is located near Columbia, SC, in two 20-hectare (50 acres) Red River bottom-land hardwood stands in a first bottom of the Congaree River. The study plots are about 1,800 meters (1,900 yards) from the river and on a moderately well-drained, low site. Flooding occurs more than once in most years but not in some, from December to May (Patterson and others 1985). The soil is deep and moderately well-drained with brown to dark brown Congaree loam, Chewacla loam, Chastain silty clay loam, and Tawcaw silty clay loam subsoils (Lawrence 1978).

¹ Associate Professor and former Research Assistants, respectively, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003.

Barry and Nix (1993) reported that elm (*Ulmus spp.*), hackberry (*Celtis spp.*), red maple (*Acer rubrum*), and sweetgum (*Liquidambar styraciflua*) accounted for more than 56 percent of the basal area removed during the improvement cut operation. The remaining overstory included a large number of cherrybark (*Q. pagoda*), water (*Q. nigra*), laurel (*Q. laurifolia*), willow (*Q. phellos*), overcup (*Q. lyrata*), and swamp chestnut (*Q. michauxii*) oaks. Pawpaw (*Asimina triloba*) and switch cane (*Arundinaria gigantea*) were abundant in the understorey as well as many herbs and sedges (*Cyperaceae*) and vines (*Vitis spp.*). The stands are in excess of 80 years old. The site has been commercially managed for timber for 25 to 30 years and at least parts of the study sites have been selectively harvested in the past. Ditches, canals, and dikes related to agriculture are present, but were built well before the establishment of the stands.

As detailed by Barry and Nix (1993), the two stands were divided into twenty-five 0.65-hectare (1.6 acres) plots. Ten plots were located in one stand called the "Red Oak Stand" (based on the species composition) and 15 plots in another stand called the "Mixed Oak Stand." Three levels of cuttings (0, 20, and 40 square feet basal area per acre removed) were assigned to the plots by random drawing. Cutting was done in December 1991, by a commercial logging crew. Equipment drivers were to enter plots only from skid trails. Trees were directionally felled with a small feller machine, limbed in place with chain saws, and skidded along predesignated trails to the logging deck. Initial results of these cuttings were reported by Barry and Nix (1993). Acorns were abundant: 150 to 200 thousand per acre.

After the flooding subsided in the spring of 1993, all oak seedlings that could be found on the 25 plots were flagged. Brightly colored flagging attached to seedlings made the relocation of the seedlings possible for later data recording and allowed some seedlings to be followed during the growing season and for the next several years.

A total of 21 temporary systematic samples were placed per plot at 0.5 chain spacing. For each sample, measurements were recorded on 10.1 square meter (1/400 acre) circular subplots, which are commonly used for this type of research (Hook and Stubbs 1965). The measurements were taken from early May to early June. For each subplot, the number of oak seedlings was counted and marked as red or white oak, and whether there were thick grass, skidder activity, or debris, an oak seed-tree in the overstory canopy, or evidence of hog rooting. The overstory basal area per acre was measured for each subplot using a BAF10 prism. Canopy closure was measured at each point using a spherical crown densiometer. The canopy vegetation was also divided into three categories: overstory only, midstory only, or both. The number of seedlings per acre for each stand, each thinning intensity, and for the entire forest was also recorded.

Development of Seedlings

In order to follow the development of the seedlings, the sampling done in June 1992, under the seed-trees by Barry

and Nix (1993) was repeated in 1993. Three dominant or codominant oaks were selected from each plot. Under the crown of each seed-tree, four 10.1 square meter (1/400 acre) circular subplots were taken. In each sample the number of oak seedlings was counted. The "age" of each seedling, i.e., whether it was a new seedling (1 or 2 growing seasons) or a residual seedling (3 or more growing seasons), and whether it was a red or a white oak seedling were recorded. Height of each seedling was also measured ± 1.25 centimeters (0.5 inch). At each subplot, hog rooting, skidder activity, thick grass, debris, and canopy closure were recorded. The overstory basal area around each seed-tree and the diameter of the seed-tree were also recorded.

The number of seedlings per acre for each stand, each thinning intensity, and for the entire forest was also recorded. Since these numbers were based on the data recorded under the oak seed-trees, they were reduced by a factor of 66 percent, which corresponds to the approximate non-oak component as a percentage of total stand basal area for trees greater than 10 centimeters (4 inches) in d.b.h. (Barry and Nix 1993).

In order to be sure that the field-estimated "age" of the seedlings was correct, vascular rings were counted under magnification for 31 oak seedlings selected at random on different plots. A paired t-test was conducted for the variable age and no significant difference at the 5 percent level appeared between the means of the two estimations. Thus, the estimates of the age of the seedlings in the field seemed to be accurate enough.

Statistical Analysis

The height, stocking, and number of seedlings were compared using a General Linear Models Procedure with analysis of variance with a 5 percent probability to determine if there were significant differences among the treatments (SAS 1985). In order to compare the results in 1992 and 1993, a paired t-test was conducted on the number of seedlings in 1992 and 1993. In order to determine which factors influenced the number and the height of the seedlings, an analysis of variance was conducted using these two variables as dependent variables and the factors studied as independent variables.

RESULTS AND DISCUSSION

Two years after the improvement cutting of midstory and defective overstory trees, the vegetative factors measured were greatly different in cut and uncut plots of two bottom-land stands (table 1). However, the intensity of hog rooting, herbaceous vegetation, skidder activity, and the number of mature oak seed-trees did not vary statistically between the light and heavy cuttings (table 1). There was an increase of 746 well-distributed seedlings per acre in the cut plots as compared to the uncut, with no difference between the two cuttings (table 2). Barry and Nix (1993) found similar relationships in the stands in 1992.

The number of seedlings in the uncut and the lightly cut plots significantly decreased from 1992 to 1993 (fig. 1).

Table 1—Occurrence of seed-trees, hog rooting activity, skidder activity, thick grass, and tree canopy in improvement cut bottom-land stands of South Carolina

Factors	Thinning intensity		
	None	Light	Heavy
	- Percentage of plots sampled -		
Seed-tree	53a	65a	57a
Hog rooting	19	10a	5a
Skidder	—	69a	79a
Grass	3	33a	45a
Overstory	9	54a	63a
Midstory	19a	15a	14a
Mid + Overstory	72	31a	23a

Means followed by the same letter in a row are not significantly different (LSD, =0.05).

Table 2—Bottom-land red and white oak seedlings in relation to intensity of cutting in bottom lands of South Carolina

Thinning intensity	Total seedlings	Red oak seedlings	White oak seedlings
	----- Per acre -----		
None	466	335a	131
Light	1212a	378a	834a
Heavy	1418a	785	633a

Means followed by the same letter in a column are not significantly different (LSD, =0.05).

Survival of seedlings was best in the heavy cutting, and even more new red oak seedlings grew in 1993 than died during the late summer and winter in these areas. The conditions in the heavy cuttings might be more favorable for oak seedlings to survive and for new seedlings to develop. The number of seedlings appeared to be positively related to the absence of herbaceous or midstory competition, presence of a mature oak seed-tree above the seedlings, and skidder activity or debris (table 3). No clear relationship was found between the number of seedlings and the activity of hogs or the amount of canopy overhead.

The number of seedlings of red oak or white oak species depended mostly on the species of the seed-tree in the overstory (fig. 2). Thus, success of these cuttings seemed to be correlated with the number and the distribution of the mature oak trees after the treatments. The number of

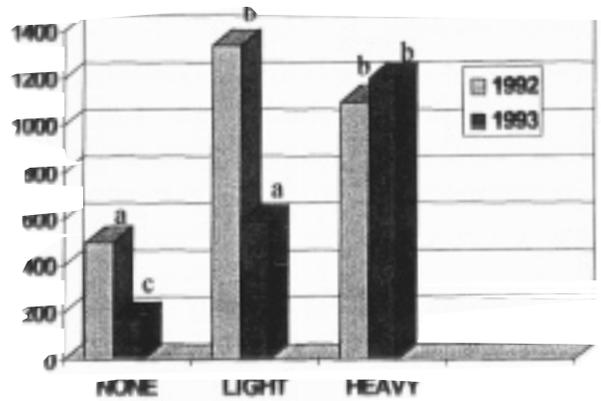


Figure 1—Bottom-land oak seedlings per acre under seed-trees in 1992 and 1993 in relation to intensity of cutting (bars with the same letter are not significantly different, LSD, =0.05).

Table 3—Number of bottom-land oak seedlings as related to thick grass, hog rooting, seed-tree, skidder activity, debris, and three types of canopies

Factor	Presence	Absence	Debris
	----- Per acre -----		
Grass	580a	1,208a	—
Rooting	788a	1,068a	—
Seed-tree	1,600b	248	—
Skidder	1,408b	572	1,048a
Canopy type	Midstory	Both	Overstory
	----- Per acre -----		
	572a	932a	1312a

Means followed by the same letter in a column are not significantly different (LSD, =0.05).

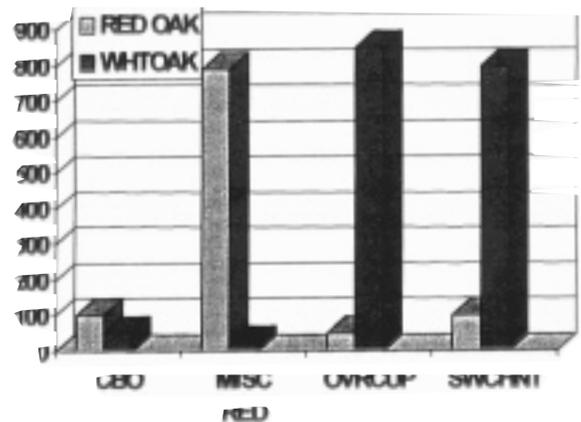


Figure 2—Total red and white oak seedlings per acre under cherrybark, miscellaneous red, overcup, and swamp chestnut oak seed-trees in improvement cut stands.

cherrybark oak seedlings was much less than that of the other oak species. These treatments may not be useful for this species or it might be possible that the acorn crop in 1991 for the cherrybark oak trees was lower than for the other oak trees.

Since many residual seedlings were broken in the cut plots, the mean height of the seedlings was greatest in the uncut plots, by 12.9 centimeters (5.08 inches) (table 4). Seedlings were also taller in the heavy cutting than in the light cutting. The latter difference was due to the effect of residual seedlings. The height of the new oak seedlings did not vary among the treatments. The number of new seedlings in the uncut areas may be too few to make accurate statistical comparisons.

Height growth of seedlings was positively correlated with the presence of thick, coarse grass or hog activity (table 5). However, the sample may have been too small to provide reliable results. Height growth of seedlings was greatest when no midstory vegetation occurred under the seed-trees. This suggests that control of midstory vegetation either mechanically or with herbicides as suggested by Hannah (1987) and Hodges and Janzen (1987) might favor the success of oak regeneration.

Table 4—Height of bottom-land oak seedlings under seed-trees according to intensity of thinning

Thinning intensity	Overall	Red oak	White oak	Residual	New
----- Centimeters -----					
None	34.5	36.5	33.1	38.7	13.4a
Light	21.6a	20.9a	21.9a	24.2a	18.4a
Heavy	24.2a	26.4a	21.7a	28.5a	19.1a

Means followed by the same letter in a column are not significantly different (LSD, =0.05).

Table 5—Height of bottom-land oak seedlings in relation to thick grass and hog rooting activity in thinned stands

Factor	Total seedlings	Residual seedlings	New seedlings
----- Centimeters -----			
Grass	27.2a	28.7a	25.4
No grass	22.4b	27.7a	18.4a
Rooting	29.3a	34.2	20.0a
No rooting	23.3b	27.0a	18.6a

Means followed by the same letter in a column are not significantly different (LSD, =0.05).

Since many residual seedling stems were broken by the logging activities, the mean height of the total seedlings was greatest when there was no skidder activity. However, new oak seedlings were at least 3.3 centimeters (1.3 inches) taller with presence of skidder activity or logging and flooding debris than without (table 6). The reason for such responses might be the impact of the equipment on the understory and midstory vegetation. The further survival and development of these oak seedlings will be monitored closely over the next decade.

ACKNOWLEDGMENT

The authors would like to express their greatest appreciation for the technical assistance and encouragement provided by Angus B. Lafaye, Chief Forester of Milliken Forestry in Columbia, SC. Appreciation is also extended to Francis Bieldler III, owner of the study tract, and to Marion Burnside, President of the Millaree Hunt Club, for the warm hospitality generously provided during the course of the study.

Table 6—Height of bottom-land oak seedlings in relation to skidder activity and debris in thinned stands

Factor	Total seedlings	Residual seedlings	New seedlings
----- Centimeters -----			
No skidder activity	29.9	35.3	15.6
Skidder activity	23.0a	26.3a	18.9a
Debris	24.4a	30.0a	19.8a

Means followed by the same letter in a column are not significantly different (LSD, =0.05).

LITERATURE CITED

- Aust, W.M.; Hodges, J.D.; Johnson, R.L.** 1985. The origin, growth and development of natural, pure, even-aged stands of bottomland oaks. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. 50-54. Atlanta, GA: U.S. Department of Agriculture, Forest Service: 163-170.
- Barry, J.E.; Nix, L.E.** 1993. Impact of harvesting activities on oak seedling establishment in a bottomland hardwood forest. Proceedings, seventh biennial southern silvicultural research conference, 1992 November. Gen. Tech. Rep. 50-93. Mobile, AL: U.S. Department of Agriculture, Forest Service: 155-159.
- Carvell, K.L.; Tryon, E.H.** 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. Forest Science. 7(2): 98-105.
- Chambers, J.L.; Henkel, M.W.** 1988. Survival and growth of natural and artificial regeneration in bottomland hardwood stands after partial overstory removal.

Proceedings of the fifth biennial southern silvicultural research conference. Gen. Tech. Rep. 50-74. U.S. Department of Agriculture, Forest Service: 277-283.

Goodrum, P.D.; Reid, V.H.; Boyd, C.E. 1971. Acorn yields, characteristics, and management criteria of oaks for wildlife. *Journal of Wildlife Management*. 35(3): 520-532.

Hannah, P.R. 1987. Regeneration methods for oaks. *Northern Journal of Applied Forestry*. 4(2): 97-101.

Hill, E.P. 1986. Management of bottomland hardwood for wildlife: a workshop. U.S. Fish and Wildlife Service, Mississippi Agriculture and Forest Experiment Station, Mississippi State University. 9 p.

Hodges, J.D.; Janzen, G.C. 1987. Studies on the biology of cherrybark oak: recommendations for regeneration. Gen. Tech. Rep. SE-42. U.S. Department of Agriculture, Forest Service: 133-139.

Hook, D.D.; Stubbs, J. 1965. Selective cutting and reproduction of cherrybark and shumard oaks. *Journal of Forestry*. 63(12): 927-929.

Kellison, R.C.; Frederich, D.J.; Gardner, W.E. 1981. A guide for regenerating and managing natural stands of southern hardwoods. North Carolina Agricultural Research Series Bulletin 463. 24 p.

Lawrence, C.B. 1978. Soil survey of Richland County, South Carolina. U.S. Department of Agriculture, Soil Conservation Service.

Nix, L.E.; Lafaye, A. 1993. Successful regeneration of quality oaks in a Red River bottomland hardwood stand of South Carolina. Proceedings, seventh biennial southern silvicultural research conference; 1992 November; Mobile, AL. Gen. Tech. Rep. 50-93. U.S. Department of Agriculture, Forest Service: 81-85.

Patterson, G.G.; Speiran, G.K.; Whetstone, B.H. 1985. Hydrology and its effects on distribution of vegetation in Congaree National Monument, South Carolina. Water-Resources Investigations Report 85-4256. U.S. Geological Survey. 31 p.

Pezeshki, S.R.; Chambers, J.L. 1985. Responses of cherrybark oak seedlings to short-term flooding. *Forest Science*. 31(3): 760-771.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advanced reproduction. *Journal of Forestry*. 69: 809-810.

SAS Institute, Inc. 1985. SAS user's guide: Statistics, Version 5. Cary, NC: SAS Institute, Inc. 956 p.

Toliver, J.R.; Jackson, B.D. 1988. Recommended silvicultural practices in southern wetland forests. In: Hook, D.D.; Lea, R., eds. Proceedings symposium. The forested wetlands of the Southern United States. Gen. Tech. Rep. SE-50. U.S. Department of Agriculture, Forest Service. 168 p.

IMPACTS OF THREE TIMBER STAND IMPROVEMENT THINNING OPTIONS ON LOW-QUALITY SOUTHERN MIXED-HARDWOOD STANDS

Brian P. Oswald and Thomas H. Green¹

Abstract—The impact of three thinning options (strip, single-tree selection, and strip with selection between strips) on low-quality southern mixed-hardwood stands was evaluated in northern Alabama. Although stand level comparisons showed no significant differences between options, individual dominant trees benefitted from the thinning treatments, exhibiting increased basal area growth during the period of the study. Intermediate treatments such as these thinning options may provide landowners with sufficient growth of selected high-quality trees to warrant the more intensive management activities on similar sites as utilized in this study.

INTRODUCTION

In general, hardwood stands in the Eastern United States have developed with little or no silvicultural or management activities. Since European settlement, these stands have been subjected to repeated cuttings (often diameter-limit cuts), insects, disease, and fire. Many of these stands are composed of mixed stands of residual individuals from past activities and a variety of shade-tolerant species (McGee 1980).

There are about 90 million acres of pure hardwood forestland in the Eastern United States. The bottom-land hardwood resource has been severely reduced in area over the last 60 years, much of it the result of conversion to agricultural uses. Although the rate of area decrease has slowed in the last 15 years (McWilliams and Faulkner 1991), the 40 million acres of bottom-land hardwoods found in 1952 has been reduced to about 29.8 million acres. Most of these forests are in private holdings (90 percent in 1988), with private nonindustrial landowners owning about 66 percent of the land (Saucier and Cost 1988).

The current hardwood stand condition in the South ranges from high-quality stands of pure or mixed even-aged timber to low-quality stands that are understocked and composed of often less than desirable species (McGee 1982). Many of these stands are continuing to deteriorate in quality as diameter-limit and individual-tree selection cuttings remove the few remaining high-quality (based on genetic quality or market factors) trees and leaving a residual stand of less-desirable species of low growth potential or low market quality.

The demand for hardwood products is increasing (McWilliams 1988, Hair 1980). It is projected that by the year 2030, the demand for hardwoods will triple, rising from the present 3.0 billion cubic feet to 9.6 billion cubic feet. Hardwood management has not kept pace with the intensive research and management strategies utilized in southern pine forests. The best management practices for these forests have not been determined. Thinning of low-quality stands is usually not practiced since the basal area of marketable trees and acceptable growing stock is low

and control costs of non-desirable species high (McGee 1982). Increasing demands for fuelwood and other hardwood products have made more intensive management of these low-quality stands possible and profitable (Koch 1980, McGee 1982, Reynolds and Gatchell 1979, Reynolds and Schroeder 1978). Intermediate thinnings may reverse the decrease in quality of these stands by removing undesirable species and trees of poor quality. The objective of this study was to quantify the silvicultural impacts of three timber stand improvement thinnings on low-quality southern mixed-hardwood bottom-land stands.

METHODS

Four square, 1-acre study plots were established on each of two research sites: the Wheeler Wildlife Refuge (WWR) southeast of Decatur, AL; and the U.S. Army Redstone Arsenal (RSA) in Huntsville, AL. Both locations represented moderately productive bottom-land mixed-hardwood stands with white oak (*Quercus alba* L.), water oak (*Q. nigra* L.), southern red oak (*Q. falcata* Michx.), black oak (*Q. velutina* Lam.) and willow oak (*Q. phellos* L.) as well as sweetgum (*Liquidambar styraciflua* L.), hickories (*Carya* Nutt. spp.), red maple (*Acer rubrum* L.) and elms (*Ulmus* L. spp.) in addition to other minor species in the overstory and understory. Soils on both sites were Melvin silty clay loams.

All trees greater than 2 inches in diameter at breast height (d.b.h.) within each plot were measured and mapped in the summer of 1986. Measurements made included species, location in plot, height, and d.b.h. The location of each tree was determined through the placement of a 16-square grid superimposed on each 1-acre plot, with the distances from each tree to two designated grid corners recorded.

Treatments utilized at each site were: control (no tree removal); selection cut (removal of all trees except identified crop trees to 75 square feet BA); strip cut (removal of all trees within six 12-foot-wide strips spaced 36 feet apart, leaving approximately 75 square feet BA); and strip-selection cut (removal of all trees within four 12-foot wide strips and any except desired crop trees between strips to leave approximately 75 square feet BA). All

¹ Arthur Temple College of Forestry, Stephen F. Austin State University, P.O. Box 6109 SFA Stn., Nacogdoches, TX 75962-6109; and Center for Forestry and Ecology, Alabama A&M University, P.O. Box 1208, Normal, AL 35762 (respectively).

removals were performed with chainsaws in 1987. The sites were revisited at the end of the 1993 growing season and the heights and d.b.h. of all residual trees recorded.

The basal area per plot was determined for both measurement periods (BA1 and BA2), as was per-plot basal area growth (BAG) and diameter growth (Growth). Statistical analysis (ANOVA and Tukey's range test) on this RCB experimental design was performed using a SAS (SAS Institute, 1991) statistical package on the mainframe computer at Alabama A&M University.

RESULTS AND DISCUSSION

The mean basal areas (square feet per acre) by plot for each of the four thinning treatments on the two sites are shown in table 1. There was no significant difference between sites for any of the treatments. Basal area for the control plots was

Table 1—Mean basal area (square feet per acre) for two sites and four thinning treatments

Site	Plot	BA1	BA2	BAG	Growth
Redstone	Control	101.8 ^a	115.4 ^a	13.6	119.9
	Selection	75.1	90.1	15.0	140.8
	Strip	70.0	84.7	14.8	159.2
	St/Sel	53.5	72.7	19.2	142.7
Wheeler	Control	108.3 ^a	131.0 ^a	24.3	209.4
	Selection	74.0	69.2	4.9	42.4
	Strip	61.4	80.1	18.7	183.7
	St/Sel	64.2	73.7	9.5	148.1

BA1 = BA/plot 1987; BA2 = BA/plot 1993; BAG = (BA2-BA1)
^a = Significantly different within same column.

significantly ($p > 0.05$) greater than for any of the treatments. This was expected, since each of the thinning treatments reduced basal area to approximately 75 square feet, while the control plots were left at their original density.

No significant differences were found between treatments for basal area growth (BAG) when both sites were combined and only treatment effects analyzed. The negative BAG of the selection thinning treatment on the Wheeler site was the result of mortality of large trees that died between the two measurement dates. We believe the lack of significant differences in response to the thinning treatments may be accounted for by not having removed enough BA initially. If the residual basal area had been reduced to between 30 and 50 square feet, we believe we would have observed greater BAG, but residual basal areas of this level are associated with a shelterwood system, not an intermediate thinning treatment.

There were significant differences between mean tree basal area (table 2) and specific species' response to thinning treatment (table 3). After treatments were applied, trees within the strip/selection plots had consistently greater BA2, BAG, and Growth than trees within other treatments, and significantly greater BAG and Growth on those plots than trees that had been selection thinned. There were insignificant differences in BAG and Growth between the control and the strip and selection treatments (table 2).

Red Oak, willow oak, black oak, water oak, and white oak (*Q. alba*) had the greatest BA in both 1987 and 1993, with red oak significantly greater in basal area (BA) than all species except the other oaks (table 3). The hickories (*Carya* spp.), green ash (*Fraxinus pennsylvanica*), sweetgum, and red maple were grouped together in BA both years, with the remaining species a third group. These groups match the results of a study performed on upland

Table 2—Mean per-tree basal area for each thinning treatment

Treatment plot	Treatment							
	Strip		Strip selection		Selection		Control	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean
-----Square feet-----								
BA1	360	0.36 BC	230	0.51 AB	259	0.57 A	686	0.31 C
BA2	343	0.48 BC	172	0.84 A	250	0.64 B	632	0.39 C
BAG	343	0.11 AB	172	0.21 A	250	0.06 B	632	0.07 AB
Gr	343	0.10 B	172	1.69 A	250	0.39 B	632	0.65 AB

No. = Number of trees within treatment plots; BA1 = BA/plot in 1987; BA2 = BA/plot in 1993; BAG = (BA2-BA1); Gr = Diameter Growth.
 Within-row means not followed by same letter are significantly different ($p < 0.05$).

Table 3—Mean basal area and diameter growth for each species (+2 occurrence) found within four treatment plots^a

Species	BA1	BA2	BAG	Growth
	-----Square feet-----			Inches
<i>Quercus falcata</i>	0.73 A	0.98 A	0.22 AB	1.56 B
<i>Q. phellos</i>	0.64 AB	0.78 AB	0.13 ABC	0.91 BC
<i>Q. velutina</i>	0.59 AB	0.78 AB	0.16 ABC	1.14 BC
<i>Q. nigra</i>	0.51 AB	0.64 ABC	0.10 ABC	0.88 BC
<i>Q. alba</i>	0.40 BC	0.49 BCD	0.08 BC	0.73 BC
<i>Carya spp.</i>	0.22 CD	0.27 DE	0.04 C	0.44 BC
<i>Fraxinus pennsylvanica</i>	0.19 CD	0.29 DE	0.06 C	0.70 BC
<i>Liquidambar styraciflua</i>	0.15 CD	0.20 DE	0.04 C	0.58 BC
<i>Acer rubrum</i>	0.12 D	0.20 DE	0.06 BC	0.93 BC
<i>Ulmus americana/rubra</i>	0.06 D	0.09 E	0.03 C	0.56 BC
<i>Nyssa sylvatica</i>	0.05 D	0.08 E	0.03 C	0.61 BC
<i>Cercis canadensis</i>	0.03 D	0.30 CDE	0.27 A	3.06 A
<i>Carpinus caroliniana</i>	0.03 D	0.04 E	0.01 C	0.35 C

BA1 = Basal area/plot in 1987; BA2 = Basal area/plot in 1993; BAG = Basal area growth (BA2- BA1); Growth = Diameter growth.

^aWithin-column means not followed by same letter are significantly different (p<0.05).

hardwood sites throughout northern Alabama (Zhang and others 1994).

The greatest BAG was by redbud (*Cercis canadensis*) (0.268 square feet), but not significantly more than the oaks. The other species had no significant differences in BAG between species. Significantly greater growth was also produced by redbud than any of the other species, where little significant variation was observed. Individual redbud appeared to have taken advantage of the increase in available resources that resulted in these thinning operations, but their low numbers (6) and small basal area (table 3) made little impact at the stand level, and would have little impact on the market value of these stands.

CONCLUSIONS

Even though growth of individual trees was stimulated by thinning, this increase was not sufficient to offset the reduction in growing stock with thinning. Therefore, stand level growth was not increased by thinning. Depending on the management objective, thinning may be a suitable intermediate treatment for hardwoods, concentrating growth of overstory trees in the stand on a few large individuals. Any of these regimes should provide additional growth response in the higher quality species if the residual BA is decreased, and undesired species removed in the thinning activity. Strip thinning appears to accomplish this objective as well as single-tree selection. As management and silvicultural options are considered for low-quality, mixed-hardwood forests of the Southern United States, intermediate operations may play a large role in the successful management of individual trees within these forests but will not affect stand level productivity. Care must be taken that whatever option is chosen, the newly

available resources do not go to the undesirable understory species such as redbud, rather than to the more valuable overstory oak species.

ACKNOWLEDGMENT

This project was made possible by USDA Forest Service Cooperative Agreement 23-91-03. Our sincere appreciation to Dr. George Brown and Dr. Basil Pinker at Alabama A&M University for the initial plot establishment, and to the USDA Forest Service Research Station Unit in Houghton, MI, for funding and technical assistance.

LITERATURE CITED

- Hair, D.** 1980. Timber situation in the U.S., 1952-2030. *Journal of Forestry*. 78(11): 683-686.
- Koch, P.** 1980. Harvesting energy chips from forest residues-some concepts for the southern pine region. Gen. Tech. Rep. SO-53. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 24 p.
- McGee, C.E.** 1980. Expanding options for reforestation of the Cumberland Plateau. *Southern Journal of Applied Forestry*. 4(4): 158-162.
- McGee, C.E.** 1982. Low-quality hardwood stands—opportunities for management in the interior uplands. Gen. Tech. Rep. SO-40. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 22 p.
- McWilliams, W.H.** 1988. Hardwood supply and availability in the midsouth highlands. Series 7: Availability of hardwoods in the upland south: 47-95.
- McWilliams, W.H; Faulkner, J.L.** 1991. The bottomland hardwood timber resource of the coastal plain province

in the South Central USA.91-A-11.Washington, DC:
American Pulpwood Association Southcentral Technical
Division Forest Management Committee. 46 p.

Reynolds, H.W.; Schroeder, J. 1978. Furniture cuttings
made from logging residue: the three-sided cant
system. Res. Pap. NE-417. Broomall, PA: U.S.
Department of Agriculture, Forest Service, Northeast
Forest Experiment Station. 8 p.

Reynolds, H.W.; Gatchell, C.J. 1979. Marketing low-grade
hardwoods for furniture stock—a new approach. Res.
Pap. NE-444. Broomall, PA: U.S. Department of
Agriculture, Forest Service, Northeast Forest
Experiment Station. 7 p.

SAS Institute, Inc. 1991. SAS User's Guide: Statistics
Version 6. Cary, NC. 956 p.

Saucier, J.R.; Cost, N.D. 1988. The wetland timber
resource of the Southeast. 88-A-11. Washington, DC:
American Pulpwood Association, Southeastern
Technical Division Wetland Logging Task Force. 15 p.

Zhang, L.; Oswald, B.P.; Green, T.H.; Stout, S.L. 1994.
Relative stands density and species composition in the
mixed upland hardwood forests of North Alabama.
Paper presented at 8th biennial southern silvicultural
research conference, 1994 November 1-2; Auburn, AL.

PRECOMMERCIAL THINNING OF WATER TUPELO STANDS ON THE MOBILE-TENSAW RIVER DELTA: STAND COMPOSITION 3 YEARS AFTER TREATMENT

J.C.G. Goelz, J.S. Meadows, T.C. Fristoe, and D.A. White¹

Abstract—We thinned water tupelo (*Nyssa aquatica* L.) and cleaned (severed all stems) the less desirable Carolina ash (*Fraxinus caroliniana* Mill.) and black willow (*Salix nigra* Marsh.) in three 4-year-old stands that arose following clearcutting of mature water tupelo-dominated stands. In this paper we investigated trends only in trees per acre. Although thinning and cleaning immediately reduced the numbers of the corresponding targeted species, the stumps sprouted and differences among treatments were not evident 3 years after treatment. However, future stand dynamics may reveal differences that are not apparent in trees per acre at 3 years after treatment. The results for water tupelo suggest that these differences will be evident soon. The results for ash and willow suggest that cleaning will have a modest long-term effect on these stands.

INTRODUCTION

Mature water tupelo stands typically are more dense than other hardwood stands (Putnam and others 1960, Goelz 1995). Young stands arising after clearcutting are also dense, particularly due to prolific sprouting from the stumps and roots of severed stems of water tupelo and Carolina ash. Black willow of seed origin often becomes well-established. Most of the stems in these stands will die during natural thinning and thus their growth will be lost to mortality rather than harvested. Furthermore, the Carolina ash and black willow are not merchantable species on these sites. As ground conditions often preclude using rubber-tired or tracked equipment for thinning, we became interested in pre-commercial thinning to achieve a merchantable size (currently, 3-inch top diameter) at an earlier age, reducing rotation length as well as reducing unsalvageable losses of growth to mortality.

Kennedy (1983) and McGarity (1979) indicate that thinning is not particularly beneficial for mature water tupelo stands. DeBell (1971) and Kennedy (1982) reported poor survival of stumps in young coppice-origin water tupelo stands. Although initial sprouting was abundant, as few as 9 percent of the stumps had living sprouts by age 6 (Kennedy 1982).

The general purpose of this paper is to describe changes in species composition after pre-commercial thinning and cleaning treatments. We were particularly interested to determine whether cleaning would effectively control less desirable species and if thinning would maintain vigor of residual sprouts and thus maintain water tupelo as the dominant species on the site. In this paper, our only variables of interest are stems per acre of the four dominant species: water tupelo, Carolina ash, black willow, and baldcypress [*Taxodium distichum* (L.) Rich.].

Initial results from this study (Goelz and others 1993) indicate that thinning increases annual diameter growth of water tupelo by 27 to 37 percent over unthinned plots, although cleaning does not improve growth. The treatments

had negligible influence on the number of water tupelo seedlings, although flooding that extended into June during the first growing season following treatment probably caused a 30 percent reduction in seedling numbers. Dissimilar to the results of DeBell (1971) and Kennedy (1982), mortality of tupelo stump sprouts was negligible.

METHODS

We chose three locations, or stands, on Kimberly-Clark Corporation land on the delta of the Mobile and Tensaw Rivers in southern Alabama. At the time of treatment in autumn of 1990, each location had a 4-year-old stand arising after the native water tupelo stands were clearcut. All stems over 2 inches in diameter at breast height (d.b.h.) were felled when the stands were clearcut. The locations are good for water tupelo and are densely stocked with water tupelo, Carolina ash, baldcypress, and black willow, with other species present.

We used a 2 by 2 factorial design. The first factor consists of two treatments: thinning or not thinning water tupelo. Thinning comprises two components: (1) All water tupelo stumps were thinned to one or two best sprouts where "best" was defined as the largest well-formed sprout that originated low on the stump. When two well-spaced sprouts of good form and low origin were present, both were left. If only one good sprout was present, that one sprout was left. (2) Water tupelo seedlings were thinned with a machete wherever they occurred in a dense patch (more than 20 per 100 square feet, in patches of 100 square feet or larger). The tallest water tupelo seedlings were left at a density of approximately 1 per 36 square feet (or a nominal 6 by 6 foot spacing).

The second factor consists of two treatments: cleaning or not cleaning the Carolina ash and black willow. All ash and willow were cut as close to the ground as possible with a chainsaw. These factors provide four treatment combinations: (1) no thinning, no cleaning (control); (2) no thinning, cleaning; (3) thinning, no cleaning; (4) thinning and cleaning.

¹ Principal Forest Biometrician, and Principal Silviculturist, respectively, Southern Hardwoods Laboratory, USDA Forest Service, Southern Research Station, Stoneville, MS; Research Forester, Kimberly-Clark Corporation, Saraland, AL, and Unit Manager, respectively, Kimberly-Clark Corporation, Mt. Vernon, AL.

We placed eight 0.786-acre square treatment plots in each location. As the soils near the riverbank are much different from the rest of the stand, all treatment plots were at least 12 chains (792 feet) from the river. The square measurement plot (0.304 acre) was in the center of each treatment plot. All stems greater than or equal to 3 feet in height were counted. Stems were tallied by species, origin (sprout or seedling), and size class (class one represents stems less than 2.5 inches d.b.h. and class two represents larger stems).

Analyses were by analysis of variance (ANOVA). We used an alpha of 0.05. The design is a 2 by 2 factorial with two levels for thinning, two levels for cleaning, and three locations (equivalent to blocks) with two replications per location. Effect of location was considered fixed. We tested interactions of location with the treatment factors. We also included time, or year, in the design as a factor. As time did not represent evenly spaced units (before treatment, immediately after treatment, 1 year posttreatment, 3 years posttreatment) we could not treat year as a continuous covariate. We also included all interactions of time with treatments and location. We conducted ANOVA's for each species at each measurement time—pre-treatment, immediate posttreatment, 1 year after treatment, and 3 years after treatment.

We estimated linear regression equations to predict number of stems at 3 years after treatment using the following as potential predictor variables: the number of stems immediately after treatment in each size class, number of stems removed by the treatments, and dummy variables for treatments, but not locations. Final models were selected by backward elimination/forward addition. All analyses were conducted on transformed data (square root of stems per plot).

RESULTS AND DISCUSSION

Trends in Trees per Acre

Water tupelo—Trees per acre of water tupelo were averaged across locations in figure 1. Significant factors were the main effects location and year, and the interaction terms location.clean, location.thin, clean.thin, and thin.year. The main effect for thinning was not significant. Rather, the effect of thinning was dependent on location and year. Trees per acre on thinned plots were significantly less than unthinned plots at age 0, and were significantly greater than unthinned plots at 1 year after treatment. By 3 years after treatment, thinned and unthinned plots did not differ in numbers of water tupelo stems. The thinned stumps produced multiple re-sprouts; however, they had naturally thinned themselves by 3 years after treatment. The slopes for the plots that were thinned or thinned and cleaned are negative from 1 to 3 years after treatment, while the slopes for plots that were not thinned were positive. The slopes for the unthinned plots reflect a recovery from mortality following a long, late flood prior to the growing season following treatment. Although stumps on the thinned plots produced many resprouts, the negative slope suggests that number per acre will be less than for the unthinned plots in the near future.

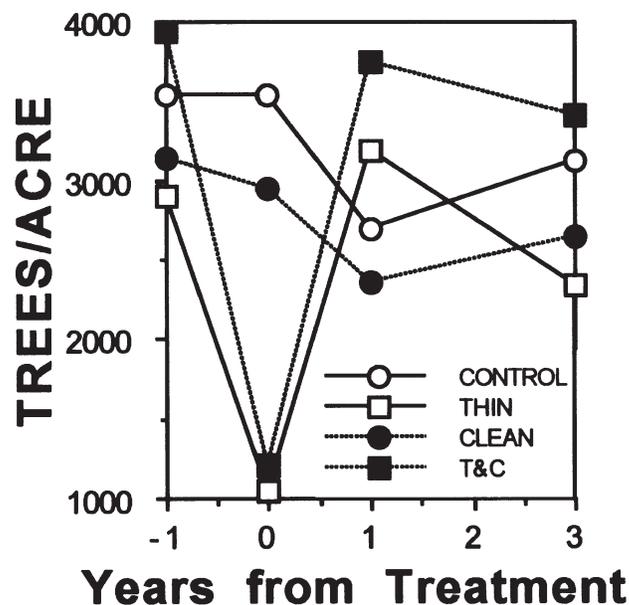


Figure 1—Trees per acre of water tupelo. Year “-1” represents pre-treatment conditions rather than 1 year prior to treatment. Year “0” represents measurements taken shortly after treatment.

Carolina ash—Trees per acre of Carolina ash were averaged across locations in figure 2. Significant factors were the main effects clean and year, and the interaction terms location.clean, and clean.year. Thus, the effect of cleaning is dependent on location and year. Although the

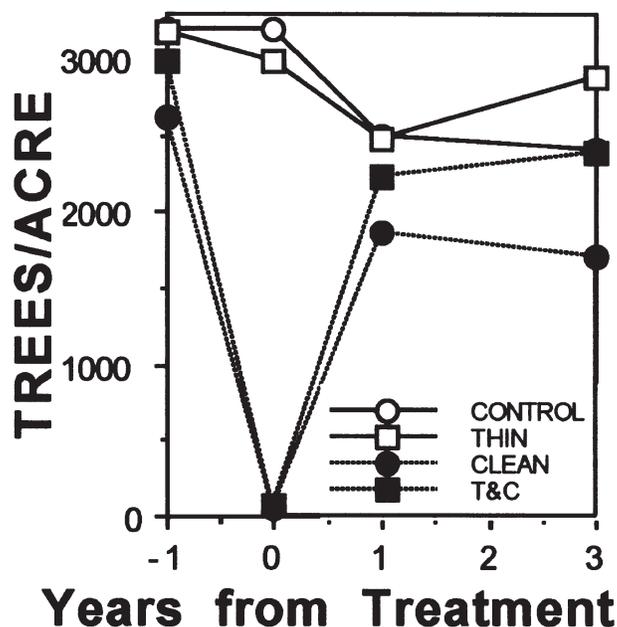


Figure 2—Trees per acre of Carolina ash. Year “-1” represents pre-treatment conditions rather than 1 year prior to treatment. Year “0” represents measurements taken shortly after treatment.

effect of cleaning was significant immediately after treatment, 1 year later there were no significant differences among treatments in trees per acre of Carolina ash.

Black willow—Trees per acre of black willow were averaged across locations in figure 3. Significant factors were the main effects location, clean, thin, and year, and the interaction terms location.clean, location.thin, location.year, clean.year, thin.year, and location.clean.year. Immediately after treatment, cleaning had a significant effect on numbers of willow stems, although this effect varied with location—one location had much more willow than the other two locations. However, by 1 and 3 years after treatment, the thinning treatment had a significant effect while cleaning had no significant effect on number of willow stems. Although thinning of the water tupelo may indeed benefit the willow, we consider it to be as likely that the thinned plots had greater recruitment of willow by random chance—the distribution of willow appeared patchy.

Baldcypress—Trees per acre of baldcypress were averaged across locations in figure 4. Significant factors were the main effects location, clean, and thin, and the interaction term clean.thin. By 3 years after treatment, baldcypress differed only among locations. Baldcypress was not directly affected by thinning or cleaning, and severing the other species provided no significant benefit to the baldcypress.

Prediction Equations

Water tupelo stems ≥ 2.5 inches d.b.h.—The final equation was:

$$\text{SQRT (Trees/Acre)} = 25.204 + 0.342 \text{ (Trees/Acre } \geq 2.5 \text{ at time 0) .}$$

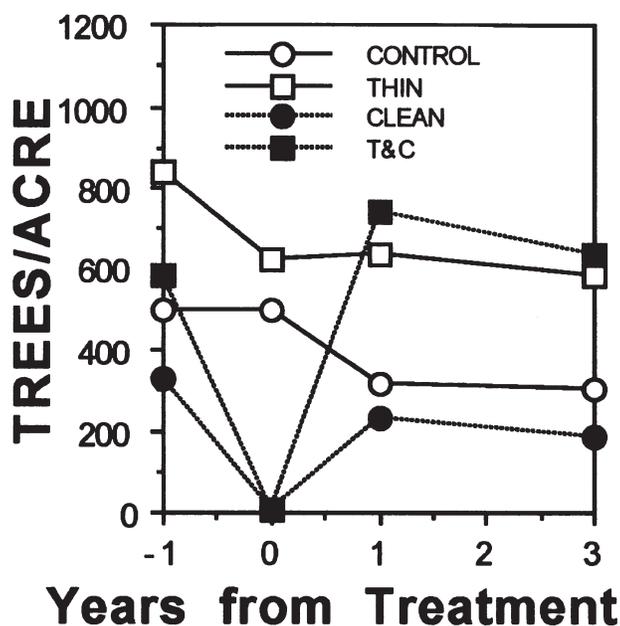


Figure 3—Trees per acre of black willow. Year “-1” represents pre-treatment conditions rather than 1 year prior to treatment. Year “0” represents measurements taken shortly after treatment.

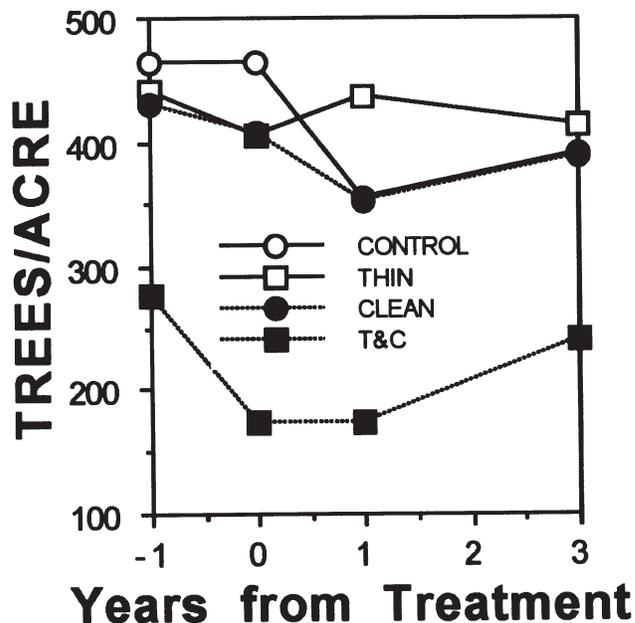


Figure 4—Trees per acre of baldcypress. Year “-1” represents pre-treatment conditions rather than 1 year prior to treatment. Year “0” represents measurements taken shortly after treatment.

The adjusted r^2 was 0.878 and the standard error was 3.6. None of the dummy variables for treatments nor the number of stems removed by the treatment entered the equation. This suggests that it matters little how a stand arrives at a given number of stems per acre at age 4—whether the number reflects intrinsic attributes of the stand or that the stand had been thinned—thus, pre-commercial thinning can be effective in controlling stems per acre. Based upon stocking guides (Goelz 1995), about 300 trees per acre would be a good target at age 7 (which is 3 years after treatment). Using the equation above, this would imply a target of about 60 trees per acre ≥ 2.5 inches d.b.h. at age 4.

Carolina ash stems—The final equation was:

$$\text{SQRT (Trees/Acre)} = 22.934 + 0.0671 \text{ (Trees/Acre at time 0)} + 0.0668 \text{ (Trees/Acre removed at time 0) .}$$

The adjusted r^2 was 0.814 and the standard error was 10.2. The coefficients for trees remaining and for trees removed are practically identical. This suggests cleaning does not effectively reduce the number of Carolina ash stems. Rather, you will have the same number of Carolina ash stems at age 7 whether you clean or not at age 4.

Black willow stems—The final equation was:

$$\text{SQRT (Trees/Acre)} = 10.322 + 0.089 \text{ (Trees/Acre at time 0)} + 0.126 \text{ (Trees/Acre removed at time 0) .}$$

The adjusted r^2 was 0.776 and the standard error was 11.7. The coefficient for trees removed is approximately 1.4 times the coefficient for the number of trees remaining at time 0. This suggests if you sever a willow tree at age 4, by

age 7 you will have 1.4 willow stems for every stem you severed.

Black willow stems ≥ 2.5 inches d.b.h.—The final equation is:

$$\text{SQRT (Trees/Acre)} = 4.223 - 3.780 (\text{CLEAN}) + 0.045 (\text{Trees/Acre of both size classes at time 0}) .$$

The adjusted r^2 is 0.856 and the standard error is 3.5. The magnitude of the coefficient for the intercept (1.284) is not significantly different from the coefficient for the dummy variable for the cleaning treatment (-1.149). This suggests that cleaning basically eliminates the presence of larger willow stems 3 years hence. If the water tupelo can approach crown closure in this time period, the very shade-intolerant willow will not survive. We observed this on one of our locations.

CONCLUSIONS

Thinning water tupelo initially caused drastic reduction in the number of water tupelo stems. The stumps sprouted again, and, by 1 year after treatment, there were more stems of water tupelo in the thinned plots. However, by 3 years after treatment, thinned plots did not have numbers of water tupelo stems that were significantly different from unthinned plots. The trend suggests that thinned plots will have fewer stems than unthinned plots in the near future. Although cleaning initially eliminated stems of Carolina ash and willow, by 3 years after treatment the number of ash and willow stems was as high as in the plots that were not cleaned. Thus, the effects of thinning on stems per acre of water tupelo will likely become greater as stand dynamics proceed, while the effects of cleaning appear to be modest. A more complete picture of the efficacy of the treatments

will be obtained with a description of basal area growth and individual tree diameter growth.

LITERATURE CITED

- DeBell, D.S.** 1971. Stump sprouting after harvest cutting in swamp tupelo. Res. Pap. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.
- Goelz, J.C.G.** 1995. Stocking guides for water tupelo and baldcypress. Southern Journal of Applied Forestry. 19: 105-108.
- Goelz, J.C.G.; Meadows, J.S.; Willingham, P.W.** 1993. Precommercial thinning of water tupelo stands on the Mobile-Tensaw River Delta. In: Brissette, John C., ed. Proceedings of the seventh biennial southern silvicultural research conference; 1992 November 17-19; Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 105-108.
- Kennedy, H.E., Jr.** 1982. Growth and survival of water tupelo coppice regeneration after six growing seasons. Southern Journal of Applied Forestry. 6: 133-135.
- Kennedy, H.E., Jr.** 1983. Water tupelo in the Atchafalaya basin does not benefit from thinning. Res. Note SO-298. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 3 p.
- McGarity, R.W.** 1979. Ten-year results of thinning and clear-cutting in a muck swamp timber type. Southern Journal of Applied Forestry. 3: 64-67.
- 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.

FIRST-YEAR GROWTH AND BOLE QUALITY RESPONSES TO THINNING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE

James S. Meadows and J.C.G. Goelz¹

Abstract—Four thinning treatments were applied to a red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in September 1994: (1) unthinned control; (2) light thinning to 70 to 75 percent residual stocking; (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to desirable residual stocking for bottomland hardwoods. The thinning operation consisted of a combination of low thinning and improvement cutting, in which the objective was to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Prior to treatment, the stand contained 196 trees per acre with a basal area of 121 square feet per acre. Average diameter of trees larger than 3.5 inches in diameter at breast height (d.b.h.) was 10.7 inches. Stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased average d.b.h. to 13.5 inches, and reduced stocking to 69 percent. Heavy thinning reduced density to 49 trees and 64 square feet of basal area per acre, increased average d.b.h. to 15.5 inches, and reduced stocking to 52 percent. B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased average d.b.h. to 15.6 inches, and reduced stocking to 70 percent. Approximately 24 percent of the residual trees across the thinned areas experienced at least some degree of logging damage from the harvesting operation. None of the thinning treatments had a significant effect on diameter growth of individual trees, across all species, during the first year after thinning. Though not statistically significant, diameter growth of red oaks was greater across the thinned areas than in the unthinned areas. Thinning also had no significant effect on the production of new epicormic branches on the butt log of residual trees. However, epicormic branching varied widely across both species and crown class.

INTRODUCTION

Profitable management of hardwood stands for sawtimber production depends not only on maintenance of satisfactory rates of growth, but also on successful development and maintenance of high-quality logs. In general, partial cuttings, usually in the form of some combination of thinning and improvement cutting, can be used in most mixed-species bottomland hardwood forests to: (1) enhance growth of individual trees, (2) improve species composition of the stand, and (3) improve bole quality of residual trees (Meadows 1996).

Thinning has been shown to dramatically increase diameter growth of residual trees within several different hardwood types, such as central upland oaks (Hilt 1979, Sonderman 1984b), Allegheny cherry-maple (*Prunus* spp.-*Acer* spp.) (Lamson 1985, Lamson and Smith 1988), and mixed Appalachian hardwoods (Lamson and others 1990). In general, the heavier the thinning, the greater the diameter growth response. For example, Hilt (1979) reported a 100 percent increase in periodic diameter growth of the 40 largest trees per acre in an upland oak stand in Missouri following the heaviest thinning treatment.

However, as thinning intensity increases, residual stand density decreases to a point where site occupancy is less than optimum. Although very heavy thinning greatly increases the diameter growth of individual residual trees, stand density becomes so low that stand-level basal area growth and volume growth are much reduced. In short, the stand does not fully realize the potential productivity of the site. Minimum residual stocking levels necessary to

maintain adequate stand-level growth and to ensure full occupancy of the site have been recommended to be 46 to 65 percent in central upland oaks (Hilt 1979) and 45 to 60 percent in cherry-maple stands (Lamson and Smith 1988). A very heavy thinning in a young water oak (*Quercus nigra* L.) plantation (equivalent to a residual stocking of 33 percent) reduced density such that stand volume growth will be suboptimal for a long period of time (Meadows and Goelz, in press).

Increased thinning intensity is also associated with increased degrade in bole quality (Sonderman 1984a, 1984b; Sonderman and Rast 1988). Specifically, the number and size of live and dead limbs increase significantly as residual stocking decreases, particularly on upland oak species. On the other hand, Sonderman and Rast (1988) reported that the production of epicormic branches on residual oak stems decreased with increasing thinning intensity. As the intensity of thinning increases, the proportion of dominant and codominant trees in the residual stand also increases. These vigorous, upper-crown-class trees are less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Although these conclusions seem to be conflicting, there does appear to be a trade-off between improved diameter growth and the potential for adverse effects on bole quality, as thinning intensity increases and residual density decreases.

Thinning is also used to improve species composition (Meadows 1996). In general, the goal is to decrease the proportion of low-value species and thus increase the

¹ Principal Silviculturist, and Principal Forest Biometrician, respectively, USDA Forest Service, Southern Research Station, P.O. Box 227, Stoneville, MS 38776.

proportion of high-value species. This objective is usually most important at the first thinning, but should be a major consideration whenever a partial cutting is conducted in a mixed-species stand.

These four components of thinning, increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, maintenance or enhancement of bole quality, and improved species composition, are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, a thinning regime should be designed to optimize value growth of the stand, as determined by these four components. Because maximization of all four components is not biologically possible, some compromises or trade-offs in expected benefits must be accepted.

Thinning in southern bottomland hardwood stands has received little attention from researchers over the years. Existing guidelines, such as those recommended by McKnight (1958), Johnson (1981), and Meadows (1996), are general in nature, and are based more on experience and observation rather than on specific research results. To effectively manage southern bottomland hardwood stands for high-quality sawtimber production, we need quantitative thinning guidelines for each of the various forest types found in southern bottomlands. These guidelines should include recommendations on: (1) timing of thinning, (2) intensity of thinning, and (3) marking rules designed to optimize value growth of the stand.

This study marks the establishment of a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. The series will consist of at least 12 studies installed over the next 10 to 15 years, using similar study designs, treatments, and methods.

This initial study addressed, as will each of the individual studies in the series, two specific objectives: (1) to determine the growth and bole quality responses of individual trees to several levels of thinning; and (2) to determine the effects of several levels of thinning on stand growth, development, and yield. Additionally, the results from the entire series of studies will be combined to address the following long-term objectives: (1) to develop practical guidelines for the intermediate management of southern bottomland hardwood stands; (2) to test the applicability of various levels of recommended residual stocking across a wide variety of site and stand conditions; and (3) to develop a growth and yield model for managed stands of southern bottomland hardwoods.

METHODS

Study Area

The study is located within the floodplain of the Tombigbee River in southwestern Pickens County, near Aliceville, in west-central Alabama, on land owned by Gulf States Paper Corporation. The study area is located within a 74-acre

stand composed primarily of red oak, sweetgum, and hickory (*Carya* spp.). Stand age at the time of study installation was approximately 60 years. A timber inventory conducted by Company personnel in April 1993 indicated an average sawtimber volume of 6,520 board feet per acre (Doyle scale), with approximately 81 percent of the volume in red oak, and an estimated pulpwood volume of 12.5 cords per acre.²

Based on preliminary observations and measurements, we classified the stand as a small sawtimber stand on a high-quality site, with high initial stocking. There was no evidence of previous harvesting activity in the stand.

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the USDA Forest Service's Northeastern Forest Experiment Station (Marquis and others 1990).

Individual treatments were applied to a 2.0-acre, rectangular treatment plot, measuring 4 by 5 chains (264 by 330 feet). Treatments were applied uniformly across each treatment plot. One measurement plot was located on the interior 0.6-acre rectangle of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), providing a 1-chain (66 feet) buffer around each.

The four treatments were replicated three times and were assigned randomly to treatment plots within each replication. The 12 treatment plots covered an area of 24 acres.

Treatments

Thinning intensity was defined by four levels of residual stocking, based on the stocking guide for southern bottomland hardwoods developed by Goelz (1995). Specifically, the study consisted of four treatments: (1) an unthinned control; (2) light thinning to 70 to 75 percent residual stocking; (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to desirable residual stocking following partial cutting in well-managed, even-aged southern bottomland hardwoods, as recommended by Putnam and others (1960).

The thinning operation consisted of a combination of low thinning and improvement cutting, in which the objective was to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Modified hardwood tree classes, as originally defined by Putnam and others (1960), formed the cutting priority for each treatment. Trees were removed from the cutting stock and cull stock classes first, and then from the reserve growing stock class, if necessary, until the target residual stocking was met.

² Personal communication. 1993. Sam G. Hopkins, Research Manager, Gulf States Paper Corporation, P.O. Box 48999, Tuscaloosa, AL 35404.

The thinning operation was performed by a contract logging crew in September 1994. All trees were directionally felled with a mechanized feller. Rubber-tired skidders were used to remove the merchantable products, in the form of longwood, from the woods. Most of the material cut was marketed as pulpwood.

Measurements and Statistical Analysis

A preharvest survey was conducted to determine species composition and initial stand density on each 0.6-acre measurement plot. Variables measured on all trees included species, diameter at breast height (d.b.h.), crown class, and tree class. After the stand was marked for thinning, but prior to harvest, the length and grade of all saw logs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section were recorded on those trees designated as "leave" trees. Merchantable height, height to the base of the live crown, and total height were also recorded on a subsample of leave trees. At the end of the first year after thinning, d.b.h. and the number of epicormic branches on each 16-foot log section were remeasured.

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

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

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the stand contained 196 trees per acre with a basal area of 121 square feet per acre. Quadratic mean diameter of trees larger than 3.5 inches d.b.h. was 10.7 inches. Stocking averaged 107 percent across the 24-acre study area. No significant differences in any of these pretreatment parameters were found among the four levels of thinning.

Prior to treatment, the stand was a typical, even-aged, mixed-species stand of bottomland hardwoods. Measures of stand density and other observations indicated that the stand could benefit from thinning. For example, average stocking across the entire study area was 107 percent. Goelz (1995) recommended thinning bottomland hardwood stands with stocking greater than 100 percent.

Species composition across the study area prior to thinning was predominantly red oak, hickory, and sweetgum. Various species of red oaks, principally water, cherrybark (*Quercus falcata* var. *pagodifolia* Ell.), and willow (*Q. phellos* L.) oaks with lesser amounts of southern red (*Q. falcata* Michx.) and

Shumard (*Q. shumardii* Buckl.) oaks, accounted for approximately 45 percent of the basal area and were found primarily in the upper canopy. Quadratic mean diameter of red oaks was 16.1 inches. Shagbark hickory [*Carya ovata* (Mill.) K. Koch] and mockernut hickory [*C. tomentosa* (Poir.) Nutt.] together accounted for about 25 percent of the basal area. Hickories were found primarily in the mid-canopy, but scattered individuals occurred as upper-crown-class trees. Sweetgum comprised approximately 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white oak (*Q. alba* L.), overcup oak (*Q. lyrata* Walt.), swamp chestnut oak (*Q. michauxii* Nutt.), green ash (*Fraxinus pennsylvanica* Marsh.), and various elms (*Ulmus* spp.).

Stand-Level Responses to Thinning

Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased quadratic mean diameter to 13.5 inches, and reduced stocking to 69 percent. It removed 62 percent of the trees and 31 percent of the basal area. Heavy thinning reduced density to 49 trees and 64 square feet of basal area per acre, increased quadratic mean diameter to 15.5 inches, and reduced stocking to 52 percent. It removed 73 percent of the trees and 43 percent of the basal area. B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased quadratic mean diameter to 15.6 inches, and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average d.b.h. of trees removed during the logging operation ranged from 7.1 inches in the light thinning treatment to 8.3 inches in the B-line thinning treatment. Overall average d.b.h. of trees removed was 8.0 inches.

Thinning also improved the species composition of the residual stand. All thinning treatments increased the proportion of red oak and decreased the proportions of both sweetgum and hickory within the residual stand. Most of the sweetgum and hickory removed from the stand were lower-crown-class trees.

Stand conditions 1 year after thinning are summarized in table 1. A small amount of mortality occurred in both the unthinned control and the B-line thinning treatments, at the rate of 2 trees per acre during the first year after thinning. No mortality was observed in either the light or heavy thinning treatments.

Slight increases in basal area and stocking were observed for all treatments during the first year after thinning, with the largest increases found in the light thinning treatment. Increases in quadratic mean diameter were also found among all treatments, with the largest increase observed in the heavy thinning treatment. Because light thinning left more trees per acre, we expected it to produce the highest stand-level growth rates (in basal area and stocking), excluding the unthinned control. By the same token, because heavy thinning left fewer trees, we expected it to

Table 1—Stand conditions 1 year after application of four thinning treatments

Treatment	Trees/acre	Basal area	D.b.h.	Stocking
		<i>Sq ft/ac</i>	<i>Inches</i>	<i>Percent</i>
Control	182 a ^a	118 a	10.9 b	103 a
Light	83 b	85 b	13.9 ab	71 b
Heavy	49 c	66 c	16.0 a	54 c
B-Line	63 bc	87 b	15.9 a	71 b

^a Treatment means within columns not followed by the same letter are significantly different at the 0.05 level of probability, as determined by Duncan's New Multiple Range Test.

produce the highest individual-tree growth rates, leading to the greatest increase in quadratic mean diameter. However, none of these first-year increases in basal area, stocking, or quadratic mean diameter were statistically significant.

Individual-Tree Diameter Growth

We found no significant differences among treatments in first-year diameter growth of individual trees. Across all species within treatments, trees in the unthinned control plots grew an average of 0.09 inches in diameter. In contrast, residual trees in the thinned plots exhibited a slightly higher diameter growth response, and averaged 0.15, 0.18, and 0.16 inches during the first year after light thinning, heavy thinning, and B-line thinning, respectively.

Even though thinning had no significant effect on first-year diameter growth, individual species groups varied in their growth response to the four levels of thinning (fig. 1). Diameter growth of residual red oaks (primarily cherrybark, water, and willow oaks) and sweetgum appeared to respond well to all thinning treatments. For example, both light and heavy thinning resulted in about twice as much diameter growth as was observed in the unthinned control plots, for both species groups. Diameter growth response of both groups to B-line thinning was somewhat less than that observed for both light and heavy thinning. In contrast, first-year diameter growth of hickory was uniformly low and was unaffected by thinning treatment. However, none of these first-year differences within species groups were statistically significant.

Although these results are preliminary and are not statistically significant, it does appear that diameter growth of residual trees will be increased by all thinning treatments, especially among the red oaks. We anticipate that treatment effects will increase as the study progresses.

Epicormic Branching

Production of new epicormic branches on the butt logs of residual trees was low during the first year after treatment and did not differ significantly among the four levels of

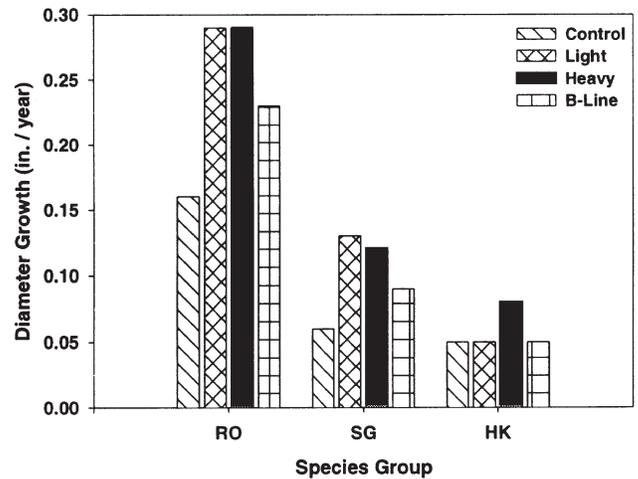


Figure 1—Diameter growth of residual trees, by species group, during the first year after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

thinning. In fact, trees in all treatments averaged fewer than one new epicormic branch on the butt log.

However, species varied greatly in the number of new epicormic branches produced in response to the four levels of thinning (fig. 2). In red oaks and, to a lesser extent, in sweetgum, the number of new epicormic branches generally increased with increasing thinning intensity. Epicormic branching response among hickory species was highly variable and yielded no obvious trends. However, it is important to note that even though there appeared to be treatment effects, at least within sweetgum and the red oak group, both species groups produced an average of fewer than 1.5 new epicormic branches on the

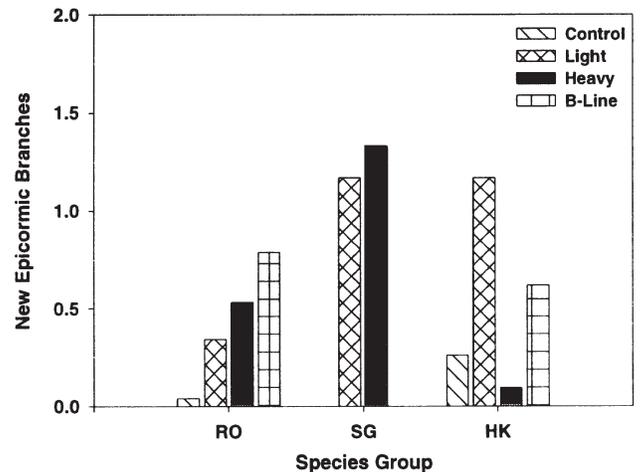


Figure 2—Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first year after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

butt log. Consequently, thinning had little effect on production of new epicormic branches during the first year after treatment.

Production of new epicormic branches also varied among crown classes (fig. 3). Lower-crown-class trees, as a group, produced more epicormic branches than did upper-crown-class trees, as a group, in response to thinning. Given that crown class is a reasonably adequate indicator of tree vigor, our data indicate that the production of new epicormic branches increases as initial tree vigor declines. In other words, residual trees of low vigor are more susceptible to the production of new epicormic branches than are residual trees of high vigor, when subjected to thinning.

These results tend to support the hypothesis advanced by Meadows (1995) that the propensity of an individual hardwood tree to produce epicormic branches in response to some disturbance, such as thinning, is largely controlled by the species and initial vigor of the particular tree. Meadows (1995) noted that hardwood species vary greatly in their likelihood to produce epicormic branches, and categorized most bottomland red oaks and sweetgum as highly susceptible to epicormic branching. Meadows (1995) also speculated that tree vigor is the mechanism that controls the production of epicormic branches when a tree is subjected to some type of disturbance, such that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Our observations in this study that epicormic branching varied not only by species but also among crown classes lend credence to these hypotheses.

Logging Damage

We surveyed the extent of logging damage across the study area following the thinning operation and found that

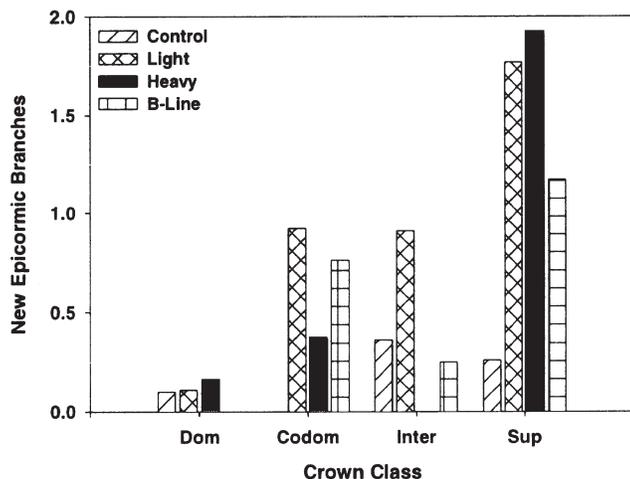


Figure 3—Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first year after application of four thinning treatments (DOM=dominant, CODOM=codominant, INTER=intermediate, SUP=suppressed).

24 percent of the residual trees experienced some type of damage. The extent of damage varied somewhat across treatments, but these differences were not statistically significant. The proportion of residual trees damaged ranged from 20 percent in the heavily thinned plots to 32 percent in the plots subjected to B-line thinning. Most of the logging damage observed in this study was minor, and does not indicate a permanent loss of tree vigor.

The overall average of 24 percent in this study was considerably lower than that reported by Meadows (1993) following partial cutting in a riverfront hardwood stand in the Mississippi Delta. In that study, Meadows (1993) found that 62 percent of the residual trees had been damaged at least to some extent.

Most of the damage observed in this study and in the one reported by Meadows (1993) occurred as logs pulled by the skidder scraped the lower boles of residual trees. Although some degree of logging damage must be expected during any partial cutting operation, the extent of damage can be minimized through better planning of the logging operation and through more careful skidder operation.

CONCLUSIONS

Thinning had no significant effect on average diameter growth across all species during the first year after treatment, but red oaks seemed to increase in growth more than did other species groups.

Thinning also had no significant effect on the production of new epicormic branches along the butt logs of residual trees during the first year after treatment. However, epicormic branching varied widely among species and among crown classes.

ACKNOWLEDGMENT

The authors wish to express appreciation to Gulf States Paper Corporation for providing the study site and for its cooperation in all phases of study installation and measurement. We wish to specifically thank Sam Hopkins, Dale Larson, John Tiley, Harry Labhart, and Warren Eatman, all of Gulf States Paper Corporation, for their continuing assistance in this study.

LITERATURE CITED

- Goelz, J.C.G.** 1995. A stocking guide for southern bottomland hardwoods. *Southern Journal of Applied Forestry*. 19(3): 103-104.
- Hilt, Donald 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.
- Johnson, Robert L.** 1981. Wetland silvicultural systems. In: Jackson, Ben D.; Chambers, Jim L., eds. *Timber harvesting in wetlands: 30th annual forestry symposium*. Baton Rouge, LA: Louisiana State University, Division of Continuing Education: 63-79.
- Lamson, Neil I.** 1985. Thinning increases growth of 60-year-old cherry-maple stands in West Virginia. Res. Pap.

- NE-571. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.
- Lamson, Neil I.; Smith, H. Clay.** 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.
- Lamson, Neil I.; Smith, H. Clay; Perkey, Arlyn W.; Brock, Samuel M.** 1990. Crown release increases growth of crop trees. Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.
- Marquis, Dave; Smith, Clay; Lamson, Neil [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.
- McKnight, J.S.** 1958. Thinning stands of water oaks. In: Management of bottomland forests: Proceedings of the seventh annual forestry symposium; 1958 April 10-11; [Baton Rouge, LA]. Baton Rouge, LA: Louisiana State University, School of Forestry: 46-50.
- Meadows, James S.** 1993. Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. In: Gillespie, Andrew R.; Parker, George R.; Pope, Phillip E.; Rink, George, eds. Proceedings of the 9th central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 248-260.
- Meadows, James S.** 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, Glenn; Meyer, Dan, eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the twenty-third annual hardwood symposium; 1995 May 17-20; Cashiers, NC. [Memphis, TN]: National Hardwood Lumber Association: 19-25.
- Meadows, James S.** 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Clemson, SC: Consortium for Research on Southern Forested Wetlands, Clemson University: 98-101.
- Meadows, James S.; Goelz, J.C.G.** [In press]. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry.
- Putnam, John A.; Furnival, George M.; McKnight, J.S.** 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.
- Rast, Everette D.; Sonderman, David L.; Gammon, Glenn 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, David L.** 1984a. Quality response of even-aged 80-year-old white oak trees after thinning. Res. Pap. NE-543. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.
- Sonderman, David L.** 1984b. Quality response of 29-year-old, even-aged central hardwoods after thinning. Res. Pap. NE-546. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.
- Sonderman, David L.; Rast, Everette 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.

SEASONAL LATERAL ROOT GROWTH OF JUVENILE LOBLOLLY PINE AFTER THINNING AND FERTILIZATION ON A GULF COASTAL PLAIN SITE

Mary Anne Sword, James D. Haywood, and C. Dan Andries¹

Abstract—In 1989, two levels each of stand density and fertilization were factorially established in an 8-year-old loblolly pine plantation on a P-deficient site. Levels of stand density were nonthinned at 2,732 trees per hectare and thinned at 721 trees per hectare. Fertilizer levels were none or application of 150 kilograms P plus 135 kilograms N per hectare. In 1994, stand basal areas of the nonthinned and thinned plots were 42 and 25 square meters per hectare, respectively, and a second thinning on the previously thinned plots left 15.6 square meters per hectare. The previously fertilized plots were refertilized with 200 kilograms N, 50 kilograms P, and 50 kilograms K per hectare. In 1994 and 1995, tree growth was quantified at the end of the growing season, and lateral root initiation and elongation, soil temperature, and soil water content were measured throughout the growing season. The maximum rate of loblolly pine root growth occurred in May through July with more root growth in the 0- to 5-cm depth than in the 5- to 30-cm depth. A positive relationship between soil water content and root growth was observed. Thinning stimulated root growth 5 years after initial thinning and immediately after rethinning. Fertilization did not affect root growth 5 years after application and refertilization had a limited positive effect on root growth. Although tree growth was not immediately affected by treatment reapplication, a positive relationship was found between current annual tree volume increment and root elongation during peak root growth. We conclude that root system growth is sensitive to environmental variables that affect root metabolism in May through July, and that on the Gulf Coastal Plain, loblolly pine volume gains after silvicultural treatment result, in part, from an increase in soil resource uptake.

INTRODUCTION

The availability of water and mineral nutrients often limits the productivity of southern pine forests on Gulf Coastal Plain sites (Allen 1987, Allen and others 1990, Bassett 1964, Cregg and others 1988, Dougherty 1996, Moehring and Ralston 1967). Low transpiration rates and a high water table during winter result in adequate water availability in the early growing season, but with increased evapotranspiration and reduced precipitation as the growing season progresses, water deficits arise (Knight and others 1994, Moehring and Ralston 1967). In addition, phosphorus (P) and nitrogen (N) deficiencies are common throughout the South (Allen and others 1990, Dougherty 1996), and can produce significant gains in loblolly pine volume (Allen 1987, Fisher and Garbett 1980).

With adequate resource availability, photosynthate is preferentially partitioned to tree branch and foliage, rather than root growth (Dickson 1989, 1991). This phenomenon was demonstrated by Haynes and Gower (1995) after fertilization of 31-year-old red pine (*Pinus resinosa* Ait.) in Wisconsin. Four years after the start of annual fertilizer amendments, litterfall was increased 49 percent and carbon allocation to root and soil processes was decreased 48 percent. In contrast, long-term water and fertility deficits cause an increase in the proportion of carbon partitioned to the root system (Eissenstat and Van Rees 1994). For example, Keyes and Grier (1981) found that the proportion of biomass partitioned to the root system in two stands of 40-year-old Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] was negatively related to soil fertility and site index.

Expansion of tree root systems may be required to offset water and fertility deficits and maximize stand productivity on resource-limited sites in the South. Root growth is affected by growth regulator relations and the availability of carbohydrates, mineral nutrients, and water (Coutts 1987, Dickson 1991, Eissenstat and Van Rees 1994, Klepper 1987). Because these variables are either directly or indirectly influenced by thinning and fertilization, we hypothesize that root system growth and resource uptake can be manipulated by these silvicultural tools. We had two primary objectives in this study: (1) characterize the seasonal root growth and soil environment of plantation loblolly pine (*P. taeda* L.) in response to thinning and fertilization, and (2) evaluate the relationship between tree and root system growth in four stand environments.

MATERIALS AND METHODS

The study was installed in an 8-year-old loblolly pine stand planted at a 1.83-meter (m) by 1.83-m spacing on the Palustris Experimental Forest in Rapides Parish, LA. The soil is a Beauregard silt loam (fine-silty, siliceous, thermic, Plinthaquic Paleudult) (Kerr and others 1980). In April 1988, 12 treatment plots—13 rows of 13 trees each—were established (Haywood 1994). Thinning and fertilization treatments were randomly assigned to the plots in a 2 by 2 factorial design with three replications. Levels of thinning were: the original stocking [2,732 trees per hectare (ha)], and removal of every other row of trees and every other tree in residual rows in November 1988 (721 trees per ha). Levels of fertilization were: no fertilization and broadcast application of 747 kilograms (kg) per ha diammonium phosphate (135 kg N and 150 kg P per ha) in April 1989. The fertilization rate was based on recommendations for

¹ Research Plant Physiologist, Research Forester, and Biological Laboratory Technician, respectively, Southern Research Station, U.S. Department of Agriculture, Forest Service, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA 71360.

loblolly pine grown on the nutrient-poor soil in this study (Kerr and others 1980, Shoulders and Tiarks 1983, Tiarks 1982).

Six growing seasons after the initial silvicultural treatments were applied, stand basal areas of the nonthinned and thinned plots were 42 and 25 square meters (m^2) per ha, respectively. In March 1995, the previously thinned plots were thinned from below to 30 percent of maximum stand density index as recommended by Dean and Baldwin (1993), resulting in a residual basal area of 15.6 m^2 per ha. Foliar mineral nutrient concentrations in August 1993 were used to determine a fertilizer recommendation for the previously fertilized plots. Urea, monocalcium phosphate, and potash [200 kg N, 50 kg P, and 50 kg potassium (K) per ha] were broadcast on the previously fertilized plots in March 1995.

Tree heights and diameters at breast height (d.b.h.) were measured quarterly (Haywood 1994) and outside bark stem volume (Baldwin and Feduccia 1987) was calculated. Two replications were chosen as blocks for measurement of root system growth and the soil environment. Blocks were identified based on the influence of topography on soil drainage. At 14-day intervals in May 1994 through January 1995, and June 1995 through January 1996, new roots [≥ 0.5 centimeters (cm) long] were cumulatively traced onto acetate sheets attached to five vertical Plexiglas rhizotrons (0.3 x 35.4 x 76 cm) per plot (Sword and others 1996). After each measurement period, a computer image file of each acetate tracing was created and the length of the lines contained in each image file was quantified using GSROOT software (PP Systems Inc., Bradford, MA). Net lateral root elongation was calculated by subtraction and expressed as millimeters per square decimeter ($mm\ dm^{-2}$) per day. After each measurement period, root initiation was quantified as the number of independently appearing new roots (≥ 0.5 cm long) in the 0- to 5-, 5- to 15-, and 15- to 30-cm depths, and expressed as number dm^{-2} per day.

Soil temperature ($^{\circ}C$) was measured by insulated solid state sensors (Sword and others 1996) inserted in the soil at 5, 15, and 30 cm through ports in the rhizotrons. The water content of the soil (percent volume) was measured by time domain reflectometry with one sensor placed at the 15-cm depth through a port in each of three randomly chosen rhizotrons per plot. Soil temperature and water content were measured at 14-day intervals in May 1994 through January 1995, and June 1995 through January 1996.

Tree height, d.b.h., and stem volume were evaluated by analysis of variance after the 1994 growing season and by analysis of covariance after the 1995 growing season, using a completely random, 2 by 2 factorial experimental design with three replications. Factors were two levels each of fertilization and thinning. Covariates were height, d.b.h., and volume at the end of the 1994 growing season. Net root elongation, soil temperature, and transformed (arcsine of the square root) volumetric soil water content data collected in 1994-95 and 1995-96 were analyzed by a

randomized, complete, block-split-plot-in-time design with two blocks. Thinning and fertilization were the whole-plot treatments; time was the subplot treatment. Root initiation in 1994-95 and 1995-96 was analyzed by a randomized, complete, block-split-plot-in-space-and-time design with two blocks. Thinning and fertilization were the whole-plot treatments; time and depth were the subplot treatments. Data were subjected to analyses of variance by measurement date to explain significant time interactions. Together, root growth and soil water content decreased as the growing season progressed. To evaluate this relationship as soil water became less available, Pearson product-moment correlations were calculated for root growth and soil water content in late June through September 1994 (SAS Institute Inc. 1991). Because our time domain reflectometer was inoperable in August through September 1995, we were unable to conduct this analysis in 1995. Main and interaction effects and Pearson correlation coefficients were considered significant at probabilities (Pr) ≤ 0.05 unless otherwise noted, and treatment means were compared with the Least Significant Difference test at $Pr \leq 0.05$.

RESULTS

At the end of the 1994 growing season, fertilization significantly increased tree height, and both thinning and fertilization significantly increased d.b.h. and stem volume (table 1). After the 1995 growing season, tree height, d.b.h., and stem volume were not significantly affected by reapplication of the thinning and fertilization treatments.

Maximum rates of root initiation and net root elongation occurred in May through July (figs. 1 and 2). Root initiation was significantly affected by soil depth and by an interaction between time and soil depth in 1994 and 1995 (table 2). Consistently, root initiation in the 0- to 5-cm depth was greater than that at either the 5- to 15-cm or 15- to 30-cm depth; whereas, root initiation at the 5- to 15-cm depth was greater than that at the 15- to 30-cm depth in May and June.

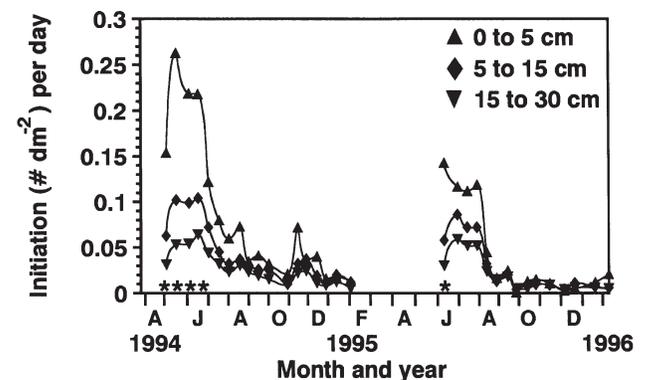


Figure 1—Seasonal number of roots per decimeter per day initiated at 0 to 5, 5 to 15, and 15 to 30 centimeters in rhizotrons during 1994 and 1995. Asterisks signify measurement intervals associated with significantly more root initiation at 0 to 5 than at 5 to 15 centimeters, and significantly more root initiation at 5 to 15 than at 15 to 30 centimeters, by the LSD test ($Pr \leq 0.05$).

Table 1—Analyses of variance and covariance of juvenile loblolly pine stem growth before and after reapplication of thinning and fertilization on a P-deficient Gulf Coastal Plain site in central Louisiana

Treatment combination	1994—Before treatment reapplication			1995—After treatment reapplication		
	Height	D.b.h.	Volume/tree	Height	D.b.h.	Volume/tree
	<i>m</i>	<i>cm</i>	<i>dm³</i>	<i>m</i>	<i>cm</i>	<i>dm³</i>
Not thinned, not fertilized	13.9	13.5	112.5	14.5	13.8	120.6
Not thinned, fertilized	15.0	14.4	140.0	15.9	14.8	161.1
Thinned, not fertilized	13.4	17.4	172.8	14.3	19.0	212.4
Thinned, fertilized	14.7	19.4	229.3	15.6	21.0	277.6

Source of variation	Analyses of variance			Analyses of covariance		
	df ^a	MS	Pr > F-value	df	MS	Pr > F-value
D.b.h. (cm)						
Covariate (C)	.	.	.	1	10.8983	0.0043
Thinning(T)	1	59.9534	0.0001	1	0.8158	0.2932
Fertilization (F)	1	6.1421	0.0054	1	1.1306	0.2228
T x F	1	0.9944	0.1673	1	0.5305	0.3900
(Error)	8	0.4311		7		
Height (m)						
C	.	.	.	1	2.8209	0.0034
T	1	0.5193	0.1706	1	0.1613	0.3332
F	1	4.3010	0.0025	1	0.0090	0.8131
T x F	1	0.0511	0.6492	1	0.1290	0.3836
(Error)	8	0.2291		7	0.1493	
Volume (dm³ tree⁻¹)						
C	.	.	.	1	7649.2760	0.0017
T	1	16803.2205	0.0001	1	289.2690	0.3680
F	1	284.9786	0.0033	1	420.7903	0.2838
T x F	1	629.4227	0.1916	1	414.0510	0.2874
(Error)	8	309.3901		7	312.3743	

^a df = degrees of freedom; MS = mean square; Pr > F-value = probability of a greater F-value.

In 1994, the interaction between time and thinning significantly affected root initiation and elongation (table 2). Thinning was associated with stimulated root initiation in May through June 1994, reduced root initiation in November through December 1994 (fig. 3), and increased root elongation during the 1994 growing season (fig. 2). Root initiation was significantly affected by interactions among time, thinning, and fertilization; and time, thinning, and soil depth. In July through early August 1994, root initiation was greater in the nonthinned, fertilized treatment than in the other treatments, and root initiation at the 0- to 5-cm depth on the nonthinned plots was greater than on the thinned plots.

After silvicultural treatments were reapplied in 1995, thinning resulted in significantly greater root elongation

(table 2, fig. 2). Root initiation was significantly affected by interactions between time and fertilization, and among time, fertilization, and thinning. In general, root initiation was stimulated 38 percent by fertilization in June through July 1995. In 1995, a significant positive correlation was observed between current annual stem volume increment and mean root elongation in early June through July ($r = 0.6228$, $Pr = 0.0991$) (fig. 4).

Soil temperature at the 5-, 15-, and 30-cm depths was significantly increased by thinning in May through September 1994 and 1995. Thinning significantly decreased soil temperature at the 30-cm depth in November through December 1994, and at the 5-, 15-, and 30-cm depths in November 1995 through January 1996 (fig. 5). In 1994, soil temperature at the 30-cm depth was

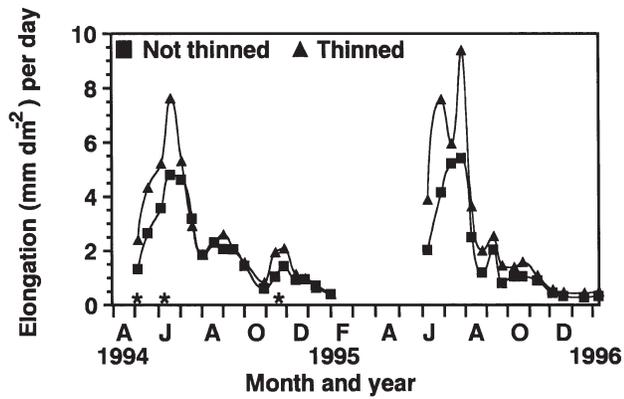


Figure 2—Seasonal net root elongation (millimeters per decimeter) per day in rhizotrons at 0 to 30 centimeters during 1994 and 1995 in response to thinning in November 1988 and March 1995. Asterisks signify measurement intervals in 1994 associated with a significant thinning effect.

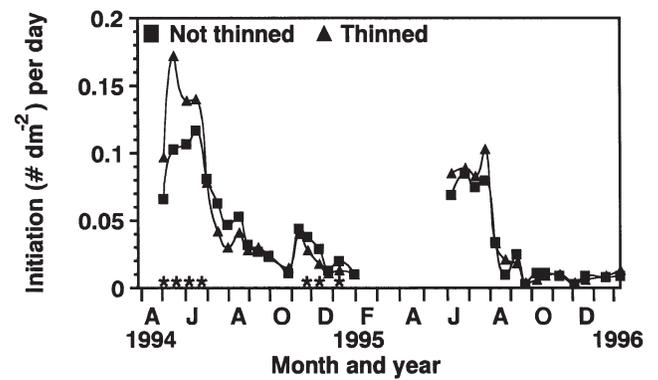


Figure 3—Seasonal number of roots per decimeter per day initiated in rhizotrons at 0 to 30 centimeters during 1994 and 1995 in response to thinning in November 1988 and March 1995. Asterisks signify measurement intervals in 1994 associated with a significant thinning effect.

Table 2—Probability of a greater F-value for the main and interaction treatment effects in the analyses of variance of loblolly pine root initiation rate (number dm^{-2}) per day in the 0- to 5-, 5- to 15- and 15- to 30-cm depths, and root elongation rate (mm dm^{-2}) per day in the 0- to 30-cm depth of the soil during the growing seasons before and after reapplication of thinning and fertilization on a P-deficient Gulf Coastal Plain site in central Louisiana

Source of variation	1994—Before treatment reapplication		1995—After treatment reapplication	
	df ^a	Pr > F-value	df	Pr > F-value
Root initiation (number dm^{-2} /day)				
Block (B)	1	0.1300	1	0.0006
Soil depth (D)	2	0.0037	2	0.0066
Thinning (T)	1	0.3261	1	0.3261
Fertilization (F)	1	0.3490	1	0.5468
T x F	1	0.9178	1	0.6346
T x D	2	0.8565	2	0.8983
F x D	2	0.4225	2	0.6471
T x F x D	2	0.8736	2	0.4874
Time	18	0.0001	14	0.0001
Time x D	36	0.0001	28	0.0001
Time x T	18	0.0001	14	0.1108
Time x F	18	0.1058	14	0.0001
Time x T x F	18	0.0143	14	0.0025
Time x T x D	36	0.0001	28	0.7652
Time x F x D	36	0.9717	28	0.1268
Time x T x F x D	36	0.6204	28	0.9709
Root elongation (mm dm^{-2} /day)				
Block (B)	1	0.2433	1	0.2932
Thinning (T)	1	0.2352	1	0.0192
Fertilization (F)	1	0.4912	1	0.3652
T x F	1	0.8296	1	0.1082
Time	17	0.0001	14	0.0001
Time x T	17	0.0286	14	0.0705
Time x F	17	0.3317	14	0.9625
Time x T x F	17	0.1452	14	0.5070

^a df = degrees of freedom; Pr > F-value = probability of a greater F-value.

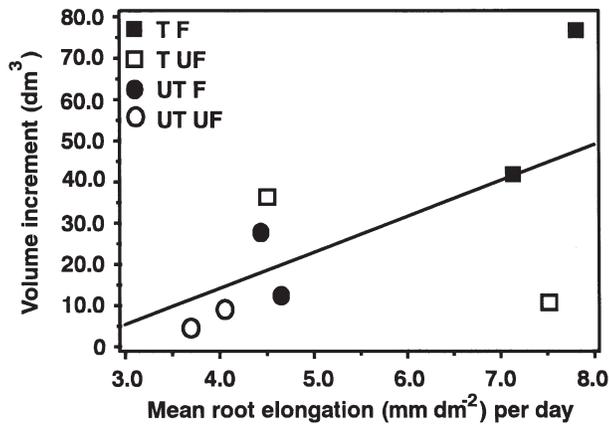


Figure 4—Relationship between the current annual stem volume increment (cubic decimeters) of loblolly pine in 1995 and the mean rate of lateral root elongation (millimeters per decimeter per day) between late June and early August 1995 ($r = 0.6228$, $Pr = 0.0991$).

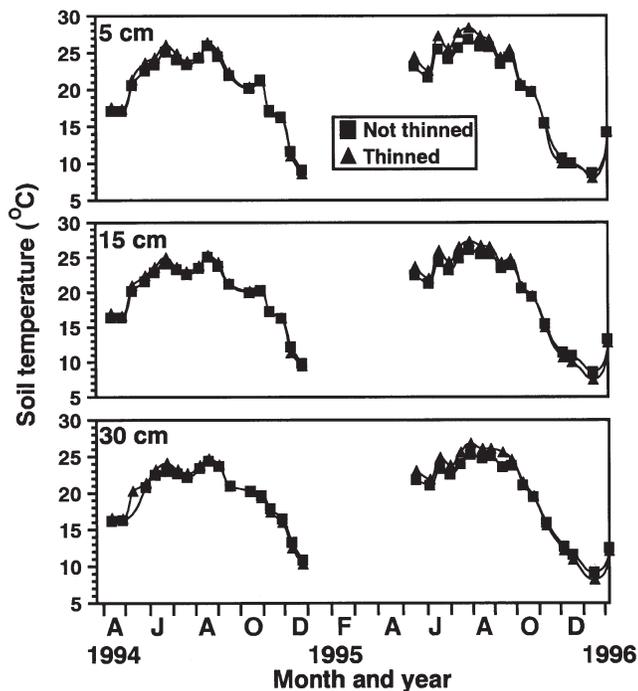


Figure 5—Soil temperature ($^{\circ}\text{C}$) at 5, 15, and 30 centimeters in rhizotrons during 1994 and 1995 in response to thinning in November 1988 and March 1995.

significantly affected by an interaction between thinning and fertilization. In May through July 1994, soil temperature at the 30-cm depth was 1.0°C greater on the thinned, nonfertilized plots compared with the other plots. In November through January 1994, soil temperature at the 30-cm depth was 0.7°C greater on the nonthinned, fertilized plots compared with the other plots.

In 1994, interaction between time and thinning had a significant effect ($Pr = 0.0895$) on soil water content at the 15-cm depth, with a tendency for greater soil water content

at 15-cm in response to thinning (fig. 6). Soil water content at the 15-cm depth in the 1994 growing season was significantly affected by an interaction among time, thinning, and fertilization. In November through December 1994, soil water content at 15-cm was less (14 percent) in response to the nonthinned, nonfertilized treatment compared with the other treatments. In 1995, soil water content at the 15-cm depth was significantly affected by an interaction between time and thinning, with periodic increases in soil water content throughout 1995 on the thinned plots.

Significant positive correlations were found between root elongation and initiation, and soil water content at the 15-cm depth in late June through September 1994. On the nonthinned plots, soil water content at the 15-cm depth was significantly correlated with root initiation at the 0- to 5-cm depth ($r = 0.5796$, $Pr = 0.0005$). On the thinned plots, soil water content at the 15-cm depth was significantly correlated with root elongation at the 0- to 30-cm depth ($r = 0.5786$, $Pr = 0.0005$), and root initiation at the 0- to 5- ($r = 0.6014$, $Pr = 0.0005$), 5- to 15- ($r = 0.6032$, $Pr = 0.0003$) (fig. 7), and 15- to 30- ($r = 0.6514$, $Pr = 0.0001$) cm depths.

DISCUSSION

In two consecutive years, we observed that new root growth of planted loblolly pine was greatest in May through July, and continued at a reduced rate in August through January. We also found more root growth near the soil surface than deeper in the soil profile. (Sword and others, in press) observed a similar pattern of seasonal root growth at this study site in 1993. Soil temperature, fertility, and moisture availability influence root system growth and development (Eissenstat and Van Rees 1994, Klepper 1987, McMichael and Burke 1996). Therefore, the expansion of loblolly pine root systems may be more sensitive to the surface soil environment in May through July than in other months of the year, and adverse soil environmental conditions in May through July could reduce root system function and soil resource uptake.

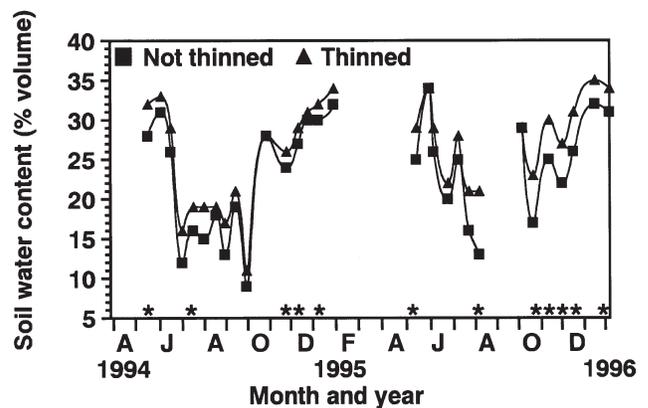


Figure 6—Soil water content (percent volume) at 15 centimeters in rhizotrons during 1994 and 1995 in response to thinning in November 1988 and March 1995. Asterisks signify measurement intervals associated with a significant thinning effect.

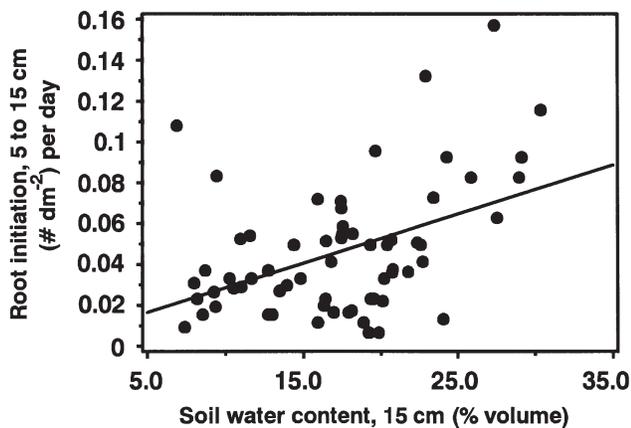


Figure 7—Relationship between the number of roots per decimeter per day initiated in rhizotrons at 5 to 15 centimeters, and soil water content at 15 centimeters (percent volume) during late June through September 1994 on the thinned plots ($r = 0.6032$, $Pr = 0.0003$).

In 1993, we observed a midsummer decrease in root elongation and initiation that corresponded to reduced soil water content (Sword and others, in press). Between June and September 1994, we found that soil water content decreased 68 percent and root growth and soil water content were significantly correlated. Midsummer water deficits are common in the southern pine region (Allen and others 1990, Dougherty 1996), and if severe enough, water deficits reduce root growth (Brissette and Chambers 1992, Sword 1995). In our study, therefore, water availability after July may have been a regulator of the duration of peak root growth.

We observed more root elongation and initiation on plots maintained at a lower stand density. A similar root growth response was observed at the same site in 1993 (Sword and others, in press). In 1993, light availability in the lower canopy was greater at the lower stand density (Gravatt 1994, Sword and others, in press). Root metabolism depends on glucose derived from either starch stored in root parenchyma or current photosynthate translocated to the root system (Dickson 1991). Thus, we conclude that thinning increased light in the canopy which increased the availability of carbohydrates for root metabolism and, therefore, root growth.

Root elongation on the thinned plots continued to be stimulated after reapplication of the thinning treatment. The positive effect of reduced stand density on root initiation was discontinued, however, by the second thinning. This suggests that the proliferation, but not the elongation of new roots in a forest stand is affected by the number of trees remaining after thinning. Auxin produced in branch apical meristems and translocated to the root pericycle regulates new root initiation (Charlton 1996, Coutts 1987). In our study, tree removal reduced the number of branch apical meristems on the site and, therefore, may have reduced the translocation of auxin to the root pericycle and hindered new root initiation.

In 1993, fertilization did not affect root initiation and only stimulated root elongation on plots that were thinned five growing seasons earlier (Sword and others, in press). By the end of 1994, fertilization had no effect on either root initiation or elongation. Fertilization increases carbon fixation and growth by enlarging leaf area (Teskey and others 1994, Vose and Allen 1988). However in 1994, Yu (1996) observed that 6 years after application, fertilization had no effect on leaf area per tree at this study site. One year earlier, Gravatt (1994) found that foliar concentrations of N on the fertilized and nonfertilized plots averaged 11.0 and 13.0 grams (g) per ha; P averaged 0.90 and 0.58 g per ha. These concentrations approach the boundary between mineral nutrient deficiency and sufficiency for loblolly pine (Allen 1987). We hypothesize that the benefits of N and P fertilization on new root growth subsided after six growing seasons because N and P amendments were either depleted or unavailable. Thus, the leaf area per tree and, therefore, the amount of photosynthate translocated to the root system, was no longer increased by fertilization.

Similar to our observations in 1994, we did not observe a strong positive root growth response to reapplication of fertilizer in early 1995. Starch metabolized in spring originates from photosynthate produced in fall and winter of the previous year (Dickson 1989, Gholz and Cropper 1991). As starch is depleted in roots, current photosynthate sustains root growth (Dickson 1989). Because the fascicle density of first-flush internodes is determined during terminal bud development in the previous year (Stenberg and others 1994), and first-flush fascicle expansion is dependent on starch previously stored in branch parenchyma and current photosynthate (Dickson 1989), the availability of carbohydrates for root metabolism in 1995 had been determined before refertilization. Therefore, a strong root growth response to fertilization in 1995 was not expected. At this study site, Haywood (1994) also found that the tree growth response to the initial fertilization was delayed 1 year.

We observed one root growth response that was inconsistent with our conclusion that root growth was not immediately affected by fertilization. Specifically, fertilization significantly increased root initiation during June through July 1995 by 38 percent. Others have documented an increase in lateral root branching in response to localized areas of high soil fertility (Eissenstat and Van Rees 1994, Mou and others 1995, Pregitzer and others 1993). The isolated increase in new root initiation we observed in response to N, P, and K application may have been caused by a pulse of mineral nutrient availability after fertilization.

A strong positive relationship exists between leaf area and productivity of loblolly pine stands (Stenberg and others 1994, Vose and Allen 1988). In 1995, we found that root elongation during peak root growth was positively related to current annual tree volume increment. We cannot specify whether volume gains were caused by greater root growth, or whether both tree volume and root growth were stimulated by foliage production and carbon fixation. However, the tree volume and root growth responses of the

four treatment combinations in our study intimate that this relationship is regulated, in part, by soil fertility and light availability in the lower crown. We hypothesize that on resource-limited Gulf Coastal Plain sites, positive stand growth responses to fertilization are a result of increased leaf area and carbon fixation together with greater root growth and soil resource uptake. However, these responses to fertilization require a canopy environment and structure conducive to increased carbon fixation.

LITERATURE CITED

- Allen, H.L.** 1987. Forest fertilizers: nutrient amendment, stand productivity, and environmental impact. *Journal of Forestry*. 85: 37-46.
- Allen, H.L.; Dougherty, P.M.; Campbell, R.G.** 1990. Manipulation of water and nutrients—practice and opportunity in Southern U.S. pine forests. *Forest Ecology and Management*. 30: 437-453.
- Baldwin V.C.; Fedducia, D.P.** 1987. Loblolly pine growth and yield prediction for managed West Gulf plantations. Gen. Tech. Rep. SO-236. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.
- Bassett, J.R.** 1964. Tree growth as affected by soil moisture availability. *Soil Science Society of America Proceedings*. 28: 436-438.
- Brissette, J.C.; Chambers, J.L.** 1992. Leaf water status and root system water flux of shortleaf pine (*Pinus echinata* Mill.) seedlings in relation to new root growth after transplanting. *Tree Physiology*. 11: 289-303.
- Charlton, W.A.** 1996. Lateral root initiation. In: Wiasel, Y.; Eshel, A.; Kafkafi, U., eds. *Plant roots, the hidden half*. New York: Marcel Dekker, Inc.: 149-173.
- Coutts, M.P.** 1987. Developmental processes in tree root systems. *Canadian Journal of Forest Research*. 17: 761-767.
- Cregg, B.M.; Dougherty, P.M.; Hennessey, T.C.** 1988. Growth and wood quality of young loblolly pine trees in relation to stand density and climate factors. *Canadian Journal of Forest Research*. 18: 851-858.
- Dean, T.J.; Baldwin, V.C., Jr.** 1993. Using a density-management diagram to develop thinning schedules for loblolly pine plantations. Res. Pap. SO-275. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 7 p.
- Dickson, R.E.** 1989. Carbon and nitrogen allocation in trees. In: Dreyer, E.; Aussenac, G.; Bonnett-Masimbert, M. [and others], eds. *Forest tree physiology*. Paris: Elsevier/INRA: 631s-647s. *Annales des Sciences Forestieres*. 46 supplement.
- Dickson, R.E.** 1991. Assimilate distribution and storage. In: Raghavendra, A.S., ed. *Physiology of trees*. New York: John Wiley & Sons: 51-85.
- Dougherty, P.M.** 1996. Response of loblolly pine to moisture and nutrient stress. In: Fox, S.; Mickler, R., eds. *Impact of air pollutants on southern forests*. New York: Springer Verlag, Inc.: 173-195. Series: *Ecological studies: analysis and synthesis* 118.
- Eissenstat, D.M.; Van Rees, K.C.J.** 1994. The growth and function of pine roots. *Ecological Bulletin*. 43: 76-91.
- Fisher, R.F.; Garbett, W.S.** 1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. *Soil Science Society of America Journal*. 44: 850-854.
- Gholz, H.L.; Cropper, W.P., Jr.** 1991. Carbohydrate dynamics in mature *Pinus elliotii* var. *elliotii* trees. *Canadian Journal of Forest Research*. 21: 1742-1747.
- Gravatt, D.A.** 1994. Physiological variation in loblolly pine (*Pinus taeda* L.) as related to crown position and stand density. Baton Rouge, LA: Louisiana State University. 199 p. Ph.D. dissertation.
- Haynes B.E.; Gower, S.T.** 1995. Belowground carbon allocation in unfertilized and fertilized red pine plantations in northern Wisconsin. *Tree Physiology*. 15: 317-325.
- Haywood, J.D.** 1994. Seasonal and cumulative loblolly pine development under two stand density and fertility levels through four growing seasons. Res. Pap. SO-283. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.
- Kerr, A., Jr.; Griffis, B.J.; Powell, J.W. [and others].** 1980. Soil survey of Rapides Parish, Louisiana. U.S. Department of Agriculture, Soil Conservation Service and Forest Service. 86 p. In cooperation with: Louisiana State University, Louisiana Agricultural Experiment Station.
- Keyes M.R.; Grier, C.C.** 1981. Above- and below-ground net production in 40-year-old Douglas-fir stands on low and high productivity sites. *Canadian Journal of Forest Research*. 11: 599-605.
- Klepper, B.** 1987. Origin, branching and distribution of root systems. In: *Root development and function*. Cambridge: Cambridge University Press: 103-124. Society of Experimental Biology Seminar Series 30.
- Knight, D.H.; Vose, J.M.; Baldwin, V.C., Jr. [and others].** 1994. Contrasting patterns in pine forest ecosystems. *Ecological Bulletin*. 43: 9-19.
- McMichael, B.L.; Burke, J.J.** 1996. Temperature effects on root growth. In: Wiasel, Y.; Eshel, A.; Kafkafi, U., eds. *Plant roots, the hidden half*. New York: Marcel Dekker, Inc.: 1383-1396.
- Moehring, D.M.; Ralston, C.W.** 1967. Diameter growth of loblolly pine related to available soil moisture and rate of soil moisture loss. *Soil Science Society of America Proceedings*. 31: 560-562.
- Mou, P.; Jones, R.H.; Mitchell, R.J.; Zutter, B.** 1995. Spatial distribution of roots in sweetgum and loblolly pine monocultures and relations with above-ground biomass and soil nutrients. *Functional Ecology*. 9: 689-699.
- Pregitzer, K.S.; Hendrick, R.L.; Fogel, R.** 1993. The demography of fine roots in response to patches of water and nitrogen. *New Phytologist*. 125: 575-580.
- SAS Institute Inc.** 1991. *SAS/STAT User's Guide*, Release 6.03. Cary, NC: SAS Institute. 1028 p.
- Shoulders, E.; Tiarks, A.E.** 1983. A continuous function design for fertilizer rate trials in young pine plantations.

In: Jones, E.P., Jr., ed. Proceedings of the second biennial southern silvicultural research conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 352-356.

Stenberg, P.; Kuuluvainen, T.; Kellomäki, S. [and others]. 1994. Crown structure, light interception and productivity of pine trees and stands. *Ecological Bulletin*. 43: 20-34.

Sword, M.A. 1995. Root-zone temperature and water availability affect early root growth of planted longleaf pine. In: Edwards, M.B., Jr., ed. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 343-353.

Sword, M.A.; Chambers, J.C.; Gravatt, D.A.; Haywood, J.D. [in press]. Ecophysiological responses of managed loblolly pine to changes in stand environment. In: Mickler, R.A., ed. The productivity and sustainability of

southern forest ecosystems in a changing environment. New York: Springer Verlag, Inc.

Sword, M.A.; Gravatt, D.A.; Faulkner, P.L.; Chambers, J.L. 1996. Seasonal root and branch growth of 13-year-old loblolly pine five years after fertilization. *Tree Physiology*. 16: 899-904.

Teskey, R.O.; Gholz, H.L.; Cropper, W.P., Jr. 1994. Influence of climate and fertilization on net photosynthesis of mature slash pine. *Tree Physiology*. 14: 1215-1227.

Tiarks, A.E. 1982. Phosphorus sorption curves for evaluating phosphorus requirements of loblolly pine (*Pinus taeda*). *Communications in Soil Science and Plant Analysis*. 13: 619-631.

Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. *Forest Science*. 34: 547-563.

Yu, S. 1996. Foliage and crown characteristics of loblolly pine (*Pinus taeda* L.) six years after thinning and fertilization. Baton Rouge, LA: Louisiana State University. 77 p. M.S. thesis.

REGULATING STAND DENSITY BY PRECOMMERCIAL THINNING IN NATURALLY REGENERATED LOBLOLLY PINE STANDS: EVALUATION OF MANAGEMENT AND ECONOMIC OPPORTUNITIES

David J. Moorhead, Coleman W. Dangerfield, Jr., and M. Boyd Edwards¹

Abstract—The economic performance of converting 13-year-old, overstocked (> 3,000 trees per acre), naturally regenerated pine stands using precommercial thinning at a cost of \$140 per acre was modeled for 25-, 35-, and 50-year rotations. The stand density was reduced to 283 trees per acre. Subsequent management scenarios recovered establishment and management costs through final harvest and in combination with periodic commercial thinnings. Indexes of financial performance were 12.3, 17.1, and 15.6 percent Internal Rate of Return; \$11.13, \$36.25, and \$ 45.65 per acre Annual Equivalent Value; and \$139.16, \$453.12, and \$570.66 per acre in Soil Expectation Value for 25, 35 and 50 year rotations, respectively.

INTRODUCTION

Natural regeneration of loblolly pine (*Pinus taeda L.*) is a common practice, both planned and unplanned, across the South. Landowners may harvest pine from their lands with the goal of allowing natural regeneration to establish the new stand. Typically a seed tree or shelterwood method is employed, leaving mature seed producing pines on each acre after harvest to provide seed for the new crop. Other options include seed, or seedlings in place, or seed from adjacent stands as a natural regeneration source (Edwards 1987b).

While natural regeneration methods can provide a low-cost and effective means to establish new stands, overstocking is common when favorable weather and seedbed conditions occur. Mechanical strip thinning is a recommended practice usually by age 3 to 5. Costs associated with precommercial thinning increase as stands age.

METHODS

Data from a precommercially thinned (PCT) natural regeneration study site on the USDA Forest Service, Hitchiti Experimental Forest, in the Piedmont of Georgia was used to project expected, potential woodflow and financial performance for 25-, 35-, and 50-year rotations.

The stands were established using (1) clearcut method with seed in place, (2) seed tree method, and (3) shelterwood method in 1983 (Edwards 1987b). Following harvest, all hardwood stems 1 inch in diameter at breast height (d.b.h.) and larger were treated by injection with Tordon 101. In the summer of 1996, the stand was precommercially thinned by hand crews using chainsaws to an approximate 12 by 12 foot spacing (302 trees per acre). Following the PCT, measurements of crop tree d.b.h., height, and density were made.

The three management scenarios were modeled using YIELDplus 4.0 (Hepp 1994). Stand inputs from the PCT plots were used in a natural loblolly pine growth and yield simulator. Site index at age 50 was 90 feet (Edwards and Dangerfield 1990). The following financial parameters were set: a 28 percent marginal Federal tax bracket, 8.0 percent before-tax discount rate, \$22 per cord for pulpwood, \$58 per cord for chip and saw (CNS), and \$200 per thousand board feet Scribner for sawtimber. Stumpage prices were inflated at 3.5 percent for pulpwood and CNS, and 4.0 percent for sawtimber over the rotation.

Per-acre management costs included \$5 for site preparation burning, \$40 for herbicide treatment, and \$140 for the PCT. Beginning in 1997, per-acre charges for prescribed burns/fire breaks at 3-year intervals were accessed at \$8 for the initial burn, \$6 for the second burn, and \$5 for the subsequent burns. Total harvest expenses were computed at 12.5 percent of the harvest value, including 10 percent for marketing and 2.5 percent for ad valorem property taxes on timber harvested.

Three management scenarios were examined: a 25-year rotation without thinning, a 35-year rotation with thinning at age 28, and a 50-year rotation with thinning at ages 30 and 40. All thinning treatments were low thinnings to a residual basal area of 65 square feet per acre. Thinnings were set in order to maintain medium to low stand risk to southern pine beetle infestations, and volume removed had to meet a minimum 5 cords per acre to be considered commercially feasible.

RESULTS

Prior to the PCT at age 13, the stand averaged 5,086 stems per acre (3,050 to 8,910). Following the PCT, an average of 283 crop trees remained per acre with average height of 3.85 inches at d.b.h. and 23.24 feet in overall height. These data were used to manually set the initial stand parameters in the model.

¹ Associate Professor, Forest Regeneration, D.B. Warnell School of Forest Resources, The University of Georgia, P.O. Box 1209, Tifton, GA 31793; Associate Professor, Agricultural and Applied Economics, The University of Georgia, College of Agricultural and Environmental Sciences, Athens, GA 30602; and Research Ecologist, USDA Forest Service, Southern Forest Experiment Station, Athens, GA 30602 (respectively).

Initial stand conditions present at harvest, residual stand components (if applicable), and harvested stand components for each rotation scenario are presented in table 1. Financial performance (before tax, adjusted for inflation), indicated by the Internal Rate of Return (IRR), Annual Equivalent Value (AEV), and Soil Expectation Value (SEV), is detailed in table 2.

25-Year Rotation

A final harvest was projected for 13 years after the PCT (table 1). Stems averaged 62 feet tall. The stand had a basal area of 83 square feet on 210 merchantable stems per acre. Total volume per acre averaged 25.33 cords, with the chip-and-saw component contributing 5.29 cords per acre.

The investment earned a 12.3 percent IRR, with an AEV of \$11.13 per acre. The SEV was \$139.16 per acre (table 2).

35-Year Rotation

A commercial thinning was projected at age 28, 16 years after the PCT (table 1). At the first thinning at age 28, the trees averaged 67 feet in height with a basal area (BA) of 98. An average of 83 pulpwood stems per acre were harvested, yielding 10.34 cords per acre.

At final harvest at age 35, trees averaged 77 feet tall. The stand has a BA of 91 in 107 stems. A total of 32.90 cords was projected per acre. The product mix shifted to chip and saw (CNS) and sawtimber with 25.13 cords and 7.77 cords, respectively. The 35-year rotation produced a total of 43.24 cords per acre in the two harvests.

The IRR equaled 17.1 percent with an AEV of \$36.25 per acre, and a SEV of \$453.12 per acre (table 2).

50-Year Rotation

Two commercial thinnings were projected at ages 30 and 40, 18 and 28 years after the PCT, respectively (table 1). At the first thinning at age 30, the stand was projected to accumulate a BA of 106 on 190 stems averaging 70 feet in height. This thinning produced 13.61 total cords per acre with 9.75 cords of pulpwood, and 3.86 cords of CNS.

The stand was projected to accumulate a BA of 99 by the second thinning at age 40. This harvest removed 12.54 cords per acre. Pulpwood classes had been removed in the first thin and CNS totaled 3.33 cords, with sawtimber totaling 9.21 total cords per acre.

At final harvest at age 50, the stand had accumulated a 90 BA on 55 stems averaging 90 feet in height. This harvest produced 36.49 cords per acre of sawtimber. Overall, a total of 62.65 cords per acre was removed in the three harvests over a 50-year rotation.

The IRR was 15.6 percent. Annual Equivalent Value was projected at \$45.65 per acre with a \$570.66 per acre SEV (table 2).

DISCUSSION

Many landowners may be hesitant to invest \$140 per acre in a 13-year old natural pine stand. However, the financial performance expected following a relatively high investment were promising. Internal rates of return ranging from 12.3

Table 1—Projected per acre stand parameters and woodflow of naturally regenerated loblolly pine at 25-, 35-, and 50-rotations

Rotation length	Stand condition			Residual component			Harvested component		
	Age	Height	PAI ^a	Basal area	Stems	Total cords	Basal area	Stems	Total cords
25 years	25	62	1.0	—	—	—	83	210	25.33
Final harvest totals per acre							83	210	25.33
35 years	28	67	1.1	65	114	21.30	33	83	10.34
	35	77	1.7	—	—	—	91	107	32.90
Final harvest totals per acre							124	190	43.24
50 years	30	70	1.2	65	99	22.28	41	91	13.61
	40	82	1.5	65	55	24.79	34	38	12.54
	50	90	1.2	—	—	—	90	55	36.49
Final harvest totals per acre							165	184	62.65

^aPAI = Periodic annual increment in cords per acre.

Table 2—Projected financial performance of naturally regenerated loblolly pine at 25-, 30-, and 50-year rotations

Rotation	Internal Rate of Return	Annual Equivalent Value	Soil Expectation Value
	<i>Percent</i>	<i>-----Dollars per acre-----</i>	
25 year	12.3	11.13	139.16
35 year	17.1	36.25	453.12
50 year	15.6	45.65	570.66

to 17.1 percent present attractive investment opportunities. Even with extending the rotation length, income from the periodic thinnings offset the carrying costs of the investment. Over time, SEV increased as the thinnings and final harvests produced greater proportions of more valuable CNS and sawtimber stumpage.

Stands that are densely stocked are expected to stagnate and/or produce only marginal yields (Mann and Lowery 1974). Precommercial thinning is generally recommended at young ages (by age 3) when mechanical equipment can be effectively used to strip-thin at relatively low costs per acre (>\$45). Despite the high cost of the PCT, it could be treated as a capital expense in the year of treatment as opposed to a site preparation or reforestation cost.

A PCT is done on an operator select basis, with high-quality crop trees to be favored. Selection criteria should include: preferred species, superior bole form (straightness, single stem, branch angle), absence of bole cankers and other stem damage, and selection of trees with dominant terminals and live crown ratios of > 40 percent. Selection of high-quality crop trees for chain and saw and sawtimber production can justify higher PCT expenses.

LITERATURE CITED

- Edwards, M.B.** 1987a. A comparison of natural regeneration alternatives for a loblolly pine forest in the lower Piedmont of Georgia. In: D.R. Phillips, comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 84-86.
- Edwards, M.B.** 1987b. A loblolly pine management guide: natural regeneration of loblolly pine. Gen. Tech. Rep. SE-47. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 17 p.
- Edwards, M.B.; Dangerfield, C.W., Jr.** 1990. Reliable, low-cost alternatives for pine regeneration in the South. Res. Pap. SE-280. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.
- Hepp, T.E.** 1994. YIELDplus 4.0 timber forecasting and planning tool. Norris, TN: Tennessee Valley Authority. 120 p.
- Mann, W.F., Jr.; Lohery, R.E.** 1974. Precommercial thinning of southern pines. *Journal of Forestry*. 72: 557-560.

MECHANIZED PRECOMMERCIAL STRIP THINNING OF LOBLOLLY PINE IN NORTH CAROLINA

Carlyle Franklin and Tom Lloyd¹

Abstract—Precommercial strip thinning has often been recommended as an economically sound silvicultural practice in natural pine stands. This study demonstrated that this can be true under certain circumstances related to species response to high density, cost of applying the practice, product goals, and prices. Extensive precommercial strip-thinning trials with a specially adapted drum chopper were done in the Coastal Plain and Piedmont of North Carolina in stands 4 to 7 years old. Subsequent measurements were made in treated and control stands at ages 12 to 25 years. Growth and yield projections through one rotation at site indexes of 65, 75, 85, and 95 (base age 50), with and without precommercial thinning, with and without subsequent commercial thinning, and with product merchandizing, obtained the following results. Precommercial thinning could not be economically justified until stand stocking exceeded 5,500 to 6,500 trees per acre, and then only with an aggressive commercial thinning program. In addition, precommercial thinning had to reduce the residual stocking to not more than 2,000 trees per acre by age 10 to obtain maximum internal rates of return. Maximum gains in internal rates of return increased slightly as site index increased from 65 to 95. Maximum gains from precommercial thinning ranged from 3.6 to 4.1 points with aggressive commercial thinning.

INTRODUCTION

Stocking control is one of the most important activities in the silviculture of loblolly pine (*Pinus taeda* L.), especially in natural stands which are often overstocked early in the rotation. Studies of mechanical, precommercial strip thinning in many conifers dates back at least to the late 1940's (Ryans 1988). Interest in this subject continues to be strong (Filip and Goheen 1995, Morris and others 1994). The rolling drum chopper pulled by a rubber-tired skidder has proven to be cost effective in some instances, especially if gathering bars are attached to the yoke to pull in saplings which would otherwise be pushed aside and scarred.² Jennette also suggested that thinning was best accomplished between ages 4 and 6 when the operator could see over the tops of the saplings. Based on measurements of many strip-thinned and control stands in the North Carolina Coastal Plain and Piedmont, we decided to do some silvicultural and economic simulations of precommercial strip-thinning with a drum chopper to develop guidelines for application of the practice. We felt that this was needed because results in the literature suggested that measurements at or before first commercial thinning were often inconclusive (Cain 1993), but later in the rotation precommercial thinning proved to be economically justified (Cain 1995).

METHODS

Growth and Yield Model

For the growth and yield simulations we used "NAT-YIELD," a stand-based simulator developed by Smith and Hafley³ at North Carolina State University with a grant from the USDA Forest Service, Southern Research Station. This simulator, when run with pine only, yields volumes based on

Schumacher and Coile (1960) for natural stands of southern pines. The developers warned that simulations initiated prior to age 20 years might not be reliable, but experience has shown that reliable results can be obtained down to age 10. Therefore, we began our simulations at age 10.

Simulations were run at site indexes (base age 50) of 65, 75, 85, and 95 feet, with and without commercial thinning. Corresponding residual stockings after each successive thinning were 60, 65, 70, and 75 square feet per acre (ft²/a) respectively, except at the last thinning when residual stocking was 40 (ft²/a) of basal area to set up a shelterwood regeneration for a rotation ending at age 35 years (table 1). Stockings used at age 10 to begin the simulations were 1, 2, 3.5, 5, 7.5, and 10 thousand trees per acre. This implies that residual stocking at ages 4 to 6 years, immediately following strip thinning, was sufficiently higher so that attrition by age 10 yielded the initial stocking used in the simulation. In the case of no strip thinning, it meant that naturally occurring stocking was the stocking specified at age 10.

In measuring many roller chopper, strip-thinned stands, we never found one that had as low as 2,000 tpa at age 10. We found several that substantially exceeded 10,000 tpa without strip-thinning.

Criteria for thinning were (1) a minimum of 500 cubic feet of wood to be removed, and (2) a minimum quadratic stand mean diameter of 6 inches. These seemed to be realistic in terms of the minimum logging chance to attract a logger to a reasonably sized tract. Number of commercial thinnings varied by scenario, decreasing as site index decreased and stocking increased. In fact, some scenarios eligible for thinning, never reached minimums to be thinned out to 35 years.

¹ Professor, Department of Forestry, North Carolina State University, Raleigh, NC, 27695; Research Forester, USDA Forest Service, Southern Research Station, Bent Creek, NC 28806 (respectively).

² Personal communication. 1986. David L. Jennette, Sr. [deceased] Consultant, Timberlands Unlimited, P.O. Box 650, Windsor, NC 27983

³ Hafley, W.L.; Smith, W.D. Unpublished material. U.S. Department of Agriculture, Forest Service, P.O. Box 12254, Research Triangle Park, NC 27709.

Table 1—Silvicultural parameters used for simulations with “Natyield”

Stocking at age 10 (trees/acre)	1,000	2,000	3,500	5,000	7,500	10,000
Residual basal area by site index (ft ²)	RBA	60	65	70	75	
Residual basal area at age 30	SI	65	75	85	95	
Top-wood added for sawtimber only	.75 cords per thousand board feet					
Final harvest	35 years					

Economic Analyses

Economic analyses were done using Quick Silver (Vasievich and others 1984). A nominal annual overhead cost of \$5 per acre per year was used. The cost used for roller drum chopping was \$45 per acre (Dubois and others 1997). Prices used for timber products were the 1996 Southeastern States averages reported by Timber Mart-South (Anon 1996): pulpwood >\$23.73 per cord; chip-n-saw >\$59.73 per cord; saw timber >\$237 per thousand board feet (Scribner) (table 2). Each yield simulation scenario was run with and without the cost of precommercial thinning.

Graphical Analysis

Results were tallied as a single internal rate of return (IRR) for each scenario. These were plotted over trees per acre, strip-thinned versus not strip-thinned within a site index, with or without commercial thinning. Graphical analysis was done as follows (fig. 1A). A horizontal line at the level of highest IRR (19.1) for the “strip-thinned” scenario was drawn from the right margin to its intersection with the line representing the “not strip-thinned” scenario. A vertical line was then extended to intersect the x-axis at the minimum number of trees per acre (6,400) at age 10 necessary to

Table 2—Activity costs and timber prices for simulations with “Quick Silver”

Cost for strip thinning	\$45/acre	
Nominal management cost	\$5/acre/year	
Pulpwood ^a	Chip-n-saw ^a	Sawtimber ^a
\$23.73/cd	\$59.73/cd	\$237/mbf (Scribner)

^a Timber Mart-South[®] 1996 S.E. State’s average.

Table 3—Minimum number of trees per acre at age 10 for strip-thinning to pay

Site index base -50	With commercial thinning ^a	Maximum gain in IRR ^b
65	5600	5.2
75	5800	5.4
85	6000	5.5
95	6400	5.5

^a No gains were found without subsequent commercial thinning.

^b For 10,000 trees/acre without strip thinning versus 2,000 trees/acre with mechanical strip thinning.

yield a net positive payoff with strip thinning. The maximum possible gain in these scenarios was obtained by subtracting the IRR without strip thinning at 10,000 trees per acre (tpa) (13.6) from the highest IRR with strip thinning (19.1) (usually at 2,000 tpa) (fig. 1A).

RESULTS AND DISCUSSION

Substantial gains in IRR were found for strip-thinned over non- strip-thinned scenarios with subsequent commercial thinning (table 3) (fig. 1A-D). Without commercial thinning, the highest IRR between 2,000 and 10,000 tpa never exceeded the lowest IRR without strip thinning, so the conclusion was that without subsequent commercial thinning, mechanical, precommercial strip thinning could not be economically justified (fig. 2A-D).

Systematic sensitivity trials were not run, but limited observations indicated that as the price of pulpwood increased relative to the price of saw timber, strip thinning was less favorable economically. Conversely, as the price of saw timber increased relative to the price of pulpwood, strip thinning was justified even without subsequent commercial thinning, but the threshold minimum number of trees per acre was higher than when subsequent commercial thinning was done. Thus, simulation scenarios of this sort must be done for local growth, yield, and product price combinations to have local applicability.

Another interesting observation was the sharply rising IRR’s for scenarios without commercial thinning as 10th-year stockings decreased from 2,000 to 1,000 tpa. As stated above, our observations indicated that 10th-year stockings lower than 2000 tpa have rarely been achieved with precommercial thinning by drum chopping. Stockings as low as 500 tpa could be achieved with a combination of drum chopping and subsequent hand thinning, as shown by Dangerfield and others (1997) in these proceedings. Our results suggest, and those of others confirm, that a combination of precommercial thinning treatments may hold promise under certain circumstances. This is an area for further research.

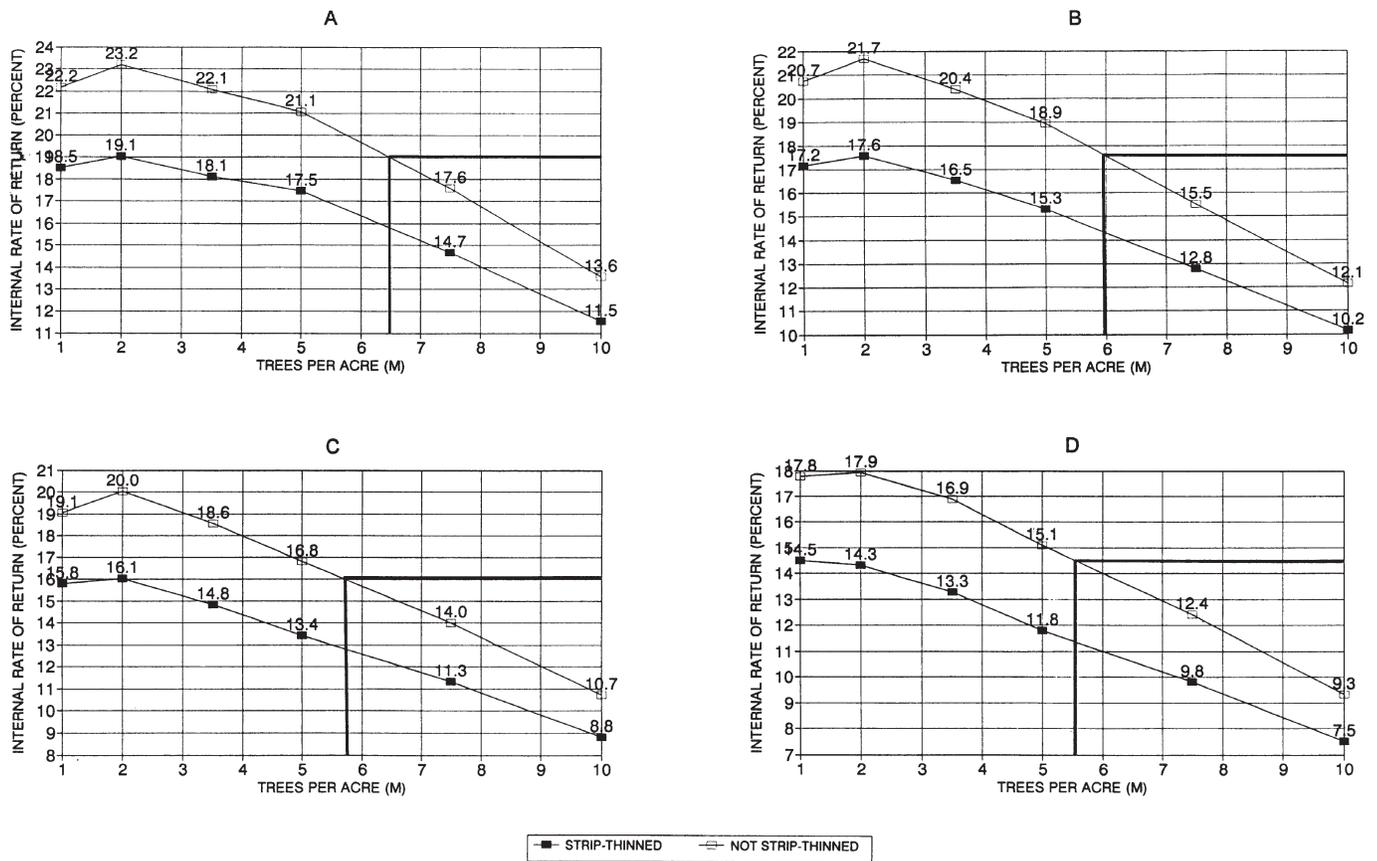


Figure 1—Internal rates of return for natural loblolly pine stands precommercially strip-thinned versus not strip-thinned, at site indexes of 95 (A), 85 (B), 75 (C), 65 (D) (base age 50), with subsequent commercial thinning, arrayed over a range of 10th-year stocking levels from 1,000 to 10,000 trees per acre. The dark horizontal line intersects the “not strip-thinned” line at the maximum IRR with strip thinning. The dark vertical line then intersects the x-axis at the corresponding minimum number of trees per acre to economically justify strip thinning.

Clearly, there are other benefits from precommercial thinning than just the economics of timber production. As other resource values such as wildlife, recreation, and esthetics become more highly valued in approaches to natural resource management, precommercial thinning of stands offers multiple benefits:

- Enhances wildlife habitat by bringing browse and insects back to ground level, allowing more light to reach the forest floor, and increasing internal stand diversity.
- Allows earlier use of prescribed fire in conifer rotations by reducing fuels and providing stand structure conducive to efficient dissipation of heat.
- Increases recreation potential of stands by providing earlier visual and user access, and by creating a more esthetically pleasing forest environment.

Valuation of these benefits may be more difficult than valuation of timber benefits, but such values are nonetheless quite real, and deserve the attention of the natural resource manager.

CONCLUSIONS

Using Southeastern U.S. average timber prices, mechanical precommercial strip thinning of natural loblolly pine stands

was economically justified when stocking in the 10th year exceeded about 6,000 tpa, and an aggressive commercial thinning regime was followed. Without commercial thinning, precommercial thinning could not be economically justified. The model is price sensitive and should be applied to local growth, yield, and market conditions before it is applied as a silvicultural decision criterion.

ACKNOWLEDGMENT

Two people played essential roles in this research. David L. Jennette, Sr., now deceased, did hundreds of acres of precommercial thinning in eastern North Carolina in the late sixties and early seventies. We were able to measure those stands as they approached time of first thinning. His knowledge of those stands and of precommercial thinning with a drum chopper was extremely helpful. Our program technician, Gene Nocerino, did yeoman's work in single-handedly inventorying hundreds of acres of strip thinned and untreated stands in the Coastal Plain and Piedmont, under difficult conditions. His dedication is gratefully acknowledged. Thanks are also due to Dr. Tom Lloyd and the USDA FS, Southern Research Station, for providing initial funding to get this project started.

LITERATURE CITED

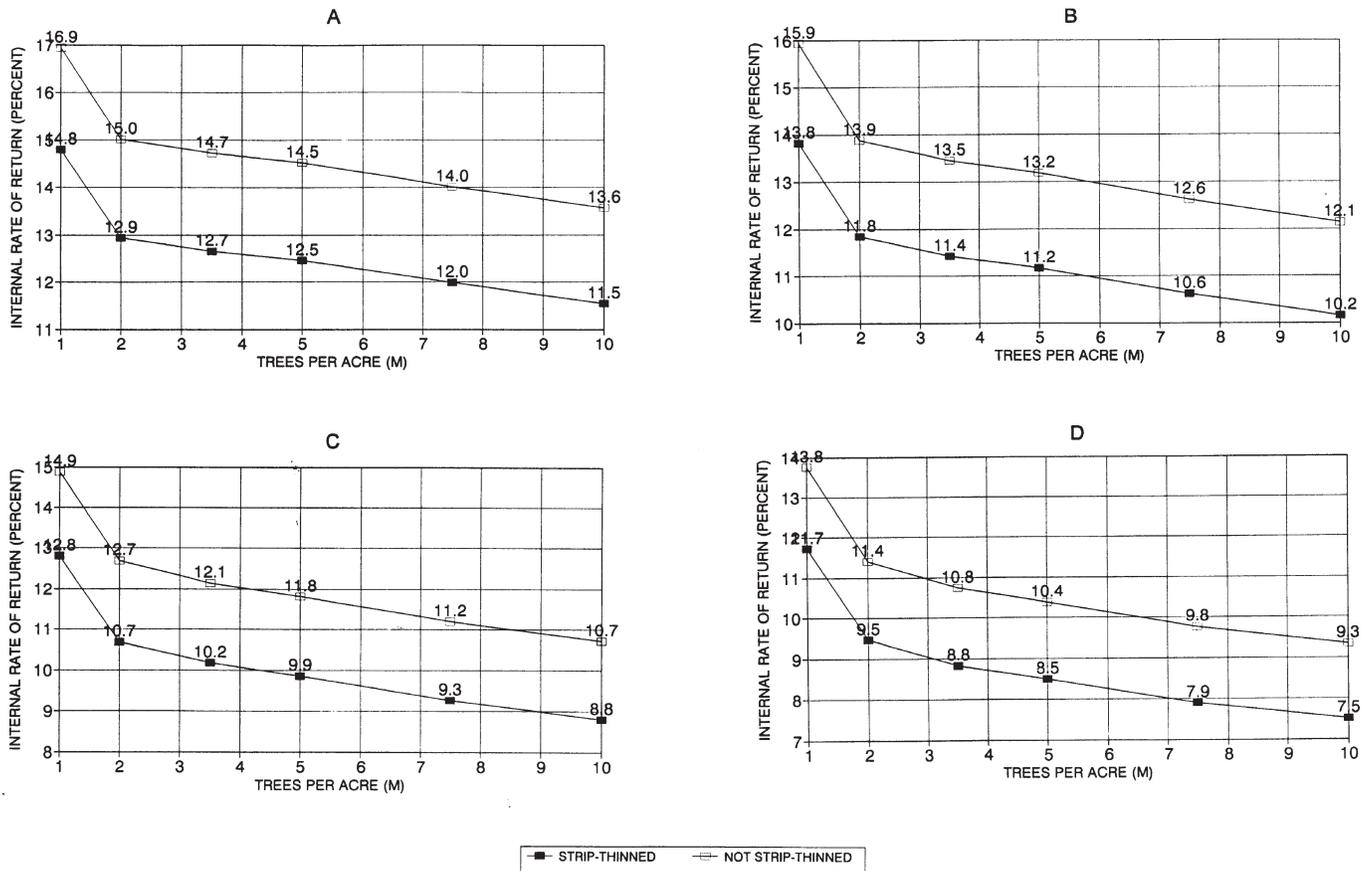


Figure 2—Internal rates of return for natural loblolly pine stands precommercially strip-thinned versus not strip-thinned, at site indexes of 95 (A), 85 (B), 75 (C), 65 (D) (base age 50), without subsequent commercial thinning, arrayed over a range of 10th-year stocking levels from 1,000 to 10,000 trees per acre.

Anonymous. 1996. Timber Mart-South®. Vol. 21. 4th quarter.

Cain, Michael D. 1993. Ten-year results from precommercial strip-thinning: paradigm lost or reinforced? Southern Journal of Applied Forestry. 17(1): 16-21.

Cain, Michael D. 1995. Growth expectations from alternative thinning regimes and prescribed burning in naturally regenerated loblolly- shortleaf pine stands through age 20. Forest Ecology and Management. 81(1996): 227-241.

Dangerfield, Coleman W.; Moorhead, Darryll J.; Edwards, M. Boyd. [In press]. Regulating stand density by pre-commercial thinning in naturally regenerated loblolly pine: evaluation of management and economic opportunities. [These Proceedings].

Dubois, Mark R.; McNabb, Kenneth; Straka, Thomas J. 1997. Costs and cost trends for forestry practices in the south. Forest Farmer. 56(1): March/April 1997.

Filip, Gregory M.; Goheen, Donald J. 1995. Precommercial thinning in *Pseudotsuga*, *Tsuga*, and *Abies* stands affected by armillaria root disease: 10-year results. Canadian Journal of Forest Research. 25: 817-823.

Morris, Douglas M.; Bowling, Colin; Hills, Steven C. 1994. Growth and form responses to pre-commercial thinning regimes in aerially seeded jack pine stands: 5th year results. The Forestry Chronicle. 70 (6): November/December 1994: 780-787.

Ryans, Mark. 1988. Mechanized precommercial thinning methods: experience to date. SR-56. Forest Engineering Research Institute of Canada. 17 p.

Schumacher, Francis X.; Coile, Theodore S. 1960. Growth and yields of natural stands of the southern pines. Durham, NC: T.S. Coile, Inc. 115 p.

Vasievich, J. Michael; Frebis, Ron; Wieth, R.W. 1984. Quick Silver - Forestry investment analysis program. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. Version 2.0PC.

STUDYING THE EFFECTS OF HARDWOOD STAND MODIFICATION, PERIODIC FLOODING, AND FIRE ON INSECT AND DISEASE COMMUNITIES IN THE LOWER MISSISSIPPI RIVER ECOSYSTEM

T. Evan Nebeker, Theodor D. Leininger, and James S. Meadows¹

Abstract—The relationship between stand modification and pest organisms (insects and diseases) has been noted in general with few specific studies to evaluate this relationship in the southern hardwoods. As a prerequisite to making the best improvement cut prescription, it is essential to have a perspective on thinning impacts that at present can only be gathered from scattered information. The goal of this study is to better understand the impacts of stand modifications on insect and disease populations. A study of practices in southern pines conducted in 1985 by Nebeker and others will serve as a template. We will examine the relationship of pest organisms to stand modifications such as improvement cuts, clear cutting, periodic flooding (e.g., green tree reservoirs) and burning. To our knowledge, this will be the first such study in southern hardwood stands aimed at understanding this relationship.

Our objectives are threefold. We propose to bring together the literature that reports positive and negative impacts of stand modifications in relation to insects and diseases of hardwoods emphasizing the southern hardwood system. We also propose to follow stand modification procedures in order to document changes in insect and disease populations that lead to degrade or mortality of hardwoods. The organisms of interest primarily include insect borers and various wood decays. The study will be conducted in the Delta National Forest near Rolling Fork, MS, where we will survey pest populations before and after an improvement cutting in a bottomland hardwood stand. In addition, pest population surveys will be conducted in stands thinned within the past 5 years on timber company land in Alabama. The envisioned product will be a document containing pest management recommendations for stand modification practices in southern hardwoods. This will be a great asset in summarizing our understanding of pest population responses to management entries into the southern hardwood ecosystem. It should serve as a benchmark for future studies as well.

INTRODUCTION

There are increasing interests in hardwood forests of the Southern United States. These interests are diverse and far-ranging. There are interests in conservation, wetland preservation, ecosystem preservation, ecosystem management, forest health, and restoration, to mention a few. There is also considerable interest in the sustainable productivity of these forests for fuel, fiber, lumber products, and chemicals. As a result of these latter interests, and in connection with broader ecological interests, the impact from harvesting, periodic flooding (including green tree reservoirs), and fire are of concern.

In a report presented by the National Research Council Committee on Forestry Research (1990), focus was given to research needs in forestry, including a mandate for change. One can generally assume that entry into the forest for improvement cuts—imposed disturbance—may result in various levels of damage. A similar assumption can be stated for periodic flooding and prescribed burning. Damage associated with these events may result in a reduction in long-term productivity. The impact (positive and negative) of insects and diseases as a result of entry into the forest for harvesting purposes is of critical interest. Similar interests also exist in relation to the practice of creating green tree reservoirs for recreational purposes such as hunting.

The forestry practice of thinning (improvement cuts) is of particular interest. While thinning is aimed primarily at improving the value of the residual stems and the stand as

a whole, there are other benefits currently gaining recognition, such as risk reduction for insect infestations, disease epidemics, and damage due to abiotic agents. Overstocked and overmature stands are generally more susceptible to insects and disease and thus warrant thinning. The mechanics by which thinning reduces these risks are not completely understood. Observations, however, indicate that thinning can cause positive and/or negative effects depending on how, where, when, and why the stand is thinned. The presence of more than one kind of hazard at any given time and place poses some problems in designing an optimum thinning strategy. Further complicating the situation are the species, stage of development, anticipated direct damages to residual stems, site quality, growth rate, and susceptibility to damaging agents, such as insects, disease, and windthrow.

The magnitude of logging damage is due to the following principal variables: (1) silvicultural (system) used, (2) type of equipment and configuration, (3) species, (4) spacing (density), (5) size class (age), (6) season of harvest (soil moisture conditions), and (7) operator carelessness. The type of damage encountered is generally limited to: (1) limb breakage, (2) bole wounding (upper and lower bole), (3) root wounding, and (4) root breaking. Additional damage includes bending and breaking of whole trees (Nyland and Gabriel 1971). Complete uprooting of trees can also occur. Biltonen and others (1976) reported greater crown damage (but little bole damage) when thinning was done with mechanized equipment than without. Hesterberg (1957) found that 80 percent of broken branches 4 inches or

¹ Entomologist, Department of Entomology and Plant Pathology, Box 9775, Mississippi State University, Mississippi State, MS 39762- 9775; Principal Research Plant Pathologist, and Principal Silviculturist, USDA Forest Service, P.O. Box 227, Stoneville, MS 38776-0227 (respectively).

greater in diameter developed defects following thinning. Lavallee and Lortie (1968) claimed that broken branches 2.5 inches or larger in diameter almost always serve as infection courts in yellow birch after a stand disturbance such as thinning. Berry (1977), working with upland oaks, found that 39 percent of the trees studied had decay. Fire scars were the most important entry courts followed by mechanical wounds, top damage, branch stubs, and parent stumps. Shigo (1966) indicated that broken branches in northern hardwoods lead to wood discoloration and serve as infection courts to decay fungi. Tree species also vary in their susceptibility to thinning-related damages such as yellow birch being more susceptible than sugar maple (Benzie and others 1963). Information concerning the impact of insects in hardwood stands following stand modification procedures is much more limited.

The relationship between thinning and pest organisms has been noted in general with few specific studies to evaluate these relationships. This is especially true for insects. As a prerequisite to making the best thinning prescription, it is essential to have a perspective on thinning impacts which at present can be gathered only from scattered information. A study by Nebeker and others (1985) will serve as a template (general protocol and expected output—publication(s)) for this study.

In the proposed study we will address the influence of stand modification on insect and disease populations associated with bottomland hardwood forests of the South. The stand modification procedures of interest are thinning (improvement cuts), clear cutting, periodic flooding (including green tree reservoirs), and prescribed burning.

The objectives of the study are to:

- (1) bring together the literature that reports positive and negative impacts of stand modifications in relation to insects and diseases of hardwoods, emphasizing the southern hardwood ecosystem;
- (2) follow stand modification procedures and disturbances in order to document changes in insect and disease incidence, primarily insect borers and wood decays, that lead to degrade or mortality of hardwoods; and
- (3) produce a document focusing on pest management recommendations associated with thinning guidelines for southern hardwoods.

Study Area

The primary study area is located on the Delta National Forest. Secondary study sites will be on industrial timberlands in Alabama that have already been thinned within the past 5 years. In addition, other areas being commercially thinned will be noted and surveyed. Preliminary information on the impact of regeneration cutting on insect and disease populations will be made on the Delta Experimental Forest near Stoneville, MS. Of special interest are the impacts (positive and negative) on insect and disease populations of prescribed burning and portions of stands left undisturbed for wildlife refuges within the regeneration area.

Methods

The literature review will consist of computer-assisted searches of data bases available through various libraries. A knowledge base will also be obtained by visiting with and surveying (see survey form) individuals and/or companies that have been involved with hardwood stand modifications.

The survey of the stand to be thinned, on the Delta National Forest, will be conducted during the spring of 1997 and will follow typical forest stand inventory methodology. Site and stand data (tree species, basal area, stand density, age, etc.), linked to fixed plots for determining current stand conditions and for monitoring growth over time, will be collected at each sample point. An assessment of insects and diseases will also be made at each sample point. Emphasis will be on the organisms that may potentially cause degrade or mortality. These primarily include insect borers and diseases of various kinds.

Following the stand modification process, surveys will be conducted to determine the extent of new insect and disease activity as a result of stand entry. These general surveys will be conducted within the year following the treatment and again the following year. Trees with limb breakage, upper and lower bole wounding, and root damage as a result of harvesting will be specifically identified. These trees will be numbered and monitored for signs and symptoms of insect and disease activity.

Analysis

Site and stand data, before and after thinning, will be compared graphically (as percentages) to reflect the changes in species composition, stand density, basal area, and size classes. The occurrence of insects and diseases will be compared in a similar manner and in percentage form. The nature of the data will also lend itself to being expressed in relation to various diversity indexes.

Significance

The relationship between thinning and pest organisms will be documented for southern hardwoods for the first time. A better understanding of the impacts of stand modification on insect and disease populations will be gained. The literature will be brought together that reports impacts of stand modifications in relation to insects and diseases of hardwoods. The results of this study will lead to a document we propose to entitle *Stand Modification Practices in Southern Hardwoods—With Pest Management Recommendations*.

Harvesting operations often cause widespread damage to the residual stand. Often more than 50 percent of the residual stems are damaged. In one survey, Meadows (1993) found logging wounds on 62 percent of the residual stems following a thinning operation in a river front hardwood stand in Mississippi. The most common types of damage include: (1) branches being broken in the residual canopy (2) upper and lower bole wounding and (3) exposure and breakage of roots. Such wounding serves as infection courts for disease organisms and attraction points for various insects that can lead to degrade and potential

mortality of the residual stems. In addition, disease propagules such as fungal spores, bacteria, and viruses may be introduced into trees through wounds created by insects, birds, or mammals. The subsequent reduced vigor of individual trees may also reduce the overall health of the residual stand, making it susceptible to further insect and disease attack.

Changes in stand structure as well as exposure to periodic flooding when water remains standing for various lengths of time can influence ecosystem functions. Food sources, especially nectar, for parasites of hardwood insect pests may be reduced as a result of these events. Insects, especially those that have one or more life stages in the ground or duff, may be affected. This is of concern if it is one of the natural enemies of an insect pest affecting the system. Having such information will further our understanding of this ecosystem and the changes in the system associated with stand intervention and periodic disturbances.

Managers of bottomland and upland hardwood stands typically remove trees with hollow bases, large disfiguring cankers, and/or many scars caused by wood-boring insects. They reason is that by removing these trees they are creating growing space for better quality residual trees, and are reducing the presence of insects and diseases in the stand. On the surface, these assumptions appear biologically sound. Our research is intended to provide the scientific basis for supporting and perhaps modifying these underlying assumptions that are already in practice. This will be a great asset in extending our understanding of entries into and disturbances of the southern hardwood ecosystem.

LITERATURE CITED

Benzie, J.W.; Hesterberg, G.A.; Ohman, J.H. 1963.

Pathological effects of logging damage four years after selective cutting in old-growth northern hardwoods. *Journal of Forestry*. 61(10): 786-792.

Berry, F.H. 1977. Decay in yellow-poplar, maple, black gum, and ash in the central hardwood region. Res. Pap. NE-242. U.S. Department of Agriculture, Forest Service. Northeast Forest Experiment Station. 4 p.

Biltonen, F.E.; Hillstrom, W.A.; Steinhilb, H.M.; Godman, R.M. 1976. Mechanized thinning of northern hardwood pole stands: methods and economics. Res. Pap. NC-137. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 17 p.

Hesterberg, G.A. 1957. Deterioration of sugar maple following logging damage. Pap. 51. U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station. 58 p.

Lavallee, A.; Lortie, M. 1968. Relationships between birch disease and thinning related damage. *Forestry Chronicle*. 44(2): 5-19.

Meadows, J.S. 1993. Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. In: Proceedings 9th central hardwood forest conference. Gen. Tech. Rep. NC-161. U.S. Department of Agriculture, Forest Service: 248-260.

National Research Council Committee on Forestry Research. 1990. *Forestry research: A mandate for change*. National Academy Press. 84 p.

Nebeker, T.E.; Hodges, J.D.; Karr, B.K.; Moehring, D.M. 1985. Thinning practices in southern pines - with pest management recommendations. Tech. Bull. 1703. U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station. 36 p.

Nyland, R.D.; Gabriel, W.J. 1971. Logging damage to partially cut hardwood stands in New York State. AFRI Res. Rep. 5. Syracuse University, College of Environmental Science and Forestry. 38 p.

Shigo, A.L. 1966. The pattern of decays and discolorations in northern hardwoods. *Phytopathology*. 55(6): 648-652.

SURVEY

We solicit the assistance of forest managers in providing information, published or unpublished, concerning increases or decreases in insect and/or disease activity associated with the general purpose of this study. We are extremely interested in actual observations concerning insects and/or diseases associated with partial cutting, improvement cutting, logging damage, periodic flooding, or fire in the southern bottomlands.

Name: _____

Address: _____

Phone: _____

Work: _____

FAX: _____

e-mail: _____

Observations: _____

We appreciate your assistance.

Please return to:
T. Evan Nebeker
Department of Entomology and Plant Pathology
Box 9775
Mississippi State University
Mississippi State, MS 39762
Phone: 601-325-2984
FAX: 601-325-8837
e-mail: enebeker@entomology.msstate.edu