EFFECTS OF PRECOMMERCIAL THINNING IN NATURALLY REGENERATED LOBLOLLY-SHORTLEAF PINE STANDS IN THE UPPER WEST GULF COASTAL PLAIN: RESULTS AFTER TWO GROWING SEASONS

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Abstract—The benefits of precommercial thinning in naturally regenerated stands of southern pines have been well documented, but questions remain about how long precommercial thinning can be delayed and still be biologically and economically effective. In 2004, a precommercial thinning demonstration study was installed in naturally regenerated loblolly-shortleaf pine (*Pinus taeda* and *P. echinata*, respectively) stands that were 8, 14, and 19 years old. Treatments consisted of three levels of precommercial thinning with an unthinned control. Precommercial thinning promoted the growth of individual pines; dominant trees in the lowest retained densities annually grew 0.05 to 0.07 square feet in basal area regardless of stand age. However, stand-level growth was greatest for moderate densities because more trees occupied the site, offsetting the lower rates of tree growth. Tree mortality increased with increasing density and was a major element of stand dynamics. These results from our study provide foresters and landowners with a first look at the implications of delayed precommercial thinning with respect to individual tree and stand growth.

INTRODUCTION

The value of precommercial thinning in naturally regenerated stands of southern pines has been well documented for the Upper West Gulf Coastal Plain. Precommercial thinning of natural stands of loblolly-shortleaf pines (*Pinus taeda* and *P. echinata*, respectively) at age 6 significantly increased volume growth by age 19 (Cain 1996) and sawtimber production at age 25 (Cain and Shelton 2003). These publications are based on an ongoing study established in 1980 on the Crossett Experimental Forest in southeastern AR, but that study has now aged to the point that it no longer has value as a demonstration of recent precommercial thinning treatments. In addition, there are other questions appropriate for consideration by private landowners: how long can precommercial thinning be delayed and remain an effective tool; what are the costs of treatments in stands where stems vary in size; and what comparable returns in growth, stand development, and added value over time can be expected above and beyond the alternative of no treatments?

An even-aged regulation demonstration was established on two 40-acre stands on the Crossett Experimental Forest in 1980, and they offered an opportunity to answer these questions. The demonstration imposed a prescription that consists of clearcut and seed-tree reproduction cutting methods applied sequentially in 5-acre blocks and strips during successive 5-year cutting cycles over a 40-year period. Each block and strip harvested to date has resulted in successful pine regeneration, and tree density in all blocks and strips far exceeded that which is needed for development of fully stocked stands.

As of 2004, none of these stands had been precommercially thinned. However, conventional recommendations for precommercial thinning call for treatment by age 5 to a residual density of 500 to 700 trees per acre (Baker and Langdon 1991). That leads to the question of whether and when precommercial thinning is needed to properly regulate tree density, and thereby to accelerate the development of the new cohort into pulpwood and sawtimber size classes. In the current study, a two-replication demonstration approach was used to evaluate the effects of precommercial thinning in different age cohorts in the even-aged regulation demonstration. Our objective was to quantify and demonstrate the growth response that can be expected when thinning even-aged, naturally regenerated stands of loblolly-shortleaf pine in the Upper West Gulf Coastal Plain to different residual density levels at ages older than conventionally are recommended.

METHODS

Study Site and Management History

The study is located within two 40-acre loblolly-shortleaf pine stands on the Crossett Experimental Forest in Ashley County, AR at 33° 02' N mean latitude and 91° 56' W mean longitude. Soil series are Bude (Glossaquic Fragiudalfs) and Providence (Typic Fragiudalfs) silt loams (Gill and others 1979). These soils have a site index of 85 to 90 feet for loblolly pine at age 50 years. Elevation is about 130 feet with nearly level topography. Annual precipitation averages 55 inches with seasonal extremes being wet winters and dry autumns. The study area is typical of productive sites for mixed stands of loblolly and shortleaf pines growing in the Upper West Gulf Coastal Plain.

From the mid-1930s through the 1960s, the areas were managed using single tree selection, which involves periodic harvests of the poorest quality trees while retaining the best trees in certain size classes for future harvests and natural seeding (Reynolds 1969). The areas were not managed from 1970 to 1980 and became overstocked (basal area over 100 square feet per acre) with pines ranging from 10 to 24 inches diameter at breast height (d.b.h.). When the areas were selected for study installation in 1980, there was a mixture of

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midstory and understory hardwoods beneath a closed pine canopy.

Each 40-acre stand was subdivided into eight 5-acre subunits. One stand was subdivided into strips (165 by 1,320 feet) and the other into blocks (330 by 660 feet) with the long axes being oriented north and south. At approximately 5-year intervals, even-aged reproduction cutting of two subunits (one strip and one block) per interval proceeded across the stands in a westerly direction to ensure that pine seeds from the residual stand would be dispersed by prevailing northwesterly winds into the subunits being cut.

Regeneration cohorts used in this study developed from seed crops principally dispersed during the autumn of 1980, 1985, 1990, and 1996; these years are used to designate the subunits established in the block and strip management areas. Reproduction cutting either occurred concurrently with seed dispersal in the autumn (1985 and 1996) or in the following spring (1981 and 1991). In the same operation as the reproduction cut, the remaining portion of the original stand in each management area was thinned to a residual basal area of 80 square feet per acre, cutting trees mainly in the lower crown classes. Clearcutting was used for the 1980 cohort in both the block and strip. Subsequently, the strips were regenerated using clearcutting, and the blocks were regenerated using the seed-tree method by retaining 10 to 15 seed trees per acre. The seed trees in the 1985 and 1990 blocks were cut after 5 years, but seed trees were retained in the 1996 block.

To promote natural pine reproduction, prescribed winter burns were periodically conducted to top-kill understory hardwoods and create a favorable pine seedbed by reducing forest floor litter. Burns were conducted in March 1980, October 1981, November 1986, February 1987, December 1989, and December 1995. All 5-acre subunits that had previously received reproduction cutting were excluded from burning after an initial site-preparation burn. In the summer of 1980, hardwoods were controlled by basal stem injection with herbicides in the two subunits designated for reproduction cutting. Likewise in summer 1984, hardwoods were controlled with a soil-applied herbicide in the two designated subunits. However, no herbicides were used in the 1990 and 1996 cohorts because the repeated fires had effectively controlled understory hardwoods and markets existed then for hardwood pulpwood, which enabled cutting midstory hardwoods. Cain and Shelton (2001) provided additional detail on the site preparation techniques employed in the study area.

Treatments

In early summer 2004, each regenerated 5-acre strip and block for the 1985, 1990, and 1996 cohorts was subdivided into four 1.25-acre treatment plots (165 by 330 feet), and four treatments were randomly assigned within the strip and block management areas separately. The thinning treatments, conducted precommercially (that is, no harvested material was removed from the site), consisted of three levels of mechanical or geometric thinning (Smith and others 1997, Helms 1998) with an unthinned control. Three methods of precommercial thinning were used: (1) chain-saw felling to a designated operational target of residual stems (100, 200, or 400 stems per acre) based on tree spacing by contract crews, (2) one-pass mowing using a farm tractor with bush-hog attachment to cut a 6-foot-wide swath and leaving a 2-foot strip between swaths and conducted by staff of the Crossett Experimental Forest, and (3) two-pass mowing as previously described but with swaths occurring at right angles. Treatments were implemented from June 1 to June 6, 2004. Treatments for the 1996 cohort were 200 trees per acre, two-pass mowing, one-pass mowing, and an untreated control. Treatments for the 1985 and 1990 cohorts were 100, 200, and 400 trees per acre and an untreated control.

No precommercial treatments were implemented in the 1980 block and strip cohorts, which were damaged by an ice storm in December 1998 (Cain and Shelton 2002, Bragg and others 2003). However, little or no damage occurred in the younger blocks and strips. The 1980 cohorts were commercially salvaged and thinned to about 200 crop trees per acre the year following ice damage. Data from these areas are included for comparative purposes.

Measurements and Analysis

For each 1.25-acre treatment plot receiving precommercial thinning or their controls, four 0.05-acre circular (26.3-foot radius) subplots were established along the long axis of the center line. Only two subplots were located in the 200 trees per acre, 1996 block, because the subplots fell within a pre-existing streamside management zone. Four 0.05-acre subplots were also located within the 1980 strip and block. On each subplot, all residual pine and hardwood stems 0.6-inches d.b.h. and larger were tagged with a prenumbered round aluminum tag, and a mark was painted at 4.5 feet aboveground. Subplot establishment and measurement began on September 7, 2004 and was completed on June 28, 2005. Subplots measured during the early part of the 2005 growing season included one subplot of the one-pass treatment in the 1996 block, the four control subplots of the 1996 block, and all subplots of the strip management area except the 1980 cohort. Tagged stems were measured for d.b.h. and species was recorded. Tagged stems were remeasured for d.b.h. from September 13, 2006 through November 2, 2006; mortality was recorded. Any untagged stems growing past the 0.6-inch d.b.h. threshold were tagged, d.b.h. measured, and species recorded.

Eight 0.05-acre subplots existed for all ages and treatments except for the 200 trees per acre, 1996 block for which there were six subplots. For each subplot, density, basal area, and mean d.b.h. were calculated by pine and hardwood components; these values were then averaged by treatment and age and standard errors calculated. No existing pine seed trees were included in the calculations. The growth of individual trees was modeled according to the procedure of Murphy and Shelton (1996). Stand-level variables for the model were from the specific 0.05-acre subplot that the subject tree occurred on. An indicator variable (Rao 1998) was included in the model to account for the late first measurement occurring on some subplots (May 12, 2005 through June 28, 2005). Data from the 1980 cohort were not included in the model. Equation coefficients were obtained from nonlinear ordinary least squares regression using SAS procedure MODEL (SAS 1988).

Variables were dropped from the equation if their coefficients did not differ from zero at $P < 0.05$. When measurements began at the end of the 2004 growing season, the reproduction cutting employed resulted in a series of even-aged natural stands that were 8 (1996 cohort), 14 (1990), and 19 (1985) years old as judged from the principal pine seed crop that resulted in their regeneration; these were the ages used in the model.

An expression of stand growth was calculated by subtracting the stand-level property of subplots obtained during the first inventory from that obtained during the second inventory. Because some plots were measured during the early part of the 2005 growing season during the first inventory, the time interval is slightly less than two growing seasons. No compensation for measurement date was attempted because of the short-term nature of the monitoring period. We chose to present these interim results because the growth interval was fairly well balanced across treatments and ages.

RESULTS AND DISCUSSION

Stand Conditions in 2006

The precommercial thinning conducted in 2004 resulted in a visible change in stand conditions 2 years later (table 1). The most intensive thinning treatment reduced pine density to 12 percent of that in the unthinned control in the 1996 cohort, 16 percent in the 1990 cohort, and 26 percent in the 1985 cohort. Although cutting hardwoods was not an objective of the thinning operation, hardwoods were cut in the mechanical one- and two-pass mowing conducted in the 1996 cohort because of their presence on the mowed strips. In the selective chain-saw thinning, hardwoods were cut to gain access to treated pines, which were the real objective of the operation. Thus, hardwood densities were fairly variable 2 years after treatment, when hardwood density in the most heavily thinned treatments ranged from 14 to 54 percent of the unthinned controls. In the selectively thinned treatments, the residual pine density was generally higher than the specified target, because the treatments were done by contractors working across the entire area rather than by research technicians working on the plots. In addition, some residual stems were below the minimum threshold for treatment, but they were included in the monitoring procedure.

For the most part, the lowest pine basal areas occurred in the more heavily thinned stands; values for these treatments ranged from 24 to 50 percent of the untreated controls (table 1). Pine basal area in the unthinned controls was 62, 143, and 144 square feet per acre for the 1996, 1990, and 1985 cohorts, respectively. The peaking of basal area at slightly over 140 square feet per acre suggested that the carrying capacity of the site was attained after 16 years. As this relationship suggests, reduced growth and increased mortality characterized stand dynamics as the carrying capacity was approached. Pine basal area in the 1980 cohort, which was commercially thinned after 19 years, was within 16 percent of the carrying capacity of the stand, suggesting that another thinning is in order. Hardwood basal area was considerably more variable than that for the pines. In fact, the most heavily thinned treatment in the 1990 cohort actually exceeded the basal area of the control by 4 square feet per acre; this reflected the fact that thinning hardwoods was not a treatment objective.

Mean pine d.b.h. generally declined as residual pine density increased (table 1). Mean d.b.h. in the most heavily thinned treatment was 2.1, 1.3, and 1.4 times greater than that of the untreated control in the 1996, 1990, and 1985 cohorts, respectively. This difference reflected the increased diameter growth associated with the lower densities resulting from thinning. In addition, some “jump” in mean d.b.h. occurred in the selectively thinned treatments because the larger, more dominant trees were retained as crop trees. The commercially thinned 1980 cohort was only 0.6 inches larger in mean d.b.h. than the untreated control in the 1985 cohort. Hardwoods in the study area were considerably smaller on average than the pines and also were considerably more variable in mean d.b.h. across the precommercial thinning treatments.

A Preliminary Look at Stand Dynamics

The two inventories conducted in our study allowed capturing some summary information on stand dynamics. Because the first inventory on about half of the plots was conducted during the early part of the growing season, the time-basis of this comparison can at best only be expressed as about 2 years. However, comparisons among treatments were valid because the timing of the first measurement was fairly well balanced across treatments.

Pine mortality was strongly affected by stand age and residual pine density, with the unthinned controls displaying the highest rates (table 2). There was relatively little mortality occurring on any treatments that were precommercially thinned at any age. The annual number of dying pines averaged 0.8 percent of initial density for the precommercially thinned treatments over all three stand ages. The number of dying pines in the control declined sharply with increasing stand age—from 653 trees per acre in the 1996 cohort to only 70 trees per acre in the 1985 cohort. However, when expressed as a percentage of the initial pine density, the annual rate was fairly uniform across the three ages and averaged 7 percent. By comparison, the pine density mortality rate in the commercially thinned stands in the 1980 cohort was 2.6 percent per year. In terms of pine basal area, the precommercially thinned treatments lost an average of 0.1 square feet per acre annually, while the unthinned controls increased from 2 square feet/acre in the 1996 cohort to 7 square feet per acre in the 1985 cohort. Most of this mortality was in the smaller trees because the d.b.h. ratio for dying to living pines ranged from 0.3 to 0.9 across all ages and treatments. Hardwoods displayed similar patterns of mortality as the pines, except that rates were generally lower for both density and basal area.

For pine density, the mortality rates observed for the precommercially thinned plots and the commercially thinned stand were comparable to the 2 percent annual mortality reported for loblolly pine plantations by Zeide and Zang (2006) and the 2 percent average mortality rate observed in managed uneven-aged loblolly pine stands by Murphy and Shelton (1998).

Table 1—Means and associated standard error for each mean for stand properties after the 2006 growing season in naturally regenerated pine stands that were commercially thinned, precommercially thinned 2 years earlier to different densities, or unthinned controls

	Density		Basal area		d.b.h.	
Cohort and treatment[a]	Mean	Std. error	Mean	Std. error	Mean	Std. error
	trees/acre		*ft^2/acre*		*inches*	
			Pines			
1996:200	447	62	31.0	4.3	3.5	0.47
Two pass	1,043	211	27.6	5.1	2.1	0.09
One pass	2,425	330	54.1	5.7	1.9	0.07
Control	3,618	779	62.3	12.0	1.7	0.07
1990:100	290	44	33.9	3.0	4.6	0.47
200	273	25	42.7	4.1	5.2	0.33
400	343	38	48.5	8.2	4.7	0.32
Control	1,780	145	143.2	10.9	3.6	0.09
1985:100	140	11	65.8	7.0	9.1	0.29
200	215	22	89.6	7.2	8.7	0.28
400	265	15	105.1	5.9	8.4	0.15
Control	535	56	144.2	12.3	6.7	0.30
1980: Commercial	368	30	120.7	11.9	7.3	0.36
			Hardwoods			
1996:200	457	383	7.1	5.5	1.4	0.13
Two pass	805	171	17.0	2.8	1.8	0.10
One pass	740	57	18.5	2.6	1.8	0.07
Control	1,858	124	28.4	3.4	1.4	0.04
1990:100	218	112	14.2	5.6	3.3	0.67
200	273	147	7.5	3.2	2.2	0.68
400	75	53	7.1	4.5	4.0	1.23
Control	405	142	9.9	2.1	2.2	0.23
1985:100	30	17	1.5	1.1	2.5	0.99
200	45	33	2.7	2.5	2.4	0.83
400	15	15	3.5	3.5	6.3	-----[b]
Control	218	93	7.5	2.1	2.6	0.24
1980: Commercial	150	34	8.1	3.1	2.6	0.20

[a]Treatments: 100, 200, and 400=precommercially thinned using chain saws in 2004 to an operational target of 100, 200, or 400 pine trees/acre, respectively; one pass=6-foot strip mowed leaving a 2-foot strip; two pass=as in one pass except two mowed strips at right angles; Control=no treatment; Commercial=commercially thinned in 1999 to 200 crop trees/acre.

[b]Only one of the eight plots had hardwoods present.

Table 2—Mortality occurring over an observation period of about 2 years in naturally regenerated pine stands that were commercially thinned, precommercially thinned 2 years earlier to different densities, or unthinned controls

	Pines			Hardwoods		
Cohort and treatment[a]	Density	Basal area	d.b.h. ratio[b]	Density	Basal area	d.b.h. ratio
	trees/acre	*ft^2/acre*		*trees/acre*	*ft^2/acre*	
1996:200	10	0.0	0.30	40	0.2	0.65
Two pass	8	0.1	0.92	18	0.1	0.68
One pass	68	0.5	0.68	25	0.2	0.70
Control	653	2.1	0.54	118	0.5	0.70
1990:100	15	0.4	0.63	0	0.0	-----[c]
200	5	0.4	0.78	5	0.0	0.15
400	5	0.2	0.59	0	0.0	-----
Control	288	6.2	0.60	53	0.4	0.57
1985:100	0	0.0	-----	5	0.2	0.90
200	0	0.0	-----	0	0.0	-----
400	0	0.0	-----	0	0.0	-----
Control	70	7.1	0.67	45	0.7	0.70
1980: Commercial	20	1.2	0.46	58	0.6	0.59

[a] Treatments: 100, 200, and 400=precommercially thinned using chain saws in 2004 to an operational target of 100, 200, or 400 pine trees/acre, respectively; one pass=6-foot strip mowed leaving a 2-foot strip; two pass=as in one pass except two mowed strips at right angles; Control=no treatment; Commercial=commercially thinned in 1999 to 200 crop trees/acre.

[b] Ratio of the d.b.h. of dying trees to the stand mean at the beginning of observation period.

[c] No trees present for analysis.

in the 1990 cohort and only 1.4 times in the 1985 cohort. In contrast, the change in stand basal area was greatest for the moderate densities, because more trees occupied the site which tended to compensate for the lower rates of d.b.h. growth. Plus, these moderate densities also had comparatively low mortality rates. The low level of net basal area change for the unthinned control in the 1985 cohort reflected the high rates of basal area loss associated with mortality. Also noteworthy was the low rates of hardwood d.b.h. growth and basal area growth when compared to the pines (table 3).

Individual Tree Growth

Annual basal area growth of individual trees was modeled from the d.b.h. of the tree and stand level properties, which were obtained from the subplot that the subject tree occurred on. A correction factor was also included to account for the difference in the initial start of the monitoring period. The pine prediction equation was:

$$\Delta B_p = \frac{29.16\left[1 - \exp\left(-0.1236 B_t\right)\right]}{1 + \exp\left(0.0003468P + 0.0001787H + 0.1868A + 0.2642M\right)} \quad (1)$$

where:

change in tree basal area in square feet from the first (2004 or early 2005) to second (2006) measurement divided by 2,

B_t = tree basal area in square feet at first measurement,
P = pine density at first measurement in trees/acre,
H = hardwood density at first measurement in trees/acre,
A = stand age in years at first measurement
M = indicator variable for timing of first measurement: 0=2004/05 dormant season, 1=2005 early growing season.

There were 4,070 observations for equation 1, the root mean square error was 0.00499 square feet, the coefficient of determination was 0.80, and all coefficients of treatment variables were significant at $P < 0.001$. A similar prediction equation was developed for hardwood basal area growth as follows:

$$\Delta B_p = \frac{29.16\left[1 - \exp\left(-0.1236 B_t\right)\right]}{1 + \exp\left(0.0003468P + 0.0001787H + 0.1868A + 0.2642M\right)} \quad (2)$$

Table 3—Change in mean stand d.b.h. and basal area occurring over an observation period of about 2 years in naturally regenerated pine stands that were commercially thinned, precommercially thinned to different densities, or unthinned controls

Cohort and treatment[a]	Pines		Hardwoods	
	d.b.h.	Basal area	d.b.h.	Basal area
	inches	*ft²/acre*	*inches*	*ft²/acre*
1996:200	1.05[b]	16.0	0.10	1.7
Two pass	0.55	13.0	0.34	5.5
One pass	0.38	18.5	0.20	4.0
Control	0.35	14.3	0.18	5.9
1990:100	0.79	9.8	0.14	1.4
200	0.74	11.5	0.18	1.1
400	0.66	13.1	0.26	0.6
Control	0.40	12.5	0.22	0.6
1985:100	0.89	12.0	-----[c]	----
200	0.66	12.8	0.16	0.6
400	0.63	16.1	0.28	0.3
Control	0.62	5.3	0.15	0.0
1980: Commercial	0.67	16.4	0.33	1.5

[a]Treatments: 100, 200, and 400=precommercially thinned using chain saws in 2004 to an operational target of 100, 200, or 400 pine trees/acre, respectively; one pass=6-foot strip mowed leaving a 2-foot strip; two pass=as in one pass except two mowed strips at right angles; Control=no treatment; Commercial=commercially thinned in 1999 to 200 crop trees/acre.
[b] Stand mean in 2006 minus that observed at beginning of monitoring.
[c] Inadequate number of trees for analysis.

Stand growth was also strongly related to precommercial thinning treatment and stand age (table 3). The change in mean pine d.b.h. was consistently greatest for the lowest residual pine density. In addition, the steepness of this relationship tended to decline through time; for example, the d.b.h. growth rate in the lowest density was 3.0 times that of the unthinned control in the 1996 cohort, but was 2.0 times where:

ΔB_h = change in hardwood tree basal area growth and all other variables are as previously defined. Equation 2 was based on 1,648 observations, the root mean square error was 0.0028 square feet, the coefficient of determination was 0.64, and all coefficients were significant at $P \leq 0.01$.

Solving equation 1 for a reasonable range of values for independent variables yielded the predicted values for pine basal area growth shown in figure 1. Growth progressed in a logical manner; increases occurred with increasing tree d.b.h. and decreases occurred with increasing pine density. The effects of stand age must be considered concomitantly with tree d.b.h., because tree d.b.h. varied considerably over the 11-year period covered by the model. The largest trees produced a relatively uniform annual basal area growth of 0.05 to 0.07 square feet over the range of stand ages represented by our study, which suggests that more rapid diameter growth of the dominant trees in the cohort will result when the cohort is precommercially thinned at an earlier age. The broadest range in basal area growth within the population was expressed at the younger ages before self-thinning substantially reduced stand density; this range changed from about 3 fold in the 1996 cohort to 1.4 fold in the 1985 cohort.

A similar relationship was developed from equation 2 for hardwoods (fig. 2). The similarity in hardwood d.b.h. range for each age probably reflected the different site preparation treatments used when the study areas were regenerated. The basal area growth pattern displayed for hardwoods substantially differed from that of pines. First, pines showed an increasing growth rate with d.b.h. throughout the range in diameters at each age, while hardwood growth became asymptotic for the larger diameters. Second, the growth rates for hardwoods were considerably below those for the pines. In the 1996 cohort, for example, the dominant hardwoods were growing at 0.03 to 0.04 square feet per year, which was only half the rate displayed by the dominant pines. In addition, hardwood growth rates decreased substantially through time, widening the growth differential between hardwoods and pines. This decline undoubtedly reflected the suppression of hardwoods by the rapidly developing pine component, which captured and dominated the site during early succession (Cain and Shelton 2001). Third, the expressed ranges in values for hardwood growth were much narrower than those displayed by pines.

CONCLUSIONS

Our study showed that controlling stand density through precommercial thinning strongly affected growth of individual trees and the patterns of stand dynamics. The lowest residual densities displayed the highest rates of individual tree growth. The effects of stand age on tree growth were minor for the dominant trees in the stand. At the stand level, however, moderate densities favored the highest levels of basal area growth, because more trees occupied the site and mortality was far lower than in the unthinned controls. Tree mortality through self-thinning was the driving force that caused the basal area growth of the stand to decline at the higher densities. Mortality was mainly from the smaller trees in the population. Results of our study reinforce the notion that the earlier precommercial thinning can be done, the better. In addition, stands are far easier to precommercially thin when the trees are smaller. Although the short-term results of this paper contribute to our knowledge of precommercial

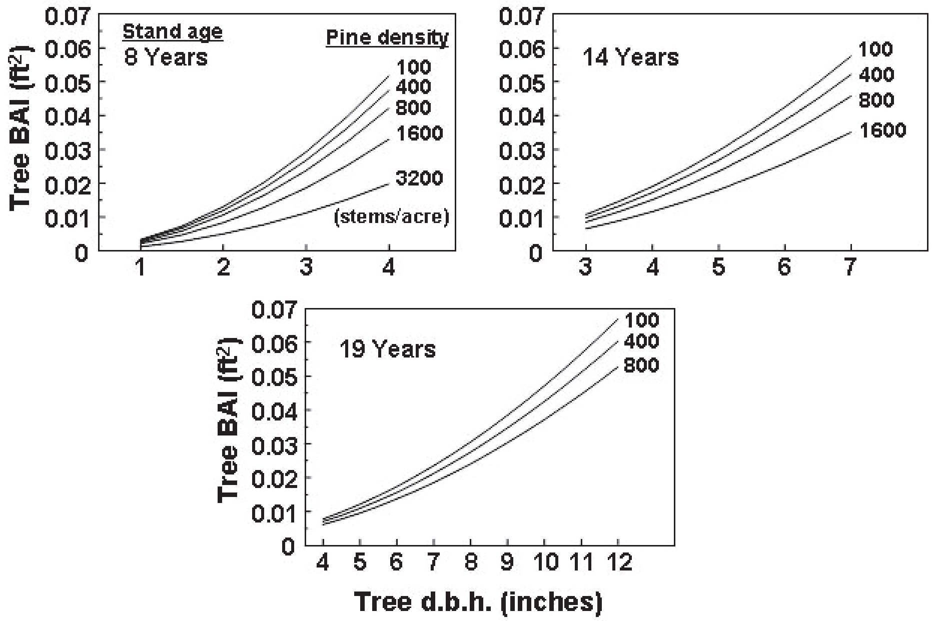

Figure 1—Annual basal area increment (BAI) of individual pines predicted from tree d.b.h., pine density, and stand age at treatment (2004) and for a uniform hardwood density of 500 trees per acre (equation 1 with $M = 0$).

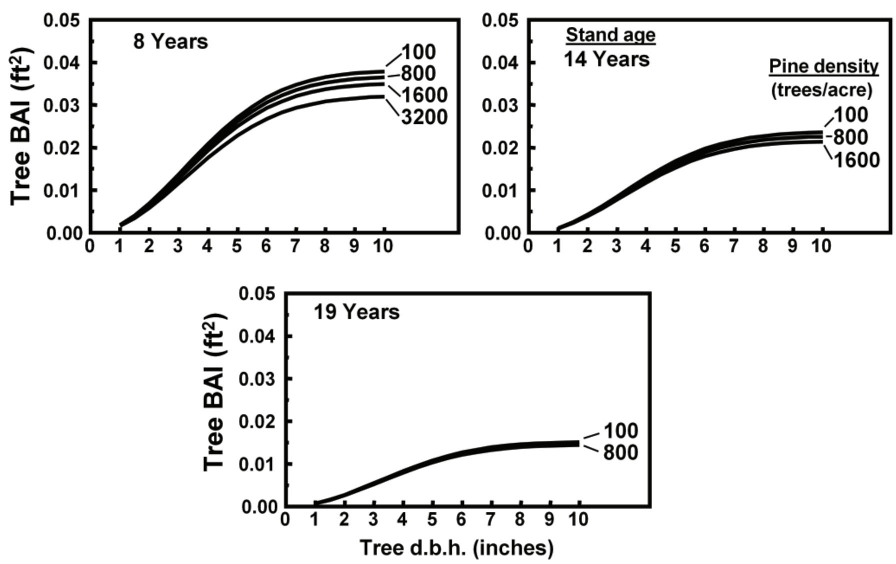

Figure 2—Annual basal area increment (BAI) of individual hardwoods predicted from tree d.b.h., pine density, and stand age at treatment (2004) and for a uniform hardwood density of 500 trees per acre (equation 2 with $M = 0$).

thinning, some issues, like economics, product yields, and tree quality, will have to wait for a longer monitoring period to resolve. This study also meets an important goal for science delivery in that we now have an active precommercial thinning demonstration on hand at the Crossett Experimental Forest for review by visitors, tour groups, short courses, and workshops.

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