RESULTS OF A LONG-TERM THINNING STUDY IN SOME NATURAL, EVEN-AGED PINE STANDS OF THE MIDSOUTH

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Abstract—This paper reports on a long-term thinning study established in stands of naturally seeded loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine in southern Arkansas and northern Louisiana. Plots were established in 1949–50 and 1954 in previously unmanaged stands, thinned about once every 5 years from age 20 to 60 years (40 years of active cutting, to 1990). The study was discontinued in 1995 when the stands were about 65 years old. Low-density stands on good sites produced bigger individual pines more quickly than denser stands on medium sites. Long-term sawtimber yields did not follow this pattern, however. While medium-quality sites produced somewhat lower gross yields, denser stands ultimately resulted in significantly higher total yields, primarily because of their better stocking.

INTRODUCTION

Thinning is crucial to managing many southern pine stands, as they often have such high stocking that stagnation, diminished sawtimber production, and mortality are of concern. For instance, Brender (1965) reported that thinned loblolly pine (*Pinus taeda* L.) stands could experience a 10-percent or more volume increase and that rotation age can be shortened by at least 10 years when thinnings are "judiciously" applied. Similarly, Williston (1978) recommended that dense shortleaf pine (*P. echinata* Mill.) plantations be aggressively thinned to avoid stagnation and elevated mortality in crop trees. Changes in technology, coupled with financial pressures to shorten rotation lengths, make it imperative that stands are appropriately treated in order to maximize return.

While many publications on the thinning of pine plantations are available (e.g., Brender 1965, Goebel and others 1974, Williston 1978), informative guidelines for long-term management of even-aged loblolly pine-dominated stands of natural origin are more limited. Mann and Lohrey (1974) provided advice on the precommercial thinning of natural southern pine stands, and Andrulot and others (1972) evaluated a thinning study initiated in 17-year-old loblolly pine-dominated stands that seeded in following the cutting of virgin forest. Both of these studies supported thinning to improve growth and yield and reduce mortality over unthinned controls. More recently, Zeide and Sharer (2000) published a management guide for parts of the Midsouth, based on results from research forests and the experiences of forest managers. For natural stands on medium-quality sites, they recommended thinnings, stocking targets, vegetation control, and a rotation age of 45 years.

This paper reports on a long-term (40+ years) thinning study in loblolly pine-dominated stands of natural origin in southern Arkansas and northern Louisiana. Originally designed to explore the possibilities of thinning mixed pine stands on different quality sites, the longevity of this research now allows for the evaluation of harvest treatments on key attributes such as tree size and stand growth and yield. These attributes, in turn, can be used to guide management recommendations for landowners interested in a specific goal for their properties.

METHODS

Plot Establishment and Description

The following description has been primarily taken from the original project establishment report[2] and a later unpublished summary.[3] The original set of study plots was established in the winter of 1949–50 on what were then Crossett Lumber Company lands in Morehouse Parish, LA, and Ashley County, AR. The Morehouse Parish sites were originally cut about 1918 to a 14-inch diameter at breast height (d.b.h.) limit, and then were repeatedly burned and grazed (but not logged), delaying the establishment of the next pine stand on this site until the late 1920s. The original forest on the Ashley County sites was cut to a 12-inch d.b.h. limit between 1925 and 1930. The initial overstory vegetation on all plots was a mixture of loblolly and shortleaf pine, but the actual proportion of loblolly vs. shortleaf pine was not recorded (Burton 1980). Plots were generally placed to avoid the remnant old pine and scattered large hardwoods (Burton 1980).

The establishment plan included 5 silvicultural treatments (70, 85, and 100 square feet per acre basal area targets; thin to increasing basal area; and best judgment thinning) using 2 thinning directions (thin from below and thin from above) for all but the best judgment thinning (which used both) on 2 levels of site quality (medium and good), each replicated 3 times [(4 treatments × 2 thin directions + 1 treatment) × 2 site qualities × 3 replicates = 54 plots]. Additional plots were included in 1954 for the good sites in Ashley County only,

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[2] Mann, W.F.; Williston, H.L. 1950. Management of young pine stands in the shortleaf-loblolly pine type west of the Mississippi River. 31 p. Unpublished project establishment report, study FS-SO-1107 1.7. On file with: Crossett Experimental Forest, U.S. Department of Agriculture, Forest Service, Southern Research Station, P.O. Box 3516, UAM Station, Monticello, AR 71656.

[3] Leduc, D. 1987. Background, history, and variables of the big thinning study. Unpublished report. On file with: Crossett Experimental Forest. U.S. Department of Agriculture, Forest Service, Southern Research Station, P.O. Box 3516, UAM Station, Monticello, AR 71656.

adding three new basal area targets (55, 115, and 130 square feet per acre) using thinning from below only, once again replicated 3 times (3 treatments × 1 thin direction × 1 site quality × 3 replicates = 9 plots). However, this paper reports (table 1) results from only 60 of the 63 plots established, as 1 plot was severely damaged by bark beetles in 1954 and then destroyed by a tornado in 1973, and 2 other plots were unintentionally logged in 1989. Each plot consisted of a core 0.1-acre circular measurement plot surrounded by a 0.255-acre isolation strip in which every tree at least 2 inches d.b.h. was inventoried (see footnote 2). Periodic losses from logging, wind, ice, and insects have been reported on some of the

Table 1—Number of replicates, measurements, and average replicate site index by thinning level and method

Thinning level[a]	Thinning method	Site quality	Plots	Measurements	Year first measured	Year 65		
						Site index[b]	Stand density	Basal area
			number	*number*		*feet*	*trees per acre*	*ft^2 per acre*
55	Below	Good[c]	3	9	1954	94.7	16.7	53.2
70	Below	Medium	3	10	1949–50	76.7	50.0	79.3
		Good	2	10	1949–50	96.5	16.7	49.8
70	Above	Medium	3	10	1949–50	77.0	46.7	80.4
		Good	3	10	1949–50	95.3	30.0	81.5
85	Below	Medium	3	10	1949–50	83.0	56.7	98.1
		Good	2	10	1949–50	96.5	45.0	92.8
85	Above	Medium	3	10	1949–50	82.3	56.7	97.1
		Good	2	10	1949–50	94.0	35.0	78.6
100	Below	Medium	3	10	1949–50	81.0	86.7	112.5
		Good	3	10	1949–50	93.3	50.0	102.0
100	Above	Medium	3	10	1949–50	83.3	70.0	106.2
		Good	3	10	1949–50	99.0	66.7	108.2
115	Below	Good[c]	3	9	1954	99.0	50.0	106.6
130	Below	Good[c]	3	9	1954	98.0	80.0	138.4
Increasing[d]	Below	Medium	3	10	1949–50	80.3	43.3	113.7
		Good	3	10	1949–50	97.3	26.7	108.8
Increasing[d]	Above	Medium	3	10	1949–50	78.7	96.7	112.6
		Good	3	10	1949–50	91.0	63.3	109.9
Judgment[e]	Both	Medium	3	10	1949–50	79.7	80.0	83.2
		Good	3	10	1949–50	97.3	53.3	68.2

[a] Levels represent postharvest basal area (in square feet per acre) thinning targets. After the stands reached their target basal areas, they were maintained at those levels using thinning from below (Burton 1980).

[b] Site index, base age = 50 years.

[c] Later treatment installed with no medium site locations.

[d] Thin from an initial basal area of 70 square feet per acre at age 20 to 105 square feet per acre at age 60.

[e] Best judgment of the staff at the Crossett Experimental Forest with no specific target basal area or fixed thinning direction (some were thinned partly from above, but most were thinned from below (Burton 1980)).

plots, but other than the three plots previously mentioned, no major catastrophic disturbances have strongly affected the plots. Effective fire control in the area began about 1935, with little to no damage from fire over the next 60 years.

When established, the study plots were segregated into two blocks (good vs. medium) based on relative site quality. Assignment to one block or the other was based on early estimates of 50-year site index (SI_{50}), and later tested directly when the stands actually reached 50 years old (Murphy and Farrar 1985). Overall, the early estimates of site quality appeared to have been reasonably effective in achieving the desired separation. However, direct determination of SI_{50} identified some discrepancies in the assignment of site quality. For example, the best quality "medium" site has a SI_{50} = 92, while the lowest quality "good" site has a SI_{50} = 90. While it would be easy to reassign plots to increase the distinctiveness of the extremes of each study, this would not be statistically appropriate because the treatments and replicates were assigned with the preliminary site index values. A comparison of mean site index values by "medium" and "good" site quality classes found that as a group, both classes were highly significantly different [medium SI_{50} = 80.2 feet, good SI_{50} = 96.0 feet, $P < 0.001$ using Welch approximate t-test for unequal sample variances (Zar 1984)], suggesting that broad references to site quality should prove robust.

Thinning Treatments

Implementation—Initially, this study considered the impacts of thinning regimes on high-value pole production (Burton 1977); however, it eventually developed into a general examination of thinning impacts on even-aged pine growth and yield. Some early implementations of thinning were designed to improve pole production, e.g., bias against trees with sweep, changing thinning direction during study, although it is not expected that these have notably influenced the final results. Every 5 years, stands were thinned to different prescriptions after each plot was inventoried. The final thinning occurred in 1989–90, although plots were also remeasured in 1994–95. The first block of plots representing medium sites (SI_{50} from 70 to 92 feet at 50 years) received half of the treatments, while the good sites (SI_{50} from 90 to 101 feet) received the other half, with three plots allocated by site quality and thinning treatment. The plots established in 1954 were only on good-quality sites (SI_{50} from 92 to 101 feet) and received different thinning treatments.

Prior to thinning, an inventory was made and basal area was calculated in the field, after which the prescriptions were applied. Thinning strategies focused on two principle approaches: thinning from below and thinning from above. The original plots were designed to consider the effects of the different direction on the developing stands, with treatments replicated on both medium- and good-quality sites. Thinning from above to target stand densities (70, 85, and 100 square feet per acre) involved cutting from above when the stands were roughly 20 to 25 years old to these targets, then maintaining them at these densities for all of the succeeding treatment periods using thinning from below. Stands assigned to be thinned from below were always thinned from below. The thinning to increasing basal areas started for both thinning directions at 70 square feet per acre, increasing to 75 square feet per acre by age 25 years, 80 square feet per acre at age 30, 85 square feet per acre at age 35, 90 square feet per acre at age 40, 95 square feet per acre at age 50, 100 square feet per acre at age 55, and finally reaching 105 square feet per acre at age 60, after which it was maintained at this level (Burton 1980, Murphy and Farrar 1985). The thinning from above approach actually only removed dominant trees during the cuts in year 20 and 25, afterwards all thinning was from below. The switch in thinning direction was designed to help improve pole production (Burton 1977). The thin from below treatment under increasing basal area used low thinning for all treatment periods. The best judgment thinnings were based on a consensus of the participants, with no restrictions on method, intensity, or residual basal area target. This resulted in mostly thinning from below to basal areas of around 75 square feet per acre (ranging from 67 to 81 square feet per acre), regardless of site quality (Burton 1980). The supplementary plots added in 1954 were thinned from below to basal areas of 55 square feet per acre, 115 square feet per acre, and 130 square feet per acre, and were maintained by low thinning at these levels for the duration of the study.

While the differentiation between loblolly and shortleaf pine was not consistently performed on the plots, the application of the treatments biased the stand in favor of loblolly pine. Burton (1980, p. 3) reported that "[f]or all thinning treatments, if the trees were of equal quality, field workers cut shortleaf and kept loblolly pines." The net effect on stand composition was the increasing dominance of loblolly pine.

Hardwood Competition Control—Since the objective of this study was to consider pine productivity under different thinning treatments, all merchantable hardwoods were cut in the first thinning and any remaining hardwoods were eliminated (Burton 1980). Periodic removal of hardwoods with herbicides was then performed as needed—(see footnote 3) reported treatments in 1949 (using Ammate), 1954 (1 percent emulsion of 2,4,5-T in water), and 1959 (10 percent 2,4,5-T in diesel oil). Mechanical removal of all live hardwoods with root-collar diameters >1.0 inch was also implemented before every inventory through at least age 40 (Burton 1980, Murphy and Farrar 1985).

Inventory Design—Detailed information was recorded over the years on the pines in the study plots, but some measures were inconsistently applied and others were missing from the data. Additionally, the long tenure of this study resulted in different techniques and measurement standards being used, thus potentially confounding possible treatment effects with observer bias. For example, before 1960, many small trees were tracked simply as tallies in diameter classes, so their individual fates were largely unknown. Additionally, no records were kept of mortality during the first couple of inventory periods (Burton 1980). Because of these inconsistencies, this paper will only consider the differences in the diameter and gross volumes of the stand at age 65 years.

Trees as small as 2.0 inches d.b.h. were tallied in the original inventories; however, only trees >3.5 inches d.b.h. (the minimum merchantable standard in the study region) have been used in the calculations of trees per acre, basal area, volume, and mortality in this paper. Merchantability standards for this analysis follow those applied by Burton (1980) and Murphy and Farrar (1985). Board-foot volume (International 1/4-inch rule) is reported in this paper, calculated with local volume equations developed by Farrar and others (1984).

Statistical Analysis and Silvicultural Interpretation—A number of factors contribute to the difficulties in interpreting field data, especially from long-term studies established decades ago. In particular, this thinning study experienced a number of challenges that could not be controlled in this analysis. First, the small sample size per treatment, coupled with the small size of study plots, resulted in a particularly high sensitivity to disturbance. Second, the relative novelty of statistically based comparative studies in the silvicultural research programs of the late 1940s led to plots being established across a broad range of initial conditions and, hence, limited replication. Finally, the duration of the study (~45 years) resulted in multiple investigators with varying goals, who thereby implemented the studies and measurements using somewhat different standards and practices. The primary result of these design and implementation weaknesses is the reduction of power in discerning treatment effects, especially as the study progressed. However, broad conclusions can still be made.

Prior researchers published different approaches to the analysis of data from this study: Burton (1980) considered each plot type (medium, good, and supplemental) as three separate entities and performed analysis on each, while Murphy and Farrar (1985) combined all the data as a completely randomized design using analysis of covariance, with site index as the covariate. This paper differs from previous efforts by concentrating on the long-term implications of the different thinning treatments. Comparisons are limited to the factors most relevant to making long-term decisions for the management regime to implement using the units that best reflect the nature of the stand. Thus, only preharvest d.b.h. and potentially usable (gross) sawtimber yield (both total and annualized) were considered. Results are presented for all treatments as means at the end of the study when the stands had reached approximately 65 years of age. All treatments were compared using Tukey's honestly significant difference test for multiple comparison with unequal numbers. To avoid problems of homogeneity of variance and nonnormality within treatments, a logarithmic transformation [$X' = \log(X + 1)$] was used on the data (Zar 1984).

RESULTS AND DISCUSSION

Because basal area was tightly controlled for this study, it is not surprising that the basal area at 65 years approached the harvest goals (table 1). Towards the end of the study, the heavy thinning treatments dropped to unacceptably low stand densities as the small plots gradually ran low on trees. Thus, for low-density treatments, this study had reached the end of its usefulness. It was clear, however, that sustained harvesting effectively regulated stocking. By the time these stands approached 50 years old, Murphy and Farrar (1985) found average annual density increases of 2.5 to 3.5 square feet per acre, most of which was occurring in sawtimber-sized individuals. This rate was slightly higher than that noted by Nelson (1963) for natural-origin loblolly pine in Georgia, South Carolina, and Virginia.

Mean Preharvest Stand Diameter

Table 2 encapsulates the influence of thinning treatments on average preharvest mean d.b.h. at 65 years. Initially, all study areas had similar d.b.h. values, ranging from 5.0 to 6.3 inches. However, scheduled treatments soon altered this parity, rapidly producing differentiation by harvest strategy. For example, thinning to 55 square feet per acre from below quickly opened the stand by removing the smallest individuals, thus producing a rapid increase in d.b.h. from 7.3 to 9.5 inches in the first 5 years of treatment. Thinning the stands to much higher densities, e.g., 115 or 130 square feet per acre, from below only produced an increase from 7.3 to 8.4 inches in the same time period. Under these conditions, the greater retention of small-diameter stems and higher stocking reduced the diameter response, especially when the canopy had closed and competition for resources was pronounced (Mann and Lohrey 1974). All of these results are intuitive and have been shown in many other thinning studies (e.g., Andrulot and others 1972, Chaiken 1941, Wiley and Zeide 1992).

Maintenance of prescribed thinning levels reinforced these differences. As expected, retaining lower stand densities produced larger individuals on average during the study (fig. 1). In most cases, thinning direction (above vs. below) slightly influenced d.b.h. during the treatment period, largely because of the preferential removal of small trees when thinning from below. For older even-aged stands that have been thinned for many years, the apparent difference between the thinning directions will probably have little practical significance because, if properly done, any size differentiation will have been ameliorated by the repeated removals of small pines.

While the limited number of sampled stands and trees contributed to the lessening of significance between treatments and site quality, differences were still apparent and meaningful. The impact of site quality on d.b.h. over time was likely more influential than thinning design. For treatments paired on both site-quality levels, d.b.h. was consistently higher on the good-quality sites throughout the treatment period (fig. 1). Better sites translate into faster stem growth, allowing the thinned stands to develop more rapidly. Under unthinned natural conditions, the accelerated growth experienced on good sites resulted in earlier canopy closure and heightened competition, thus triggering density-dependent mortality at an earlier age (see also Turnblom and Burk 2000). However, properly thinned stands are precluded from reaching canopy closure, thus ensuring better exploitation of site resources by the residual trees (Wiley and Zeide 1992) and allowing d.b.h. increases to be maintained.

Table 2—Comparison of preharvest average diameter by harvest treatment and site quality

Thin level[a]	Thin method	Site quality	Average age = 25 years	Average age = 65 years[b]	Year 65 Average minimum	Year 65 Average maximum	Year 65 Standard deviation
			d.b.h. inches				
55	Below	Good	7.3	23.9 f	22.5	25.6	1.58
70	Above	Medium	5.7	17.1 a,b,c,d,e	15.6	18.8	1.61
		Good	6.8	23.1 f	21.2	25.5	2.18
70	Below	Medium	5.7	18.0 a,b,c,d,e	15.3	19.8	2.38
		Good	6.6	22.3 d,e,f	21.5	23.1	1.13
85	Above	Medium	5.7	17.7 a,b,c,d,e	17.1	18.7	0.87
		Good	6.0	19.4 a,b,c,d,e,f	18.6	20.2	1.13
85	Below	Medium	5.9	18.0 a,b,c,d,e	15.7	21.2	2.84
		Good	7.0	20.2 b,c,d,e,f	20.2	20.3	0.07
100	Above	Medium	5.8	15.3 a,b	15.0	16.0	0.58
		Good	6.5	19.4 b,c,d,e,f	18.5	21.2	1.53
100	Below	Medium	5.9	16.7 a,b,c,e	16.3	17.0	0.35
		Good	6.3	17.1 a,b,c,d,e	16.5	18.1	0.87
115	Below	Good	7.3	19.8 c,d,e,f	17.7	21.6	1.97
130	Below	Good	7.3	17.9 a,b,c,d,e	16.4	20.5	2.29
INC	Above	Medium	5.2	14.7 a	13.7	15.9	1.12
		Good	5.8	17.7 a,b,c,d,e	16.8	18.3	0.79
INC	Below	Medium	6.1	16.0 a,b,c	15.9	16.0	0.06
		Good	6.8	19.4 b,c,d,e,f	18.5	19.9	0.81
JUD	Both	Medium	5.6	18.8 b,c,d,e,f	17.9	19.2	0.75
		Good	6.4	21.7 d,f	20.3	23.0	1.36

[a] Number represents postharvest basal area (square feet per acre) targets; INC = thin to increasing basal area; JUD = best judgment thinning. See text for detailed descriptions of the thinnings.

[b] Diameters with the same letters are not significantly different at $\alpha = 0.05$ (tests were conducted on transformed data but reported for untransformed). Significance of treatment differences determined with Tukey's honestly significant difference (HD) test for unequal *n* using an $\alpha = 0.05$ (StatSoft 2000).

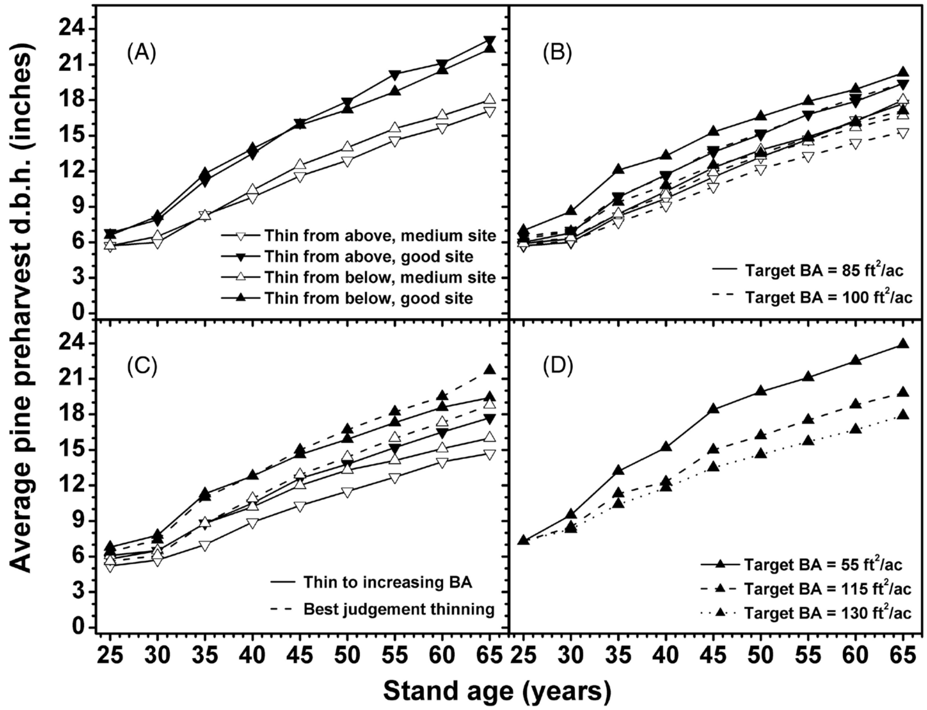

Figure 1—Average pine preharvest d.b.h. over the duration of this thinning study. Target residual basal areas (BA) were (A) 70 square feet per acre, (B) 85 or 100 square feet per acre, (C) thin to increasing BA or best judgment thinning, or (D) thinning from below to varying BA on good sites.

Growth and Yield

According to Miscellaneous Publication 50 (U.S. Department of Agriculture Forest Service 1929), unthinned, natural loblolly pine-dominated sawtimber stands of comparable age and site indices (averaging between 80 and 100 feet at 50 years) have an average periodic annual increment of between 750 and 900 board feet (International 1/8-inch rule) per acre (U.S. Department of Agriculture Forest Service 1929). This study (table 3) showed a 65-year gross annual increment between about 350 and 600 board feet (International 1/4-inch rule) per acre, which is somewhat greater than the production of most uneven-aged naturally regenerated pine stands in this region (Baker and Murphy 1982) but only one-half to two-thirds of that reported in Miscellaneous Publication 50 (U.S. Department of Agriculture Forest Service 1929). However, note that this was for the first 65 years of the stands' lives—not a periodic increment from a single, fast-growing decade. In the decades prior to this, both Burton (1980) and Murphy and Farrar (1985) reported 10 to 20 percent higher volume growth from this study than that reported in U.S. Department of Agriculture Forest Service (1929) over comparable intervals.

Though few differences proved significant, a general trend of increasing sawtimber increments with increasing residual stocking (at least through the range used) was evident (table 3). This long-term trend has been reported by others (e.g., Curtis and others 1997) and explained conceptually (Zeide 2001). It would appear that greater site occupancy by larger numbers of trees eventually produces a larger quantity of wood, even though a portion of it may be lost to mortality. None of the treatments in this study approached the level of stocking that would have resulted in stand-level growth stagnation, nor were any uncut control plots established to approximate this threshold.

Growth started to decline in these sample plots as the study progressed due to a combination of lower stocking levels and the reduced increment of larger, older pines. Burton (1980) reported the highest periodic annual growth rates for these treatments when they were 35 to 40 years old, averaging about 875 board feet per acre (Doyle rule), with few differences between the densest and most open stands. A decade later, Murphy and Farrar (1985) reported that growth decreased to an average of just under 730 board feet per acre per year (Doyle rule), with the three stands with the lowest residual basal areas (55 and 70 square feet per acre) distinctly lower [averaging 611 board feet (Doyle) per acre per year] than the rest of the treatments. This difference was even more pronounced by the time the stands reached 65 years (about 500 board feet per acre per year, International 1/4-inch rule, data not shown).

Impacts of Thinning on Sawtimber Yield

Unless a stand is grossly overstocked, thinning is generally thought not to significantly affect long-term gross yields (Baldwin and others 2000, Smith 1986, Zeide 2001). Short-term increases in sawtimber production following thinning

Table 3—Potentially usable sawtimber yield (averaged by replicates) for each harvest treatment by year 65

Thin level[a]	Thin method	Site quality	Volume at age 65[b]	Total harvest[c]	Mortality loss[c]	Total gross yield[d]	Gross annual increment[e]
			thousand board feet per acre, International 1/4-inch rule				*board feet per acre*
55	Below	Good	12.0	17.0	1.9	31.0 a,b,c,d,e	476
70	Above	Medium	14.3	8.3	0.0	22.6 e	348
		Good	11.0	16.5	4.4	31.9 a,b,c,d,e	491
70	Below	Medium	15.0	9.0	0.0	23.9 d,e	368
		Good	17.5	14.1	0.0	31.6 a,b,c,d,e	486
85	Above	Medium	18.3	10.7	0.0	29.0 a,b,c,d,e	446
		Good	18.2	13.0	1.3	32.6 a,b,c,d	501
85	Below	Medium	18.2	10.4	0.0	28.6 a,b,c,d,e	440
		Good	15.8	16.5	2.5	34.7 a,b,c	534
100	Above	Medium	19.0	6.8	0.0	25.8 c,d,e	396
		Good	20.0	10.3	3.8	34.1 a,b,c	524
100	Below	Medium	18.8	9.4	2.5	30.7 a,b,c,d,e	472
		Good	19.8	8.8	1.6	30.2 a,b,c,d,e	465
115	Below	Good	21.3	12.3	5.4	39.0 a	600
130	Below	Good	26.0	6.4	5.4	37.8 a,b	581
INC	Above	Medium	18.7	5.9	0.2	24.8 c,d,e	381
		Good	20.2	7.5	1.3	28.9 a,b,c,d,e	445
INC	Below	Medium	19.4	6.8	0.2	26.5 b,c,d,e	407
		Good	21.5	12.4	1.1	35.0 a,b,c	539
JUD	Both	Medium	15.9	11.3	0.0	27.2 a,b,c,d,e	418
		Good	14.4	14.6	3.4	32.4 a,b,c,d	499

[a] Numbers represent postharvest basal area (square feet per acre) targets; INC = thin to increasing basal area; JUD = best judgment thinning. See text for detailed descriptions of the thinnings.

[b] Volume at age 65 = standing (live) board-foot volume at stand age = 65 years, in thousands of board feet per acre, International 1/4-inch rule.

[c] Total harvest = cumulative amount of harvested sawtimber from year 25 to year 65; mortality lost = cumulative volume of sawtimber lost to natural causes from year 25 to year 65.

[d] Total gross yield = volume at age 65 + total harvest + mortality lost. Total gross yield values with the same letters are not significantly different at $\alpha = 0.05$ (tests were conducted on transformed data but reported for untransformed, Tukey's HSD test).

[e] Gross annual increment = total gross yield/65 years, in board feet per acre (International 1/4-inch rule).

are possible, especially in younger stands when thinning accelerates individual tree growth, thereby allowing pines to reach the minimum size threshold for sawtimber faster. The results of this study generally support this interpretation within site-quality limitations (table 3). Medium-quality sites generated between 22 and 31 thousand board feet (mbf) per acre over the duration of this study. Good sites were noticeably more productive, yielding a gross sawtimber range of 29 to 39 mbf per acre during the study. Variability in harvest implementation and mortality introduced considerable noise into the treatments, obscuring some of the differences between treatments. Broadly, the most heavily thinned stands (regardless of site quality) had somewhat lower gross yields (table 3), largely due to suboptimal stocking of the sites as the stands aged.

Thinning Removals

Over the years, the stands maintained at the lowest residual basal areas (those ≤85 square feet per acre) typically produced the greatest harvest of pine sawtimber, with the 55-square-feet-per-acre residual treatment producing just over 17 mbf per acre (table 3). Conversely, those treatments retaining the most basal area yielded the least harvested sawtimber during this period. Differences were significant between only a few of the treatments because of mortality-related losses and some variability in initial conditions between treatments. These differences would have become more pronounced if the study had been continued even longer, as the heaviest thinning treatments were too understocked to reach minimum basal area harvest thresholds. For example, by year 65 the 55-square-feet-per-acre treatment, with a mere 17 trees per acre, had failed to reach the 50-square-feet-per-acre target in consecutive treatment cycles.

Site quality also dramatically influenced sawtimber production, with good sites averaging 25 to 50 percent more harvested yield than medium sites. An exception to this pattern was for the 100-square-feet-per-acre treatment thinned from below, in which the medium site had 9.4 mbf per acre cut during the study compared to 8.8 mbf per acre from the good sites. Since both stocking and mortality patterns between these treatments were similar, the most logical explanation for the difference was inconsistency in harvesting, resulting in a greater proportion of unharvested volume on the good site (table 3).

Thinning and Mortality

A combination of small plots, coupled with the lack of an unthinned control, makes it difficult to glean much from the mortality records of this study. Due to a high level of variability, none of the treatments produced statistically significant differences in cumulative mortality, even though no mortality was reported for some treatments, while others generated cumulative losses of up to 5.4 mbf per acre (table 3). In general, the more heavily thinned stands experienced lower natural mortality than those sustaining higher basal areas. Comparable research in other southern pine stands has also shown dramatic declines in mortality following thinning (Andrulot and others 1972, Guttenberg 1954). In addition, the residual pines in thinned stands also tend to be less vulnerable to insect and disease problems, so long as they are not extensively wounded during harvest (Brown and others 1987, Chaiken 1941) or are too spindly to respond quickly to release, thus making them vulnerable to ice damage (Guttenberg 1954).

MANAGEMENT IMPLICATIONS

As in all cases, deciding on a management regime for even-aged pine stands of natural origin in the Midsouth depends on the objectives of the landowner, the nature of the site, and initial forest conditions. Long-term research studies that consider different silvicultural treatments as well as site and species potential are invaluable tools for guiding the forest manager towards the best decision.

Timber Production

Fundamentally, the rapid growth expressed in these treatments has significant implications for regional timber production. As expected, heavily thinned stands had more sawtimber cut and less of a residual stocking than treatments geared towards a higher target basal area. From a management perspective, this range represents a gradient of opportunity based on economics and nontimber attributes. For instance, landowners primarily interested in monetary returns from timber sales would be best served by the heaviest thinning regimes, which produce more harvested timber earlier in the history of the stand. Not only are more trees removed, but the residual experiences more release, thus permitting individual pines to grow more rapidly. Given the past strength of the sawtimber market in southern Arkansas and northern Louisiana, the diameter threshold between sawtimber and lower value products becomes critical. The sooner a pine reaches sawtimber merchantability, the quicker higher returns can be realized.

Another consideration is the timing of the initial thinnings. When this study was established in the middle of the 20th century, it was not uncommon to let naturally regenerated pine stands grow unthinned until they reached merchantable size. In this case, thinning was not started until they were 20 to 25 years old (even on good sites). However, considerable evidence has since accumulated on the value of early precommercial thinning to reduce the extremely high stocking found in most naturally seeded pine stands (e.g., Brender 1965, Burton 1982, Mann and Lohrey 1974). When properly timed, precommercial thinning occurs after canopy closure (to allow for self-pruning) but before competition becomes so intense to result in stagnation and mortality. Often implemented when the stand reaches 5 to 15 years old, precommercial thinning accelerates the growth and reduces the number of years it takes to reach sawtimber size.

A radical example of precommercial thinning can be seen in the “Sudden Sawlog” study (Baldwin and others 1998, Burton 1982, Zahner and Whitmore 1960). In this study, an old field near the Crossett Experimental Forest was planted with unimproved 1-0 loblolly pine seedlings to a density of about 1,100 trees per acre. Four thinning strategies were implemented, with thinnings starting between 9 and 12 years of age and some treatments reduced to as low as 100 crop trees per acre (Burton 1982). The three most dramatic treatments (the fourth being a traditionally thinned control, starting at age 12) produced stands of average diameters of 17 to 18 inches at age 33 years. The use of precommercial thinnings dramatically reduced the time it took the treatments to reach merchantable size, with sawtimber-sized average stand diameters appearing at 15 to 18 years, or approximately half of the time it took the stands in this study. However, limbiness, juvenile wood production, bole taper, and ice or wind damage are major challenges for radically thinned pine stands (Baldwin and others 2000, Bragg and others 2003, Burton 1982).

Quantity vs. Quality

Foresters have long recognized that individual trees grow most rapidly in diameter when they have few neighbors, but that wide spacing does not always optimize the potential of a piece of land. In other words, maximizing tree growth does not necessarily maximize stand growth. Understocked stands are a management concern when the primary objective is total fiber production (Baker and Shelton 1998a), although there is good evidence that for rapid sawtimber production, such conditions may be advantageous (Burton 1977, Burton and Shoulders 1974). It is also important to keep in mind that the dollar value of a pine is nonlinearly related to size, as there typically is a dramatic step increase in value when the tree crosses the threshold from pulpwood size-only to poles or sawlogs (Burton 1977, Prestemon and Buongiorno 2000). Thus, determining the value of silvicultural treatments is not as straightforward as simply calculating volumetric bole increment.

In young, even-aged pine stands, rapid stem growth is best sustained by periodic thinnings that release sufficient resources such that self-thinning-based growth reductions and mortality are minimized between their applications. Fast growing trees, however, have different physiological properties that should be considered when thinning regimes are designed. For example, widely spaced and unpruned young stands (natural or planted) result in trees with coarser and more abundant branches, a higher proportion of less desirable juvenile wood, and more bole taper (Baldwin and others 2000, Burton 1982, Clark and others 2004). On average, rapidly grown loblolly pines produce less dense wood with lower bending strength than slower growing individuals (Paul 1932, see also review in Bendtsen 1978). Indeed, logs with a greater core of juvenile wood are decidedly less valuable than those that have mature wood (Clark and others 1994, Guilkey and Nelson 1963, Paul 1932). As a result, Guldin and Fitzpatrick (1991) found that uneven-aged loblolly pine stands produced better quality sawlogs on average than even-aged plantations (and, presumably, thinned even-aged natural stands), although it took longer to produce these logs.

Mortality Patterns and Thinning

Thinning is also known to help reduce density-dependent mortality. For example, Guttenberg (1954) and Andrulot and others (1972) reported significantly greater mortality in unthinned stands than those that were thinned, attributable largely to suppression and related forest health problems. Guttenberg (1954) also reported a shift in the cause of mortality, with ice storms claiming over twice that of competition (59 vs. 28 percent) in the thinned plots, whereas competition took 11 times (89 vs. 8 percent) that lost to glazing in unthinned stands. A recent paper (Bragg and others 2003) echoed this conclusion in a review of many studies that pointed to a greatly pronounced risk of glaze-related losses in recently thinned timber.

In general, thinning improves the health and vigor of the residual pines by permitting individuals with stunted crowns to recover and even thrive (Baker and Shelton 1998b, Guttenberg 1954). High-vigor loblolly pine are less vulnerable to insect pests such as the southern pine beetle (*Dendroctonus frontalis*) (Belanger 1980, Brown and others 1987), and once they have adjusted to the lower stand densities and increased in size, can better tolerate severe winds or ice accumulation (Bragg and others 2003, Zeide and Sharer 2000). However, thinning can lead to additional mortality in residual loblolly pine if they are excessively damaged by the logging, or if poorly formed or suppressed trees are left behind (Belanger 1980, Chaiken 1941).

CONCLUSIONS

One of the greatest difficulties in assessing the success of silvicultural systems is the ability to conduct long-term studies. Rarely do the appropriate combinations of institutional interest and commitment, vegetative conditions, and market forces coincide. Thus, thinning studies that span decades are of particular value, even if their original implementation leaves something to be desired. This study of different thinning techniques in loblolly pine stands of natural origin provided a long-term assessment of stand growth and yield for typical sites in the Upper West Gulf Coastal Plain Province of southern Arkansas and northern Louisiana. Coupled with other similar efforts, a clearer picture of the implications of thinning has been developed, allowing for a range of recommendations to be made based on landowner preferences.

In this portion of the Midsouth, conventional wisdom on even-aged loblolly and shortleaf pine stands suggests a 35- to 45-year rotation, depending on site quality and management objectives (Burton 1980, Zeide and Sharer 2000). Industrially oriented forest landowners typically intensively manage their improved pine plantations on a 25- to 30-year sawtimber rotation, driven by the goal of maximizing return on investment (Arano and Munn 2006, Hotvedt and Straka 1987). Even though these silvicultural prescriptions have a reasonable basis in their application, they should not necessarily be considered the only options available to forest managers. One of the greatest benefits of the 40+ years of growth-and-yield information presented here is the ability to use this long-term data to compare different thinning treatments for not only their fiber productivity, but to understand the nature of the stands during their development and at the end of the study. This perspective can then be matched to the objectives of the landowner(s).

After all, not every landowner is interested in the same end product, and hence may not maximally realize their management goals under a one-size-fits-all prescription. For instance, Burton (1980) recommended heavy early thinnings and aggressive thinning from below and competition control to promote sawtimber production, while suggesting a higher residual density strategy for those interested in wood fiber production. A landowner interested in high-value pole production would focus on straight, relatively limb-free crop trees, perhaps through pruning or high-residual basal areas. By necessity, this represents a management strategy applied differently with different goals than one focused on optimizing sawtimber or fiber production (Burton 1977, Zeide 2001). Furthermore, though they may appreciate the income generated from managing their timber, many landowners are also interested in attributes such as aesthetics, recreation, wildlife habitat, carbon storage, deferred income, or leaving a legacy for their descendants (Hoover and others 2000, Johnson 1995, Zeide 2001), all of which will affect long-term stand structure and composition.

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