Effects of Alternative Thinning Regimes and Prescribed Burning in Natural, Even-Aged Loblolly-Shortleaf Pine Stands: 25Year Results

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ABSTRACT: *In southeastern Arkansas, pine growth was monitored for 19 yr after mechanically strip thinning a dense, naturally regenerated, even-aged stand of 6-yr-old loblolly pines (*Pinus taeda *L.) and shortleafpines (*P. echinata *Mill.) that averaged 16,600 stems/ac. Prescribed winter burns were conducted biennially between ages 9 and 20 yr and at 24 yr. Commercial thinnings during the 17th and 23rd growing seasons left a residual stocking of either 85 ft²/ac or 200 crop trees/ac (75 ft²/ac) in merchantable-sized (>3.5 in. dbh)pines on plots that wereprecommercially thinnedand on plots that were not. Precommercial thinning enhanced pine growth in dbh and sawlog volume through 25 yr. Because of increased sawlog production, present net value averaged highest on plots that were precommercially thinned at age 6 then commercially thinned during the 17th yr to 200 crop trees/ac and during the 23rd yr to 7.5 ft²/ac. In the year following prescribed winter burns, both dbh growth and volume growth were reduced by about one-half when crown scorch was 75%. South. J. Appl. For. 27(1):18–29.*

Key Words: Crown scorch, even-aged management, mechanical strip thinning, natural regeneration, prescribed burning, loblolly pine, *Pinus taeda* L., shortleaf pine, *Pinus echinata* Mill., Upper Coastal Plain.

In the southeastern United States, a major physiographic subregion is the Upper Coastal Plain, where loblolly and shortleaf pines (*Pinus taeda* L. and *P. echinata* Mill.) predominate (Baker and Langdon 1990, Lawson 1990). In the West Gulf Region, which extends from the Mississippi River into East Texas and southeast Oklahoma, loblolly and shortleaf pines occur naturally in pure stands or mixed with hardwoods. From the standpoint of forest management, natural regeneration of loblolly and shortleaf pines is considered successful on cutover sites when density of pine seedlings averages more than 1,500 stems/ac the first year after establishment or more than 700 stems/ac by the third growing season (Grano 1967). Milacre stocking of these natural seedlings should range from 40% (Campbell and Mann 1973) to 60% (Trousdell 1963).

An often cited disadvantage for natural, even-aged management of southern pines is the inability to control density at the time of establishment. Loblolly pines, for example, tend to produce good (≥40,000 sound seeds/ac) seed crops during 15 out of 20 yr on the Upper Coastal Plain of southeastern Arkansas (Cain and Shelton 2001). When these wind-disseminated seeds fall onto receptive sites during good seed years, dense even-aged stands usually result.

Precommercial thinning of loblolly and shortleafpines is recommended to shorten the rotation of crop trees in overly dense, natural stands and to reduce the risk of loss by fire, insects, diseases, and weather. Generally, that recommendation only applies to stands where density exceeds 5,000 stems/ac or where live-crown ratio of the dominant pines is expected to be less than 35% at the time of the first commercial thinning (Mann and Lohrey 1974). When assessing the need for precommercial thinning in dense natural pine stands, the number of dominant and codominant pines is a more important criterion than total density (Cain 1993).

When a landowner's objective is sawlog production, precommercial thinning of dense natural pine regeneration has more merit than if a pulpwood rotation is planned. Moreover, a variety of commercial thinning regimes can be adopted to enhance early sawlog production in even-aged natural stands. To that end, one objective of this study was to evaluate four thinning treatments and an unthinned control

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relative to the growth of naturally regenerated loblolly and shortleaf pines. Precommercial strip thinning was applied when the pines were 6 yr old. That was followed by commercial thinnings during the 17th and 23rd growing seasons. Results through 25 yr are reported here. Because prescribed burning is an important part of managing the southern pines, a second objective in this study was to investigate the effects of a prescribed winter burn on pine growth and on understory vegetation.

Methods

Study Area

The study is located on the Crossett Experimental Forest in southeastern Arkansas. Soils are Providence and Bude silt loams-Typic and Glossaquic Fragiudalfs, respectively (USDA 1979). Site indices at 50 yr average 90 ft for loblolly pines and 85 ft for shortleaf pines.

Within a mature pine stand, a 10 ac strip (330 ft east-west by 1,320 ft north-south) was clearcut and root-raked in 197 1. Residual slash was piled and burned for the establishment of a research planting area. The area was maintained for planting by periodic mowing through 1973, but planting was never done. Between 1972 and 1974, the clearcut naturally regenerated because it was bounded on the west by a mature stand of loblolly and shortleaf pines. The area remained undisturbed until 1979 when an inventory revealed an average of 16,600 pines/ac in seedling (20.5 in. dbh) and sapling (0.6 – 3.5 in. dbh) size classes. Although natural seeding may have occurred over a period of 2 to 3 yr until the receptive seedbed disappeared, a count of annual growth rings at groundline indicated that the pines were 6 yr old in the autumn of 1979, when species composition was 70% loblolly and 30% shortleaf pines.

Cultural Treatments

Precommercial Thinning

In October 1979, twelve 0.4 ac plots were established within the 10 ac clearcut on areas with the most uniform pine density and milacre stocking. Plots measured either 132 ft by 132 ft or 122 ft by 143 ft and were located throughout the 10 ac strip. Six plots were randomly selected for precommercial thinning, and the other six were retained as unthinnedcontrols. Thinning was accomplished with a heavy-duty rotary-mower attached to an industrial-sized wheeled tractor. Plots were strip-thinned by mowing 12-ft-wide swaths that alternated with I-ft-wide uncut strips. Mowing was facilitated by the intensive site preparation from 8 yr earlier in which stumps and other obstructions had been removed. A time study indicated that pines on the entire 10 ac strip could have been precommercially thinned by this technique for less than $251 ac, which was comparable to mechanical precommercial thinning costs ($33/ac) reported across the South in 1979 (Dubois et al. 1999).

Prescribed Burning

In January 1983, when the pines were 9 yr old, a prescribed burning program was initiated on all 12 plots for fuel hazard reduction and for control of nonpine vegetation. Three additional 0.4 ac plots were established in residual unthinned areas before burning and were retained as untreated controls (noprecommercial thinning and no burning). Plot dimensions for these checks were the same as for the original 12 plots. Prescribed bums were repeated as follows: February 1985, March 1989, February 1991, February 1993, and February 1998. Of the original 12 plots, the six that were not precommercially thinned were also prescribe burned in March 1987; burning was deferred on the six precommercially thinned plots that year because the two earlier bums resulted in undesirable crown scorch.

Commercial Thinning

Pines on each of the 12 original 0.4 ac plots were commercially thinned during the 17th (1990) and 23rd (1996) growing seasons, in accordance with the following treatments:

- *Conventional* thinning-Merchantable-sized pines (>3.5 in. dbh) were thinned from below to a residual basal area of 85 ft^2/ac. There are three replications on prethin/burn plots (PT/85BA) and three replications on no-prethin/bum plots (NPT/85BA).
- *200 crop trees/ac or* 7.5 *ft^2/ac*—All merchantable-sized pines were harvested with the exception of 200 crop trees/ac, but residual basal area was not to exceed 75 ft^2/ac. There are three replications on prethin/burn plots (PT/75BA) and three replications on no-prethin/burn plots (NPT/75BA).
- Control-There are three replications with no prescribed thinning and no prescribed burning. To protect these plots from loss by destructive agents, a salvage cut was necessary in 1997 because of a bark beetle infestation on two control plots (38 pines/ac were salvaged).

The two commercial thinnings (1990 and 1996) were accomplished by contract vendors. Both employed three two-man crews and one rubber-tired tractor with a self-contained grapple and pallet to forward 4 ft lengths of pulpwood ricks to a loading point. One man on each crew operated a chain saw and the other man hand-stacked the pulpwood bolts for grapple-loading onto the forwarder. Following the first commercial thinning, density of residual submerchantable-sized pines (<3.6 in. dbh) was equalized across all commercially thinned plots by chain-saw felling to 10 ft^2/ac of basal area. In spring 1991, residual hardwoods (>0.5 in. dbh) on all commercially thinned plots were controlled by stem injection of glyphosate herbicide (50% dilution with water). Hardwoods on control plots were left untreated.

Measurements

During the course of each prescribed bum, ocular estimates of flame length were recorded by treatment. These estimates were used to calculate fireline intensity according to Byram (1959). Weather and fuel conditions were recorded at the time of each bum, but only results from the 1998 burn (24 yr) are reported here.

When pines were 12 yr old, 40 dominant and/or codominant pines per interior 0.2 ac plot (200 trees/ac) were selected as future crop trees on all 15 plots and were tagged for identification. Crop trees were selected on the basis of crown class, tree quality, and spacing. More loblolly pines (94%) than shortleaf pines (6%) were chosen as crop trees because fewer shortleaf had achieved dominant or codominant crown status by age 12. From age 12 to 16 yr, total height (to 0.1 ft) and dbh (to 0.1 in.) measurements were taken biennially on the 40 crop pines per plot. At stand ages 18, 20, 23, and 25 yr, dbh measurements (to 0.1 in.) were taken on all crop pines. At 18 yr, a 25% sample of these crop pines was selected on each plot for measurement of total height (to 0.1 ft), height to live crown (to 0.1 ft), and crown width at the widest axis and perpendicular to that axis (to 0.1 ft). Height and crown measurements were repeated on these sample pines at ages 20, 23, and 25. Selection criteria for these sample pines were as follows: (1) An equal number of sample trees was chosen from each dbh class per plot. (2) The number of sample trees was proportional to the species represented (loblolly or shortleaf) on any one plot. (3) Initially, sample trees were free from obvious defects (i.e., bole fusiform, forked mainstem, broken tops, bark beetle infestations, or logging damage). An ice storm in 1994 resulted in broken tops on 4 out of 150 sample crop pines, but only one of these had severe enough damage to be dropped from analyses.

Following commercial thinning, residual noncrop pines and hardwoods that were larger than 0.5 in. dbh were counted by 1 in. dbh classes on each of the 15 plots, using the same inventory schedule as crop pines. Inventories on interior 0.2 ac subplots were kept separate from the 0.2 ac isolations.

In autumn 1997, ocular estimates of percent ground cover were made to the nearest 5% for herbaceous vegetation (grass, forbs, vines, and semiwoody plants) and woody vegetation(shrubs and hardwoods) within five, systematically spaced 0.001 ac sample quadrats on each interior 0.2 ac subplot. Seedling-sized woody rootstocks were counted on these same quadrats. Counts were made of sapling-sized nonpine woody stems within five, systematically spaced 0.0 I ac sample quadrats per interior plot. In autumn 1998, one growing season after a prescribed winter burn, estimates of percent ground cover and counts of nonpine seedlings and saplings were repeated on all plots, as previously described.

Within 4 wk after the February 1998 prescribed winter burn, crown scorch was ocularly estimated on all crop pines by two individuals standing at different angles from each tree. Crown scorch is defined as the browning of needles in the crown of a tree and is caused by heat from a tire (McPherson et al. 1990). Scorch estimates were made to the nearest 10% between the values of 10% and 90%. Below 10% and above 90%, crown scorch was assessed to the nearest 2%. At the same time, dbh's were measured to 0. I in. on each tree.

Volumes for crop pines and merchantable-sized noncrop pines were computed according to local volume equations (Farrar et al. 1984). Pulpwood volumes were inside bark to a 3.5 in. top, inside bark. Sawlog volumes were inside bark to a 7.5 in. top, inside bark. On a plot-by-plot basis, total volume production was calculated from pines marked to cut during two commercial thinnings, plus (1) salvage following an ice storm at 20 yr, (2) salvage following insect losses at 24 yr, and (3) volume in standing pines at 25 yr.

Data Analysis

For crop pines 18 yr and older, regression equations were developed to predict height, crown length, and crown width from the dbh of sample trees for each treatment. When plot means were calculated for crop pines, predicted values were calculated from these equations for all unmeasured crop pines. Analysis of variance (ANOVA) was used to compare mean quadratic dbh, total height, volume/tree, crown width, and live-crown ratio of crop pines among the four commercial thinning treatments and the unthinned control. Similarly, ANOVA's were used for comparing the density and stocking of sapling hardwoods, as well as pine densities, basal area, and volume production among treatments. Percent data were analyzed following arcsine transformation. Statistically significant differences (a = 0.05) among treatment means were isolated by orthogonal contrasts.

Nonlinear regression analyses were used to predict reductions in crop-pine growth during the 25th yr based on dbh measurements after the prescribed burn at age 24 and the estimated crown scorch. Indicator variables were used to test for effects of precommercial and commercial thinning. The reported fit index for these equations is analogous to r^2 (coefficient of determination).

Present net value was the difference in discounted costs and discounted returns (Duerr 1960) through 25 yr at rates of 4%, 7%, and 1 0%, which were used to reflect low, medium, and high values. Present net value was based on the following assumptions. The cost of precommercial thinning in 1979 was $33.22 (Dubois et al. 1999). Prescribed burning costs were also derived from Dubois et al. (1999), by year of treatment. These costs ranged from $4.12/ac in 1982 to $16.58 in 1998. Costs for timber cruising and marking trees for harvest were $10.77/ac in 1989 and $15.78/ac in 1995 (Dubois et al. 1999). Costs also included $39.00/ac for mechanical site preparation in 1973 (Straka et al. 1989), annual management costs of $1.08/ac for fire protection (Straka et al. 1989), and $1.15/ac for property tax (Hickman 1989). Hardwood control cost was based on stem density and the retail price of herbicide at the time of treatment in 199 1; costs were $8/ac for precommercially thinned plots and $20/ac for unthinned plots, excluding the control.

Product prices in southern Arkansas were obtained from the *Forest Marketing Bulletin*, published by Arkansas Cooperative Extension Service, Little Rock, AR. Prices for pine pulpwood were $14/cord in 1989 (third quarter), $22.801 cord in 1994 (first quarter), $18.13/cord in 1995 (thirdquarter), $2 1.76/cord in 1997 (third quarter), and $14.70/cord in 1998 (third quarter). Full pulpwood prices were used for the two commercial thinnings, but prices were reduced by one-half for the salvage operations conducted in 1994 and 1997. Pine sawlog stumpage averaged $238/MBF (International 1/4-in.) in the third quarter of 1998. Harvested or standing volumes were used to convert these prices to monetary returns.

Results

Crop Pine Response to Thinning Treatments

At age 25, crop pines on precommercially thinned plots averaged more than 1 in. larger ($P \leq 0.0034$) in dbh compared

Table 1. Mean size of crop pines in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas at age 25.

Thinning treatments and orthogonal contrasts	Quadratic dbh (in.)	Height (ft)	Volume (ft^3/tree)	Crown width (ft)	Live-crown ratio (%)
	Mean tree size				
1. Control	8.45	60.10	9.32	12.27	28.79
2. No prethin, commercial thin to 85 ft^2/ac	8.64	60.64	9.75	16.00	37.21
3. Prethin at 6 yr, commercial thin to 85 ft^2/ac	9.73	60.22	13.31	18.51	41.02
4. No prethin, commercial thin to 75 ft^2/ac	9.68	60.92	13.07	18.10	39.73
5. Prethin at 5 yr, commercial thin to 75 ft^2/ac	10.94	62.15	17.77	22.13	47.46
Mean square error	0.1246	1.1549	1.5336	0.4841	0.2829
$P > F$*	0.0001	0.2164	0.0001	0.0001	0.0001
Treatment contrasts	Probability of a greater F*				
1 vs 2 + 3 + 4 + 5	0.0002	0.2307	0.0004	0.0001	0.0001
2 + 3 vs 4 + 5	0.0003	0.1058	0.0003	0.0001	0.0001
2 vs 3	0.0034	0.6488	0.0055	0.0013	0.0001
4 vs 5	0.0014	0.1908	0.0009	0.0001	0.0001

* The probability of obtaining a larger F-ratio under the null hypothesis.

to crop pines on plots that were commercially thinned without prethinning (Table 1). Similarly, crop pines on plots thinned to a basal area of 75 ft^2/ac were 12% larger (P = 0.0003) than those thinned to 85 ft^2/ac. Lastly, crop pines across all thinned plots were 15% larger (P = 0.0002) in dbh at 25 yr compared to those on control plots.

Twelve-year trends (age 13 to 25 yr) in periodic diameter growth of crop pines are illustrated in Figure 1. Before the

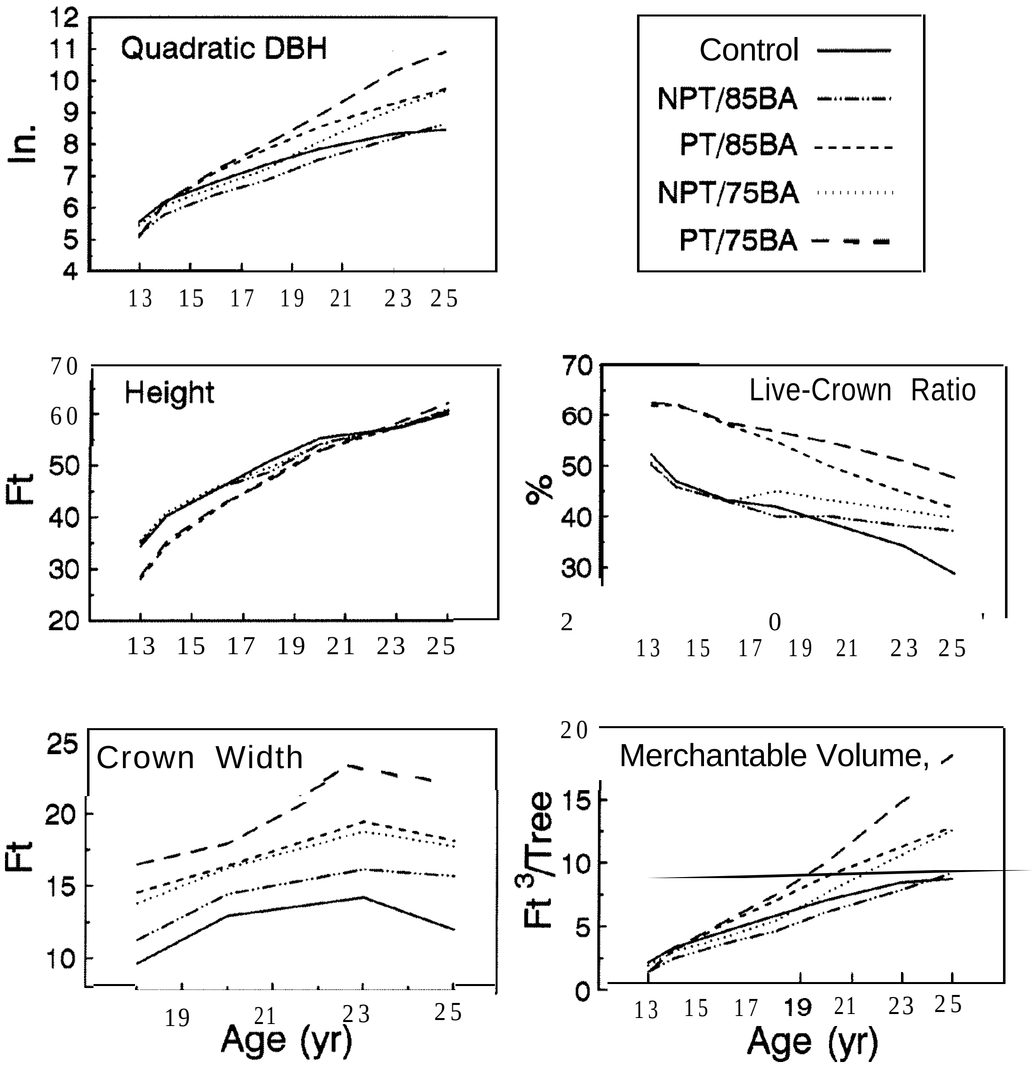

Figure 1. Long-term trends in crop pine development relative to alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas. Abbreviations are: NPT = not precommercially thinned; PT = precommercially thinned; 85BA = residual basal area of 85 ft^2/ac after commercial thinning; 75BA = residual basal area of 75 ft^2/ac after commercial thinning.

first commercial thinning, mean diameters of crop pines on control plots were comparable to other treatments but rapidly declined during the next 12 yr as intraspecies competition reduced growth. As would be expected, commercial thinnings improved diameter growth of residual crop pines through time.

Mean total height of crop pines averaged 60.8 ft at 25 yr (Table 1), and neither precommercial thinning nor commercial thinning resulted in taller pines (P = 0.2164). In fact, pine heights tended to equalize through time (Figure 1). One noticeable trend was a slight reduction in height growth on control plots between 20 and 23 yr for no apparent reason.

Because thinnings improved diameter growth, crop pine volumes were significantly different (P = 0.0001) among treatments at 25 yr (Table 1). As a result of precommercial thinning at age 6, mean crop tree volumes at age 25 increased by 31% (***P*** = 0.0055) and 36% (*P* = 0.0009) on plots thinned to 85 ft^2/ac and 75 ft^2/ac, respectively. Likewise, thinning to 75 ft^2/ac improved (***P*** = 0.0003) mean tree volumes by 34% over the 85 ft^2/ac treatment. When compared to unthinned controls, thinning treatments produced 45% more (P=0.0004) volume per tree at 25 yr. During the last 12 yr, improved volume growth was most apparent on plots that were precommercially thinned at 6 yr and on plots commercially thinned to 75 ft^2/ac (Figure 1).

As would be expected, crop pines on thinned plots had substantially wider crowns (***P*** = 0.0001) and larger live-crown ratios (***P*** = 0.0001) compared to those on unthinned controls (Table 1). Moreover, precommercial thinning increased (***P*** $\leq$ 0.00 13) crown size within commercial thinning treatments. Most noteworthy was the mean 29% live-crown ratio of crop pines on control plots at 25 yr. Past research suggests that diameter growth of dominant loblolly pines cannot be adequately sustained once live-crown ratio drops below 40% (Chapman 1953).

Diameter distributions for all merchantable-sized pines and the largest 100 crop pines/ac are illustrated in Figure 2 by thinning treatments at age 25. Diameter growth gains were most apparent when stocking was first reduced by precommercial thinning followed by commercial thinning to 75 ft^2/ac. The least effective thinning treatment in terms of diameter growth gains was the conventional technique of commercial thinning to 85 ft^2/ac without the benefit of precommercial thinning.

Pine Density, Basal Area, and Volume Production

As a result of natural mortality, merchantable pine density on unthinned control plots declined from more than 800 stems/ac at 18 yr to less than 700 stems/ac at 25 yr (Figure 3). Since survivors on check plots were principally dominant and codominant trees, 99% had attained merchantable size (23.6 in. dbh) by age 25 (Table 2). With 667 trees/ac, control plots had 200% more (***P*** = 0.000 1) pines of merchantable size than commercially thinned plots. There were no significant differences (***P*** $\geq$ 0.3334) in mean densities of merchantable-sized pines among the other treatments, but plots thinned to 75 ft^2/ac had six times more (***P*** = 0.02 13) pine saplings than plots thinned to 85 ft^2/ac. The radical decline in pine sapling density on thinned plots between yr 16 and 18 (Figure 3) was the result of hand felling to equalize residual basal areas in submerchantable size classes among treatments following the first commercial thinning.

At 25 yr, merchantable pine basal area averaged 170 ft^2/ac on control plots versus a mean of 98 ft^2/ac on thinned plots (Table 2), and the difference was significant (***P*** = 0.0001). Among commercially thinned plots, there were no differences (***P*** $\geq$ 0.2556) in mean basal area for these pines. Merchantable pine basal area peaked on control plots at age 23 with 176 ft^2/ac (Figure 3). In contrast, variation in basal area on thinned plots was associated with the commercial thinning treatments during 17 and 23 yr.

Total merchantable volume production through 25 yr differed by only 341 ft^3/ac across all thinning treatments (Table 2), and that difference was statistically nonsignificant (***P*** = 0.5423). However, residual sawlog (>9.5 in. dbh) volume at 25 yr was substantially improved by precommercial thinning 19 yr earlier. Precommercial thinning resulted in a 127% increase (*P* = 0.0035) in sawlog volume on plots commercially thinned to 85 ft^2/ac and a 45% increase (***P*** = 0.02 14) on plots commercially thinned to 75 ft^2/ac (Figure 4). After two commercial thinnings, plots thinned to 75 ft^2/ac had produced 392 ft^3/ac more (***P*** = 0.0058) sawlog volume (50% increase) than plots thinned to 85 ft^2/ac.

Prescribed Burning Effects

Fuel and weather variables are presented at age 24 yr, when the most recent prescribed burns were conducted (Table 3). Mean fireline intensities ranged from 23 to 148 btu/ft-sec, with the highest intensities on precommercially thinned plots. As a result, 3 1% of crop pines on precommercially thinned plots were crown scorched versus only 14% on plots that were not precommercially thinned. For pines that were crown scorched, the mean degree of scorch was as follows: 18% on NPT/85BA, 24% on PT/85BA, 17% on NPT/75BA, and 16% on PT/75BA. According to Byram (1959), a fireline intensity of 160 btu/ft-sec is probably near the maximum for headtires or flanking tires when used in prescribed burning work.

We used data from all thinned treatments to develop an individual-tree model to predict tree growth from tree size and severity of crown scorch. The equation predicting basal area growth of individual trees during the growing season after the February 1997 prescribed bum follows:

$$\text{AB} = \exp(4.367 + 1.299B \quad 0.01092S - 0.2344C) \quad (1)$$

where AB is the basal area growth during the 25th growing season (ft^2/tree), exp is the exponential function, ***B*** is the basal area immediately after the bum (ft^2/tree), *S* is the percentage of crown scorch for the tree, C is an indicator variable for the basal area after commercial thinning (0 for 75 ft^2/ac; 1 for 85 ft^2/ac), and the regression coefficients were fitted by nonlinear regression. The precommercial thinning treatment was also tested in the full model using an indicator variable but was eliminated because it was not significant (***P*** = 0.2899). For Equation(l), there were 43 1 observations, fit index was 0.43, root mean square error was 0.010, and all regression coefficients were significantly different from zero at ***P*** = 0.000 1. A similar equation was developed for the volume growth of individual trees as follows:

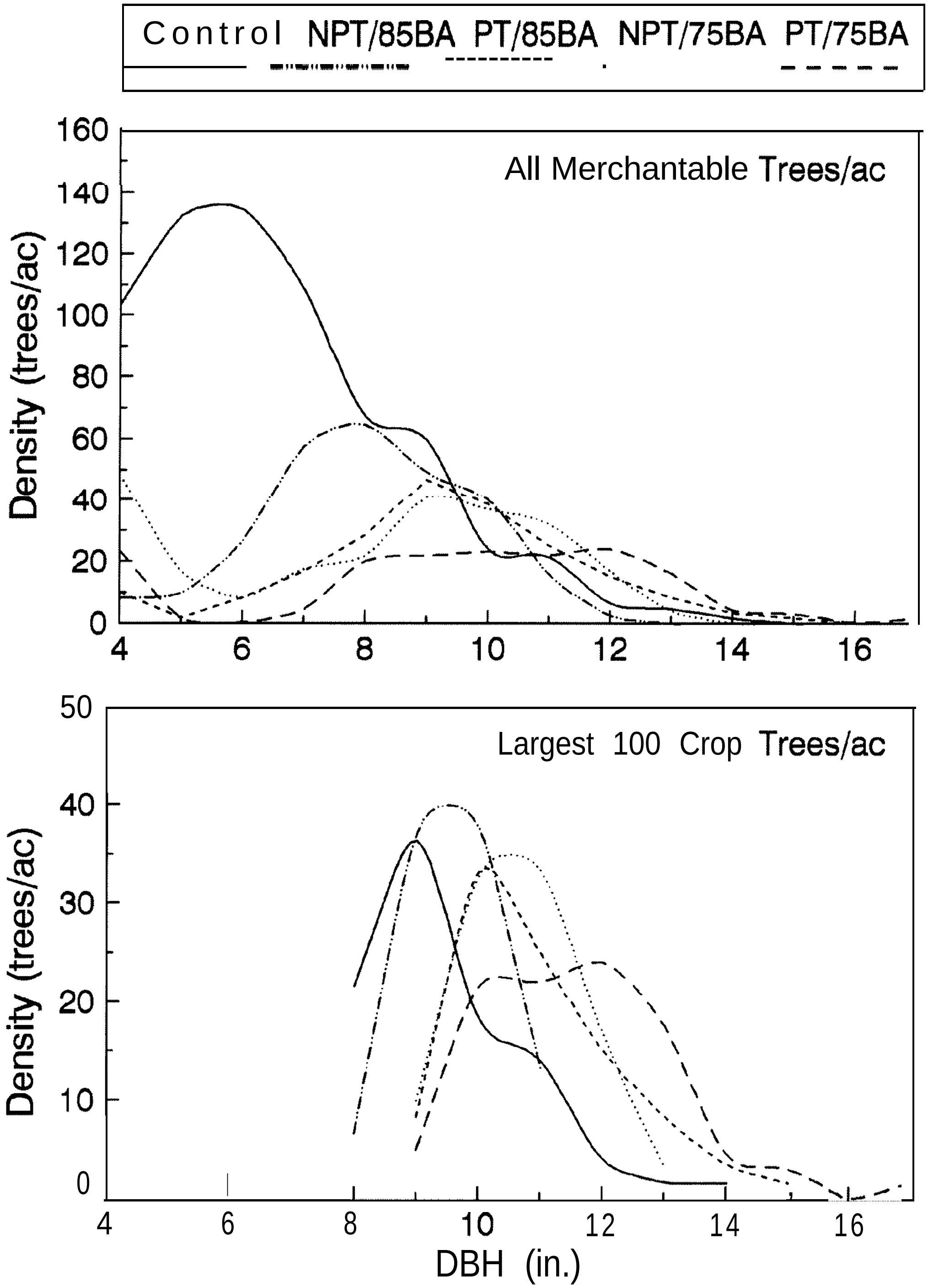

Figure 2. Diameter distribution of all merchantable-sized pines and the largest 100 crop pines/ac relative to alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas at 25 yr. Abbreviations are: NPT = not precommercially thinned; PT = precommercially thinned; 85BA = residual basal area of 85 ft²/ac after commercial thinning; 75BA = residual basal area of 75 ft²/ac after commercial thinning.

$$\Delta V = \exp(-0.9426 + 1.401B - 0.01087S - 0.2436C) \quad (2)$$

where ΔV is the merchantable volume growth during the 25th growing season (ft^3/tree), and the other terms are as previously defined. The precommercial thinning treatment was also tested in the full model but was eliminated because it was not significant (P = 0.3467). For equation (2), fit index was 0.47, root mean square error was 0.33, and all regression coefficients were significantly different from zero at $P \leq 0.0002$.

Equation (1) can be used to predict either basal area or diameter growth. For example, the mean tree (9.8 in. dbh) of plots commercially thinned to 75 ft^2/ac was predicted to grow 0.23, 0. 18, 0. 13, and 0.10 in. dbh the first growing season after controlled burning when percent crown scorch was 0, 25, 50, and 75%, respectively. Similar values for volume growth were 0.81, 0.62, 0.47, and 0.36 ft^3/tree when scorch was 0, 25, 50, and 75%, respectively. Thus, both dbh and volume growth were reduced by about one-half when crown scorch was 75%.

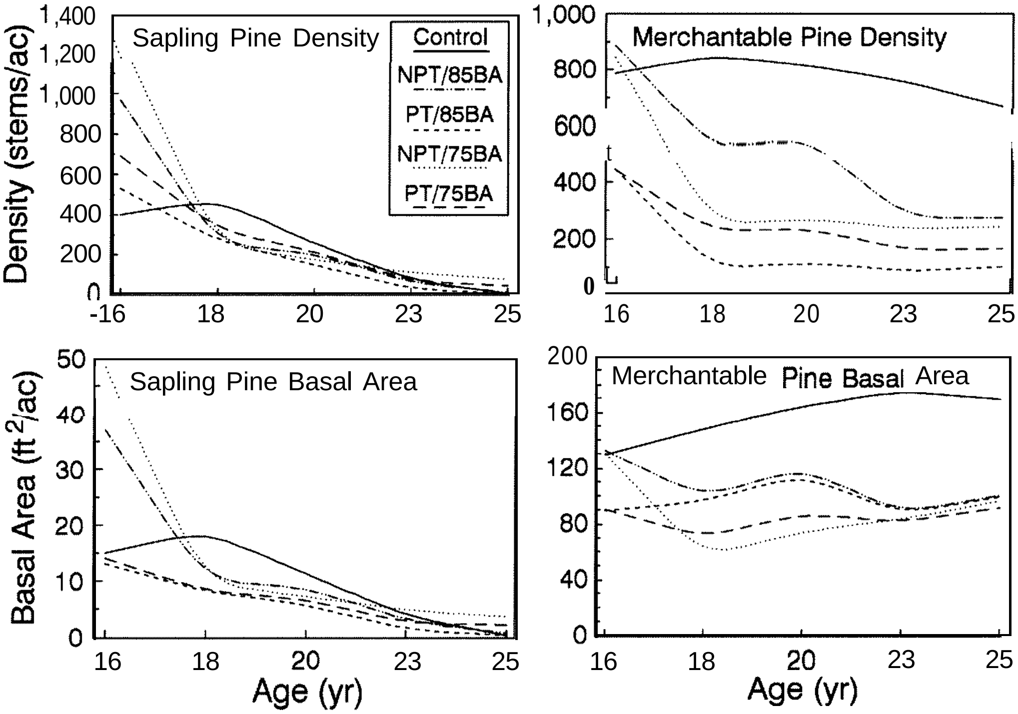

Figure 3. Long-term trends in density and basal area of pine saplings and merchantable-sized trees relative to alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas. Abbreviations are: NPT = not precommercially thinned; PT = precommercially thinned; 85BA = residual basal area of 85 ft^2/ac after commercial thinning; 75BA = residual basal area of 75 ft^2/ac after commercial thinning.

Nonpine Vegetation

Because of the intensive site preparation in 1971, hardwoods were never a major vegetative component on the study area. At stand age 25, hardwood basal area in saplings and trees averaged only 15 ft^2/ac on untreated control plots.

There was a 5 yr lag between the two most recent prescribed burns (1993 and 1998); as such, prebum density and quadrat stocking of hardwood saplings was not different ($P > 0.05$) among treatments and averaged 288 stems/ac and 69%, respectively (Figure 5). The prescribed winter burn on all commercially thinned plots in February 1998 was effective in reducing both the density and quadrat stocking of hardwood saplings on thinned plots versus control plots by 87% (P = 0.0001) and 72% (P = 0.0039), respectively.

Although the size and distribution of hardwoods were reduced by prescribed burning, hardwood ground cover was not different ($P \geq 0.4041$) among treatments either before (26%) or after (22%) the 1998 prescribed burn (Table 4) because of regrowth from sprouts. Ground cover from woody shrubs was also not different (P = 0.3727) among treatments before the burn and averaged 9%. One year after burning, shrub cover was actually 8 percentage points greater (P = 0.02 18) on burned plots compared to the controls. Probably because of more open conditions,

Table 2. Pine density, basal area, and volume production in natural, even-aged loblolly-shot-deaf pine stands in southeastern Arkansas at age 25.

Thinning treatments and orthogonal contrasts	Density (stems/ac) Saplings	Density (stems/ac) Trees*	Basal area* (ft^2/ac)	Volume production* (ft^3/ac)[†]
1. Check	7	667	170	3,827
2. No prethin, commercial thin to 85 ft^2/ac	13	275	101	3,780
3. Prethin at 6 yr, commercial thin to 85 ft^2/ac	7	203	100	3,486
4. No prethin, commercial thin to 75 ft^2/ac	80	242	97	3,629
5. Prethin at 6 yr, commercial thin to 75 ft^2/ac	47	165	92	3,503
Mean square error	1,147	8,535	79	88,617
$P > F$[††]	0.0917	0.0004	0.000 I	0.5423
Treatment contrasts	Probability of a greater F[††]			
1 vs 2 + 3 + 4 + 5	0.1999	0.0001	0.0001	0.2647
2 + 3 vs 4 + 5	0.0213	0.5169	0.2556	0.7053
2 vs 3	0.8143	0.3645	0.8733	0.2556
4 vs 5	0.2557	0.3334	0.5600	0.6151

* Pines at least 3.6 in. dbh.
† Volumes commercially thinned during the 17"' and 23'" growing seasons + salvage of ice-damaged and beetle-infested trees + residual volumes at 25 yr in trees at least 3.6 in. dbh.
†† The probability of obtaining a larger F-ratio under the null hypothesis.

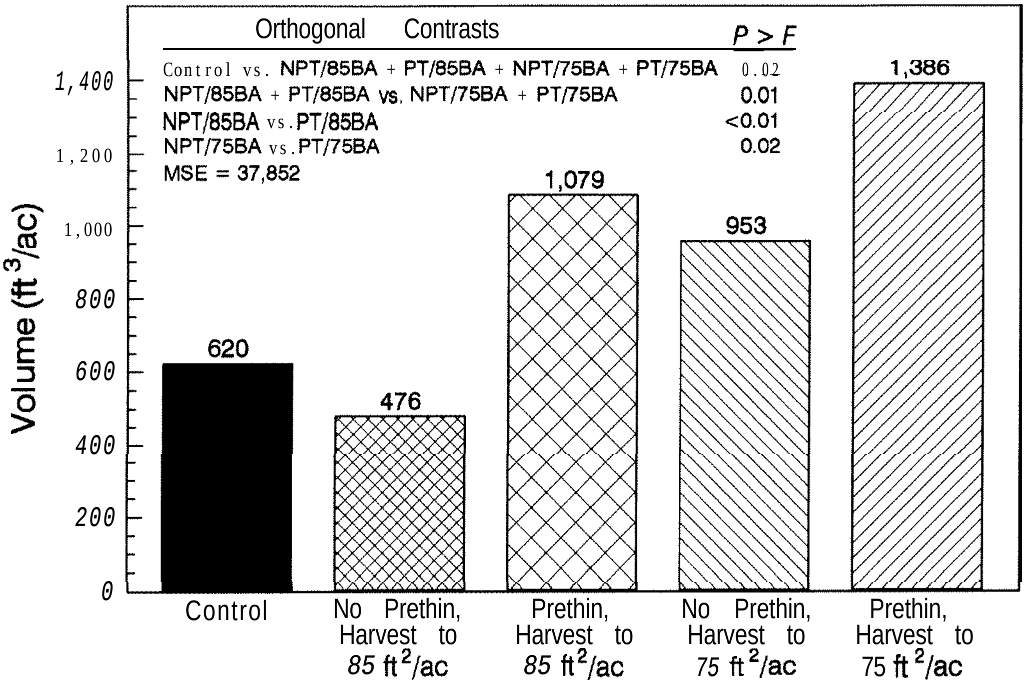

Figure 4. Sawlog volume in residual pines relative to alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas at 25 yr.

shrub ground cover was 7 percentage points higher (P = 0.0355) on plots thinned to 75 ft^2/ac than those thinned to 85 ft^2/ac. Similarly, precommercial thinning increased (P = 0.0458) shrub cover by 9 percentage points on plots thinned to 85 ft^2/ac.

Because the forest floor on control plots was shaded by pines, ground cover from all forms of shade-intolerant herbaceous vegetation (grasses, forbs, vines, and semi-woody plants) averaged less (P = 0.02) compared to the commercially thinned plots, before and after prescribed burning (Table 4). Among commercial thinning treatments, there were generally no differences (P > 0.05) in herbaceous ground cover either before or one growing season after the 1998 prescribed burn. The only significant difference in herbaceous ground cover was for vines after 24 yr on plots thinned to 85 ft^2/ac, with precommercially thinned plots having 84% more (P = 0.0083) ground cover. Within treatments, prescribed burning tended to decrease grass cover, increase forb cover, and increase vine cover, but total herbaceous ground cover was similar before and one growing season after burning.

Economic Returns

Because of the higher value from sawlogs, the most intensive thinning regime, i.e., precommercial thinning plus commercial thinning to 75 ft^2/ac, resulted in the highest present net value (PNV) at 25 yr, regardless of the discount rate (Figure 6). The lowest PNV through 25 yr occurred with conventional thinning-commercial thinning

Table 3. Fuel and weather conditions during a prescribed winter burn in natural, even-aged, loblolly-shortleaf pine stands in southeastern Arkansas at age 24 yr by thinning treatment.

	Thinning treatments			
Fuel and weather variables	No prethin 85 ft^2/ac	Prethin 85 ft^2/ac	No prethin 75 ft^2/ac	Prethin 75 ft^2/ac
Date of bum	February 09, 1998			
Days since last precipitation	7			
Time of burning (hr CST)	1145–1330			
Air temperature (°F)	55–60			
Relative humidity (%)	48–58			
Wind direction	From the south			
Wind speed (mph)	2–4			
Fine fuel moisture (%)*	30	32	31	30
Dry wt of fine fuel (tons/ac)†	6.1	6.8	7.3	7.4
Dry wt of heavy fuel (tons/ac)††	11.8	8.1	1.4	7.0
Rate of spread (ft/min)	6.7	10.0	6.2	7.6
Fireline intensity (btu/ft-sec)§	50	121	90	75
Range in fireline intensity (btu/ft-sec)	49-5 1	97-148	53–118	23-148
Type of bum	strips			

* Samples taken in the field from fine-fuel surface litter.

† Litter samples and logging slash less than 0.6 in. diameter.

†† Logging slash larger than 0.5 in. diameter, from commercial thinning 19 months earlier.

§ Fireline intensity = $5.67 L_f^{2.17}$, where L_f = Ocular estimates of flame length to nearest 0.5 ft (Byram 1959).

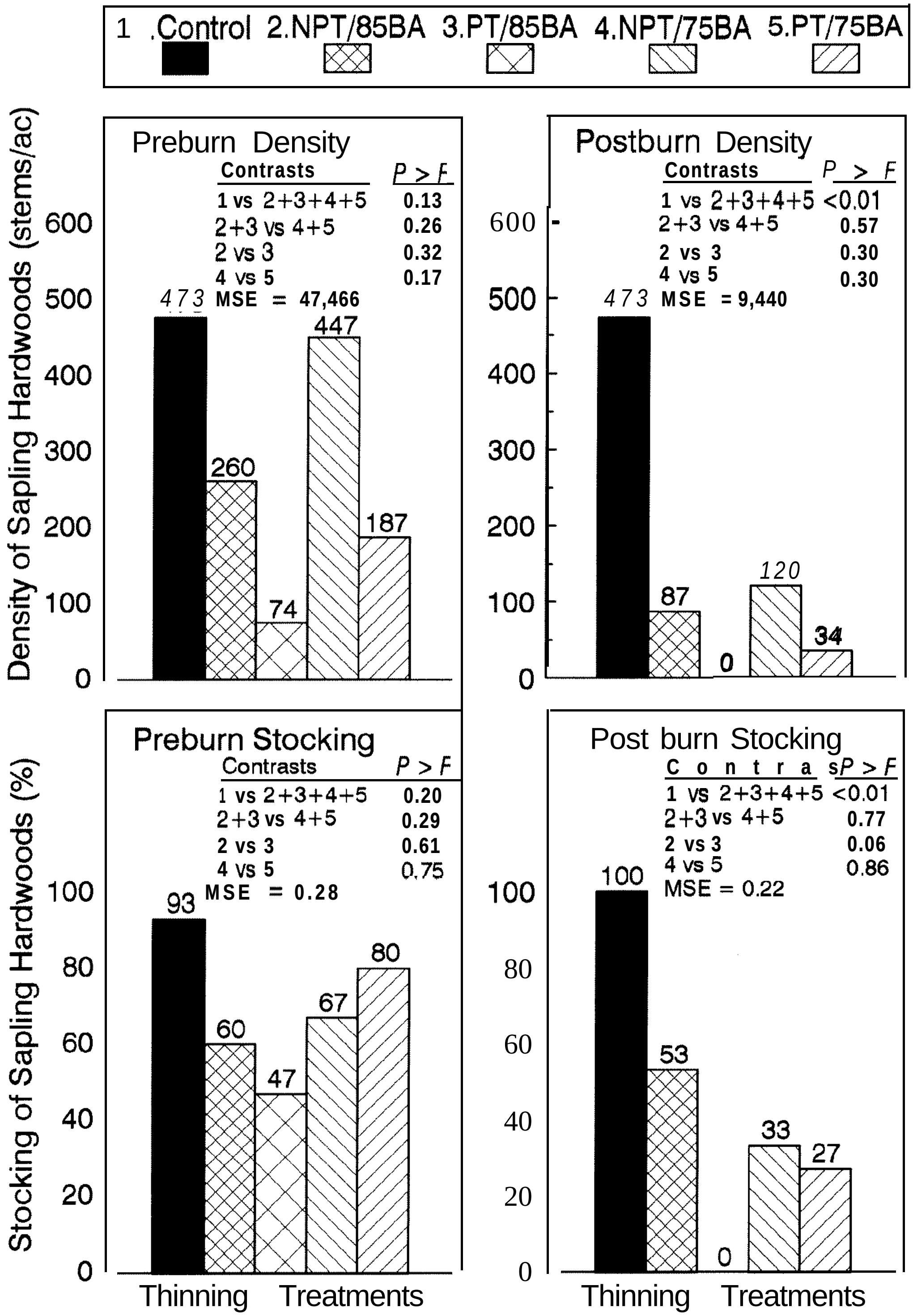

Figure 5. Density and quadrat stocking of sapling-sized hardwoods before and one growing season after a prescribed winter burn, relative to alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas. Abbreviations are: NPT = not precommercially thinned; PT = precommercially thinned; 85BA = residual basal area of 85 ft^2/ac after commercial thinning; 75BA = residual basal area of 75 ft^2/ac after commercial thinning.

to 85 ft^2/ac without precommercial thinning. Since there were no costs for precommercial thinning or prescribed burning on control plots, their PNV at 25 yr averaged higher than the conventional thinning technique across all discount rates. PNV for the remaining two treatments—PT/85BA and NPT/75BA—was similar through 25 yr. This suggests that precommercial thinning would probably not be as good an investment if the forest landowner chose to lightly thin during commercial harvests because residual pines would attain sawlog size more slowly.

Discussion

Nineteen years after precommercial thinning, the beneficial effects of that treatment on pine diameter growth were still

Table 4. Ground cover by nonpine vegetative components in natural, even-aged loblolly-shortleaf pine stand in southeastern Arkansas, before (24 yr) and after (25 yr) a prescribed winter burn.

Thinning treatments and orthogonal contrasts	Woody: Hardwoods 24 yr	Woody: Hardwoods 25 yr	Woody: Shrubs 24 yr	Woody: Shrubs 25 yr	Herbaceous: Grasses 24 yr	Herbaceous: Grasses 25 yr	Herbaceous: Forbs 24 yr	Herbaceous: Forbs 25 yr	Herbaceous: Vines 24 yr	Herbaceous: Vines 25 yr	Herbaceous: Semi-woody 24 yr	Herbaceous: Semi-woody 25 yr	Total herbaceous 24 yr	Total herbaceous 25 yr
	Ground cover (%)													
1. Control	41.3	41.6	3.1	4.0	13.3	14.0	0.3	0.0	10.0	20.3	0.3	0.0	21.7	29.7
2. No prethin, commercial thin to 85 ft²/ac	23.7	16.3	6.3	4.0	63.3	45.3	6.7	11.7	27.0	50.3	16.3	19.7	83.0	90.3
3. Prethin at 6 yr, commercial thin to 85 ft²/ac	8.7	11.7	8.7	13.3	66.0	39.7	30.0	34.0	49.7	64.3	25.7	14.3	97.3	97.7
4. No prethin, commercial thin to 75 ft²/ac	35.7	22.0	13.3	13.7	56.3	35.0	10.0	21.3	34.0	54.0	22.7	17.7	80.3	83.3
5. Prethin at 6 yr, commercial thin to 75 ft²/ac	21.0	17.0	11.3	18.3	50.0	34.7	12.0	20.3	43.7	61.7	15.7	19.3	83.7	93.0
Mean square error	0.0810	0.0512	0.0153	0.0080	0.0239	0.0275	0.0323	0.0373	0.0080	0.0265	0.0123	0.0088	0.0442	0.0469
$P > F$*	0.5345	0.4041	0.3727	0.0201	0.0056	0.1471	0.0610	0.0306	0.0006	0.0293	0.0020	0.0006	0.0022	0.0040
Treatment contrasts	Probability of a greater F*													
1 vs 2 + 3 + 4 + 5	0.2760	0.0709	0.0847	0.0218	0.0004	0.0193	0.0179	0.0041	0.0001	0.0028	0.0002	0.0001	0.0002	0.0003
2 + 3 vs 4 + 5	0.3439	0.6314	0.3582	0.0355	0.2124	0.4195	0.4544	0.7962	0.8689	0.9235	0.8062	0.6724	0.2713	0.5832
2 vs 3	0.4452	0.7602	0.6887	0.0458	0.8466	0.6745	0.0681	0.1248	0.0083	0.3050	0.1684	0.4610	0.1055	0.3775
4 vs 5	0.5502	0.9102	0.9641	0.4015	0.6215	0.9922	0.7946	0.8464	0.1999	0.6058	0.3378	0.8610	0.8911	0.5282.

The probability of obtaining a larger F-ratio under the null hypothesis.

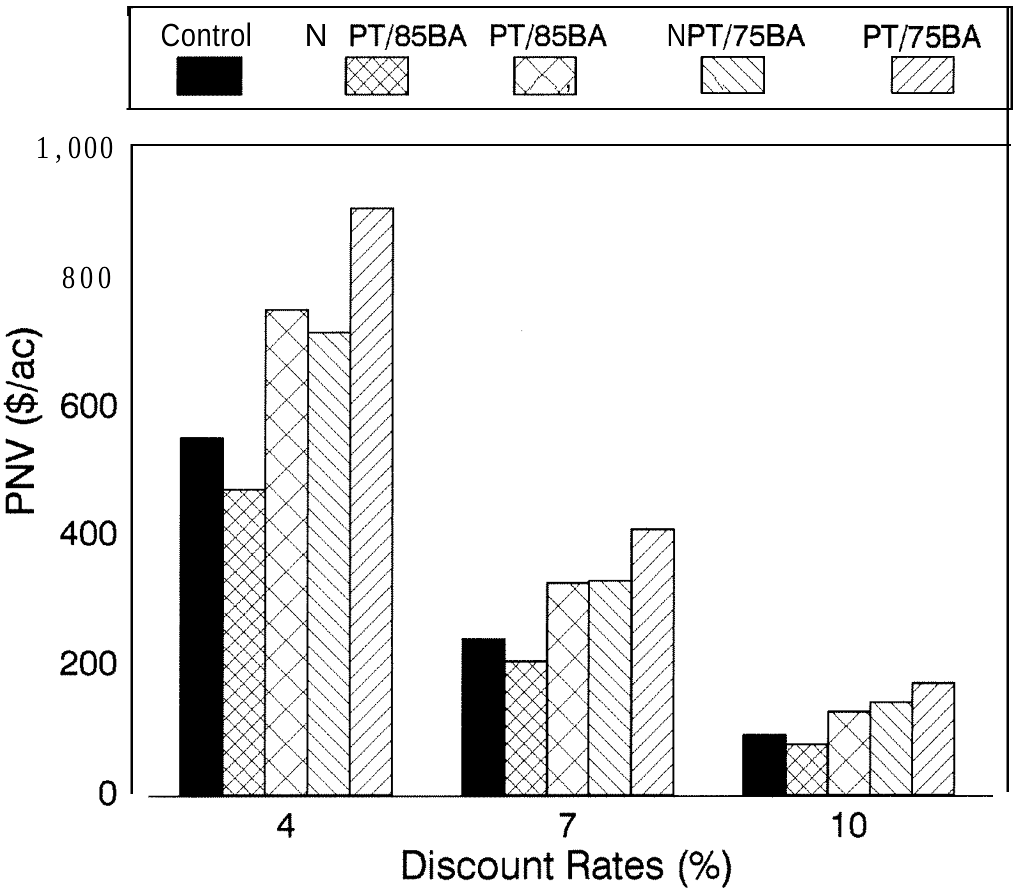

Figure 6. Present net value of investment in precommercial thinning (age 6), seven prescribed winter burns (between ages 9 and 24), hardwood control, and cruising and marking costs associated with alternative thinning regimes in natural, even-aged loblolly-shortleaf pine stands in southeastern Arkansas through 25 yr. Additional costs for all treatments included initial site preparation, annual fire protection, and annual property tax. Abbreviations are: NPT = not precommercially thinned; PT = precommercially thinned; 85BA = residual basal area of 85 ft²/ac after commercial thinning; 75BA = residual basal area of 75 ft²/ac after commercial thinning.

apparent. Although total cubic-foot volume production was similar ($P > 0.05$) on precommercially thinned plots compared to other thinning treatments, sawlog volumes at 25 yr were significantly higher ($P < 0.01$) as a result of precommercial thinning at 6 yr.

Through age 25, annual volume growth ranged from 1.8 to 2.0 cords/ac across all treatments, which is consistent with expected growth rates on these sites (Grano 1969). The fact that cubic-foot volumes averaged somewhat higher on untreated control plots is consistent with earlier research. For direct-seeded stands of loblolly pine in central Louisiana, Lohrey (1977) reported higher volumes for all surviving pines on unthinned check plots (3,626 ft^3/ac) at age 16 when compared to yields from plots (2,178 to 3,280 ft^3/ac) that were precommercially thinned 13 yr earlier.

If landowners had liquidated their timber assets on a 25 yr rotation, then untreated control plots in the present study would have been a desirable economic alternative to only one othertreatment, which was conventional thinning to 85 ft^2/ac during the 17th and 23rd growing seasons, without the benefit ofprecommercial thinning. That held true because there were no costs for precommercial thinning, hardwood control, or prescribed burning on control plots. The fact that pines on two of the three control plots became infested with bark beetles during the 24th yr and required salvage to stop the infestation should be a warning to forest landowners that high basal areas (> 100 ft^2/ac) in loblolly pine stands can increase the risk of loss by these destructive agents.

In most cases, forest landowners prefer to increase the value of their standing timber by managing for sawlog-size trees. For that reason, precommercial thinning proved to be an important part of the long-term management strategy by producing larger-diameter trees within 19 yr after treatment. At 25 yr, higher stumpage prices for sawlog products more than offset the costs associated with precommercial thinning, prescribed burning, and hardwood control in this investigation.

Landowners can increase their returns on silvicultural investments by timing harvests to coincide with higher stumpage prices. For example, in 1998, pine sawtimber stumpage prices in southern Arkansas ranged from $238/mbf (International 1/4-in.) in the third quarter to $338/mbf in the first quarter. Similar fluctuations occurred in 1998 stumpage prices for other pine products, such as pulpwood ($11 to $22/cord) and chip-n-saw ($60 to $97/cord).

Crown scorch on pines from dormant-season prescribed bums has been a recurring problem in this study (Cain 1996). That is because of a negative correlation between crown scorch and dbh growth-as the degree of crown scorch increases, diameter growth decreases during the year after burning. This was especially true on precommercially thinned plots during earlier years because of the accumulation of tall grasses in the thinned strips. These grasses tended to be quite flammable during winter, and they contributed to a higher degree of crown scorch because grasses dry much sooner after winter rains than the ground layer of pine litter on plots that were not precommercially thinned. These fine-fuel differences among treatments during early years became less important after commercial thinnings reduced canopy shading of the forest floor, thereby increasing ground cover from shade-intolerant herbaceous vegetation and the drying potential brought about by open stand conditions.

Other investigations have reported reductions in loblolly pine dbh growth as a result of crown scorch after prescribed burning. Villarrubia and Chambers (1978) found that mean diameter growth decreased with increasing crown scorch in a 20-yr-old loblolly pine plantation. They reported that the negative effects of crown scorch on diameter growth were more pronounced in the larger diameter classes as the degree of scorch increased. Similarly, Lilieholm and Hu (1987) found that diameter growth decreased with increasing crown scorch in 19-yr-old natural stands of loblolly pines that had been precommercially thinned several weeks before burning by reducing density from 450 treesiac down to 200,300, and 400 trees/ac, but growth reductions did not extend beyond 1 yr after burning. These results suggest that forest managers should try to minimize crown scorch by coordinating their prescribed bums to coincide with appropriate weather and fuel conditions as prescribed by Wade and Lunsford (1989).

In contrast to control plots, commercially thinned plots in this investigation had significantly more ($P < 0.05$) ground cover from shrubs and all forms of herbaceous vegetation before andone growing season after the most recent prescribed bum. Consequently, thinning treatments were more conducive to wildlife habitat because of an increase in desirable food plants and protective cover from low-ground vegetation. For example, of the live most prevalent seedling-sized woody plants on commercially thinned plots at stand ages 24 and 25 yr, at least three species (*Callicarpa americana*, *Rhus* spp., and *Vaccinium* spp.) have been identified as important to wildlife in southern forests (Oefinger and Halls 1974).

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