A 5-YEAR ASSESSMENT OF SHORTLEAF PINE AND HARDWOOD SPROUTS RELATIVE TO THREE METHODS OF HARDWOOD CONTROL IN THE ARKANSAS OZARKS

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Abstract—Compared with untreated checks, manual hardwood control and herbicide injection of hardwoods facilitated the development of direct seeded shortleaf pine (*Pinus echinata* Mill.) regeneration following a single-tree selection harvest in a mature natural stand of shortleaf pines in northwest Arkansas. Five years after hardwood control, shortleaf pine seedlings on treated plots were 215 percent taller ($P = 0.02$) and 242 percent larger ($P = 0.01$) in groundline diameter than pine seedlings on check plots. Resprouting hardwoods on herbicide injection plots were 42 percent shorter ($P < 0.01$) and had 72 percent less ($P = 0.01$) crown area compared with those on manual control plots.

INTRODUCTION

For regulated uneven-aged silviculture of shortleaf pine (*Pinus echinata* Mill.), the majority of stems in a stand should be in the seedling, sapling, and pulpwood size classes to allow for a continuous progression of trees into more valuable saw logs. To accomplish that objective, the hardwood component must be periodically controlled; otherwise, shade-intolerant pine seedlings that develop in the understory will most likely die (Cain 1987, 1988b).

Alternative methods for vegetation management include prescribed fire, mechanical methods, manual methods, herbicide treatments, and biological methods. In the Final Environmental Impact Statement for the Ozark/Ouachita Mountains (U.S. Department of Agriculture 1990), the preferred alternative for vegetation management specified an increase in the use of manual methods and a decrease in the use of herbicides and soil-disturbing mechanical methods. When herbicides are used, priority is to be given to chemicals and application methods that pose minimum risks to humans, wildlife, and nontarget plants.

This study was initiated to demonstrate uneven-aged silviculture of shortleaf pine by converting a mature even-aged stand using single-tree selection. Objectives were (1) to compare the cost and effectiveness of hardwood control by manual methods with that of stem-injected herbicides and (2) to monitor the establishment and development of shortleaf pine regeneration and hardwood regrowth following manual control and herbicide control of the hardwood component.

MATERIALS AND METHODS

Study Area

The study was located in Johnson County, AR, on the Bayou Ranger District of the Ozark National Forest. Plots were situated on a south-facing slope, and the elevation ranged from 760 to 920 feet. Soils are Nella (Typic Paleudult) and Mountainburg (Lithic Hapludult), gravelly or stony, fine sandy loam (U.S. Department of Agriculture 1977). Annual precipitation averages 46 inches with seasonal extremes being wet springs and dry autumns and winters.

The south-facing slope contained a mature stand of shortleaf pines with basal area averaging 85 square feet per acre in trees > 4.5 inches in diameter at breast height (d.b.h.). Most pines were from 14 to 18 inches d.b.h., and the understory was devoid of pine regeneration. Overstory and midstory hardwood basal area (> 4.5 inches d.b.h.) averaged 32 square feet per acre. There had been no apparent forest management activity in the stand during the last 20 years. Site indices at 50 years for shortleaf pine were determined by slope position in accordance with U.S. Department of Agriculture (1976): upper slope = 59 feet, midslope = 64 feet, and lower slope = 69 feet.

Study Installation

Twelve plots of 0.5 acre (147.6 by 147.6 feet) each, with interior subplots of 0.25 acre (104.4 by 104.4 feet), were established in the summer of 1990. The experimental design was a randomized complete block with three replications of four treatments. Blocking was based on topographic position—upper (22-percent slope), middle (26-percent slope), and lower (10-percent slope). Within each interior subplot, 25 systematically spaced sample points were permanently established to serve as centers of circular 1-milacre and 2-milacre quadrats for monitoring seedbed disturbance, pine seedling and sapling development, and nonpine competition.

All merchantable-sized pines (> 4.5 inches d.b.h.) were inventoried by 1-inch d.b.h. classes on a plot-by-plot basis. These data were used to determine the allowable cut based on the basal area–maximum diameter–quotient (BD*q*) technique (Farrar 1984). The BD*q* technique was applied according to three guidelines, in order of importance: (1) a basal area of 60 square feet per acre was to be left in merchantable-sized pines after harvest; (2) all pines larger than a maximum d.b.h. of 18 inches were to be cut, but some larger pines were retained to achieve the desired basal area; and (3) the residual diameter distribution should approach a balanced uneven-aged structure, characterized by a constant ratio (q) between the number of trees in succeeding diameter classes ($q = 1.22$ for 1-inch d.b.h. classes).

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Pine harvesting on study plots was completed in late June 1990. Cut pines were removed tree-length using an articulated rubber-tired skidder. Merchantable pines on an additional 40 acres surrounding the research plots were also marked for harvest using single-tree selection guidelines, but harvesting was delayed until the summer of 1991.

Treatments

Hardwood control was accomplished in early September 1990 by an independent contractor. An untreated check was compared with three methods of postharvest hardwood control as follows:

Check—No hardwood control, but there was disturbance from logging.

Herbicide injection—All hardwood trees and shrubs that were ≥ 1.0 inch groundline diameter (g.l.d.) were stem injected near the root collar with Garlon® 3A (triclopyr) at the rate of 0.02 ounce of undiluted herbicide per incision and one incision per inch of g.l.d. This treatment was accomplished with Jim-Gem® tree injectors.

Manual hardwood control—All hardwood trees and shrubs that were ≥ 1.0 inch g.l.d. were manually cut using chain saws. Stump heights averaged < 1.0 foot.

Manual hardwood control plus release—Hardwoods were controlled using the same method as the previous treatment, but pine regeneration was manually released during the fourth growing season (June 1994) after the initial treatment. For release, brush axes and lopping shears were used to cut competing vegetation near the groundline but only within 4 feet of established pine seedlings. If no pine seedlings were visually observed as workers traversed each plot, then no vegetation was cut in the release treatment.

In order to assess the cost of herbicide and manual treatments for controlling hardwoods, the time required to inject or manually fell the hardwoods was recorded, and the volume of injected herbicide was measured. Six 0.5-acre plots were assessed for herbicide injection cost, and six plots were assessed for chain saw felling cost. To assess labor cost, the minimum wage in 1990 was doubled to $8.50 per hour to account for vendor contract fees. The cost of Garlon herbicide was based on the retail price in 1991 ($169 for 2.5 gallons). The cost of chain saw operation was based on dollar amounts taken from Miller (1984) with an addition of 5 percent annually for 6 years to account for inflation and was determined to be $2.76 per hour of chain saw use.

On the 40-acre nonresearch area that surrounded study plots, residual hardwoods > 1 inch d.b.h. were controlled after pine harvesting was completed by using an edge-to-edge cut-surface treatment at waist height and applying Accord® (glyphosate) herbicide at recommended rates (25 to 50 percent concentration).

Pine Seed Crops

Natural pine seed fall was monitored during 3 consecutive seed years (1990-91, 1991-92, and 1992-93), from October through January, using 4 seed traps on each of the 12 plots. The four interior subplot corners were used as monumentation points for the seed traps. Individual seed traps had an opening of 0.9 square foot (Cain and Shelton 1993). All 3 seed years were judged to be complete failures, because the number of potentially viable seeds ranged from 1,000 to 3,000 per acre per year. According to Liming (1945), 40,000 viable shortleaf pine seeds per acre are purported to be necessary during any one seed year for adequate regeneration under natural conditions.

To ensure regeneration of the area, Bayou Ranger District personnel obtained from an Ozark Mountain source shortleaf pine seeds that had been in cold storage. Using cyclone hand-seeders, district personnel broadcast the seeds onto the 12 study plots at the rate of 3 pounds per plot (6 pounds per acre) in mid-February 1991. These seeds were reported to average 28,100 seeds per pound and had a germination rate of 86 percent. A heavy sowing rate was used because the seeds were not treated with repellents to control predators or stratified before direct seeding. The recommended rate for broadcast sowing of repellent-treated, stratified, shortleaf pine seeds is 0.48 pound per acre (Ezell 1988).

One year after direct seeding, the 40-acre area surrounding the research plots was hand-planted with 1-0, genetically improved, bare-root shortleaf pine seedlings from an eastern Oklahoma seed source. These seedlings were outplanted with hoedads on a 12- by 12-foot spacing (302 trees per acre). To monitor the development of planted seedlings, an additional 0.2-acre plot was established contiguous to each of the herbicide injection plots in the main study. During autumn of 1992, 25 planted shortleaf pine seedlings were randomly selected for measurement within each planted plot and tagged for identification.

Measurements and Data Analysis

Following harvest and hardwood control, seedbed conditions were ocularly estimated to the nearest 10 percent on each of the twenty-five 1-milacre sample quadrats per plot. Eight disturbance codes were used in that assessment (Cain 1993), but only the percentage of forest floor covered by manually cut hardwood slash is presented here.

In the winter of 1995-96, 5 years after hardwood control, merchantable-sized pines (> 4.5 inches d.b.h.) on each 0.5-acre plot were remeasured to 0.1 inch at d.b.h. for calculation of basal area. Pine seedlings were counted within each of twenty-five 1-milacre sample quadrats per interior subplot. The two tallest (dominant) pine seedlings (stems ≤ 0.5 inch d.b.h.) within each milacre quadrat were measured for total height to 0.1 foot and g.l.d. to 0.04 inch. Within a 2-milacre circular plot on even-numbered quadrats, pine saplings (stems > 0.5 inch but < 4.6 inches d.b.h.) were measured, but only two saplings were present across all 12 plots 5 years after harvest. Within the twenty-five 1-milacre quadrats per plot, ground coverage was ocularly estimated to the nearest 10 percent for herbaceous vegetation (forbs, grasses, semiwoody plants, and vines) and for merchantable and submerchantable pines and hardwoods (including shrubs) by vertical projection of foliar cover to the ground.

During the winter measurements, hardwood rootstocks of seedling size were counted within each of the twenty-five 1-milacre quadrats per plot. A rootstock was comprised of either single or multiple stems (clump) of seedling size, which obviously arose from the same root system. The tallest seedling-sized hardwood was identified by species and measured for total height to 0.1 foot and for crown width at the widest axis and perpendicular to that axis to 0.1 foot. Within the 2-milacre quadrats at even-numbered sample points, hardwood saplings were counted by 1-inch d.b.h. classes, and the dominant hardwood sapling was identified by species.

For residual hardwoods that were > 4.5 inches d.b.h., a 100-percent inventory was conducted within each 0.5-acre plot. The numbers of hardwood stems were recorded by 1-inch d.b.h. classes and were categorized into four species groups: red oaks (principally *Quercus falcata* Michx., *Q. rubra* L., and *Q. velutina* Lam.), white oaks (*Q. alba* L. and *Q. stellata* Wangenh.), hickories (*Carya* spp.), and other hardwoods.

On the three plots established for monitoring planted pine development, surviving crop seedlings were also measured in the winter of 1995-96 to obtain total height to 0.1 foot and g.l.d. to 0.04 inch. On these plots, merchantable-sized pines were measured to 0.1 inch d.b.h. for calculation of basal area.

Analysis of variance was used to evaluate treatment effects on measured variables. Percentage values for quadrat stocking and ground coverage were compared following arcsine transformation. Treatment means were compared using orthogonal contrasts. Analysis of variance was also used to compare the mean size of planted pines with that of dominant seeded pines on herbicide injection plots in the main study.

RESULTS AND DISCUSSION

Cost of Postharvest Hardwood Control

Averaged over an area of 3 acres for each method of hardwood control, the initial cost of manually felling the hardwoods was half the cost of tree injection (Cain 1993). Chain saw felling was accomplished at a cost of $0.07 per treated stem as compared with $0.14 per stem for herbicide injection. For the injection treatment, Garlon accounted for 78 percent of the cost, with labor at 22 percent. For manual hardwood control, labor was the highest cost factor at 79 percent, and chain saw use accounted for 21 percent of the cost. Expenses incurred during the fourth growing season for release of established pine seedlings averaged $68 per acre, thereby increasing total cost for manual hardwood control in that treatment to $100 per acre and exceeding the cost of herbicide injection by $37 per acre.

During initial hardwood control, all hardwoods > 1.0 inch g.l.d. were treated, even if they were of merchantable size. On an operational scale, merchantable hardwoods should be sold and removed from the site, which would reduce the cost of postharvest hardwood control.

Postharvest Seedbed Condition

Cut-and-leave hardwood control techniques result in too much detritus being left on the site, and slash cover has been shown to impede natural pine regeneration (Trousdell 1950). In the present study, a preliminary analysis of posttreatment seedbed conditions indicated that, on the six plots subjected to manual hardwood control, 88 percent of sampled 1-milacre quadrats contained hardwood slash, and ground coverage from felled hardwoods averaged 62 percent of the area within those quadrats. Because such heavy slash restricted accessibility and was considered to be unacceptable for pine seedling establishment, the slash was removed from within plot boundaries if > 4.0 inches in diameter.

Seeded Pine Regeneration

In uneven-aged silviculture, 200 submerchantable-sized pines per acre are considered to be the minimum for adequate density, with 50-percent milacre stocking being optimum (Cain 1991). The preharvest inventory revealed no pine seedlings, but five growing seasons after direct seeding, pine seedling density averaged 1,164 stems per acre across all treatments. Herbicide injection plots had the most ($P = 0.03$) pine seedlings compared with other treatments; even so, all plots averaged > 500 seedlings per acre (table 1). Hardwood control plots also had better milacre stocking ($P = 0.01$) of pine seedlings than check plots, and milacre stocking on herbicide injection plots was better ($P = 0.01$) than on manual control plots. Herbicide injection of hardwoods was also the only treatment to result in > 50-percent milacre stocking of pine seedlings.

With direct seeding, the study area was successfully regenerated. However, stand structure was a long way from a well-regulated condition. Results from uneven-aged management of shortleaf pines in the Ouachita Mountains of Arkansas suggest that old, even-aged sawtimber stands are the most difficult to convert to uneven-aged structure and will require the longest conversion period of any existing stand type (Murphy and others 1991).

Five growing seasons after establishment, dominant pine seedlings averaged 1.90 feet tall and 0.34 inch g.l.d. (table 1). Dominant seedlings on hardwood control plots were 215 percent taller ($P = 0.02$) and 242 percent larger in g.l.d. ($P = 0.01$) than those on check plots (table 1). There was no difference ($P > 0.05$) in total height or g.l.d. for dominant pine seedlings on herbicide injection plots versus manual control plots.

Planted Pine Regeneration

In January 1992, 1 year after direct seeding of the plots in the main study, the nonresearch areas surrounding the main study plots were hand-planted with 1-0 bare-root shortleaf pine seedlings. At the time of remeasurement in the winter of 1995-96, both the dominant, direct-seeded shortleaf and the planted shortleaf were assumed to be 5 years old from seed. At that time, merchantable pine basal area on planted plots averaged 69 square feet per acre and did not differ ($P = 0.91$) from the 70 square feet per acre on herbicide injection plots in the main study. Therefore, the negative effect of overstory pines on the development of pine regeneration should have been the same regardless of establishment technique.

Table 1—Status of shortleaf pine regeneration 5 years after hardwood control

Hardwood control and orthogonal contrasts	Density	Milacre stocking[a]	Total height[b]	G.l.d.[b]
	stems/ac	*percent*	*feet*	*inches*
1. Check	586	20	0.73	0.12
2. Herbicide injection	1,987	59	2.50	0.47
3. Manual hardwood control	961	41	2.04	0.35
4. Manual hardwood control, plus release	1,121	32	2.35	0.42
Mean square error	236,578	0.011	0.59	0.02
PR > F [c]	0.06	0.01	0.10	0.06
	Probabilities of a greater F-ratio			
1 vs 2 + 3 + 4	0.06	0.01	0.02	0.01
2 vs 3 + 4	0.03	0.01	0.59	0.37
3 vs 4	0.70	0.28	0.64	0.51

G.l.d. = groundline diameter.
[a] Based on the presence of at least one pine seedling per 1-milacre quadrat.
[b] Mean total height and groundline diameter of the two dominant pine seedlings per 1-milacre quadrat.
[c] The probability of obtaining a larger F-ratio under the null hypothesis.

Planted shortleaf seedlings averaged 4.44 feet in height and were 78 percent taller (*P* < 0.01) than the dominant seeded shortleaf seedlings on herbicide injection plots in the main study. At 0.92 inch g.l.d., planted shortleaf seedlings were also 96 percent larger (*P* = 0.01) than dominant seedlings on herbicide injection plots. Survival of these planted shortleaf pines averaged 88 percent.

Because of a natural seed crop failure during the winter after harvest, direct seeding was chosen in the main study to simulate natural seed fall. Although no cost comparison was made between planting and direct seeding, 5-year results suggest that planting of shortleaf seedlings was superior to direct seeding in terms of growth response after controlling hardwoods by herbicide injection.

Competing Vegetation

Five years after hardwood control, density of seedling-sized hardwoods averaged nearly 3,700 rootstocks per acre (table 2). Although manual control plots averaged 32 percent more hardwood rootstocks of seedling size than plots that were treated by herbicide injection, treatment differences were not statistically significant (*P* = 0.20). However, dominant hardwood sprouts of seedling size were 73 percent taller (*P* < 0.01) on manual control plots than on herbicide injection plots. In addition to being taller, these dominant sprouts had crowns that averaged 253 percent larger (*P* = 0.01) than those on injected plots (table 2). Obviously, herbicide injection was more effective than chain saw felling by reducing the regrowth of hardwoods during the first 5 years after treatment.

Six woody species, or groups of species, predominated the seedling size class, and they accounted for 78-percent milacre stocking of all nonpine woody vegetation. These were *Cornus florida* L. (24 percent), *Quercus* spp. (20 percent), *Carya* spp. (13 percent), *Nyssa sylvatica* Marsh. (11 percent), *Vaccinium* spp. (6 percent), and *Acer rubrum* L. (4 percent). Milacre stocking was < 4 percent for other seedling-sized woody species.

Density of hardwood saplings averaged 556 stems per acre (table 2), and manual control plots had 633 percent more (*P* = 0.02) saplings than herbicide injection plots. Quadrat stocking of these sapling hardwoods averaged 42 percent across all plots (table 2). Manual control plots had 159 percent more (*P* = 0.03) quadrats stocked with hardwood saplings than did herbicide injection plots. This result again reflects the efficacy of herbicide injection versus chain saw felling when used to control hardwoods in pine management. As would be expected, the mean d.b.h. of hardwood saplings on check plots averaged 36 percent larger (*P* = 0.03) compared with those on treated plots (table 2). On check plots and manual control plots, *Cornus florida* L. were the predominant hardwoods of sapling size, whereas *Ulmus alata* Michx. saplings predominated on herbicide injection plots.

Five years after hardwood control, ground coverage by pine regeneration averaged only 5 percent (table 3). Herbicide injection resulted in greater (*P* = 0.04) ground coverage by pine seedlings compared with manual control treatments, but all hardwood control treatments had more (*P* = 0.03) pine seedling ground coverage than check plots. Ocular estimates of percentage ground cover from hardwoods of submerchantable size substantiates the differences in efficacy of the hardwood control treatments that were tested in this investigation. Ground coverage from these hardwoods averaged about 27 percentage points higher (*P* < 0.01) on manual control plots than on herbicide injection plots (table

Table 2—Status of nonpine competition 5 years after hardwood control

Hardwood control and orthogonal contrasts	Seedling-sized hardwoods: Rootstock density	Total height[a]	Crown area[a]	Sapling-sized hardwoods: Density	Quadrat stocking[b]	Weighted d.b.h.[c]
	no./ac	*feet*	*ft²/rtstk*	*stems/ac*	*percent*	*inches*
1. Check	3,080	4.89	11.14	264	30	1.45
2. Herbicide injection	3,213	4.16	4.10	125	22	1.11
3. Manual hardwood control	4,693	7.01	14.68	986	67	1.03
4. Manual hardwood control, plus release	3,800	7.41	14.28	847	47	1.08
Mean square error	10.46×10^5	0.90	18.42	13.53×10^4	0.04	0.04
PR > F[d]	0.30	0.01	0.07	0.07	0.07	0.15
			Probabilities of a greater F-ratio			
1 vs 2 + 3 + 4	0.27	0.08	0.97	0.16	0.21	0.03
2 vs 3 + 4	0.20	< 0.01	0.01	0.02	0.03	0.73
3 vs 4	0.33	0.62	0.91	0.66	0.21	0.78

D.b.h. = diameter at breast height.
[a] Data from the dominant seedling-sized hardwood rootstock (rtstk) per 1-milacre quadrat.
[b] Based on the presence of at least one hardwood sapling per 2-milacre quadrat.
[c] Means weighted by number of hardwood saplings in the 1-, 2-, 3-, and 4-inch d.b.h. classes.
[d] The probability of obtaining a larger F-ratio under the null hypothesis.

Table 3—Ground cover by vegetative component 5 years after hardwood control

Hardwood control and orthogonal contrasts	Ground cover: Pine seedlings	Hardwoods <4.6 in. d.b.h.	Hardwoods >4.5 in. d.b.h.	Herbaceous vegetation
	- - - - - - - -	- - - - *percent*	- - - -	- - - - - - - -
1. Check	1.8	36.5	48.8	29.9
2. Herbicide injection	8.6	24.3	3.9	60.3
3. Manual hardwood control	4.6	52.7	0.0	58.8
4. Manual hardwood control, plus release	4.6	50.5	0.0	58.2
Mean square error	0.00048	0.006	0.008	0.032
PR > F[a]	0.05	0.01	< 0.01	0.14
		Probabilities of a greater F-ratio		
1 vs 2 + 3 + 4	0.03	0.22	< 0.01	0.03
2 vs 3 + 4	0.04	< 0.01	0.57	0.76
3 vs 4	0.99	0.73	1.00	0.97

in. = inches; d.b.h. = diameter at breast height.
[a] The probability of obtaining a larger F-ratio under the null hypothesis.

3). Ground coverage from merchantable-sized hardwoods averaged 48 percentage points higher ($P < 0.01$) on check plots compared with plots where these trees were controlled 5 years earlier (table 3). On check plots, the multistoried hardwood cover, in combination with overstory pines, contributed to almost complete shading of the forest floor.

Residual basal area in merchantable-sized hardwoods on check plots averaged 36 square feet per acre. These hardwoods ranged from 5 to 18 inches d.b.h. and averaged 116 trees per acre. Of that density, 43 percent was in the white oak group, 28 percent in hickories, 18 percent in the red oak group, and 11 percent in other hardwoods.

Five years after treatment, ground coverage from herbaceous vegetation averaged 52 percent (table 3). Because of their intolerance to shade, herbaceous plants had less (P = 0.03) ground cover on check plots than on hardwood control plots. In the first few years after establishment of pine regeneration, competition from herbaceous vegetation can be more detrimental to survival and growth of pine seedlings than woody competition, especially on good sites (site index > 85 feet at 50 years) where herbaceous ground cover can approach 100 percent, with multistoried layers (Cain 1988a). Given the combined ground cover from sprouting hardwoods and herbaceous vegetation in the present study, and in the absence of site disturbance, it is unlikely that additional pine regeneration will become established from natural seed fall on this site, even in better-than-average seed years.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

In order for shade-intolerant shortleaf pines to become established at recommended levels of density and quadrat stocking and grow at an acceptable rate for sustaining uneven-aged silviculture, removal of overtopping hardwoods is required. If a landowner wishes to retain some midstory and overstory hardwoods while managing for pine, then clumping of hardwoods would be more desirable than random distribution (Shelton and Murphy 1993). In fact, Leopold and others (1985) found that most hardwood species in a midwestern hardwood forest exhibited an aggregated distribution under natural conditions.

In the present investigation, herbicide injection of hardwoods after the pine single-tree selection harvest was more beneficial in terms of enhancing the establishment and growth of direct-seeded shortleaf pine regeneration when compared with untreated checks or manual hardwood control treatments. Followup manual release of established pine regeneration in the fourth growing season resulted in no measurable benefit in terms of competition control or pine seedling growth when compared with initial hardwood control by chain saw felling. The release treatment also negated the initial cost advantage of chain saw felling. If herbicide use is not an option on National Forest System lands because of public concerns, then manual girdling of the hardwood component is likely to result in fewer sprouts of smaller size than chain saw felling (Liming 1945, 1946).

During the first 5 years of this study, residual overstory pines grew at the rate of only 0.14 inch d.b.h. per year. Without ingrowth from submerchantable to merchantable size classes, data suggest that cycle cuts may be needed only every 10 to 12 years for conversion of mature even-aged shortleaf pine stands to uneven-aged structure on south-facing slopes where site conditions are similar to those tested here. This assumes that residual basal area averages 60 square feet per acre in merchantable-size pines after the initial harvest.

Although the evaluation of planted shortleaf pine seedlings was conducted only as a side test to the main study, the genetically improved, nursery-grown pines provided better stocking and outperformed dominant shortleaf seedlings that were established by seeding. Consequently, when converting mature even-aged shortleaf pine stands to uneven-aged structure, planting appears to be a viable regeneration alternative to direct seeding or natural seeding, especially at locations where natural seed crops are consistently below average.

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LITERATURE CITED

Cain, M.D. 1987. Survival patterns of understory woody species in a pine-hardwood forest during 28 years without timber management. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the sixth central hardwood forest conference. Knoxville, TN: University of Tennessee: 141-147.

Cain, M.D. 1988a. Competition impacts on growth of naturally regenerated loblolly pine seedlings. Res. Note SO-345. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.

Cain, M.D. 1988b. Hardwood control before harvest improves natural pine regeneration. Res. Pap. SO-249. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 6 p.

Cain, M.D. 1991. Importance of seedyear, seedbed, and overstory for establishment of natural loblolly and shortleaf pine regeneration in southern Arkansas. Res. Pap. SO-268. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 10 p.

Cain, M.D. 1993. First-year response of direct-seeded shortleaf pine and hardwood sprouts to three methods of hardwood control in the Arkansas Ozarks. In: Brissette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 317-326.

Cain, M.D.; Shelton, M.G. 1993. Modification of GSA metal wastebaskets for use as seed and litter traps. Engineering Field Notes. 26: 65-69.

Ezell, A.W. 1988. Direct seeding—a forest regeneration alternative. Publ. 1588. Mississippi State, MS: Mississippi State University, Mississippi Cooperative Extension Service. 5 p.

Farrar, R.M., Jr. 1984. Density control—natural stands. In: Proceedings of the symposium on the loblolly pine ecosystem (west region). Mississippi State, MS: Mississippi Cooperative Extension Service, Extension Forestry Department: 129-154.

Leopold, D.J.; Parker, G.R.; Ward, J.S. 1985. Tree spatial patterns in an old-growth forest in east-central Indiana. In: Dawson, J.O.; Majerus, K.A., eds. Proceedings of the fifth central hardwood forest conference. Society of American Foresters Publ. 85-05. Urbana-Champaign, IL: University of Illinois, Department of Forestry: 151-164.

Liming, F.G. 1945. Natural regeneration of shortleaf pine in the Missouri Ozarks. Journal of Forestry. 43: 339-345.

Liming, F.G. 1946. Response of planted shortleaf pine to overhead release. Tech. Pap. 105. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station. 20 p.

Miller, G.W. 1984. Releasing young hardwood crop trees—use of a chain saw costs less than herbicides. Res. Pap. NE-550. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Murphy, P.A.; Baker, J.B.; Lawson, E.R. 1991. Selection management of shortleaf pine in the Ouachita Mountains. Southern Journal of Applied Forestry. 15: 61-67.

Shelton, M.G.; Murphy, P.A. 1993. Pine regeneration and understory vegetation 1 year after implementing uneven-aged silviculture in pine-hardwood stands of the silty uplands of Mississippi. In: Brissette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 333-341.

Trousdell, K.B. 1950. Seed and seedbed requirements to regenerate loblolly pine. Sta. Pap. No. 8. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 13 p.

U.S. Department of Agriculture. 1976. Volume, yield, and stand tables for second-growth southern pines. Rev. Misc. Publ. 50. Washington, DC: U.S. Department of Agriculture, Forest Service. 202 p.

U.S. Department of Agriculture. 1977. Soil survey of Johnson County, Arkansas. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service and Forest Service. 80 p. + maps. In cooperation with: The Arkansas Agricultural Experiment Station.

U.S. Department of Agriculture. 1990. Final environmental impact statement for vegetation management in the Ozark/Ouachita Mountains. Manage. Bull. R8-MB 45. Atlanta, GA: U.S. Department of Agriculture, Forest Service. 352 p. Vol. 1.