EFFECTS OF RETAINING A HARDWOOD COMPONENT DURING THE APPLICATION OF UNEVEN-AGED SILVICULTURE IN A SHORTLEAF PINE-OAK STAND: 6-YEAR RESULTS

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Abstract—Treatments were the following hardwood basal areas (square feet per acre) and spatial arrangements: 0, 15-grouped, 15-scattered, 30-scattered, and an untreated control. Pine basal area was reduced by harvesting to 60 square feet per acre in all treatments except the control. After six growing seasons, pine regeneration ranged from 8,890 stems per acre in the 0-hardwood treatment to 0 stems per acre in the control, and stems were 6.2 times taller in the 0-hardwood treatment than in the 30-scattered treatment. Height growth of pine regeneration was acceptable in the 0-hardwood and 15-grouped treatments, but was inadequate elsewhere. Oak regeneration averaged 1,510 stems per acre after 6 years with no significant differences among treatments. Coverage of understory vegetation was greatest in the 0-hardwood treatment and declined as hardwood retention increased. Volume growth of merchantable pines surviving the 6-year period was 34 percent higher in the 0-hardwood treatment than in the 15- and 30-scattered treatments. However, high rates of postharvest mortality resulted in no significant differences in rates of net growth among treatments.

INTRODUCTION

Knowledge about implementing uneven-aged silviculture in shortleaf pine (*Pinus echinata* Mill.) stands is very limited (Murphy and others 1991). Techniques and guidelines developed for loblolly (*P. taeda* L.)–shortleaf pine stands at the Crossett Experimental Forest in the Coastal Plain of Arkansas (Baker and others 1996) may be adaptable, but most of the Crossett experience applies to managing existing uneven-aged pine stands or rehabilitating understocked pine stands. Stands in the Ouachita Mountains are mostly mature pines and oaks (*Quercus* spp.) that have developed an even-aged character, and a hardwood component is desired to enhance nontimber resources. Such stands pose a unique set of problems: (1) some hardwoods must be removed to create a favorable environment for the establishment and development of pine regeneration; (2) a reverse-J diameter distribution must be developed, which will likely take several decades; and (3) the response of suppressed pines of the original stand to release is questionable (Shelton and Murphy 1991, 1993).

This ongoing research focuses on some of the problems of applying uneven-aged silviculture in mature pine-oak stands on poor sites. Such stands are common on public lands, and knowledge is needed concerning alternative silvicultural systems. Study objectives are to test the traditional application of uneven-aged pine silviculture using single-tree selection and to determine the limits for hardwood retention within this system. Response of understory vegetation and merchantable growth is reported at 6 years after implementation of the study. This paper updates an earlier one reporting 3-year results (Shelton and Murphy 1997).

METHODS

Study Area

The study was installed on the Winona Ranger District of the Ouachita National Forest in Perry County, AR. Plots were oriented along an east-west ridge, which is typical of the physiography of the Ouachita Mountains. Elevations ranged from 640 to 790 feet above sea level. Blocks were located on the following slope positions: the lower, middle, and upper north slopes and the upper south slope. Slopes of individual plots ranged from 8 to 21 percent; aspects ranged from north to northwest on the north-slope positions and from southeast to southwest on the south-slope position.

Soils of the study area are mapped as the Carnasaw and Pirum series, both Typic Hapludults. These are well-drained, moderately deep soils that developed in colluvium and residuum weathered from sandstone and shale. Natural fertility and organic matter are low, and the soils are strongly acidic. Site index for shortleaf pine averaged 57 feet at 50 years and ranged from 53 to 64 feet, which is typical of upland sites in the Ouachita Mountains (Graney 1992). The lower north slope had a slightly higher site index than the other three slope positions (61 versus 56 feet). Site index averaged 53 feet at 50 years for white oak (*Quercus alba* L.) and 54 feet for black oak (*Q. velutina* Lam.).

Vegetation in the study area was typical of forested landscapes in the Ouachita Mountains, where upland forests are dominated by shortleaf pine and mixed oaks (Guldin and others 1994). Before treatment, overstory basal area [trees ≥ 3.6 inches in diameter at breast height (d.b.h.)] in this mature, second-growth, shortleaf pine-oak stand averaged 90 square feet per acre for shortleaf pine and 32 square feet per acre for hardwoods. Oaks accounted for 84 percent of the total hardwood basal area. White oak was the most prevalent hardwood, with lesser amounts of post oak (*Q. stellata* Wangenh.), black oak, blackjack oak (*Q. marilandica* Muenchh.), and southern red oak (*Q. falcata* Michx.). The remaining 16 percent of hardwood basal area was ash (*Fraxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), serviceberry [*Amelanchier arborea* (Michx. f.) Fern.], blackgum (*Nyssa sylvatica* Marsh.), and flowering dogwood (*Cornus florida* L.). The understory was mainly

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regeneration of the more shade-tolerant species and a variety of common shrubs, such as huckleberries (*Vaccinium* spp.) and hawthorns (*Crataegus* spp.).

Overstory pines and oaks ranged in age from 30 to over 110 years (Shelton and Murphy 1991). However, most of the pines were 50 to 80 years old, and the oaks were 40 to 70 years old. The scarcity of younger overstory trees indicated that regeneration and subsequent recruitment of both the pines and oaks had been limited for 30 to 40 years of stand development.

Study Design and Treatments

Sixteen square 0.5-acre plots were installed and surrounded by a 58.2-foot isolation strip that received the same treatment. Basal area of overstory pines (trees ≥ 3.6 inches d.b.h.) was reduced to 60 square feet per acre in all plots. Treatments retained the following hardwood basal areas (square feet per acre) and spatial arrangements for overstory trees: 0, 15-grouped, 15-scattered, and 30-scattered. Openings in the pine canopy ranged from 0.10 to 0.25 acre and often extended from the 0.5-acre plots into the isolation strip. In the scattered arrangements, hardwoods were uniformly distributed across each plot, while in the grouped arrangement they were located outside openings in the pine canopy. For the grouped arrangement, no attempt was made to create openings in the pine canopy other than those resulting from application of single-tree selection. The grouped spatial arrangement was similar to the 0-hardwood treatment within openings and to the 30-scattered treatment outside openings. Treatments were assigned in a randomized, complete block design with four replications of each treatment. In 1991, permanent 0.5-acre plots were established in untreated areas adjacent to each block to serve as untreated controls.

The pine component was regulated using the basal area–maximum diameter–quotient (BDq) method of single-tree selection (Baker and others 1996). Targets were 60 square feet per acre for basal area, 18 inches for maximum d.b.h., and a quotient of 1.2 for 1-inch d.b.h. classes. Targets for maximum diameter and quotient were followed as closely as feasible, because the stand lacked a balanced reverse-J diameter distribution characteristic of uneven-aged structure. Hardwood retention favored the higher quality red and white oaks, which typically were the largest hardwoods in the study area.

Plots were harvested from December 1988 through early March 1989 using mules to skid logs to landings. Because there were no local markets for hardwoods, all hardwoods ≥ 1 inch d.b.h. that were not designated for retention were injected with triclopyr amine in April 1989. Herbicide treatments were applied by contract crews following label directions, although research crews did some followup work.

Measurements

During March 1989, all retained pines and hardwoods (≥ 3.6 inches d.b.h.) in the 0.5-acre plots were measured for d.b.h., and the location of each stem was mapped by determining azimuth and distance from plot center. About one-third of the trees were measured for height and age. Ten permanent points were systematically located within each 0.5-acre plot for monitoring the development of understory vegetation. The monitoring points were located so that none were closer than 30 feet from the 0.5-acre plot boundary and 88 feet from the isolation boundary.

In June 1994, coverage of understory vegetation was visually estimated in milacre plots (3.72-foot radius) centered around the 10 permanent monitoring points in each 0.5-acre plot. The following groups were used: grasses, forbs, vines, shrubs, hardwoods, pines, and total vegetation. Evaluations were conducted in June because coverage was observed to maximize before the summer droughts that typically occur on such sites. During mid-September 1994, all woody seedlings (≤ 0.5 inch d.b.h.) were counted in the milacre plots by species or species group. Multiple-stemmed rootstocks were tallied as one individual. Woody saplings (0.6 to 3.5 inches d.b.h.) were counted in 0.01-acre circular subplots centered around each of the 10 permanent points per 0.5-acre plot. The two tallest pines (if any) and two tallest hardwoods in each 0.01-acre subplot were selected as the dominant regeneration and were measured for groundline diameter, height, and crown width.

Data Analysis

Mean values for understory vegetation were calculated for the 10 regeneration subplots in each 0.5-acre plot. Regeneration subplots were considered to be stocked by pine and nonpine woody species if at least one individual was present to represent the species or species group. To facilitate data presentation, nonpine species were grouped as follows: oaks, other overstory trees, midcanopy trees, and shrubs. Other overstory trees included blackgum, hickory, ash, and sweetgum (*Liquidambar styraciflua* L.). Midcanopy trees included red maple, serviceberry, dogwood, elms (*Ulmus* spp.), persimmon (*Diospyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). Shrubs were mostly huckleberries, hawthorns, and plums (*Prunus* spp.).

Pine volume in each 0.5-acre plot was calculated using taper curves for natural shortleaf pine (Farrar and Murphy 1987). Inside-bark cubic-foot volume for merchantable trees (d.b.h. ≥ 3.6 inches) was computed from a 1-foot stump to a 4.0-inch diameter outside-bark top. Volume for sawtimber trees (d.b.h. ≥ 9.6 inches) was computed from a 1-foot stump to an 8-inch diameter outside-bark top. Cubic-foot volume was inside bark. Hardwood volume was calculated using equations of Clark and others (1986). Hardwood merchantability limits were the same as for pines except that stump heights varied as follows: 0.2 foot for trees 3.6 to 4.9 inches d.b.h., 0.6 foot for trees 5.0 to 10.9 inches d.b.h., and 1.0 foot for larger trees. Sawtimber volume was not calculated for hardwoods because of their small size and generally poor quality.

Analysis of variance for a randomized, complete block design was used to compare expressions of understory vegetation and volume growth among treatments. Significance was accepted at a probability level (P) ≤ 0.05. Density and stocking values were transformed to homogenize the error term. Differences among treatment means were isolated using the Ryan-Einot-Gabriel-Welsch multiple range test (P = 0.05). This procedure, which is one of the most powerful stepdown, multiple-range tests available, controls the experiment-wise error rate (SAS Institute 1989).

RESULTS AND DISCUSSION

Regeneration Density

Most shortleaf pine seedlings became established from seeds dispersed following harvest and site preparation. At 6 years, there was an average of 6,175 seedlings per acre in treatments with timber harvesting, but no significant differences occurred among these treatments (table 1). However, no pine seedlings were found in the untreated controls. Apparently, environmental conditions in the 30-scattered treatment were sufficiently different from the untreated control to allow the establishment of 6,075 seedlings per acre. The 30-scattered treatment had about the same merchantable hardwood basal area as the control, but the control had an additional 30 square feet per acre of pine basal area and 4 square feet per acre of submerchantable hardwoods. Shelton and Murphy (1997) reported a mean across all harvested treatments of only 756 seedlings per acre at 3 years, which means that most of the pine seedlings present at 6 years became established after 3 years.

The generally accepted minimum stocking for pine regeneration in uneven-aged pine stands is 200 submerchantable stems per acre (Cain and others 1987). Although all of the harvested treatments exceeded this minimum, shortleaf pine seedlings in the 15-scattered and 30-scattered treatments are not expected to survive. Other researchers have observed that pine seedlings can become established under a dense canopy and persist for several years before dying (Becton 1936, Wahlenberg 1960). This observation suggests that newly established pine seedlings are moderately shade tolerant but become shade intolerant with age. Bormann (1956) reported, for example, that the photosynthetic efficiency of loblolly pine seedlings at low light intensities declined substantially as secondary growth characteristics developed.

Shortleaf pine saplings occurred only in the 0-hardwood (65 stems per acre) and 15-grouped (15 stems per acre) treatments at 6 years, and differences among treatments were significant. Saplings in the 15-grouped treatment were only in openings where no hardwoods were retained.

For nonpine species, an average of 8,365 rootstocks per acre occurred in the seedling size class at 6 years with no significant treatment differences (table 1). This represents a 40-percent decline from levels reported at 3 years (Shelton and Murphy 1997) and probably reflects mortality from self-thinning and outgrowth to the sapling size class. Shrubs were the most common nonpine species group, and oaks represented 17 percent of the total.

Treatments significantly affected the density of sapling oaks and other canopy trees; the fewest saplings occurred in the 30-scattered treatment where they had been controlled during site preparation. The greatest density of oak saplings occurred in the 0-hardwood treatment (128 stems per acre) and the untreated control (132 stems per acre). Saplings of other canopy species were most prevalent in the 0-hardwood treatment (108 stems per acre) followed by the 15-grouped

Table 1—Density of seedlings and saplings 6 years after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand

Species or group	Density (number/acre) by hardwood treatment: 0 ft^2/ac	15 ft^2/ac grouped	15 ft^2/ac scattered	30 ft^2/ac scattered	Control	Mean square error[a]	P[b]
			seedlings				
Shortleaf pine	8,825a[c]	3,275a	6,525a	6,075a	0b	571	<0.01
Oaks	825	1,225	1,900	1,100	2,175	135	0.22
Other canopy trees	1,375a	925ab	925ab	1,300a	100b	111	0.02
Midcanopy trees	350	1,825	1,100	1,300	700	272	0.50
Shrubs	2,275	3,050	4,550	6,425	8,400	1,031	0.37
Nonpine total	4,825	7,025	8,475	10,125	11,375	349	0.12
			saplings				
Shortleaf pine	65a	15ab	0b	0b	0b	6.1	<0.01
Oaks	128a	35b	28bc	2c	132a	3.1	<0.01
Other canopy trees	108a	72a	28ab	5b	65a	5.6	<0.01
Midcanopy trees	55	55	10	5	60	13.2	0.32
Shrubs	10	2	0	2	12	3.8	0.42
Nonpine total	301a	164ab	66bc	14c	269a	7.2	<0.01

[a] Based on transformed values: (number per acre)$^{0.5}$.
[b] Probability level.
[c] Row means followed by the same letter or no letter are not significantly different at $P = 0.05$.

treatment (72 stems per acre). Most saplings in the 15-grouped treatment were located in the openings created by hardwood control.

Regeneration Stocking

Percentage stocking is often a better measure of regeneration success than density because stocking expresses the spatial distribution of seedlings, whereas density does not. Stocking is less sensitive to the clumped-spatial pattern that often occurs with natural regeneration (Daniels 1978). The stocking of shortleaf pine seedlings and saplings was similar in pattern to density. For the harvested treatments, pine seedling stocking averaged 66 percent with no significant differences (table 2). The generally accepted optimum stocking limit for pine regeneration in uneven-aged pine stands is 50 percent (Cain and others 1987). All harvested treatments either met or exceeded this limit at 6 years, although seedlings are not expected to survive in the 15-scattered and 30-scattered treatments. The treatments had a significant effect on the stocking of shortleaf pine saplings, which occurred only in the 0-hardwood and 15-grouped treatments.

A nonpine species in the seedling size class occurred on nearly all milacre subplots; stocking levels averaged 92 percent with no significant differences among treatments. Stocking for oaks averaged 58 percent with no significant differences among treatments. Seedlings of other canopy trees had a significantly lower stocking in the unharvested control (8 percent) than in the harvested treatments (47 percent).

For stocking of nonpine saplings, significant differences occurred among treatments for oaks, other canopy trees, and all nonpines. The pattern displayed across treatments was the same for each species group; the 0-hardwood treatment nearly equaled the control, and stocking decreased in the following order: 0-hardwood > 15-grouped > 15-scattered > 30-scattered.

Size of Dominant Regeneration

After the sixth growing season, shortleaf pine regeneration decreased in size as hardwood retention increased (table 3). Pines in the 0-hardwood treatment were larger than those in the 30-scattered treatment by 7.5 times for groundline diameter, 4.1 times for crown width, and 6.2 times for height. Differences were highly significant in all cases. Baker and others (1996) state that annual height growth of pines should be ≥ 0.5 feet for acceptable development. This guideline was met in the 0-hardwood and 15-grouped treatment but not in the other treatments.

The nonpine groups showed a pattern similar to the pines except that the magnitude of suppression was not as great. For example, regeneration in the 0-hardwood treatment was taller than in the 30-scattered treatment by 2.7 times for the oaks, 1.9 for other canopy trees, and 1.9 for midcanopy trees. Hardwood regeneration was still larger than shortleaf pine regeneration at 6 years. This reflected a difference in the principal reproductive strategy of the two groups—seeds for pines versus advanced regeneration and sprouts for hardwoods. Experience elsewhere has shown that the height

Table 2—Stocking of seedlings and saplings 6 years after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand

	Stocking (percent) by hardwood treatment[a]						
Species or group	0 ft^2/ac	15 ft^2/ac grouped	15 ft^2/ac scattered	30 ft^2/ac scattered	Control	Mean square error[b]	*P*[c]
	seedlings						
Shortleaf pine	78a[d]	60a	65a	62a	0b	0.062	<0.01
Oaks	50	50	70	52	70	0.041	0.31
Other canopy trees	52a	50a	42a	45a	8b	0.025	<0.01
Midcanopy trees	25	48	45	45	32	0.080	0.58
Shrubs	38	52	52	58	60	0.061	0.67
All nonpines	88	92	98	92	92	0.062	0.76
	saplings						
Shortleaf pine	25a	10ab	0b	0b	0b	0.024	<0.01
Oaks	58a	22b	15bc	2c	58a	0.021	<0.01
Other canopy trees	50a	40a	18ab	5b	45a	0.053	<0.01
Midcanopy trees	28	25	8	5	25	0.076	0.45
Shrubs	8	2	0	2	10	0.034	0.43
All nonpines	88a	58ab	35bc	15c	88a	0.047	<0.01

[a] Stocking is based on milacre plots for seedlings and 0.01-acre plots for saplings.
[b] Based on transformed values: arcsine (percent/100)$^{0.5}$.
[c] Probability level.
[d] Row means followed by the same letter or no letter are not significantly different at $P = 0.05$.

Table 3—Mean size of the dominant regeneration 6 years after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand

Species or group	Regeneration size by hardwood treatment[a] 0 ft²/ac	15 ft²/ac grouped	15 ft²/ac scattered	30 ft²/ac scattered	Mean square error	*P*[b]
	- - - - *Groundline diameter* (*inches*) - - - -					
Shortleaf pine	0.82a[c]	0.53ab	0.24bc	0.11c	0.033	<0.01
Oaks	1.71a	0.87b	0.91b	0.66b	0.093	<0.01
Other canopy trees	1.50a	1.21ab	1.08bc	0.80c	0.036	<0.01
Midcanopy trees	1.50a	1.21ab	0.83b	0.76b	0.045	0.03
	- - - - - - *Crown diameter* (*feet*) - - - - - - -					
Shortleaf pine	1.96a	1.48a	0.80b	0.48b	0.104	<0.01
Oaks	5.11a	3.17b	3.33b	2.69b	0.503	<0.01
Other canopy trees	5.45a	4.28ab	4.27ab	3.98b	0.357	0.03
Midcanopy trees	5.72	5.61	3.72	3.62	1.184	0.10
	- - - - - - - - *Total height* (*feet*) - - - - - - - -					
Shortleaf pine	4.66a	3.19ab	1.61bc	0.75c	0.89	<0.01
Oaks	9.07a	5.05b	5.17b	3.41b	2.28	<0.01
Other canopy trees	9.40a	7.34b	7.46b	4.93c	0.90	<0.01
Midcanopy trees	11.47a	9.44ab	6.74b	5.95b	2.07	0.04

[a] The unharvested control was not included in this comparison because no pines occurred and the hardwoods present were a different age class than those in the harvested treatments.
[b] Probability level.
[c] Row means followed by the same letter or no letter are not significantly different at $P = 0.05$.

growth of free-to-grow pine regeneration will eventually exceed that of hardwoods on most upland sites (Wahlenberg 1960), but the 6-year results of this study may be too early to confirm this. At 3 years, hardwoods were 2.1 times taller than pines in the 0-hardwood treatment (Shelton and Murphy 1997), and this was the same value observed at 6 years.

Understory Coverage

The effect of treatments on understory coverage varied among species groups, with significant differences occurring for grasses, vines, shortleaf pine, and total vegetation (table 4). Generally, coverage declined as more overstory hardwoods were retained, although some variation occurred in this pattern. Coverage was greater in the 0-hardwood treatment than in the control by 15.1 times for grasses, 2.4 for vines, and 2.1 for hardwoods. In contrast, shrub coverage was higher in the unharvested control than in the harvested treatments. Comparison of the 6-year results with those reported at 3 years (Shelton and Murphy 1997) showed that pines and hardwoods doubled in coverage, vines increased slightly, and grasses decreased. This suggests that pines and hardwoods will dominate the subsequent pattern of successional change in understory vegetation.

Growth of Merchantable Trees

Postharvest mortality of shortleaf pines was high and required expressing growth by its functional components—survivor growth, mortality, and net growth (Husch and others 1982). Survivor growth for total merchantable volume was significantly higher in the 0-hardwood treatment (42 cubic feet per acre per year) than in the 15- and 30-scattered treatments by 34 percent (table 5). Mortality losses of shortleaf pine averaged 9 cubic feet per acre per year for merchantable volume with no significant differences among treatments; mortality averaged 1.0 tree per acre per year and was mostly from the smaller trees in the stand. Dying trees had a mean d.b.h. of 7.4 inches compared with 10.1 inches for surviving trees. Tree mortality was from multiple causes, such as insects, lightning, suppression, and windthrow, but in the majority of cases the cause was not discernable (58 percent). Cain (1998) also observed high rates of inexplicable mortality following the implementation of uneven-aged silviculture in a shortleaf pine stand in southern Arkansas. Net growth of merchantable pines averaged 25 cubic feet per acre per year with no significant differences among treatments.

Net volume growth for sawtimber averaged 122 board feet (Doyle) per acre per year for shortleaf pine with no significant differences among treatments (table 5). Murphy and others (1991) reported sawtimber growth in three well-structured, uneven-aged shortleaf pine stands in the Ouachita Mountains. In a stand with the same site index as this study (57 feet at 50 years), they reported growth of 209 board feet (Doyle) per acre per year; on poorer sites they reported lower growth rates (137 and 126 board feet per acre per year for stands with site indices of 50 and 55 feet, respectively). Thus, the sawtimber growth for this study, which lacks an uneven-aged structure, appears somewhat lower than well-structured stands on similar sites.

Table 4—Coverage of understory vegetation 6 years after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand

Species or group	Understory coverage by hardwood treatment: 0 ft²/ac	15 ft²/ac grouped	15 ft²/ac scattered	30 ft²/ac scattered	Control	Mean square error[a]	P[b]
	- - - - - -	- - - - - -	*percent*	- - - - - -	- - - - - -		
Grasses	24.1a[c]	8.4bc	10.8b	4.5cd	1.6d	0.003	<0.01
Forbs	1.8	1.5	0.9	1.4	0.2	0.006	0.59
Vines	22.0ab	27.0a	16.0ab	7.7b	9.0b	0.012	0.03
Shrubs	7.6	6.5	5.5	7.0	10.9	0.016	0.72
Hardwoods	31.9	29.5	16.1	13.2	15.1	0.016	0.07
Shortleaf pine	3.9a	1.1ab	0.3b	0.2b	0.0b	0.003	<0.01
Total vegetation[d]	78.4a	63.8ab	45.5bc	33.9c	32.0c	0.010	<0.01

[a] Based on transformed values: arcsine $(\text{percent}/100)^{0.5}$.
[b] Probability level.
[c] Row means followed by the same letter or no letter are not significantly different at $P = 0.05$.
[d] Coverage of total vegetation is less than the sum of individual species groups because of multiple occupancy.

Table 5—Growth of merchantable-sized trees for the 6-year period after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand

Growth component by species or group	Annual growth by hardwood treatment[a]: 0 ft²/ac	15 ft²/ac grouped	15 ft²/ac scattered	30 ft²/ac scattered	Mean square error	P[b]
	- - - - *Merchantable volume (ft³/ac)* - - - -					
Shortleaf pine						
Survivor	42.3a[c]	33.4ab	32.3b	30.6b	24	0.03
Mortality	17.6	7.3	3.1	9.8	269	0.66
Net	24.7	26.1	29.2	20.8	388	0.94
Hardwoods						
Survivor	—	12.4b	16.0ab	20.0a	19	0.12
Mortality	—	2.7	0.4	1.4	9	0.58
Net	—	9.7b	15.6ab	18.6a	17	0.05
	- - - - - *Sawtimber volume*[d] (*ft³/ac*) - - - - -					
Shortleaf pine						
Survivor	39.2	38.9	33.7	30.8	41	0.24
Mortality	14.0	4.9	0.0	8.5	248	0.65
Net	25.2	34.0	33.7	22.3	336	0.74
	- - *Sawtimber volume*[d] (*fbm Doyle/ac*) - -					
Shortleaf pine						
Survivor	166	157	133	132	688	0.24
Mortality	56	15	0	31	3,976	0.65
Net	110	142	133	101	5,148	0.83

[a] Control plots were not monitored for growth.
[b] Probability level.
[c] Row means followed by the same letter or no letter are not significantly different at P=0.05.
[d] Too few hardwoods occurred in sawtimber size classes for analysis.

Hardwoods contributed to the stand's growth in total merchantable volume; net growth averaged 15 cubic feet per acre per year. Mortality of hardwoods was considerably less than shortleaf pine and averaged only 1.5 cubic feet per acre per year. Because of their small size and generally low quality, hardwoods did not contribute to the stand's sawtimber growth.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The amount and spatial distribution of natural pine regeneration depend on seed supply, seedbed conditions, and environmental conditions. The treatments evaluated in this study principally affected the environmental conditions that govern seedling survival and growth. Because of shortleaf pine's shade intolerance, seedling development will be suppressed to some extent in any reproductive cutting method that retains an overstory. The key to successful application of uneven-aged silviculture is to reach a balance between retaining an adequate overstory stocking for acceptable merchantable growth and reducing overstory stocking enough to provide the environmental conditions needed for regeneration. Pine growth rates in both the overstory and understory will be below their short-term potential, but this compromise provides a system that should be sustainable through time.

Recurring pine regeneration is crucial for the long-term sustainability of uneven-aged stands in which shortleaf pine is the dominant species. Retaining hardwoods within the single-tree selection system will most severely impact environmental conditions in the understory. Hardwoods apparently suppress the development of pine seedlings more than an equivalent basal area of pines, which reflects differences in crown and foliar features. Thus, acceptable limits for hardwoods within an uneven-aged pine stand are apparently low, even if the pine basal area is reduced accordingly. Early results of this study show that retaining as little as 15 square feet per acre of hardwood basal area in a scattered distribution with a pine basal area of 60 square feet per acre (the 15-scattered treatment) will prevent the acceptable development of sufficient pine regeneration to sustain long-term pine timber production. However, reducing pine basal area to 45 square feet per acre might allow retention of 5 to 10 square feet per acre of scattered hardwoods (Baker and others 1996).

Results also suggest that 15 square feet per acre of hardwood basal area can be retained outside openings in the pine canopy (the 15-grouped treatment) while still obtaining adequate development of pine regeneration within the openings. However, the success of this treatment can only be measured by evaluating long-term developmental rates of regeneration. In addition, the feasibility of implementing the 15-grouped treatment needs to be operationally tested. This treatment was difficult to implement even on these small research plots, because it was hard to determine where opening boundaries occurred. Creating openings to promote stand regeneration would have been easier using group selection, where both pines and hardwoods are removed within well-defined openings (Murphy and others 1993).

This study shows that adequate pine regeneration will occur in shortleaf pine stands in the Ouachita Mountains when: (1) traditional guidelines for uneven-aged pine silviculture are followed (that is, the 0-hardwood treatment), (2) seed supply and environmental conditions are favorable, and (3) competing understory vegetation is low. More time, however, is needed to fully assess developmental rates of regeneration and to evaluate the growth of overstory trees. Although traditional guidelines for uneven-aged pine stands exclude a hardwood component at a local scale, they can be retained at the stand level along drainages or in clumps or clusters in an area-wise distribution. Permissible levels of hardwood retention within this spatial pattern are probably not limited by biology, as long as pine-dominated areas are large enough to provide relative freedom from the edge effects of retained hardwoods. Rather, landowner objectives and operational concerns will probably set realistic limits. According to Baker and others (1996), the area-wise distribution of pines and hardwoods in uneven-aged stands under single-tree selection has a number of advantages for landowners who want to retain hardwoods: (1) a favorable environment is provided for the shade-intolerant pine regeneration, (2) a significant hardwood component can be retained, (3) species-site relationships are optimized, (4) sensitive areas are protected, (5) hardwoods are protected during silvicultural operations, (6) stand regulation and marking are simplified, and (7) a varied wildlife habitat is provided.

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