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Understory Vegetation 3 Years after Implementing Uneven-Aged Silviculture in a Shortleaf Pine-Oak Stand

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SUMMARY

The effects of retaining overstory hardwoods on understory vegetation were determined after implementing uneven-aged silviculture using single-tree selection in a shortleaf pine-oak stand (*Pinus echinata* Mill. and *Quercus* spp.) in the Ouachita Mountains. 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 ft^2/acre in all treatments except the control, and the desired hardwood basal area and arrangement were achieved by injecting unwanted hardwoods with herbicide. Monitoring was conducted at 10 permanent locations within each 0.5-acre plot of the randomized, complete block design with four replications. Pine regeneration during the first growing season following harvest was virtually nil because there was little advance regeneration and the preceding seed crop was poor. A good seed crop occurred during 1989 (180,000 sound pine seeds per acre), resulting in a mean of 2,730 seedlings per acre the following growing season with no significant differences among treatments. Mortality over the next 2 years reduced this base to 1,925 seedlings per acre for the O-hardwood treatment and 0 seedlings per acre for the control. Oak regeneration averaged 2,370 rootstocks per acre after the third growing season and had a mean milacre stocking of 63 percent; no significant differences occurred among treatments. Pine regeneration was judged to be adequate for the O-hardwood treatment and within openings for the 15-grouped treatment but was inadequate elsewhere. Results indicate the importance of overstory-understory relationships in uneven-aged silviculture.

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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 (Reynolds 1959, 1969; Reynolds and others 1984) 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 pine-oak (*Quercus* spp.) stands that have developed an even-aged character, and a hardwood component is desired to enhance the stand's 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 was initiated in 1988 by personnel with the USDA Forest Service's Ouachita National Forest and Southern Research Station. The study 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 is reported here for the first 3 years after implementation of the study

METHODS

Study Area

The study was installed in 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 ft above sea level. Blocks were located with 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, and 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 ft at 50 years and ranged from 53 to 64 ft, which is typical of upland sites in the Ouachita Mountains (Graney 1992). The lower north slope was slightly higher in site index than the other three slope positions (61 versus 56 ft). Site index averaged 53 ft at 50 years for white oak (*Quercus alba* L.) and 54 ft for black oak (*Q. velutina* Lam.).

Vegetation in the study area was typical of much of the forested landscape in the Ouachita Mountains, where upland forests are dominated by shortleaf pine and mixed oaks (Guldin and others 1994). Overstory basal area (trees ≥ 3.6 inches in d.b.h.) in this mature, second-growth, shortleaf pine-oak stand averaged 90 ft^2/acre for shortleaf pine and 32 ft^2/acre for hardwoods before treatment implementation. 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 the hardwood basal area was composed of ash (*Frczxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), serviceberry (*Amelanchier urboreu* [Michx. f.] Fern.), blackgum (*Nyssa sylvatica* Marsh.), and dogwood (*Cornus florida* L.). The understory was mainly composed of regeneration of the more shade-tolerant species and a

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variety of common shrubs, such as huckleberries (*Vaccinium* spp.) and hawthorns (*Crataegus* spp.).

Overstory pines and oaks in the initial stand 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 trees in the overstory indicated that regeneration and subsequent development in both the pines and oaks had been limited for 30 to 40 years of stand development before implementation of the study

Study Design and Treatments

Sixteen square 0.5-acre plots were installed and surrounded by a 58.2-ft isolation strip that received the same treatment. Basal area of overstory pines (trees ≥ 3.6 inches in d.b.h.) was reduced to 60 ft^2/acre in all plots. Hardwood treatments were the following basal areas (square feet per acre) and spatial arrangements for overstory trees: 0, 15-grouped, 15-scattered, and 30-scattered. In the scattered arrangements, hardwoods were uniformly distributed across each plot, whereas hardwoods in the grouped arrangement were located outside the openings in the pine canopy (fig. 1). For the grouped arrangement, no attempt was made to create openings in the pine canopy other than those occurring as a matter of course in the application of single-tree selection. Openings in the pine canopy ranged from 0.1 to 0.25 acre and often extended from the 0.5-acre plots into the isolation strip. Thus, 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.

The pine component was regulated using the basal area-maximum diameter-quotient (BDq) method of single-tree selection (Farrar 1984). Targets were 60 ft^2/acre for basal area, 18 inches for maximum d.b.h., and a quotient of 1.2 for l-inch diameter 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 (fig. 2). Hardwood retention favored the higher quality red and white oaks; these were typically the larger hardwoods in the study area.

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

In 1991, permanent 0.5-acre plots were established in untreated areas adjacent to each block to serve as untreated controls.

Measurements

During March 1989, all retained pines and hardwoods (≥ 3.6 inches in 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, crown dimensions, 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 such that none was closer than 30 ft from the 0.5-acre plot boundary and 88 ft from the isolation boundary

Seedbed conditions after harvest were evaluated at 12 locations spaced along a 22-ft line transect that was centered at each of the 10 permanent monitoring points. The direction of the transect was randomly selected for each permanent point. Seedbed condition at each location was classified as undisturbed litter, disturbed litter, exposed mineral soil, logging debris, or some natural feature, such as a rock or natural coarse woody debris (diameter ≥ 4 inches).

Pine seedlings were inventoried in milacre plots (3.72 ft in radius) centered around the permanent monitoring points by the following size classes: ≤ 0.5, 0.6 to 2.5, 2.6 to 4.5 and ≥ 4.6 ft in height and ≤ 0.5 inch in d.b.h. Pine saplings (stems with a d.b.h. of 0.6 to 3.5 inches) were inventoried in O.Ol-acre plots (11.78 ft in radius) centered around each permanent monitoring point. Inventories were conducted in June 1989, June 1990, December 1990, and October 1991. The 1989 and 1990 inventories were restricted to pine regeneration. However, all woody vegetation was inventoried in 1991 by species or species group using the previously described size classes. Multiple-stemmed rootstocks were tallied as one individual, evaluating the tallest stem for size. In the December 1990 and October 1991 inventories, the two tallest pine seedlings (if any) on each milacre plot were selected as the dominant pine seedlings and were measured for groundline diameter, height, and crown width.

Preharvest conditions were estimated during the 1989 inventory by measuring woody vegetation on 30 temporary milacre plots located in untreated areas adjacent to each block. Permanent control plots were evaluated in the 1991 inventory and thereafter.

Percentage of coverage for understory vegetation was estimated on milacre plots by the following groups: grasses, herbs, vines, shrubs, hardwoods, pines, and total coverage. Evaluations were conducted in June, because coverage was observed to maximize before the summer droughts that typically occur on these sites. All evaluations were conducted by the same person. Coverage was evaluated during 1989, 1990, and 1992, or the first, second, and fourth growing seasons, respectively, after harvest.

In 1989 and 1990, pine seed production was monitored from October through February of the next year in four 0.9-ft^2 seed traps (Cain and Shelton 1993) on each 0.5-acre plot. The seed traps were located about 30 ft from the center of the plot in a square pattern and about 100 ft from the outer boundary of the plot. Collections were made during the middle and end of the October to February period. Seed production was not monitored in the E-grouped treatment or the control at that time. Viability was determined by splitting seeds and inspecting the contents (Bonner 1974). Seeds with full, firm, undamaged, healthy tissue were judged to be potentially viable and were tallied as sound seeds.

Percentage of coverage for the canopy was determined in June 1992 using a spherical densiometer at 4.5 ft above each permanent monitoring point. Photosynthetically active radiation (PAR) was determined at 4.5 ft above each permanent monitoring point during clear sky conditions on August 2, 1991, using an 80-sensor Sunfleck Ceptometer (Decagon Devices, Inc., Pullman, WA). Ten readings were taken across each milacre plot. Measurements were taken

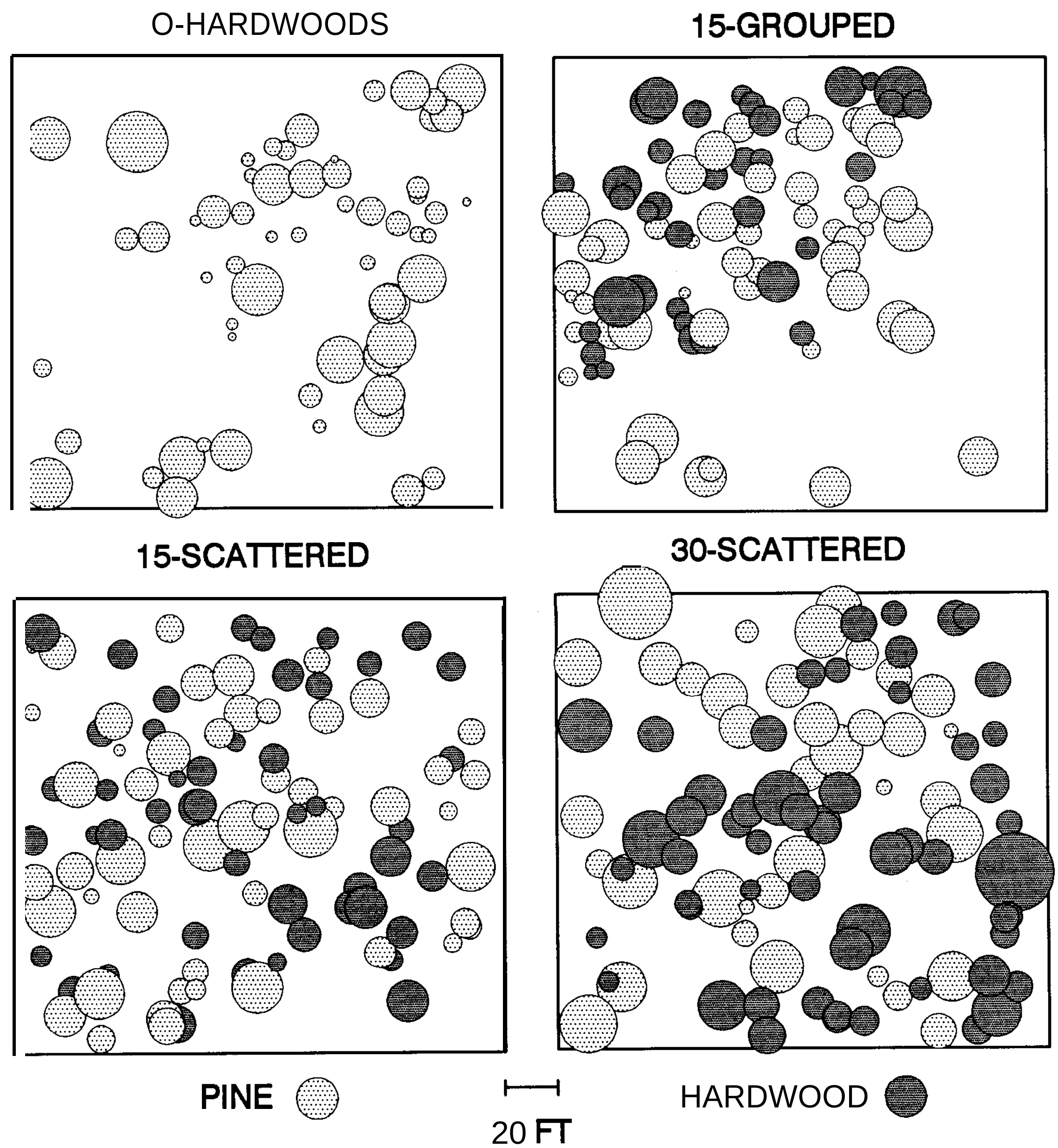

Figure 1. — ***Spatial distribution of pine and hardwood tree crowns observed for the block on the upper north-slope position. Crown width is drawn to** scale **and was calculated from d.b.h.** using **prediction equations developed from the data.***

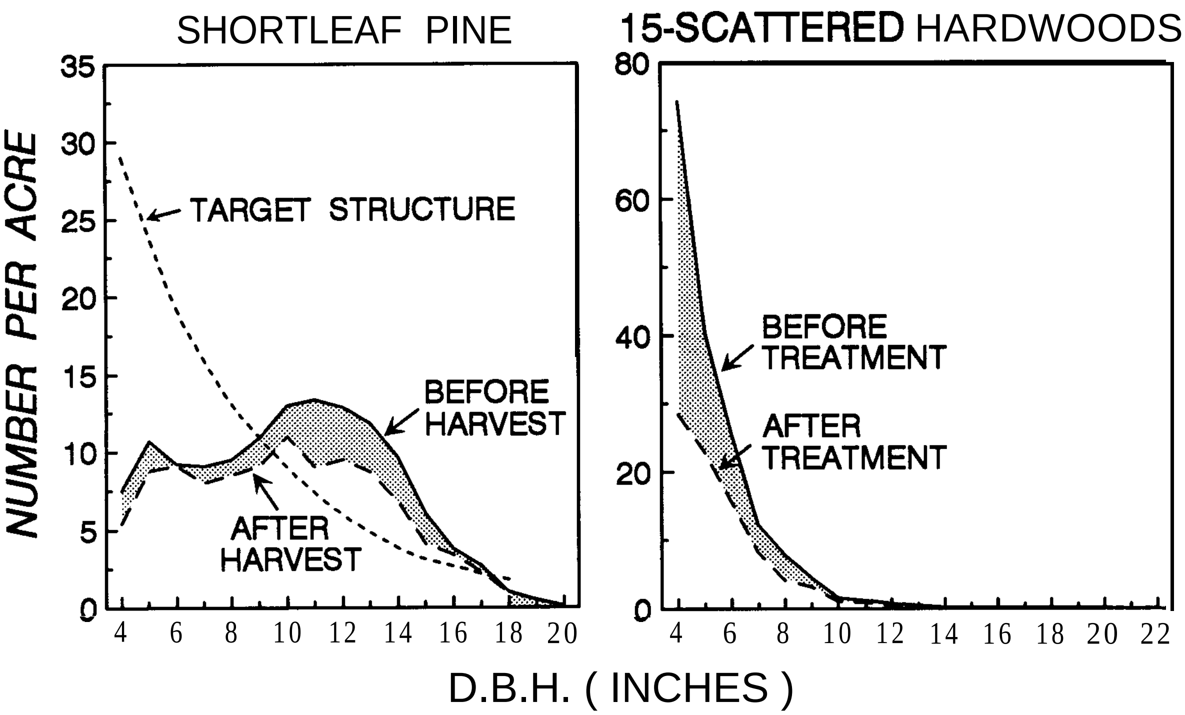

Figure 2. —*D.b.h.-class distribution for shortleaf pine before and after harvest and hardwood control; the target distribution is for a basal area of 60 ft^2/acre, a maximum d.b.h. of 18 inches, and a quotient of 1.2 for l-inch d.b.h. classes. An example of the d.b.h.-class distribution for hardwoods is shown for the 15-scattered treatment.*

between 1030 and 1330 solar time. Measurements also were made in full sunlight, which permitted the calculation of relative light intensity (PAR at 4.5 ft expressed as a percentage of PAR in full sunlight).

Data Analysis

Mean values for understory vegetation were calculated for the 10 regeneration subplots in each 0.5-acre plot. Milacre plots were considered to be stocked by pine and deciduous woody species if at least one individual of seedling size was present to represent the species or species group. To facilitate data presentation, deciduous species were grouped as follows: oaks, other overstory trees, midcanopy trees, and shrubs. The other overstory trees included blackgum, hickory, ash, and sweetgum (*Liquidambar styraciflua* L.), and the midcanopy trees included red maple, serviceberry, dogwood, elms (*Ulmus* spp.), persimmon (*Diospyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). The shrubs were huckleberries, hawthorns, plums (*Prunus* spp.), and several other common species. Mean seedling height of deciduous groups was calculated from the number of rootstocks in each height class and the class midpoint.

Analysis of variance for a randomized, complete block design was used to compare expressions of understory vegetation and stand conditions among treatments. Differences among treatment means were isolated by using the Ryan-Einot-Gabriel-Welsch Multiple Range Test (P = 0.05). This procedure, which is one of the most powerful step-down, multiple-range tests available, controls the experiment-wise error rate (SAS Institute 1989).

RESULTS AND DISCUSSION

The Post-Harvest Environment

Canopy coverage and light intensity were both strongly related to prevailing stand conditions (fig. 3). The untreated control had 93 percent canopy coverage indicating the closed nature of the canopy. This resulted in a PAR that was only 13 percent of full sunlight at 4.5 ft above ground. By contrast, the 0-hardwood treatment had the lowest canopy coverage (55 percent) and the greatest PAR (59 percent of full sunlight). Retention of successive increments of hardwoods increased canopy coverage and correspondingly reduced PAR. This relationship reflected the combined effects of the increase in total basal area and the fact that hardwoods tend to produce more shade per unit of basal area than pines. This result occurs because hardwoods have broader leaves, larger crowns, and shorter heights than pines (Shelton and Murphy 1993, Tappe and others 1993). Values for the 15-grouped treatment are a weighted mean of two conditions-an open environment within canopy gaps where hardwoods were removed, and a closed environment outside the openings where hardwoods were retained.

Harvesting resulted in fairly low levels of soil disturbance (table 1). These results reflect the use of mules for skidding and the relatively low volume harvested (a mean of 3,800 fbm Schribner per acre) when compared to harvests implementing even-aged reproduction cutting methods such as clearcut, seed tree, and shelterwood. No significant differences were observed among treatments, and averages were 76, 10, 8, and 4 percent for undisturbed litter, disturbed litter, logging debris, and mineral soil, respectively. Soil disturbance from logging generally creates favorable seedbed conditions for pine regeneration by exposing mineral soil and disturbing litter (Shelton and Wittwer 1992). However, adequate pine regeneration can become established in a seedbed of undisturbed litter if ample seed production occurs (Cain 1991, Grano 1949).

Production of Shortleaf Pine Seeds

Seed production was not monitored during 1988, the year of harvest. However, production was apparently poor because virtually no new seedlings were observed during the following growing season. Seed production during 1989 averaged 180,000 sound seeds per acre, and no significant differences occurred among the treatments (table 2). This seed crop is considered a good one for shortleaf pine stands in the Ouachita Mountains (Shelton and Wittwer 1996). Another seed crop failure occurred in 1990 when seed production averaged only 3,100 sound seeds per acre. This episodic pattern of seed production is fairly typical for shortleaf pine stands (Wittwer and Shelton 1992).

The percentage of total seeds that are sound is an expression of seed quality During each year of evaluation, the O-hardwood treatment had the highest percentage of sound seeds, and the 30-scattered treatment had the lowest, but differences were not significant (table 2). Yocom (1971) observed that releasing shortleaf pine trees significantly increased the percentage of sound seeds. The percentage of sound seeds varied substantially between the years, averaging 42 percent in 1989 and 2 percent in 1990. Shelton and Wittwer (1996) reported that the percentage of sound seeds increased significantly with the size of the shortleaf pine seed crop, approaching 75 percent in bumper years.

The lack of significant differences among the treatments for seed production may indicate that more time is needed before the pines respond to release. Others have observed that hardwood control and release by thinning enhance pine seed production. Yocom (1971), for example, reported that the cone production of shortleaf pine trees doubled when all competing trees within 30 ft were removed. In a shortleaf pine thinning study, Phares and Rogers (1962) found that the lowest basal area (50 ft^2/acre) resulted in the greatest seed production. However, the influence of stand conditions on the seed production of shortleaf pine is far less than the inherent variation due to environmental factors and cone and seed consumers.

Density of Shortleaf Pine Seedlings

An average of only 177 pine seedlings per acre occurred during the 1989 growing season, which followed harvesting (table 3). This result reflected the suspected poor seed crop during the preceding year and the absence of advance regeneration in the initial stand. However, the good seed crop in 1989 resulted

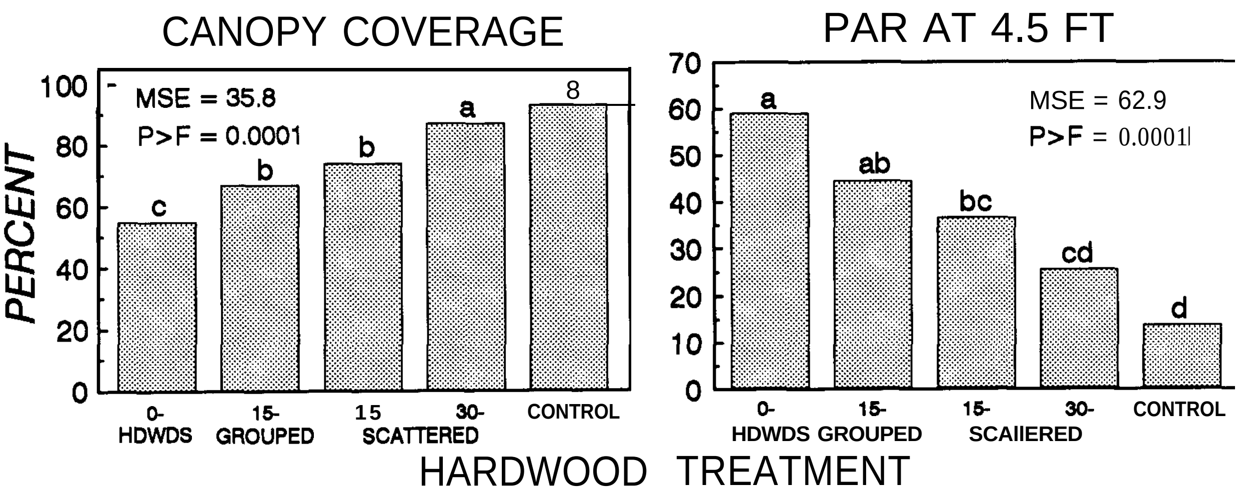

Figure 3. — *Canopy coverage of the overstory and photosynthetically active radiation (PAR at 4.5 ft expressed as a percentage of PAR in full sunlight) occurring after treatment implementation. Bars with different letters are significantly different (P=0.05).*

Table 1. — *Seedbed conditions after the initial harvest implementing uneven-aged silviculture in a shortleafpine-hardwood stand*

Seedbed condition	Hardwood treatment* 0 ft²/acre	15 ft²/acre grouped	15 ft²/acre scattered	30 ft²/acre scattered	Mean square error†	*P>F*
	percent of area					
Undisturbed litter	73	80	71	81	5.60E1	0.22
Disturbed litter	10	8	13	8	2.01E1	0.32
Mineral soil	4	2	6	2	6.6730	0.14
Logging debris	9	8	8	6	2.2731	0.84
Natural feature	4	3	1	2	9.06E0	0.67

*Columns may not sum to 100 percent because of rounding.
†In this and the other tables, values for mean square error are in exponential format; for example, $1.23E4 = 1.23 \times 10^4 = 12,300$.

Table 2. -Annual *production and percentage of sound shortleaf pine seed after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand*

Seed crop	Hardwood treatment* 0 ft²/acre	15 ft²/acre scattered	30 ft²/acre scattered	Mean square error	*P>F*
	Thousands of sound seeds per acre				
1989	197.0	144.0	200.0	6.7839	0.58
1990	3.1	3.1	3.1	3.4837	1.00
	Sound seeds (percent of total)				
1989	44.5	42.7	38.4	1.81E2	0.81
1990	3.1	2.3	1.4	2.15E1	0.91

*The 15 ft²/acre-grouped treatment and control were not monitored during this period.

Table 3. -Density *of shortleafpine seedlings after the initial harvest implementing uneven-aged silviculture in a shortleafpine-hardwood stand*

Heigh class†	Seedling density (number per acre) by hardwood treatment* 0 ft²/acre	15 ft²/acre grouped	15 ft²/acre scattered	30 ft²/acre scattered	Control‡	Mean square error	*P>F*
-- Feet --	*1989: Middle of first growing season*						
5 0.5	*150*	*50*	*25*	100	217	3.8634	0.66
0.6 to 2.5	275	0	0	25	42	5.4634	0.44
Total seedlings	425	50	25	125	259	8.7534	0.34
	1990: Middle of second growing *season*						
I 0.5	3,800	1,650	1,825	3,500	.	3.8736	0.34
0.6 to 2.5	75	50	0		25	4.1733	0.44
Total seedlings	3,875	1,700	1,825	3,525	.	3.8936	0.33
	1990: *End of second growing season*						
5 0.5	*2,225*	*625*	*575*	*800*	. .	9.4835	0.12
0.6 to 2.5	100	25	0		50	3.9633	0.21
Total seedlings	2,325	650	575	850	. . .	9.9335	0.11
	1991: End of third growing season						
≤ 0.5	325ab	**100ab**	75ab	450a	0b	3.8634	0.03
0.6 to 2.5	**1,600a**	400b	50b	25b	0b	3.8735	0.02
Total seedlings	**1,925a**	500ab	125b	475ab	0b	5.3135	0.02

*Row means followed by different letters are significantly different.
†No taller seedlings or saplings were observed.
‡Temporary control plots were evaluated during the first growing season; no evaluations were made during the second growing season; permanent plots were evaluated in the third growing season.

in an average of 2,730 pine seedlings during the middle of the 1990 growing season, with no significant differences among treatments. Seedling density was reduced by subsequent mortality to an average of 1,100 seedlings at the end of the 1990 growing season; treatment differences were not significant. The mortality rate during the 1990 growing season was about 40 percent in the O-hardwood treatment and 80 percent in the 30-scattered treatment. This first-year mortality was exacerbated by a drought that developed because of low summer precipitation. The precipitation during June, July, and August at the nearby Perry, AR, weather station totaled 5.6 inches, which was 5.1 inches below normal. Soil samples collected during this period from the surface 2 inches had only 6.8, 7.4, and 7.7 percent moisture for the 0-hardwood, E-scattered, and 30-scattered treatments, respectively (mean square error=0.522; $P>F=0.18$).

About 0.6 percent of the sound seeds produced in 1989 resulted in established seedlings at the end of the 1990 growing season. This value is similar to the seedling-to-seed ratios reported elsewhere for natural shortleaf pine regeneration. Yocom and Lawson (19771, for example, reported a seedling-to-seed ratio of 0.4 percent for undisturbed areas within a seed-tree stand in the Ouachita Mountains and 1 percent for disturbed areas. Haney (1962) observed a seedling-to-seed ratio of 0.3 percent for undisturbed areas and 2.0 percent for scarified areas in a sawtimber stand. In poorly stocked shortleaf pine stands, untreated areas had a seedling-to-seed ratio of 0.4 percent, and burned areas had a ratio of 1.3 percent (Maple 1965).

Significant differences among the treatment means for seedling density did not become apparent until the end of the 1991 growing season, when most seedlings were 2 years old (table 3). More and taller seedlings were observed in the O-hardwood treatment, and values progressively declined as additional hardwoods were retained. Over 80 percent of the seedlings in the O-hardwood treatment was in the 0.6 to 2.5-ft height class, whereas only 5 percent of the seedlings in the 30-scattered treatment was in this height class. The decrease in seedling density through time reflected mortality. Seedling mortality over the 1990-91 growing seasons was 50 percent for the O-hardwood treatment compared to 86 percent for the 30-scattered treatment. Mortality principally resulted from competition with overstory trees and understory vegetation. There was little competition among pine seedlings at this stage of development because of the small size and scattered distribution of the seedlings. Competition from the understory vegetation was apparently secondary to that of the overstory trees because the best seedling survival occurred in the 0-hardwood treatment where understory vegetation was most prolific.

A few pine seedlings were able to survive in the 15- and 30-scattered treatments, but no seedlings were observed in the control plots. 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.

Stocking of Shortleaf Pine Seedlings

Milacre stocking of pine seedlings displayed a similar pattern to that of density, except that significant differences among treatments occurred earlier than those for density (table 4). Stocking was 15 percent or less for all treatments in 1989, the first growing season after harvest. After the good seed crop of 1989, stocking increased to about 60 to 90 percent during the middle of the 1990 growing season, but differences among treatments were not significant. Stocking then declined to 30 to 65 percent at the end of the 1990 growing season, and the O-hardwood treatment had significantly higher stocking than the 15-grouped and 15-scattered treatments. In 1991, stocking for seedlings ≤ 0.5 ft tall was greatest for the 30-scattered treatment, while stocking for seedlings 0.6 to 2.5 ft tall was greatest for the O-hardwood treatment.

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). For example, one of the milacre plots inventoried in 1990 had 23 pine seedlings, which contributed the equivalent of 2,300 seedlings per acre to the mean for the 10 milacre plots but only 10 percent for stocking.

The generally accepted minimum stocking limits for pine regeneration in uneven-aged pine stands is 50 percent stocking and 200 submerchantable stems per acre (Cain and others 1987). Only the O-hardwood treatment was above both of these thresholds in 1991. The 15-grouped treatment would be considered adequately stocked within the openings created by hardwood removal.

Density and Stocking of Deciduous Rootstocks

The number and stocking of hardwood rootstocks in the seedling size class were generally not significantly affected by treatments (table 5). The possible exception to this is percentage stocking for the other

Table 4. — *Stacking of shortleafpine seedlings after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand*

Height class†	Milacre stocking (percent) by hardwood treatment* 0 ft²/acre	15 ft²/acre grouped	1.5 ft²/acre scattered	30 ft²/acre scattered	Control‡	Mean square error	P>F
-- *Feet* --	*1989: Middle of first growing season*						
I 0.5	10.0	*5.0*	*2.5*	*5.0*	*7.5*	7.7831	0.79
0.6 to *2.5*	*7.5*	*0.0*	*0.0*	*2.5*	*4.2*	3.9731	*0.44*
Total stocking	15.0	5.0	2.5	7.5	9.2	7.60E1	*0.37*
	1990: Middle of second growing season						
< 0.5	*72.5*	*67.5*	*62.5*	*92.5*	. . .	2.5332	0.11
0.6 to *2.5*	*7.5*	*5.0*	*0.0*	*2.5*	. . .	4.17E1	0.44
Total stocking	75.0	67.5	62.5	92.5		2.4032	0.10
	1990: End of second growing season						
≤ 0.5	65.0a	32.5b	30.0b	40.0ab	. .	1.90E2	*0.02*
0.6 to *2.5*	10.0	*2.5*	*0.0*	*2.5*	.	2.50E1	*0.09*
Total stocking	65.0a	35.0b	30.0b	40.0ab		2.1732	*0.04*
	1991: End of third growing season						
≤ *0.5*	17.5ab	7.5ab	7.5ab	30.0a	0.0b	1.3832	*0.03*
0.6 to 2.5	52.5a	25.0ab	5.0b	2.5b	0.0b	2.5832	*0.003*
Total stocking	52.5a	25.0ab	12.5b	30.0ab	0.0b	3.1432	0.01

*Row means followed by different letters are significantly different.
†No taller seedlings or saplings were observed. Total stocking was based on the presence of seedlings in either size class and therefore is not additive.
‡Temporary control plots were evaluated during the first growing season; no evaluations were made during the second growing season; permanent plots were evaluated in the third growing season.

Table 5. -Density *and stocking of deciduous rootstocks in the seedling-size class in 1991, the third growing season after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand*

Species group	Hardwood treatment* 0 ft²/acre	15 ft²/acre grouped	15 ft²/acre scattered	30 ft²/acre scattered	Control	Mean square error	P>F
	Density (number per acre)						
Oaks	1,850	2,325	3,500	1,450	2,725	2.0536	0.35
Other overstory trees	2,950	2,400	1,875	1,675	350	1.9636	0.17
Midcanopy trees	900	2,550	1,100	1,950	675	3.7136	0.63
Shrubs	4,350	6,825	8,450	9,210	12,450	3.7337	0.46
Total rootstocks	10,050	14,100	14,925	14,285	16,200	2.9537	0.59
	Milacre stocking (percent)						
Oaks	*57.5*	*57.5*	*77.5*	*52.5*	*70.0*	2.9332	*0.27*
Other overstory trees	52.5a	57.5a	37.5ab	45.0a	15.0b	1.7432	0.006
Midcanopy trees	30.0	40.0	32.5	37.5	27.5	3.7832	0.88
Shrubs	35.0	67.5	65.0	57.5	60.0	3.4432	0.17
Total stocking†	90.0	92.5	100.0	90.0	95.0	5.00E1	0.29

*Row means followed by different letters are significantly different. No rootstocks were observed in the sapling-size class.
†Total stocking was based on the presence of rootstocks in any deciduous species group and therefore is not additive.

overstory tree group, which includes species that are intermediate in shade tolerance, such as blackgum, ash, and hickory. Stocking in this group averaged 48 percent for treatments that were harvested and treated with herbicides, compared to 15 percent for the untreated control. This difference might reflect sprouting of top-killed stems or development from seeds. There was a respectable component of oak regeneration in all treatments, averaging 2,370 rootstocks per acre and 63 percent stocking. Shrubs were the most common deciduous group present, averaging over 8,000 rootstocks per acre and 57 percent stocking. Huckleberries were the most common shrub.

Deciduous rootstocks in the seedling size class after harvest reflect several sources: (1) development from seeds, (2) advanced regeneration that was below the minimum size limit for herbicide treatment, and (3) sprouting of stems that were top killed during the logging operation and herbicide application.

A total of 28 woody species or species groups was recorded for the seedling size class across the study area; included were one pine, seven oaks, four other overstory trees, seven midcanopy trees, and nine shrubs. The number of species or species groups present in the plots did not vary significantly across treatments, but the means followed a distinctive order: 11.2 for O-hardwoods, 11.0 for E-grouped, 10.2 for l&scattered, 10.0 for 30-scattered, and 8.8 for the control (mean square error=0.517; $P>F$=0.30).

Curiously, Cain and Shelton (1994) also recorded 28 woody species or species groups in the understory of a mature pine-hardwood stand on a good Coastal Plain site (site index of about 90 ft at 50 years) that had not been disturbed for over 50 years. This comparison demonstrates the richness of understory woody species on these poor Ouachita Mountain sites and the resiliency of the understory to stand disturbances.

Size of the Dominant Seedlings

After the 1990 growing season, groundline diameter of dominant pine seedlings in the O-hardwood treatment averaged 37-percent larger than that of seedlings in the 30-scattered treatment (table 6). However, differences among treatments for crown width and height were not significant. In fact, the mean total heights were surprisingly uniform across all treatments at this time, ranging from only 0.18 to 0.24 ft. Large increases in all seedling dimensions occurred during the 1991 growing season, the seedlings' second year. Seedlings in the O-hardwood and 15-grouped treatments doubled or tripled in each dimension, whereas seedlings in the 30-scattered treatment changed substantially only in groundline diameter. The larger crown widths of seedlings in the O-hardwood and 15-grouped treatments (about 0.5 ft) indicate that these seedlings had developed secondary needles, whereas the smaller crown widths of seedlings in the 30-scattered treatment (0.12 ft) indicate the presence of only juvenile needles.

Mean height of deciduous rootstocks was significantly different among treatments for the oaks and midcanopy trees (table 7). Means were generally greatest for the O-hardwood, 15-grouped, and control treatments. These results probably reflect greater growth rates resulting from the lower overstory competition in the O-hardwood and 15-grouped treatments and the fact that seedling-sized stems were not top killed by stand disturbances in the control plots.

Mean height of the deciduous species in 1991 was considerably greater than that of the dominant pines (an overall mean of 0.6 ft for the dominant pines versus a mean of 1.3 ft for all deciduous groups). These results reflect a difference in the reproductive strategy of the two groups-pine regeneration principally develops from seeds, and deciduous groups principally

Table 6. -Mean *size of the two dominant shortleafpine seedlings (if any) within each milacre plot during the second and third growing seasons after the initial harvest implementing uneven-aged silviculture in* a *shortleaf pine-hardwood stand*

Property†	Hardwood treatment*: 0 ft^2/acre	15 ft^2/acre grouped	15 ft^2/acre scattered	30 ft^2/acre scattered	Control‡	Mean square error	$P>F$
	1990: Second growing season						
Groundline diameter	0.054a	0.049a	0.041ab	0.034b		4.473-5	0.01
Crown width	0.15	0.14	0.14	0.11		2.27E-3	0.67
Height	0.22	0.24	0.18	0.20	.	2.233-3	0.32
	1991: Third growing season						
Groundline diameter	0.13	0.14	0.10	0.06		1.743-3	0.10
Crown width	0.48a	0.47a	0.26ab	0.12b	.	1.263-2	0.003
Height	0.74	0.82	0.58	0.30	.	1.06E-1	0.19

*Row means followed by different letters are significantly different.
†Groundline diameter is in inches; crown width and height are in feet.
‡Control plots were not evaluated during 1990; no shortleaf pine seedlings were observed in milacre plots during the 1991 inventory.

Table 7. -Mean *total height of deciduous rootstocks in the seedling-size class in 1991, the third growing season after the initial harvest implementing uneven-aged silviculture in a shortleaf pine-hardwood stand*

Species group	Hardwood treatment*					Mean square error	P>F
	0 ft²/acre	15 ft²/acre grouped	15 ft²/acre scattered	30 ft²/acre scattered	Control		
	Total height (feet)						
oaks	1.5ab	1.6a	1.1bc	0.9c	1.6a	5.403-2	0.001
Other overstory trees	1.6	1.9	1.4	1.4	1.1	7.05E-1	0.70
Midcanopy trees	1.2ab	2.0a	0.8b	0.8b	1.0b	2.17E-1	0.02
Shrubs	1.3	1.2	0.9	1.0	1.2	4.053-2	0.22
Mean height†	1.6	1.5	1.1	1.0	1.3	6.023-2	0.04

*Row means followed by different letters are significantly different,.
†Weighted by the number of rootstocks present for each group.

develop from advance regeneration and sprouts. Experience elsewhere has shown that the height growth of pine regeneration will usually exceed that of deciduous species on upland sites when the pines are free to grow and are in the grand period of growth (Wahlenberg 1960). Thus, this relative ranking of pine and hardwood height is expected to be short-lived for the O-hardwood treatment and within openings for the l&grouped treatment.

Understory Coverage

Vines, grasses, and herbs responded rapidly to the reduction in overstory competition and to the disturbance brought about by harvesting and herbicide application; and the responses were strongly related to the treatments (table 8). Vines were the only group in which significant differences occurred among the treatments in 1989, the first growing season after harvest. Significant differences among the treatment means for grasses and herbs became apparent in 1990 and were still apparent in 1992; coverage was greatest for the O-hardwood and 15-grouped treatments and progressively declined as additional hardwoods were retained. By contrast, coverage of shrubs did not significantly vary among the treatments nor did substantial changes occur through time. Hardwood coverage increased substantially through time, especially for the O-hardwood and l&grouped treatments, but differences among treatments were not significant. Coverage of pines began to appear in 1992; the greatest values occurred for the O-hardwood treatments and declined as additional hardwoods were retained. Treatment means were significantly different for total coverage in 1990 and 1992. Total coverage for the O-hardwood treatment was more than twice that for the 30-scattered treatment and the control. A similar response of the understory community has been described for a wide variety of reproduction cutting methods and overstory conditions (Blair and Brunett 1976, Ehrenreich and Crosby 1960, Joyce and Baker 1987, Nixon and others 1981, Schuster 1967).

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The amount and spatial distribution of natural pine regeneration depends on seed supply, seedbed conditions, and environmental conditions. Of these causal factors, the treatments evaluated in this study principally affected the environmental conditions that govern the survival and growth of seedlings. The linkage between study treatments and environmental conditions was most easily demonstrated for levels of PAR in the understory but undoubtedly involved other factors that were not measured, such as soil moisture, temperature and, perhaps, nutrients. Because of shortleaf pine's shade intolerance, seedling development will be suppressed to some extent by any reproductive cutting method retaining an overstory. Thus, successful application of uneven-aged silviculture must compromise between retaining an adequate overstory stocking for acceptable merchantable growth and reducing overstory stocking sufficiently to provide the environmental conditions needed for regeneration. The growth rates of pines in both the overstory and understory will be below the 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 featuring shortleaf pine as the dominant species. Retaining hardwoods within the single-tree selection system will most severely affect environmental conditions in the understory. Hardwoods apparently suppress the development of pine seedlings to a greater degree than do 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 ft²/acre of hardwood basal area in a scattered distribution with a pine basal area of 60 ft²/acre (the 15-scattered treatment) will prevent the establishment and development of sufficient pine regeneration to sustain long-term production of pine timber. However, reducing the pine basal area to 45 ft^2/acre might allow the retention of 5 to 10 ft^2/acre of scattered hardwoods (Baker and others 1996).

Early results suggest that a hardwood basal area of 15 ft^2/acre can be retained outside the openings in the pine canopy (the 15-grouped treatment) while still obtaining adequate pine regeneration within openings. However, the success of this treatment will not be certain until long-term developmental rates of regeneration are fully evaluated. In addition, the feasibility of implementing the 15-grouped treatment needs to be adequately tested at an operational level. This treatment was difficult to implement even on these small research plots because of problems in determining where opening boundaries occurred within the pine canopy Obviously, 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).

Because of the high rates of seedling mortality observed during the first growing season, this study shows that the prompt removal of competing hardwoods is critical to establishing pine seedlings, especially if soil moisture is limited. Thus, hardwood basal areas of 15 ft^2/acre or greater should be substantially reduced no later than the beginning of the growing season following an acceptable pine seed crop. However, retaining hardwoods until an acceptable pine seed crop occurs would be beneficial to seedling establishment, because hardwoods suppress the development of competing understory vegetation.

Results show that adequate pine regeneration will occur in shortleaf pine stands in the Ouachita

Table 8. — *Coverage of understory vegetation after the initial harvest implementing uneven-aged silviculture in a shortleafpine-hardwood stand*

Growing season†	Coverage (percent) by hardwood treatment*: 0 ft^2/acre	15 ft^2/acre grouped	15 ft^2/acre scattered	30 ft^2/acre scattered	Control‡	Mean square error	*P>F*
			Grasses				
1989	2.3	1.5	0.8	1.0	2.2	1.23E0	0.24
1990	17.9a	7.1b	6.2b	2.9b		1.68E1	0.003
1992	33.2a	12.6b	12.9b	4.9bc	1.8c	1.87E1	0.0001
			Herbs				
1989	0.7	0.4	0.2	0.3	0.6	1.01E-1	0.24
1990	7.2a	8.4a	1.5b	1.1b		9.2230	0.01
1992	3.2ab	3.6a	1.6ab	1.9ab	0.9b	1.30E0	0.03
			Vines				
1989	5.5a	5.2ab	5.1ab	2.0b	7.2a	2.7630	0.01
1990	9.6a	11.9a	10.6a	3.9b	. . .	1.14E1	0.04
1992	17.0ab	23.3a	14.3ab	6.6b	9.6ab	5.30E1	0.05
			Shrubs				
1989	3.9	8.3	6.0	8.4	9.1	1.69E1	0.39
1990	3.6	4.6	3.9	3.1	.	1.69E1	0.96
1992	5.2	5.8	5.6	6.8	10.8	2.4731	0.53
			Hardwoods				
1989	2.4	5.1	3.7	5.2	5.6	4.4230	0.23
1990	4.5	7.5	5.2	4.2		2.07E1	0.74
1992	17.0	19.4	11.2	9.8	14.5	6.40E1	0.45
			Pines				
1989	0.0	0.0	0.0	0.0	0.0		
1990	0.0	0.0	0.0	0.0	0.0		
1992	1.5a	0.5b	0.2b	0.2b	0.0	2.333-1	0.01
			Total coverage§				
1989	14.8	20.5	15.8	16.9	23.9	3.3331	0.21
1990	40.8	36.6ab	26.3bc	15.6c	. . .	4.7731	0.03
1992	69.8a	59.6a	41.8b	27.6b	33.3b	6.60E1	0.0001

*Row means followed by different letters are significantly different.
†These are the first (1989), second (1990), and fourth (1992) growing seasons after harvest.
‡Temporary control plots were evaluated in 1989; no evaluations were made in 1990; permanent plots were evaluated in 1992.
§Total coverage is often less than the sum of individual species groups because of multiple occupancy.

Mountains when: (1) the traditional guidelines for uneven-aged pine silviculture are imposed (that is, the O-hardwood treatment), (2) the seed supply and environmental conditions are acceptable, and (3) the 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, hardwoods can still be retained at the stand level in natural occurrences along drainages or in clumps or clusters (called an area-wise distribution of hardwoods). Permissible levels of hardwood retention within this spatial pattern are probably not limited by biology, as long as the pine-dominated matrix is sufficiently large to provide relative freedom from the edge effects of retained hardwoods. Rather, landowner objectives and operational concerns will probably dictate realistic limits. The area-wise distribution of pines and hardwoods in uneven-aged stands under single-tree selection seems to have a number of advantages: (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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The effects of overstory hardwood basal area and spatial arrangement on the establishment of shortleaf pine regeneration are described in this publication. Results indicate the importance of overstory-understory relationships in uneven-aged silviculture.

Keywords: Natural regeneration, pine-hardwood stands, *Pinus echinata* Mill., site preparation, uneven-aged silviculture.

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