UNDERSTORY VEGETATION AND OVERSTORY GROWTH IN PINE AND PINE-HARDWOOD SHELTERWOOD STANDS IN THE OUACHITA MOUNTAINS: 5-YEAR RESULTS

Michael G. Shelton[1]

Abstract—Treatments were two overstory compositions (a pine basal area of 30 square feet per acre with and without 15 square feet per acre of hardwoods) and two methods of submerchantable hardwood control (chainsaw felling with and without stump-applied herbicide). After the fifth growing season, pine regeneration averaged 1,870 seedlings per acre and 500 saplings per acre in the pine-overstory treatment; there were more pine seedlings when overstory hardwoods were retained (3,090 seedlings per acre) but fewer saplings (27 saplings per acre). Pine regeneration was twice as tall in the pine-overstory treatment than in the pine-hardwood treatment. Oak regeneration averaged 1,100 stems per acre. Overstory pines responded to hardwood removal, averaging 0.84 square feet per acre per year for basal area growth in the pine-overstory treatment and 0.58 square feet per acre per year in the pine-hardwood treatment. Very few overstory pines died after harvesting (0.04 trees per acre per year). Results indicate that 15 square feet per acre of scattered hardwoods can be retained through at least 5 years after harvest.

INTRODUCTION

The shelterwood reproduction cutting method is a versatile way of naturally regenerating even-aged or two-aged stands that is increasingly being used on national forest lands. This method gradually removes mature trees in a series of partial cuts and retains more trees than other even-aged reproduction cutting methods. The higher density of retained trees may satisfy some silvicultural and landowner objectives by making the stand more visually pleasing during regeneration and increasing timber yields through enhanced growth of high-quality trees. Shelterwood stands also tend to have high rates of seed production, which may improve chances for successful natural regeneration in areas with low or erratic seed production. For example, Brender and McNab (1972) reported that enough seeds for successful regeneration were produced 50 percent of the time in shelterwood stands compared with 21 percent in seed-tree stands. The shelterwood method may be favorable in regenerating shortleaf pine (*Pinus echinata* Mill.) stands in the Ouachita Mountains, where seed production is variable (Shelton and Wittwer 1996) and may reduce the intensity of site preparation needed.

Hardwood retention is desired to enhance nontimber resources on many public and nonindustrial private lands, and a pine-hardwood mixture is often the target composition in the regenerated stand. Objectives of this study are to test the traditional application of the shelterwood reproduction cutting method in shortleaf pine-oak stands, to evaluate the effects of hardwood retention within this system, and to determine the type of submerchantable hardwood control needed. The development of understory vegetation is reported 5 years after harvesting and hardwood control, and this paper updates an earlier one reporting 3-year results (Shelton 1997).

METHODS

Study Area

The study area was located in the Winona Ranger District of the Ouachita National Forest in Perry County, AR. Plots were oriented along an east-west ridge typical of the physiography of the Ouachita Mountains. Elevations ranged from 640 to 810 feet above sea level. Blocks were located along the lower, middle, and upper north slope and the upper south slope. Slopes of individual subplots ranged from 5 to 26 percent. Aspect was south on the south-slope position and ranged from north to east on the north-slope positions.

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 60 feet at 50 years, ranging from 56 to 65 feet; this is typical of upland sites in the Ouachita Mountains (Graney 1992). The lower north slope had a slightly higher site index than the other slope positions (62 versus 59 feet). White oak (*Quercus alba* L.) site index averaged 54 feet at 50 years. The dominant pines were slightly older than the dominant white oaks (66 versus 61 years).

Vegetation in the study area was typical of forested landscapes in the Ouachita Mountains, where mature, second-growth shortleaf pine and mixed oaks dominate upland forests (Guldin and others 1994). Preharvest overstory basal area in trees ≥ 3.6 inches in diameter at breast height (d.b.h.) averaged 74 square feet per acre for shortleaf pine and 41 square feet per acre for hardwoods. Oaks accounted for 92 percent of the hardwood basal area. White oak was the most prevalent hardwood, followed by post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), blackjack oak (*Q. marilandica* Muench.), and southern red oak (*Q.*

[1] Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516.

Citation for proceedings: Guldin, James M., tech. comp. 2004. Ouachita and Ozark Mountains symposium: ecosystem management research. Gen. Tech. Rep. SRS–74. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 321 p.

falcata Michx.). The remaining 8 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 dogwood (*Cornus florida* L.). The understory consisted of tree regeneration, mainly the more shade-tolerant species, and a variety of common shrubs, such as huckleberries (*Vaccinium* spp.), snowbell (*Styrax grandifolia* Ait.), and hawthorns (*Crataegus* spp.).

Study Design and Treatments

The study was a split-plot design with four randomized complete blocks. Two overstory compositions (pine only and pine-hardwood) were established in eight 3.50-acre whole plots, each split into two 1.75-acre subplots for testing two hardwood control methods (manual versus chemical control of submerchantable hardwoods). Each subplot consisted of a 0.70-acre measurement area (103 by 295 feet) and an isolation strip of 1.05-acre. The isolation strip for a subplot was 66 feet wide when adjacent to the untreated stand, 50 feet wide when adjacent to the neighboring whole plot that made up the block, and 20 feet wide along the internal boundary separating the two subplots within a whole plot. Within each 0.70-acre measurement area, 18 permanent points were systematically located to monitor understory vegetation. These points were at least 80 feet from the external boundary of the whole plot and 50 feet from the internal boundary separating the two subplots.

Target retention for all overstories was 30 square feet per acre of pine basal area. The pine-overstory treatment had no hardwoods; retention in the pine-hardwood treatment was 15 square feet per acre of hardwoods and 30 square feet per acre of pines. Pine seed trees were selected for a past history of high cone production, a d.b.h. of 12 to 16 inches, good vigor and stem quality, and a uniform spatial distribution. Selection criteria were sometimes relaxed to achieve the target basal area. Large, well-formed, vigorous red and white oaks were preferred for the hardwood component, but less desirable species or low-quality stems were sometimes kept to meet target basal area.

Whole plots were temporarily subdivided into seven 0.5-acre areas to facilitate marking the target basal areas for overstory trees and to ensure a uniform distribution. All merchantable pines, except seed trees, were harvested using rubber-tired skidders and tree-length skidding from November 1989 to early January 1990. A commercial firewood vendor harvested merchantable hardwoods ≥ 6 inches d.b.h. beginning in early April 1990 but was stopped shortly afterward by wet weather. Harvesting resumed in July and was completed in October.

Treatments to control submerchantable hardwoods (0.6 to 5.5 inches d.b.h.) began in mid-August 1990 and were completed in early September 1990. Treatments were either manual (chainsaw felling) or chemical (chainsaw felling followed immediately by application of undiluted Garlon® 3A to the stump). In the manual treatment, submerchantable pines were chainsaw felled but not treated with herbicide.

Measurements

Understory vegetation was inventoried during mid-September 1995 using 18 permanent plots for each 0.70-acre subplot. Horizontal coverage of understory vegetation (grasses, herbs, vines, shrubs, hardwoods, pines, and total vegetation) was estimated on milacre plots centered on each point. All woody plants in the seedling size class (≤ 0.5 inch d.b.h.) were counted on the milacre plot, tallying multiple-stemmed rootstocks as one individual. Woody saplings (0.6 to 3.5 inches d.b.h.) were counted by species or species group and 1-inch d.b.h. classes on a 0.01-acre plot centered around each permanent point. On each 0.01-acre plot, the tallest two pines (if present) and tallest two hardwoods were measured for groundline diameter, crown width, and total height.

In March 1990, all retained pines and hardwoods (≥ 3.6 inches d.b.h.) on the 0.7-acre subplots were measured for d.b.h., and stem location was mapped by determining azimuth and distance from plot center. All pines and about a third of the hardwoods were measured for height. Tree d.b.h. was reinventoried biennially during the dormant season.

Data Analysis

Milacre plots were considered stocked by pine or deciduous woody species if at least one seedling was present for the species or species group; similarly, 0.01-acre plots were considered stocked if at least one sapling was present. Means were calculated for understory variables for each 0.7-acre subplot. To facilitate data presentation, deciduous species were grouped as oaks, other canopy trees, midcanopy trees, or shrubs. Other canopy trees included blackgum, hickory, ash, and sweetgum (*Liquidambar styraciflua* L.); midcanopy trees included maple, serviceberry, dogwood, elms (*Ulmus* spp.), persimmon (*Diospyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). Shrubs included huckleberries, hawthorns, plums (*Prunus* spp.), snowbell, and several other common species.

Pine volumes were calculated from 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 outside-bark top. Volumes for sawtimber trees (d.b.h. ≥ 9.6 inches) were computed from a 1-foot stump to an 8-inch, outside-bark top; cubic-foot volume was inside bark. Hardwood volumes were calculated from the equations of Clark and others (1986). 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 volumes were not calculated for hardwoods because of their small size and generally poor quality.

Data were analyzed by analysis of variance for a split-plot randomized complete block design using the SAS procedure GLM (SAS Institute 1989). Since there were only two levels for each treatment, means were not separated but were presented with the associated mean square error (MSE) and probability level (*P*). Significance was accepted at $P \leq 0.05$.

Table 1—Density of seedlings and saplings in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable-hardwood control

	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
Species or group	Manual	Chemical	Manual	Chemical	MSE[a]	P[b]	MSE	P
	- - - - - - - *Seedlings* (*number/acre*) - - - - - - -							
Shortleaf pine	1,500	2,236	2,764	3,416	6.47E5	0.06	4.51E6	0.54
Oaks	736	667	806	1,014	6.93E4	0.21	8.27E4	0.65
Other canopy trees	639	806	694	819	9.28E4	0.84	6.81E4	0.31
Midcanopy trees	444	944	500	514	2.14E5	0.48	2.10E5	0.31
Shrubs	3,680	3,806	4,792	5,194	4.32E6	0.32	5.70E6	0.83
Nonpine total	5,499	6,223	6,792	7,541	4.16E6	0.29	8.58E6	0.63
	- - - - - - - *Saplings* (*number/acre*) - - - - - - -							
Shortleaf pine	475	514	24	30	5.18E4	0.03	9.23E3	0.65
Oaks	476	374	179	163	1.31E4	0.02	6.13E3	0.18
Other canopy trees	174	182	89	71	4.95E3	0.07	1.28E4	0.94
Midcanopy trees	178	160	178	71	7.19E2	0.05	8.55E3	0.23
Shrubs	24	17	25	21	3.37E2	0.78	2.46E2	0.49
Nonpine total	852	733	471	326	6.20E5	<0.01	2.18E4	0.12

[a] Mean square error (MSE) are in exponential format; for example, 1.23E4 = 1.23×10^4 = 12,300.
[b] Probability level (*P*).

RESULTS AND DISCUSSION

Regeneration Density and Stocking

Virtually all the shortleaf pine seedlings became established from seeds dispersed after harvesting and site preparation. At 5 years, there was an average of 2,479 seedlings per acre with no significant differences between overstory or hardwood control treatments (table 1). However, hardwoods have been shown to substantially reduce the establishment of shortleaf pine regeneration when levels were greater than those tested in this study (Becton 1936, Shelton and Murphy 1997). Shelton (1997) reported an average of only 1,550 seedlings per acre at 3 years, so some shortleaf pine seedling establishment occurred between 3 and 5 years. The overstory treatment had a substantial and significant effect on the density of shortleaf pine saplings, averaging 494 stems per acre in the pine-overstory treatment and 27 stems per acre in the pine-hardwood treatment. By contrast, the submerchantable control treatment did not have a significant effect on sapling density. The generally accepted minimum density for pine regeneration in natural, even-aged pine stands is 700 stems per acre (Campbell and Mann 1973, Grano 1967). All overstory and hardwood control treatments either met or exceeded this at 5 years.

In the seedling size class, an average of 6,514 rootstocks per acre occurred for nonpine species at 5 years after harvesting with no significant treatment differences (table 1). This represented a 24-percent decline from levels reported at 3 years (Shelton 1997), which probably reflected mortality through self-thinning and outgrowth to the sapling size class. Shrubs were the most common nonpine species group, and the oaks represented 12 percent of the total. The overstory treatment significantly affected the sapling density of oaks and midcanopy trees, but the differences between treatments were not as great as with the pines. There were 2.5 times more oak saplings in the pine-overstory treatment than in the pine-hardwood treatment, but the treatment difference was only 1.4 times for midcanopy trees.

The stocking of shortleaf pine seedlings and saplings reflected a similar pattern as density. Stocking averaged 60 percent for seedlings, and no significant treatment differences occurred (table 2). The generally accepted minimum stocking for pine regeneration in natural, even-aged pine stands is 40 percent (Campbell and Mann 1973, Grano 1967). All overstory and hardwood control treatments either met or exceeded this at 5 years. The overstory treatment had a large and significant effect on sapling stocking; the pine-overstory treatment averaged 6.8 times more stocking than the pine-hardwood treatment. The submerchantable hardwood control treatment had no significant effect. A nonpine species occurred on nearly all regeneration plots, with stocking levels averaging 95 percent for seedlings and 90 percent for saplings. For saplings, oaks were the only group significantly affected by overstory treatment; stocking averaged 86 percent for the pine-overstory treatment compared with 55 percent for the pine-hardwood treatment.

Regeneration Size

After the fifth growing season, pine regeneration in the pine-overstory treatment was more than twice as large as that in the pine-hardwood treatment for groundline diameter, crown width, and height (table 3). Differences were highly significant in all cases. However, the hardwood control treatments did not significantly affect the size of pine regeneration. Oak regeneration responded to the overstory treatments in a manner similar to shortleaf pine, although the magnitude of the response was not as great. Differences were significant

Table 2—Stocking of seedlings and saplings in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable-hardwood control

	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
Species or group	Manual	Chemical	Manual	Chemical	MSE[a]	P^b	MSE	P
	- - - - - - - - *Seedlings*[c] (*percent*) - - - - - - - -							
Shortleaf pine	48	60	68	65	197	0.16	212	0.54
Oaks	43	40	46	57	90	0.13	225	0.60
Other canopy trees	29	44	30	42	227	0.91	218	0.13
Midcanopy trees	29	43	32	24	416	0.48	175	0.69
Shrubs	54	56	67	61	28	0.04	248	0.81
Nonpine total	87	94	93	92	61	0.75	92	0.57
	- - - - - - - - - *Saplings* (*percent*) - - - - - - - -							
Shortleaf pine	86	76	7	17	292	<0.01	87	0.98
Oaks	82	89	58	52	47	<0.01	120	0.90
Other canopy trees	48	58	43	38	348	0.25	206	0.75
Midcanopy trees	39	44	42	32	313	0.64	225	0.79
Shrubs	20	14	18	8	138	0.57	98	0.17
Nonpine total	96	97	88	80	88	0.07	73	0.53

[a] Mean square error (MSE).
[b] Probability level (*P*).
[c] Stocking is based on milacre plots seedlings and 0.01-acre plots for saplings.

Table 3—Size of the dominant regeneration in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable-hardwood control

	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
Species or group	Manual	Chemical	Manual	Chemical	MSE[a]	P^b	MSE	P
	- - - - - *Groundline diameter* (*inches*) - - - - -							
Shortleaf pine	1.8	1.8	0.7	0.8	0.08	<0.01	0.01	0.31
Oaks	2.6	2.5	1.9	1.8	0.03	<0.01	0.05	0.68
Other canopy trees	2.2	1.8	1.6	1.7	0.10	0.08	0.20	0.42
Midcanopy trees	1.7	1.8	1.7	1.3	0.02	0.02	0.30	0.95
	- - - - - - - - - *Crown width* (*feet*) - - - - - - - - -							
Shortleaf pine	3.2	3.3	1.5	1.7	0.17	<0.01	0.03	0.19
Oaks	6.6	6.4	5.0	5.1	0.22	<0.01	0.49	0.83
Other canopy trees	6.0	5.7	5.7	5.7	0.27	0.22	3.06	0.72
Midcanopy trees	6.1	6.4	5.5	4.9	0.82	0.06	3.43	0.86
	- - - - - - - - - - - *height* (*feet*) - - - - - - - - - - -							
Shortleaf pine	8.4	8.5	3.6	4.0	1.54	<0.01	0.11	0.27
Oaks	11.6	11.0	10.0	9.5	1.08	0.06	1.05	0.36
Other canopy trees	10.0	10.0	9.0	8.5	1.58	0.09	2.14	0.39
Midcanopy trees	11.8	14.2	12.6	9.9	0.74	0.02	12.45	0.90

[a] Mean square error (MSE).
[b] Probability level (*P*).

for groundline diameter and crown width but not for height. For the other canopy trees and midcanopy trees, regeneration also tended to be slightly larger under the pine-overstory treatment, but differences were not consistently significant.

Hardwood regeneration was larger than shortleaf pine regeneration after the fifth growing season. 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 growth of free-to-grow pine regeneration will eventually exceed that of hardwoods on most upland sites (Wahlenberg 1960), and the 5-year results of this study seem to confirm this. At 3 years, hardwoods were 2.0 times taller than pines for the pine-overstory treatment and 3.8 times for the pine-hardwood treatment, but at 5 years the differences had diminished to 1.4 times for the pine-overstory treatment and 2.6 for the pine-hardwood treatment.

Understory Coverage

Effects of the overstory treatment on understory coverage was variable among species groups, with significant differences occurring for forbs, hardwoods, and total vegetation (table 4). Differences for grasses and pines were nearly significant. Coverage was greater in the pine-overstory treatment than in the pine-hardwood treatment: 2.3 times for grasses, 1.8 for forbs, 1.5 for hardwoods, and 3.7 for pines. In contrast, coverage of vines and shrubs was only slightly affected by overstory treatment. Differences in coverage between hardwood control methods were small and only significant for herbs and total vegetation. Herbs had slightly greater coverage in the chemical control treatment. This may be the result of reduced coverage of hardwoods and shrubs, which were the only groups treated with herbicide. However, it may also be an anomaly because the coverage of shrubs and hardwoods was only slightly lower for chemical hardwood control, and these treatment differences were not significant. Total vegetative coverage for the chemical treatment averaged 70 percent compared with 65 percent for the manual treatment.

Coverage of pines and hardwoods showed large increases in the pine-overstory treatment between 3 and 5 years, while the other groups remained fairly constant. Shelton (1997) reported that hardwoods averaged 27 percent coverage at 3 years and pines 2 percent. Thus, increases from 3 to 5 years were 1.5 times for hardwoods and 3.8 times for pines. This observation suggests that pines and hardwoods will dominate subsequent patterns of successional change in the understory.

Merchantable Tree Growth

Hardwood retention significantly reduced the growth of merchantable-sized pines: by 31 percent for basal area, 30 percent for total merchantable volume, and 28 percent for sawtimber volume (table 5). Annual growth in pine sawtimber volume averaged 135 board feet (Doyle) per acre in pine-overstory treatment and 95 board feet per acre in pine-hardwood treatment. Unthinned shortleaf pine stands are expected to be growing 260 board feet per acre per year on similar sites and ages as this shelterwood stand (U.S. Department of Agriculture 1929). Thus, the shelterwood cutting reduced pine growth by about one-half for the pine-overstory treatment and about two-thirds for the pine-hardwood treatment. Hardwood growth was surprisingly high after harvesting and actually exceeded that of shortleaf pine by 45 percent for basal area and 24 percent for total merchantable volume. The different growth rate between pines and hardwoods may reflect the younger age of the hardwoods (a mean of 61 years for hardwoods versus 66 years for pines) or inherent differences in growth patterns and ability to respond to release. Although hardwoods contributed to total merchantable growth, they did not contribute to the stand's sawtimber growth because of their small size and generally low quality. Annual mortality of shortleaf pines was very low after harvesting, averaging only 0.04 trees per acre.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Results 5 years after harvesting showed that the shelterwood method can effectively regenerate mixed pine-hardwood stands in the Ouachita Mountains when combined

Table 4—Coverage of understory vegetation in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable-hardwood control

	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
Species or group	Manual	Chemical	Manual	Chemical	MSE[a]	*P*[b]	MSE	*P*
	- - - - - - - - *Coverage* (*percent*) - - - - - - - -							
Grasses	20.6	24.7	11.5	9.4	66.4	0.06	38.7	0.76
Forbs	0.7	2.2	0.5	1.1	0.1	0.01	0.4	0.02
Vines	15.9	13.3	12.1	12.0	29.8	0.42	4.3	0.25
Shrubs	13.4	10.3	18.6	13.8	20.6	0.15	28.6	0.19
Hardwoods	43.8	37.0	25.3	28.5	52.9	0.03	50.2	0.62
Pines	7.9	9.7	2.2	2.5	20.0	0.06	4.6	0.35
Total vegetation[c]	80.5	75.5	58.6	54.9	1.6	<0.01	13.3	0.05

[a] Mean square error (MSE).
[b] Probability level (*P*).
[c] Coverage of total vegetation is less than the sum of individual species groups because of multiple occupancy.

Table 5—Mean annual net growth of merchantable-sized trees in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable-hardwood control

	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
Species or group	Manual	Chemical	Manual	Chemical	MSE[a]	*P*[b]	MSE	*P*
	Basal area (ft^2*/acre*)							
Shortleaf pine	0.85	0.84	0.55	0.62	0.007	<0.01	0.018	0.64
Hardwoods	0	0	1.01	1.10	—[c]	—	0.019	0.43
	Merchantable volume (ft^3*/acre*)							
Shortleaf pine	27	27	18	20	6.3	<0.01	15.1	0.73
Hardwoods	0	0	24	26	—	—	7.4	0.36
	Sawtimber volume (ft^3*/acre*)							
Shortleaf pine	29	29	20	22	4.0	<0.01	12.6	0.86
Hardwoods	0	0	0	0	—	—	—	—
	Sawtimber volume (*fbm/acre*)							
Shortleaf pine	137	131	94	100	158	0.01	228	0.98
Hardwoods	0	0	0	0	—	—	—	—

[a] Mean square error (MSE).
[b] Probability level (*P*).
[c] Too few hardwoods existed in sawtimber size class for analysis.

with low-cost, low-impact site preparation that controls the submerchantable trees left after harvesting. Despite substantial undisturbed litter and slash after harvesting and hardwood control, enough favorable microsites were available to establish acceptable shortleaf pine and hardwood regeneration. Pine regeneration principally came from seeds dispersed after treatment, but hardwoods developed from advanced reproduction and sprouting. This difference in reproduction strategy gives hardwoods an initial growth advantage. However, pines generally grow rapidly after establishment, providing acceptable regeneration when density and stocking are at levels similar to those reported here.

Retention of overstory hardwoods within a shelterwood pine stand will have the most significant impact on environmental conditions in the understory. Such hardwoods appear to suppress development of pine regeneration to a greater degree than an equivalent pine basal area, reflecting differences in the crown features of the two species groups. The limit for retaining hardwoods within a pine shelterwood stand appears to be fairly low. Results suggest that 15 square feet per acre of hardwood basal area can be retained in a scattered distribution for at least the first 5 years after the reproduction cut. This seems logical based on the generality that hardwoods produce about twice the overstory competition as the same pine basal area. An overstory basal area of 30 square feet per acre of pines and 15 square feet per acre of hardwoods is equivalent to a pine overstory 60 square feet per acre, which is generally considered to provide an acceptable environment for the development of pine regeneration in uneven-aged stands (Baker and others 1996). However, the long-term success of either overstory treatment is doubtful unless overstory trees are removed entirely or periodically reduced to acceptable stocking levels. Although subsequent harvesting will damage existing regeneration, Grano (1961) found that the loss in pine milacre stocking was only 10 percent for a basal area removal of 31 square feet per acre and 16 percent for 42 square feet per acre.

The upper limit for acceptable overstory stocking has not been well established for even-aged reproduction cutting methods, probably because traditional guidelines call for overstory removal as soon as regeneration reaches acceptable levels. Undoubtedly, the pine-hardwood overstory treatment of this study will reach the upper limit for acceptable stocking much sooner than the pine-overstory treatment. Based on observed growth rates, basal areas in the pine-overstory treatment should take well over 20 years to reach 75 square feet per acre, which is considered the upper stocking level for adequate development of pine regeneration in uneven-aged pine stands (Baker and others 1996). Because of its higher initial stocking, the pine-hardwood overstory treatment should reach this limit in 7 years, when projected basal areas are 35 square feet per acre for pines and 20 square feet per acre for hardwoods (equivalent to a pine basal area of $35 + 2 \times 20 = 75$ square feet per acre). Of course, this prediction needs confirmation by the continued monitoring of overstory and understory dynamics, but the general contrast between overstory treatments is clear: the pine-hardwood overstory treatment stocking must be reduced within 5 to 10 years after harvest to sustain the development of regeneration.

Because merchantable hardwoods were removed in this study during harvesting, subsequent control treatments were low in intensity and cost. The chemical control treatment was restricted to stumps of individual stems in the 1- to 5-inch d.b.h. classes and, therefore, was applied to only a fraction of the stand's hardwoods. The herbicide effectively controlled sprouting in some but not all species. Early results suggest that chemical control was not justified in the conditions tested here because it failed to substantially improve the amount or size of shortleaf pine regeneration. Other conditions had more influence on the acceptable establishment of shortleaf pine regeneration, including abundant pine seed production and low initial levels of competing vegetation.

LITERATURE CITED

Baker, J.B.; Cain, M.D.; Guldin, J.M.; Murphy, P.A.; Shelton, M.G. 1996. Uneven-aged silviculture for the loblolly shortleaf pine forest types. Gen. Tech. Rep. SO-118. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 65 p.

Becton, W.R. 1936. Effects of varying densities of hardwood cover on growth and survival of shortleaf pine reproduction. Journal of Forestry. 34(2): 160-164.

Brender, E.V.; McNab, W.H. 1972. Loblolly pine seed production in the lower Piedmont under various harvesting methods. Journal of Forestry. 70(6): 345-349.

Campbell, T.E.; Mann, W.F., Jr. 1973. Regenerating loblolly pine by direct seeding, natural seeding, and planting. Res. Pap. SO-84. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 9 p.

Clark, A., III; Phillips, D.R.; Frederick, D.J. 1986. Weight, volume, and physical properties of major hardwood species in the upland-South. Res. Pap. SE-257. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 55 p.

Farrar, R.M., Jr.; Murphy, P.A. 1987. Taper functions for predicting product volumes in natural shortleaf pines. Res. Pap. SO-234. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 9 p.

Graney, D.L. 1992. Site index relationships for shortleaf pine. In: Brissette, J.C.; Barnett, J.P. comps. Proceedings of the shortleaf pine regeneration workshop. Gen. Tech. Rep. SO-90. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 142-157.

Grano, C.X. 1961. Shortleaf-loblolly reproduction losses moderate following seed tree felling. Journal of Forestry. 59(1): 24-25.

Grano, C.X. 1967. Growing loblolly and shortleaf pine in the Midsouth. Farmer's Bulletin 2102. Washington, DC: U.S. Department of Agriculture: 27 p.

Guldin, J.M.; Baker, J.B.; Shelton, M.G. 1994. Midstory and overstory plants in mature pine/hardwood stands on south-facing slopes of the Ouachita/Ozark National Forests. In: Baker, J.B., comp. Proceedings of the symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary findings. Gen. Tech. Rep. SO-112, New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 29-49.

SAS Institute. 1989. SAS/STAT user's guide. Version 6, 4th ed., vol. 2. Cary, NC: SAS Institute, Inc. 846 p.

Shelton, M.G. 1997. Development of understory vegetation in pine and pine-hardwood shelterwood stands in the Ouachita Mountains—the first 3 years. Res. Pap. SRS-8. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 18 p.

Shelton, M.G.; Murphy, P.A. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. Res. Pap. SO-296. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Research Station. 13 p.

Shelton, M.G.; Wittwer, R.F. 1996. Seed production in natural shortleaf pine stands in the Ouachita and Ozark Mountains. Southern Journal of Applied Forestry. 20(2): 74-80.

U.S. Department of Agriculture. 1929. Volume, yield, and stand tables for second-growth southern pines. Misc. Pub. 50. Washington, DC: U.S. Department of Agriculture, Forest Service. 202 p.

Wahlenberg, W.G. 1960. Loblolly pine. Durham, NC: School of Forestry, Duke University. 603 p.