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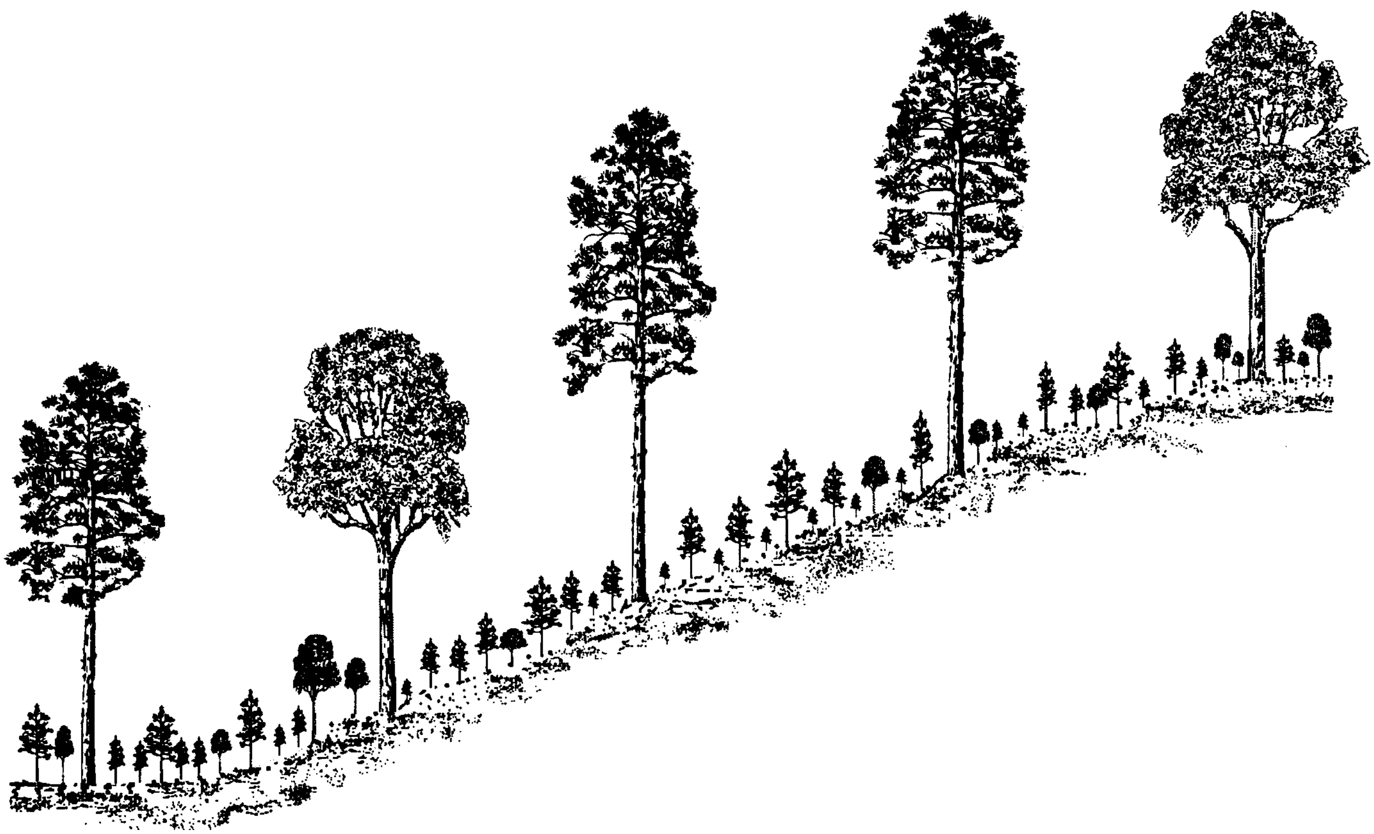

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Abstract

The shelterwood reproduction cutting method using two overstory compositions (a pine basal area of 30 ft^2 per acre with and without 15 ft^2 per acre of hardwoods) and two methods of submerchantable hardwood control (chain-saw felling with and without stump-applied herbicide) was tested in a 2x2 factorial, split-plot design with four randomized complete blocks. Production of sound pine seeds after treatment was marginal to good, averaging 39,000, 28,000, and 155,000 per acre in 1990, 1991, and 1992, respectively. After the third growing season, pine seedlings averaged 1,550 stems per acre and 54 percent milacre stocking; no significant differences occurred between either overstory or hardwood control treatments. Hardwood reproduction after treatment generally reflected the amount and composition that was present in the original stand, with oaks averaging 8 IO rootstocks per acre and 48 percent milacre stocking. The size of pine reproduction in the pine overstory treatment was twice as large as that in the pine-hardwood overstory treatment, and fewer of the stems in the pine overstory treatment were overtopped by understory vegetation. Total coverage of understory vegetation after 3 years was greater in the pine overstory treatment (68 percent) than in the pine-hardwood overstory treatment (46 percent) and was slightly greater for manual than chemical hardwood control (60 versus 55 percent). Results indicate that 15 ft^2 per acre of scattered hardwoods can be retained through at least 3 years after harvest, but additional monitoring will be needed to determine the long-term success of reproduction. Early results suggest that the herbicide treatment was not justified in the stand and site conditions tested in this study; contributing factors were the abundant pine seed production and low levels of competing vegetation.

Keywords: Even-aged silviculture, natural regeneration, pine-hardwood stands, *Pinus echinata* Mill., shelterwood reproduction cutting method, site preparation.

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. The shelterwood 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 the enhanced growth of these high-quality trees. Shelter-wood stands also tend to have high rates of seed production, which may improve chances for successful natural regeneration in areas where low or erratic seed production is a limiting factor. For example, Brender and McNab (1972) reported that shelterwood stands in the lower Piedmont produced enough seeds for successful regeneration 50 percent of the time compared to 2 1 percent for 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.

On many public and nonindustrial private lands, hardwood retention is desired to enhance nontimber resources, and a pine-hardwood mixture is the target composition in the regenerated stand. The objectives of this study are to test the traditional application of the shelterwood reproduction cutting method in shortleaf pine-oak (*Quercus* spp.) stands, to evaluate the effects of hardwoods retention within this system, and to determine type of submerchantable hardwood control needed. The development of understory vegetation is reported for the first 3 years after harvesting and hardwood control.

Methods

Study Area

The study area was located on the Winona Ranger District of the Ouachita National Forest in Perry County, AR. Orientation was along an east-west ridge typical of the physiography of the Ouachita Mountains. Elevations ranged from 640 to 8 10 feet (ft) 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, and the 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 Camasaw 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 ft at 50 years, ranging from 56 to 65 ft; 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 ft). White oak (*Q. alba* L.) site index averaged 54 ft at 50 years. The dominant pines were slightly older than the dominant white oaks (66 versus 6 1 years).

The vegetation in the study area was typical of the forested landscape 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 at least 3.6 inches (in) diameter at breast height (d.b.h.) averaged 74 ft^2 per acre for shortleaf pine and 4 1 ft^2 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* Muenchh.), and southern red oak (Q. *falcata* Michx.). The remaining 8 percent of the hardwood basal area was ash (*Fraxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), serviceberry [*Amelanchier arborea* (Michx. f.) Fem.], blackgum (*Nyssa sylvatica* Marsh.), and dogwood (*Cornus florida* L.). The understory consisted of tree reproduction, mainly the more shade-tolerant species, and a variety of common shrubs, such as huckleberries (*Vuccinium* spp.), snowbell (*Styrax grandifolius* Ait.), and hawthorns (*Crataegus* spp.).

Study Design and Treatments

The study was a 2x2 factorial, split-plot design with four randomized complete blocks. Two overstory compositions (pine-only versus pine-hardwood) were established in eight 3.5-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 0.7-acre measurement area (103 by 295 ft) and an isolation strip of about 1.05 acre. The isolation strip for a subplot was 66 ft wide when adjacent to the untreated stand, 50 ft wide when adjacent to the neighboring whole plot that made up the block, and 20 ft wide along the internal boundary separating the two subplots within a whole plot. Within each 0.7-acre measurement area, 18 permanent points were systematically located to monitor understory vegetation. These points were at least 80 ft from the external boundary of the whole plot and 50 ft from the internal boundary separating the two subplots.

Overstory treatments-Target retention for all overstories was 30 ft^2 per acre of pine basal area. The pine overstory treatment had no hardwoods; retention in the pine-hardwood overstory was 15 ft^2 per acre of hardwoods and 30 ft^2 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 in, 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 the 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 insure a fairly 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 in 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. Firewood was hauled to a central location in the front bucket of a farm tractor.

Figure 1 shows the diameter-class distribution before and after harvest and hardwood control. The harvest narrowed the normal distribution of the pine component. The stand was essentially harvested from below with additional removal of a few low-quality trees and poor seed producers from the larger diameter classes. The hardwood component initially had a typical reverse-J distribution, but the harvest and submerchantable control treatment created a normal distribution by retaining the larger white and red oaks.

The pine harvest removed an average basal area of 46 ft^2 per acre. Harvested pine volume averaged 3,800 board feet Scribner per ace for sawtimber and 427 ft^3 per acre for pulpwood. Residual pine volume averaged 3,600 board feet Scribner per acre and did not vary significantly with treatments. Pine basal area averaged 28 ft^2 per acre after harvest and ranged from 25 to 3 1 ft^2 per acre for individual subplots. The average pine seed tree was 13.6 in d.b.h. and 64 ft tall. On pine-hardwood plots, residual hardwoods averaged 16 ft^2 per acre for basal area and 4 15 ft^3 per acre for volume. Retained hardwoods averaged 8.4 in d.b.h. and 52 ft tall and were virtually all oaks (82 percent white oaks and 16 percent red oaks by volume).

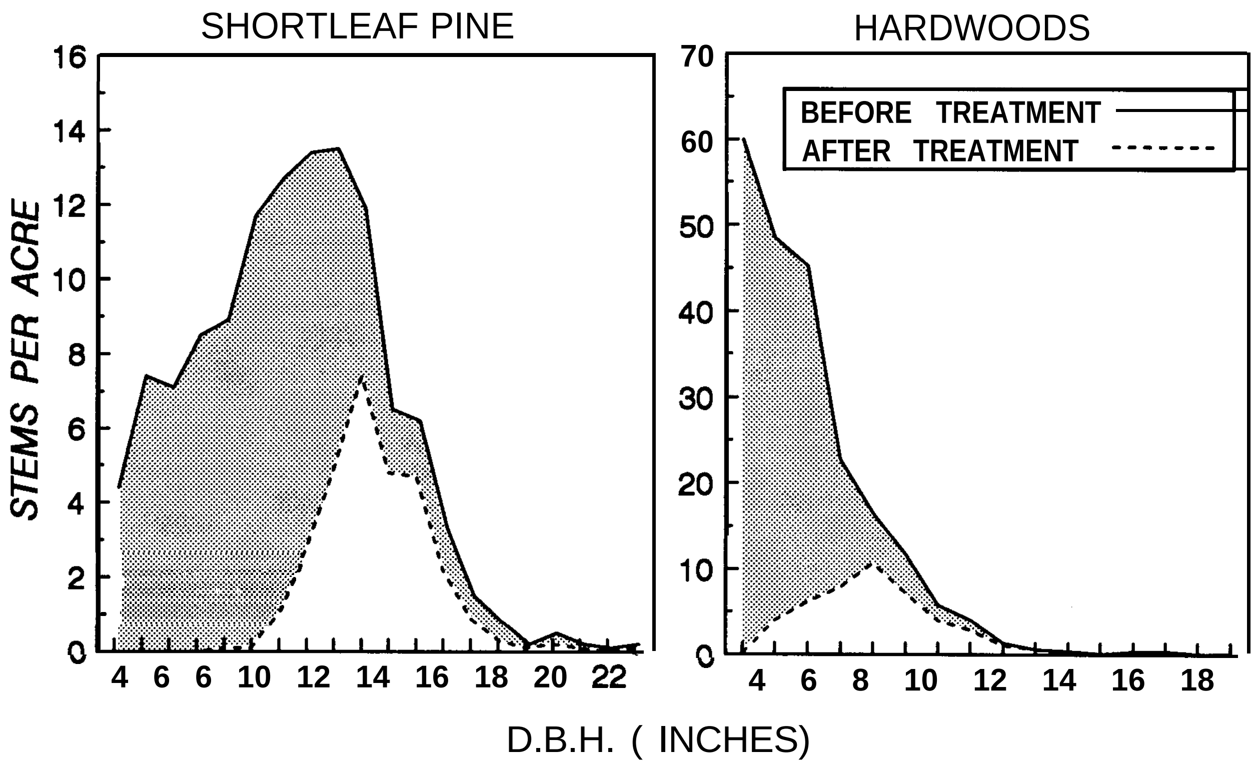

Figure l-Diameter at breast height (d.b.h.)-class distribution for shortleaf pine and hardwoods before and after implementing the shelterwood reproductive cutting method.

Table l-Number of submerchantable hardwoods (1 to 5 inches d.b.h.) controlled using manual and chemical methods in shelterwood stands with pine and pine-hardwood overstory compositions

Species group	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	Stems per acre							
Oaks	65	45	90	65	1,760	0.36	992	0.20
Other canopy trees	50	58	60	45	16,400	.95	1,260	.84
Midcanopy trees	12	8	12	10	223	.88	65	.39
Shrubs	2	2	5	2	229	.64	562	.75
Total	129	113	167	122	5,940	.58	1,510	.16

MSE = mean square error; *P* = probability level.

Submerchantable-hardwood control-Submerchantable woody stems **in** the **l-** to **5-in d.b.h.** classes were counted on 10 temporary 0.0 l-acre plots (11.78 ft in radius) systematically located in each subplot just before applying hardwood control treatments. Hardwood control treatments began in mid-August 1990, toward the end of the hardwood harvest, and were completed in early September 1990. Treatments were either manual (chain-saw felling) or chemical (chain-saw felling followed immediately by application of undiluted Garlon® 3A to the stump). Average stump height in the manual control treatment (0.73 ft) did not significantly differ from that in the chemical treatment (0.76 ft). Submerchantable stems treated during hardwood control averaged 133 stems per acre (table 1). Most were oaks or other canopy trees. No significant differences occurred with either the overstory treatments or the hardwood control treatments. Submerchantable pines, which were chain-saw felled but not treated with herbicide, averaged six stems per acre. No sprouting was observed, although young shortleaf pines often sprout after being top-killed.

Measurements

A preharvest inventory was conducted for reproduction in September 1989. All woody plants in the seedling-size class (≤0.5 in d.b.h.) were counted on 10 temporary milacre plots (3.72 ft in radius) in each subplot by species or species group and the following size classes: ≤0.5 ft, 0.6 to 2.5 ft, 2.6 to 4.5 ft, and 4.6 ft and taller but ≤0.5 in d.b.h. Multiple-stemmed rootstocks were tallied as one individual, evaluating size for the tallest stem. Woody saplings (stems with a d.b.h. of 0.6 to 3.5 in) were counted by species or species group and l-in d.b.h. classes on O.Ol-acre plots centered around each temporary point.

In March 1990, all retained pines and hardwoods (≥3.6 in 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 one-third of the hardwoods were measured for height and crown dimensions. In each subplot, age was determined for about four pines and four white oaks that were dominants or codominants.

Seedbed conditions after harvesting and hardwood control were evaluated at 12 locations spaced along a 22-ft line transect centered around each permanent point. Transect direction was randomly selected for each permanent point. Seedbed conditions were classified as undisturbed litter, disturbed litter, exposed mineral soil, slash from both logging and hardwood control, or some natural feature such as a rock or natural coarse woody debris (diameter≥4 in).

Postharvest inventories in early September 1991 and late August 1993 followed the same procedures as the preharvest inventory, except reproduction plots were centered around the 18 permanent points. In the 199 1 inventory, the two tallest pine seedlings present on each milacre plot (if any) were measured for ground-line diameter, height, and crown width. In the 1993 inventory, the two tallest pines and the two tallest two hardwoods on the O.Ol-acre plot were measured for ground-line diameter, height, and crown width. Measured hardwoods were classified as being from: (1) advance reproduction that was too small to be controlled, (2) sprouting of submerchantable trees that were cut during hardwood control, (3) sprouting of harvested merchantable trees, and (4) sprouting of trees damaged during logging. Classification of trees near the merchantability limit was based on the presence or absence of the cut stem; those cut and left were classified as submerchantable, while harvested stems were classified as merchantable. The herbicide treatment of all cut submerchantable stems was uncertain because some trees may have been cut by loggers for access. During each reproduction inventory, the same person estimated coverage of understory vegetation (grasses, herbs, vines, shrubs, hardwoods, pines, and total vegetation) on all milacre plots.

From October 1990 to February 1993, pine seed production in each 0.7-acre subplot was monitored in three 0.9-ft^2 seed traps (Cain and Shelton 1993). Seed traps were located along the subplot's center line at least 120 ft from the boundary with the untreated stand and 100 ft from the boundary with the adjacent whole plot. Collections were made during the middle and the end of each October-to-February period. Viability was determined by splitting seeds and inspecting the contents (Bonner 1974). Seeds with full, firm, undamaged, and healthy tissue were judged to be potentially viable and were tallied as sound seeds.

Photosynthetically active radiation (PAR) was determined at 4.5 ft aboveground on 10 temporary milacre plots located along the subplot's center line during clear sky conditions between 1030 and 1330 solar time on August 1, 1991, using an 80-sensor Sunfleck Ceptometer (Decagon Devices, Inc., Pullman, WA). Ten readings were taken across each milacre plot. Several measurements were also made in full sunlight for calculating relative light intensity (PAR at 4.5 ft expressed as a percentage of PAR in full sunlight). Canopy coverage was determined using a spherical densitometer at 4.5 ft above each of the 18 permanent points during the 1993 inventory.

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, O.Ol-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. Data were analyzed by analysis of variance for a 2x2 factorial, split-plot randomized complete block design using the SAS procedure GLM (SAS Institute 1989). Since there were only two levels for each factor, means were not separated but were presented with the associated mean square error (MSE) and probability level (*P*). Significance was accepted at $P \leq 0.05$. Shortleaf pine site index was calculated from Graney and Burkhart (1973); white oak site index was calculated from Farrar (1985).

Results And Discussion

The Postharvest Environment

The most common seedbed conditions after harvesting and hardwood control were undisturbed litter and slash, averaging 44 and 36 percent coverage, respectively (table 2). The harvesting intensity was lower for pine-hardwood treatment because some hardwoods were retained. This resulted in a higher percentage of undisturbed litter for the pine-hardwood overstory treatment (5 1 percent) compared to the pine treatment (38 percent). Exposed mineral soil was 2.8 percent coverage for the manual hardwood control treatment compared to 5.2 percent for chemical control. One reason for this small but significant difference may be that the chemical treatment produced less slash (32 percent) than the manual treatment (40 percent). The chemical hardwood control was applied several weeks after the manual treatments, possibly resulting in additional leaf fall during this period and, thus, less slash when trees were felled. Slash from harvesting and hardwood control averaged 36 percent coverage, which was much higher than the 7 percent slash observed in a nearby uneven-aged harvest that removed a similar pine volume but no hardwoods (Shelton and Murphy, in press). Large amounts of slash apparently resulted from the robust crowns of felled hardwoods.

Canopy coverage and light intensity were both strongly related to overstory treatments (fig. 2). Canopy coverage in the pine overstory was about 30 percent; retaining 15 ft^2 per acre of hardwoods essentially doubled coverage to 60 percent. The higher canopy coverage associated with hardwood retention resulted in less PAR reaching the understory; PAR averaged about 80 percent of full sunlight for the pine overstory treatment compared to 50 percent for the pine-hardwood overstory treatment. The coverage and PAR of the overstory treatments reflected differences in total basal area (that is, 30 versus 45 ft^2 per acre) and differences in the crown features of pines and hardwoods. Hardwoods tend to produce more shade and canopy coverage than an equivalent basal area of pines, because they have large crowns, short heights, and broad leaves (Shelton and Murphy 1993, Tappe and others 1993).

Table 2—Seedbed conditions after harvesting and applying manual and chemical methods of submerchantable hardwood control in shelterwood stands with pine and pine-hardwood over-story compositions

Seedbed condition	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	Percent of area							
Undisturbed litter	36.1	39.4	52.3	48.8	10	0.004	21.2	0.96
Disturbed litter	15.4	18.2	6.8	15.5	19	.08	33.7	.10
Mineral soil	3.7	4.6	1.9	5.7	4	.71	.4	.0003[a]
Slash[b]	42.9	35.6	36.9	28.1	46	.14	54.0	.07
Natural feature	1.8	2.2	2.1	1.8	2	.93	3.4	.95

MSE = mean square error; *P* = probability level.
[a] The interaction of the overstory and hardwood control treatments was significant ($P = 0.004$).
[b] Includes slash from both logging and hardwood control.

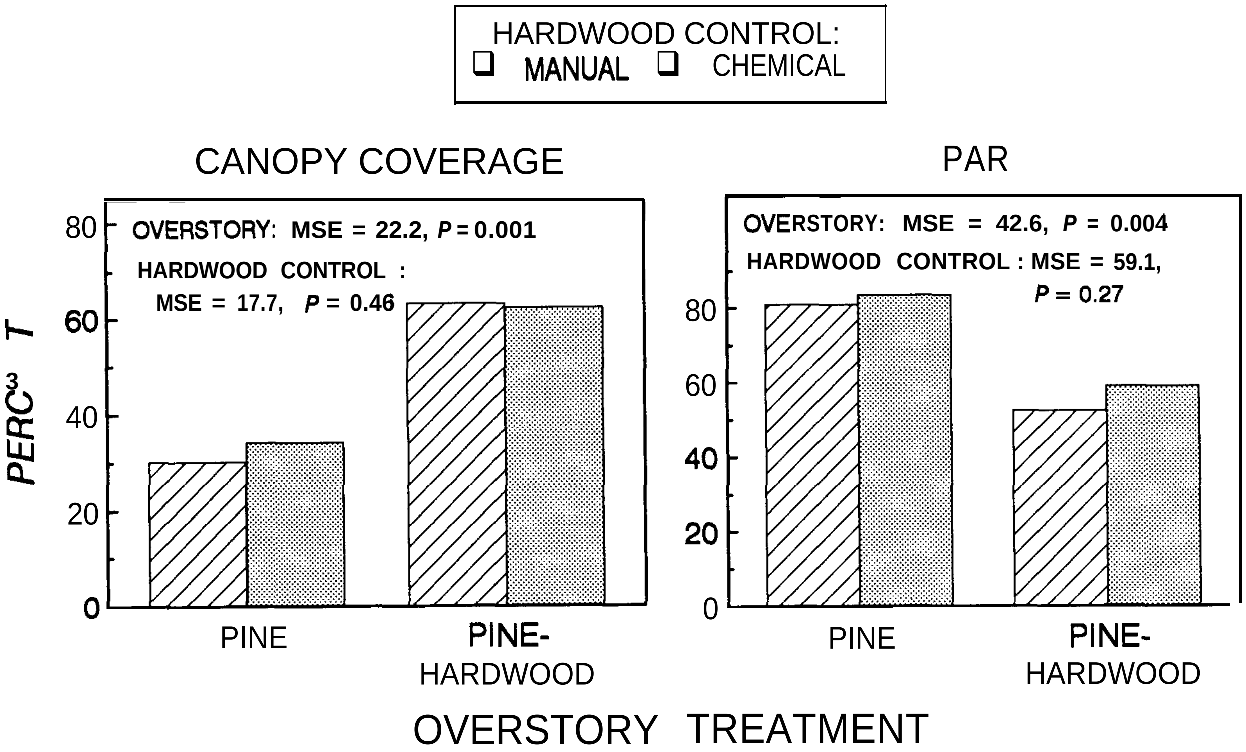

Figure 2—Canopy coverage of the overstory and photosynthetically active radiation (PAR expressed as a percentage of that in full sunlight) occurring in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable hardwood control. (MSE = mean square error; *P* = probability level).

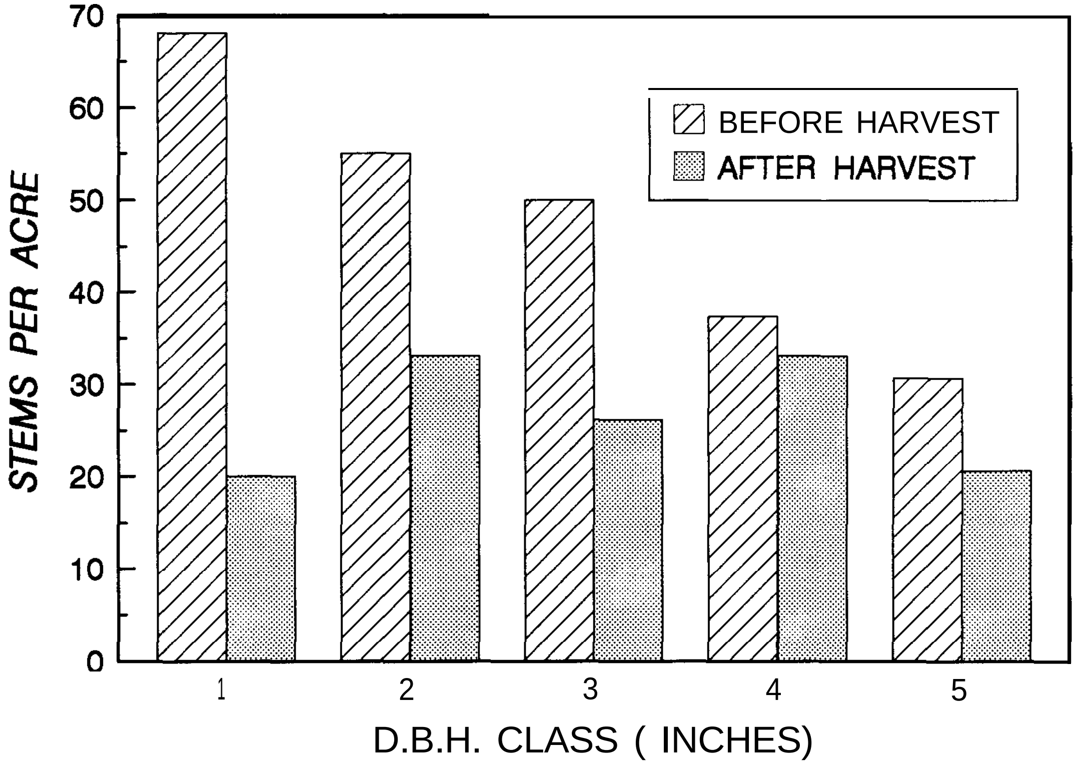

Figure 3-Diameter at breast height (d.b.h.)-class distribution of submerchantable hardwoods before and after the harvest implementing the shelterwood reproduction method.

Table 3-Annual production of sound shortleaf pine seeds 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	
Seed year	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	- - - - - - - - - Thousands *per acre* - - - - - - - - -							
1990	66.8	50.1	20.9	16.7	2,710	0.23	249	0.23
1991	33.4	25.0	16.7	37.6	528	.87	366	.54
1992	141.9	171.1	133.5	175.2	3,870	.95	4,450	.33
Total	242.1	246.2	171.1	229.5	4,940	.30	4,870	.40
	- - - - - - - - Percent *of* total *seeds* - - - - - - - - -							
1990	12.5	15.1	11.6	5.6	124	.42	30	.56
1991	18.3	16.5	31.8	29.6	1,140	.49	574	.87
1992	48.1	56.7	55.2	66.9	266	.37	124	.12
Mean”	30.2	33.1	31.1	36.7	212	.78	40	.23

MSE = mean square error; *P* = probability level
[a] Weighted mean based on 3-year totals.

The potential for hardwood sprouting was large, even for the plots where submerchantable hardwoods were chemically treated. Before harvest, submerchantable-size classes contained 240 stems per acre, but damage during harvesting reduced density to 133 stems per acre (fig. 3). Losses were especially high in the smaller d.b.h. classes, where trees were broken off or uprooted during the harvesting of merchantable trees. In addition, some submerchantable trees were cut by loggers for access. The density of merchantable hardwoods averaged 92 stems per acre before harvesting. All were harvested in the pine overstory treatment, compared to an average of 52 stems per acre harvested in the pine-hardwood treatment.

Shortleaf Pine Seed Production

Some sound seeds were produced for each of the 3 years after harvest and hardwood control, averaging 39,000, 28,000, and 155,000 per acre in 1990, 1991, and 1992, respectively (table 3). No significant differences occurred among treatments. Mean annual seed production in this stand (74,000 sound seeds per acre) was about 25 percent lower than the long-term mean for shortleaf pine stands in the Ouachita Mountains (Shelton and Wittwer 1996).

However, yearly shortleaf pine seed crops vary greatly, and a longer observation period is needed to validate comparisons. The higher 1992 seed production seems to support the common belief that at least 2 years are required for the pine reproductive cycle to respond to release. However, a nearby uneven-aged stand, harvested several years before this one, also had a good seed crop in 1992.

The absence of significant differences among the treatments for seed production may indicate that more time is needed for trees to respond to release. In addition, pine seed trees were released to some extent by harvesting and hardwood control in both overstory treatments. Others have observed that hardwood control and release by thinning enhances pine seed production. Yocom (197 1), for example, reported that 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 per acre) had the greatest seed production. However, the influence of stand conditions on shortleaf pine seed production is far less than the inherent variation due to environmental factors and seed and cone consumers.

Table 4-Density and stocking of sbortleaf pine seedlings in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable hardwood control

Growing season[a]	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	Density (stems per acre)							
Preharvest	50	125	125	75	10,600	0.82	8,120	0.79
First	486	764	667	430	127,000	.70	81,500	.89
Third	1,010	1,940	1,740	1,510	257,000	.61	699,000	.43
	Milacre stocking (percent)							
Preharvest	2	10	12	5	42	.50	62	1.00
First	28	40	38	29	457	.94	184	.76
Third	40	58	57	62	328	.33	149	.10

MSE = mean square error; *P* = probability level.
[a] Inventories conducted in 1989 for preharvest, 1991 for the first growing season, and 1993 for the third growing season.

The percentage of the total seeds that were sound averaged 11 percent in 1990, 24 percent in 1991, and 57 percent in 1992, with no significant differences among treatments. The greatest percentage of sound seeds was observed for the most abundant seed crop. Shelton and Wittwer (1996) also observed that the percentage of sound seeds increased with the size of the shortleaf pine seed crop, approaching 75 percent in bumper years.

Shortleaf Pine Seedlings

Density averaged only 94 seedlings per acre before harvesting and hardwood control, reflecting the closed canopy condition and high level of overstory competition (table 4). After harvesting and hardwood control, seedling density increased to 590 seedlings per acre after the first growing season and 1,550 seedlings per acre after the third, indicating that some seedlings became established from each succeeding seed crop. Seedlings became established despite fairly large amounts of slash and undisturbed litter. Thus, a few favorable microsites can provide acceptable regeneration when seed production is abundant. No significant differences occurred between overstory or hardwood control treatments. However, hardwoods have been shown to substantially reduce the establishment of shortleaf pine reproduction when levels were greater than those tested in this study (Becton 1936, Shelton and Murphy, in press). Milacre stocking of pine seedlings displayed a pattern similar to density (table 4). Stocking averaged 7 percent before treatment, but gradually increased to 45 percent after the first growing season and 54 percent after the third.

Over the 3-year period, about 0.7 percent of the sound seeds yielded established seedlings, which agrees well with other studies of natural shortleaf pine regeneration: 0.3 percent in undisturbed areas and 2.0 percent in scarified areas in a sawtimber stand (Haney 1962), 0.4 percent in untreated areas and 1.3 percent in burned areas in a poorly stocked stand (Maple 1965), 0.4 percent in undisturbed areas and 1 .O percent for disturbed areas in a seed-tree stand (Yocom and Lawson 1977), and 0.6 percent after the initial harvest in a nearby shortleaf pine-hardwood stand (Shelton and Murphy, in press).

The generally accepted minimum stocking limit for pine reproduction in natural, even-aged pine stands is 700 stems per acre and 40 percent milacre stocking (Campbell and Mann 1973, Grano 1967). All overstory and hardwood control treatments either met or exceeded this limit after the third growing season.

Table 5-Density of deciduous rootstocks in the seedling-size class (≤0.5 inches d.b.h.) in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable hardwood control

Species group and growing season	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	***P***	MSE	***P***
	- - - - - - - - *Rootstocks per acre* - - - - - - - -							
Oaks								
Preharvest	**1,020**	1,350	875	775	1.51E5	0.16	4.89E5	0.76
First	**972**	694	667	1,000	2.57E5	1 .00	2.36E5	.91
Third	**680**	694	820	1,060	7.78E4	.17	1.22E5	.50
Other canopy trees								
Preharvest	**325**	600	200	375	1.64E5	.45	1.26E5	.25
First	**694**	1,190	805	944	2.67E5	.80	2.92E5	.28
Third	**1,030**	1,010	778	1,060	1.45E5	.62	3.41E5	.67
Midcanopy trees								
Preharvest	**575**	600	2,050	650	4.36E6	.52	2.15E6	.38
First	**417**	806	1,530	472	7.31E5	.43	8.42E5	.49
Third	**500**	1,030	916	694	1.97E5	.86	2.95E5	.59
Shrubs								
Preharvest	**7,620**	4,580	7,220	9,220	5.80E6	.18	2.36E7	.84
First	**3,750**	3,610	6,190	6,530	1.52E7	.26	9.46E6	.95
Third	**4,970**	5,190	6,170	7,580	1.54E7	.43	2.04E7	.73
Total								
Preharvest	**9,540**	7,130	10,345	11,020	1.58E7	.32	1.99E7	.71
First	**5,833**	6,300	9,192	8,946	1.07E7	.16	1.38E7	.95
Third	**7,180**	7,924	8,684	10,394	1.25E7	.35	2.36E7	.69

MSE = mean square error; *P* = probability level; MSE is presented in exponential format, for example, $1.23E4=1.23X10^{4}=12{,}300$.

Deciduous Rootstocks in the Seedling-Size Class

Treatments had no significant effect on the density of deciduous rootstocks in the seedling-size class (table 5). The sources of deciduous rootstocks after harvest and hardwood control were development from seeds, advance reproduction that was below the minimum size for hardwood control, and sprouting of stems that were cut or damaged during harvesting. After the third growing season, there were about equal numbers of oaks, other canopy trees, and midcanopy trees, which averaged 8 10,970, and 780 rootstocks per acre, respectively. Shrubs were the most common group, accounting for about two-thirds of the total.

Oak density averaged 1,005 rootstocks per acre before harvest. Their density decreased slightly after harvest and hardwood control to 830 rootstocks per acre after the first growing season and 8 10 rootstocks per acre after the third. Milacre stocking of oak rootstocks averaged 49 percent before harvest, 47 percent after the first growing season, and 48 percent after the third. There was an acceptable component of the preferred oak species in the regenerated stand, with white oak accounting for 38 percent of the oak density after the third growing season, followed by the desirable red oaks [black, northern red (Q. *rubra* L.), and southern red oaks] at 33 percent.

Density of other canopy trees, which initially averaged 375 rootstocks per acre, increased substantially after harvest and hardwood control to 9 10 rootstocks per acre after the first growing season and 970 rootstocks per acre after the third growing season. Milacre stocking for this group averaged 18 percent before harvest and increased to 4 1 and 43 percent after the first and third growing seasons, respectively.

Midcanopy trees, which averaged 970 rootstocks per acre before harvest, decreased slightly to 8 10 rootstocks per acre after the first growing season and 780 rootstocks per acre after the third growing season. Milacre stocking for this group averaged 28 percent before harvest, 29 percent after the first growing season, and 34 percent after the third.

After the third growing season, the number of woody species or species groups per subplot averaged 12.6 for the pine overstory treatment and 11 .O for pine-hardwood overstory treatment (MSE=4.48, P=0.02). Hardwood control treatments did not differ significantly, averaging 11.9 species for the manual control treatment and 11.8 species for the chemical treatment (MSE=0.562, P=0.91). After the third growing season, the seedling-size class contained 24 woody species or species groups including 1 pine, 7 oaks, 4 other canopy trees, 6 midcanopy trees, and 6 shrubs. Cain and Shelton (1994) 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. The similarity of the diversity in these widely differing stands demonstrates the resiliency of the understory to disturbance and the richness of understory woody species on these poor Ouachita Mountain sites.

Reproduction in Sapling-Size Classes

Density of shortleaf pine saplings averaged only seven stems per acre before harvesting, indicating that the high stocking of overstory trees suppressed development of pine reproduction (table 6). After the third growing season, a few pine saplings appeared in the pine overstory treatment, but variation was so great that the treatment difference was not significant. These saplings probably developed from advance reproduction.

Deciduous saplings averaged 184 stems per acre before harvest, and the distribution was 36 percent oaks, 38 percent other canopy trees, 17 percent midcanopy trees, and 9 percent shrubs (table 6). The hardwood control treatment was thorough, resulting in almost no saplings after the first growing season. By the end of the third growing season, however, sapling density had increased to near preharvest levels. The density of deciduous saplings in the pine overstory treatment (270 stems per acre) was significantly greater than that in the pine-hardwood overstory treatment (110 stems per acre), reflecting the increased competition from retained overstory hardwoods. Effects of hardwood control treatments were also significant after the third growing season, when sapling density was about 40 percent greater for the manual hardwood control than the chemical hardwood control. The herbicide application suppressed the sprouting of treated stumps.

Reproduction Size

The pine overstory treatment resulted in larger shortleaf pine reproduction than that of the pine-hardwood treatment by an average of 2.1 times for ground line diameter, 1.6 times for crown width, and 1.3 times for height (table 7). After the third growing season, pine reproduction in the pine overstory treatment was more than twice as large as that in the pine-hardwood overstory treatment for all dimensions. Hardwood control treatments did not significantly affect the size of pine reproduction after the first growing season. After the third growing season, chemical hardwood control resulted in significantly larger pine reproduction than manual control for the pine-hardwood overstory treatment but significantly smaller reproduction for the pine overstory treatment. A possible explanation for this difference may involve a subtle shift from woody to herbaceous vegetation in the pine overstory treatment. Herbaceous vegetation, which can severely suppress the early development of pine reproduction (Cain 1988), might have been quicker to respond to the reduced sprouting of hardwoods caused by the herbicide application than pine reproduction. By contrast, pine reproduction in the pine-hardwood overstory treatment may have been under more woody competition because of: (1) the relatively small size of reproduction, (2) the greater shading by the overstory, and (3) the suppression of herbaceous vegetation by the overstory.

Because of their larger size, the dominant pine reproduction was overtopped by understory vegetation only 2 1 percent of the time in the pine overstory treatment compared to 36 percent in the pine-hardwood treatment (table 8). The

Table 6—Density of pines and deciduous saplings (20.6 to 3.5 inches d.b.h.) in shelterwood stands with pine and pine-hardwood overstory compositions and manual and chemical methods of submerchantable hardwood control

Species group and growing season	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	- - - - - - - - - - - *Stems per acre*	- - - - - - - - - - -						
Pines								
Preharvest	0	15	0	12	373	0.91	248	0.13
First	0	0	0	0	--[a]	—	—	—
Third	12	3	0	0	57	.14	62	.26
Oaks								
Preharvest	68	88	45	55	1,440	.24	567	.25
First	0	0	0	0	—	—	—	—
Third	188	139	44	51	3,840	.03	1,650	.17
Other canopy trees								
Preharvest	50	80	52	70	1,720	.87	990	.18
First	0	0	0	0	—	--	—	—
Third	60	47	28	24	1,650	.26	2,210	.73
Midcanopy trees								
Preharvest	25	10	18	68	7,120	.60	2,880	.54
First	2	0	2	0	6	1.00	4	.21
Third	44	42	61	12	517	.62	1,050	.16
Shrubs								
Preharvest	22	18	10	15	1,080	.68	50	1.00
First	0	0	0	0	—	—	—	—
Third	2	2	2	2	0	1.00	12	1.00
Deciduous total								
Preharvest	165	210	125	220	12,200	.80	5,120	.10
First	2	0	2	0	6	1.00	4	.21
Third	294	230	135	89	4,700	.02	1,040	.01

MSE = mean square error; *P* = probability level.
[a] No saplings were recorded, and thus, analysis of variance was not conducted

Table 7—Mean size of the dominant shortleaf pine reproduction 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	
Property”	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	---------- First growing season ----------							
G.l.d. (in)	0.30	0.29	0.13	0.15	0.0012	0.003	0.0005	0.43
Crown width (ft)	.69	.65	.40	.45	.0113	.02	.0048	.86
Height (ft)	.81	.67	.38	.78	.1670	.49	.2230	.60
	---------- Third growing season ----------							
G.l.d. (in)	.91	.79	.29	.35	.0187	.004	.0011	.07[b]
Crown width (ft)	2.00	1.77	.83	.90	.0646	.004	.0029	.03[b]
Height (ft)	4.65	4.07	1.85	2.02	.3760	.004	.0191	.03[b]

MSE = mean square error; *P* = probability level; g.l.d. = groundline diameter.
[a] The largest two seedlings or saplings (if present) were measured in milacre plots after first growing season and O.Ol-acre plots after the third growing season.
[b] The interaction of the overstory and hardwood control treatments was significant $P \leq 0.05$.

Table 8—Overtopping of the dominant pine reproduction by understory vegetation after the third growing season 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 group	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	----- *Percent of stems[a] overtopped* -----							
Grasses	0	1.5	0	0.8	2.2	0.65	1.4	0.10
Herbs	0	0	1.1	.8	3.5	.39	0.1	.36
Vines	.7	1.5	2.5	1.8	1.0	.13	4.9	.99
Shrubs	2.9	4.5	14.0	9.2	10.3	.02	65.2	.72
Hardwoods	15.4	13.4	23.6	18.9	26.7	.08	85.3	.49
Pines[b]	0	.7	0	1.0	2.0	.86	1.5	.21
Total	19.0	21.6	41.2	32.5	76.5	.04	156.0	.60

MSE = mean square error; *P* = probability level.
[a] The largest two seedlings or saplings (if present) i0.01-acre plots.
[b] From pine reproduction outside the reproduction plot or, if inside the plot, from the largest pine overtopping the next-to-largest.

Table 9-Mean size of the dominant hardwood reproduction after the third growing **season 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	
Property[a]	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	---------------- Oaks ----------------							
G.l.d. (in)	1.47	1.51	1.04	1.04	0.009	0.002	0.005	0.73
D.b.h. (in)	.74	.66	.44	.40	.006	.006	.026	.50
Crown width (ft)	4.21	4.40	3.67	3.48	.211	.05	.071	.86
Height (ft)	8.71	8.08	7.05	6.34	1.550	.07	.221	.03
	Other canopy trees							
G.l.d. (in)	1.20	1.34	.94	1.06	.105	.19	.090	.43
D.b.h. (in)	.48	.60	.35	.39	.027	.13	.061	.52
Crown width (ft)	3.54	4.38	3.64	4.07	.807	.83	.863	.22
Height (ft)	7.54	8.47	6.95	6.87	.881	.10	3.840	.68
	Midcanopy trees							
G.l.d. (in)	1.25	1.08	1.11	.85	.098	.22	.032	.20
D.b.h. (in)	.69	.67	.63	.32	.030	.08	.023	.18
Crown width (ft)	4.36	3.92	4.06	3.32	1.080	.28	.139	.19
Height (ft)	9.66	9.61	9.92	6.92	4.880	.27	2.580	.25

MSE = mean square error; *P* = probability level; g.l.d. = groundline diameter.
[a] Based on the largest two deciduous rootstocks occurring in 0.01-acre plots.

difference between the hardwood control treatments was not significant. Overtopping of the dominant pine reproduction by overstory trees was also strongly related to overstory treatment, averaging 20 percent for the pine overstory treatment and 37 percent for the pine-hardwood overstory treatment (MSE=77.6, *P*=0.002).

Oak reproduction showed a response to overstory treatments similar to shortleaf pine, although the magnitude was not as great (table 9). Differences were significant for ground line diameter, d.b.h., and crown width but not for height. Oak reproduction from the chemical hardwood control treatment (7.2 ft) was slightly shorter than that from the manual treatment (7.9 ft). This was the only significant difference observed for the hardwood control treatments. For the other canopy trees and midcanopy trees, reproduction also tended to be slightly larger under the pine overstory treatment, but these differences and differences between the hardwood control treatments were not significant.

Hardwood reproduction was considerably larger than shortleaf pine reproduction after the third growing season (fig. 4). This reflected a difference in the principal reproductive strategy of the two groups-seeds for pines versus advance reproduction and sprouts for hardwoods. Experience elsewhere has shown that the height growth of free-to-grow pine reproduction will eventually exceed that of hardwoods on most upland sites (Wahlenberg 1960). Although less is known about the long-term growth rates of reproduction beneath a partial canopy, this study suggests that pine growth will be suppressed to a greater degree than hardwood growth. For example, the suppression of height growth by retained overstory hardwoods was 56 percent for

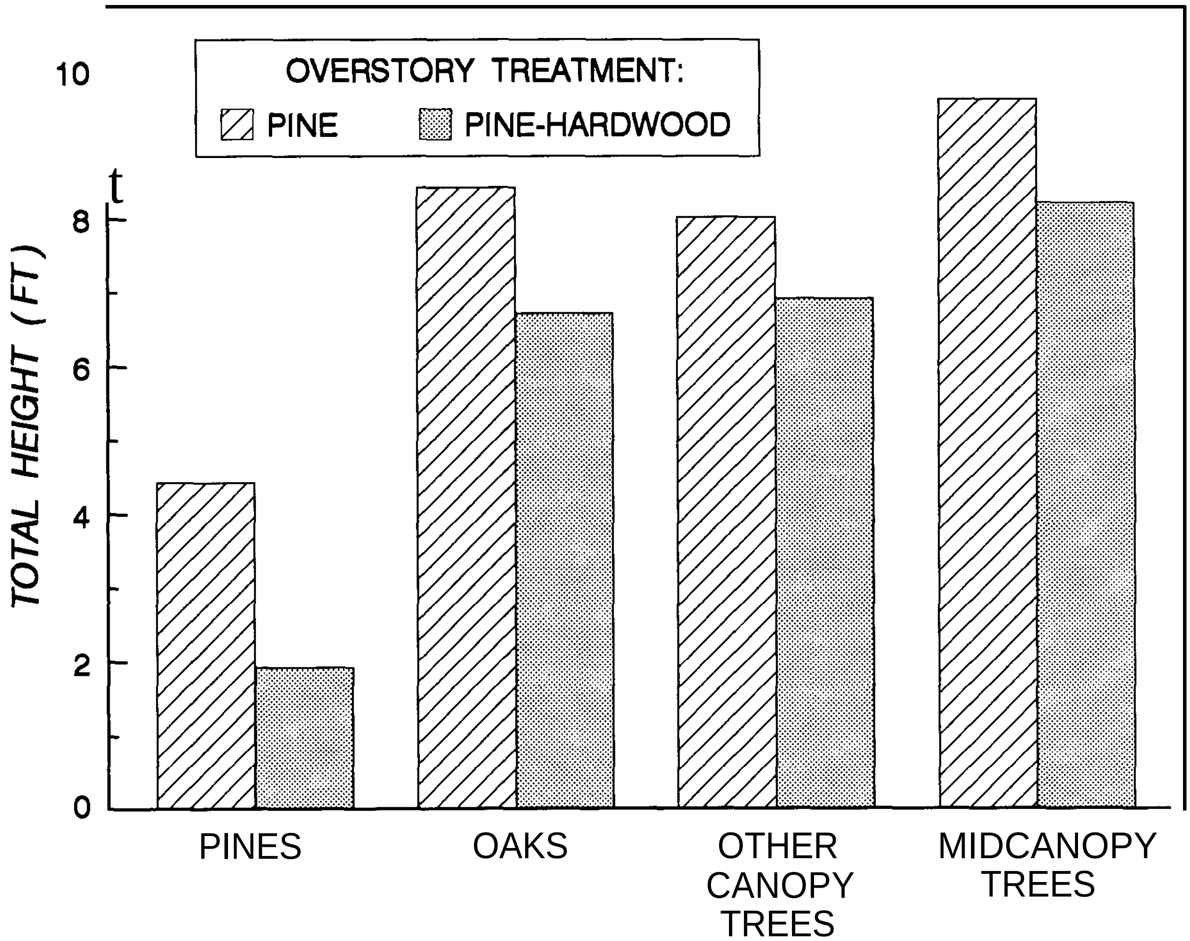

Figure 4—Mean total height of dominant reproduction after the third growing season in shelterwood stands with pine and pine-hardwood overstory compositions

pine reproduction but only 20 percent for oaks, 14 percent for other canopy trees, and 12 percent for midcanopy trees.

Sources of the dominant hardwood reproduction were from advance reproduction or the sprouts from cut submerchantable trees, cut merchantable trees, or trees damaged during logging. Of these sources, the herbicide application was limited to stumps of submerchantable stems cut during the chemical hardwood control treatment. The source of the dominant deciduous reproduction was influenced by the hardwood control treatment (fig. 5). More of the dominant hardwood stems came from cut submerchantable stems in the manual hardwood control treatment (26 percent) than in the chemical treatment (13 percent). Advance reproduction was the dominant hardwood reproduction 6 1 percent of the time for the chemical hardwood control treatment and 47 percent for the manual treatment. This difference probably reflected the reduced sprouting of the herbicide-treated stumps, which favored advance reproduction as the dominant reproduction. The high susceptibility of oaks to Garlon 3A was indicated by their low representation as dominant reproduction in the chemical hardwood control treatment.

Understory Coverage

First growing season-Grasses, herbs, and hardwoods responded rapidly to the stand disturbance and the reduction in overstory competition (table 10). Herbs showed the greatest response, increasing about 20 times over pre-harvest levels in the pine overstory treatment and 5 times in the pine-hardwood overstory treatment. The most common herb was fireweed *(Erechtites hieracijblia* Raf.), which often flourishes after disturbance. By contrast, coverage of vines and shrubs was generally greatest before treatment, and the first-year growth for these groups apparently did

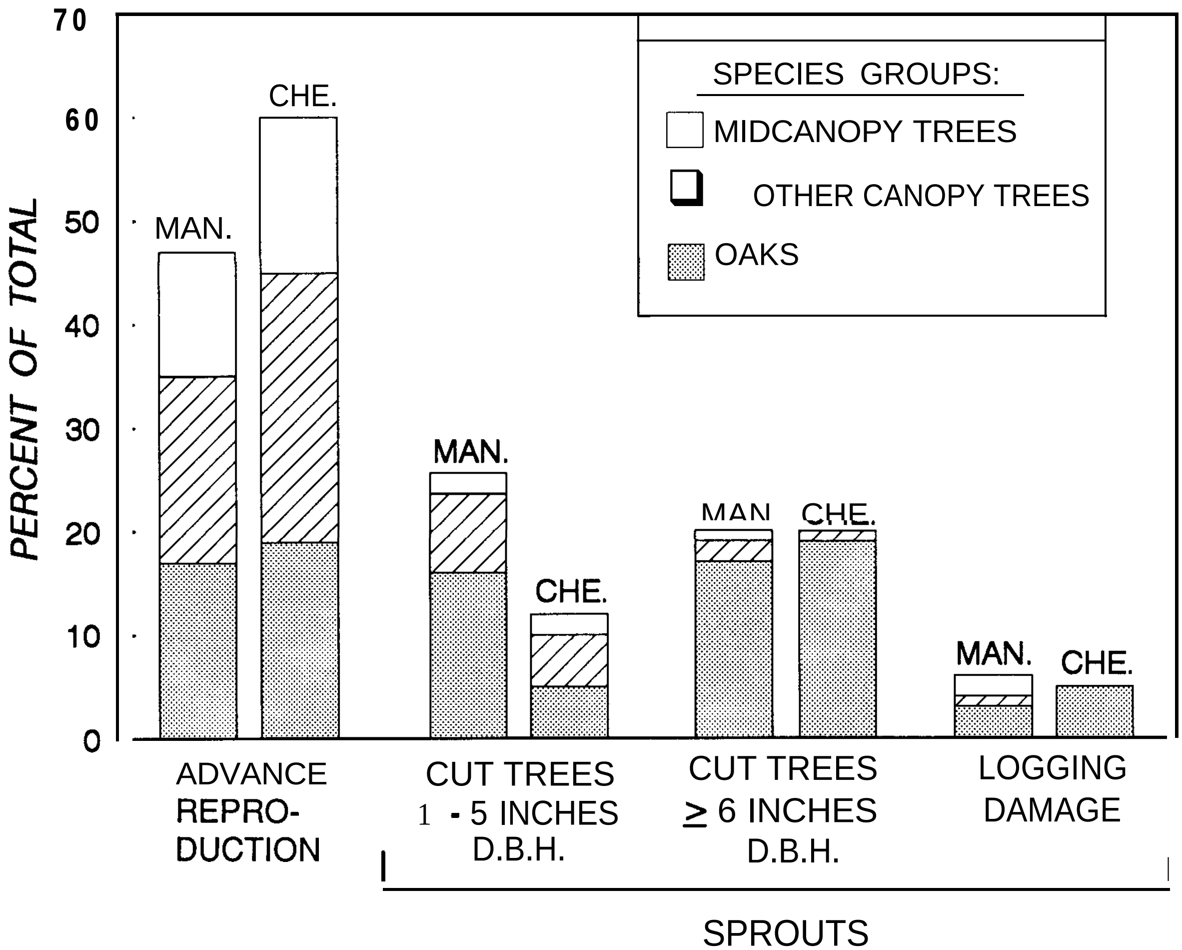

Figure 5—Origin of the dominant hardwood reproduction in shelterwood stands three growing seasons after controlling submerchantable hardwoods by manual (MAN.) and chemical (CHE.) methods. Herbicide was applied only to trees 1 to 5 inches diameter at breast height (d.b.h.) in the chemical control treatment.

not compensate for the losses incurred during disturbance. All vegetative groups except the pines were present in the stand before harvest and were able to respond rapidly to dominate the understory after the first growing season. The coverage of pines was nil at this time. Total vegetative coverage essentially doubled in the pine overstory treatment compared to an increase of only 17 percent in the pine-hardwood overstory treatment. 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 198 1, Schuster 1967).

Third growing season-Most groups increased in coverage between the first and third growing seasons (table 10). The exception was herbs, which declined almost as dramatically as they bloomed immediately after stand disturbance. The two overstory treatments were significantly different for all groups except pines, and total vegetative coverage averaged 68 percent in the pine overstory treatment compared to 46 percent in the pine-hardwood 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 hardwood 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 hardwood control averaged 55 percent compared to 60 percent for the manual treatment.

Table **10—Coverage** of understory vegetation **in shelterwood stands with pine and pine-hardwood over-story compositions and manual and chemical methods of submerchantable hardwood control**

Species group and growing season	Pine overstory		Pine-hardwood overstory		Overstory treatment		Hardwood control treatment	
	Manual	Chemical	Manual	Chemical	MSE	*P*	MSE	*P*
	Percent							
Grasses								
Preharvest	4.6	1.6	3.0	2.8	2.4	0.77	3.9	0.15
First	11.2	11.9	9.0	4.6	13.3	.08	12.1	.32
Third	25.5	24.4	11.4	10.1	71.7	.04	35.3	.70
Herbs								
Preharvest	1.0	0	.4	.5	.3	.82	.4	.23
First	10.1	9.7	2.2	2.3	6.5	.01	11.0	.90
Third	1.3	3.1	.4	1.5	.1	.01	.4	.004
Vines								
Preharvest	5.1	4.4	8.5	6.9	15.2	.23	7.6	.42
First	7.4	4.0	4.9	4.1	2.2	.21	7.2	.17
Third	14.7	9.5	8.9	6.6	4.0	.02	13.7	.09
Shrubs								
Preharvest	9.2	7.8	11.9	11.6	53.5	.44	34.4	.78
First	4.2	3.4	8.8	7.0	5.4	.04	7.0	.36
Third	8.6	6.5	15.7	10.5	12.8	.05	19.8	.15
Hardwoods								
Preharvest	4.1	4.8	2.8	4.2	8.4	.56	7.4	.46
First	10.7	10.7	8.4	7.0	6.9	.11	11.2	.70
Third	27.2	26.5	16.4	17.3	23.2	.03	34.5	.97
Pines								
Preharvest	0	0	0	0	--[a]	--	--	--
First	0	0	0	0	--	--	--	--
Third	1.9	2.7	.2	.3	3.9	.10	.9	.21
Total vegetation[b]								
Preharvest	21.4	17.3	25.1	24.3	52.8	.24	21.5	.33
First	42.9	39.0	33.1	24.6	16.7	.01	35.5	.08
Third	70.3	66.4	49.1	42.7	9.3	.001	16.7	.05

MSE = mean square error; *P* = probability level

[a] No coverage was recorded, and thus, analysis of variance was not conducted.

[b] Total vegetation coverage is often less than the sum of the species groups because of multiple occupancy.

Conclusions and Management Implications

These early results show that the shelterwood method can effectively regenerate mixed pine-hardwood stands in the Ouachita Mountains when combined 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, the stand had enough favorable microsites to establish acceptable shortleaf pine and hardwood reproduction. Pine reproduction principally came from seeds dispersed after treatment, but hardwoods developed from advance reproduction and sprouting. This difference in reproduction strategy gives hardwoods an initial growth advantage. However, pines usually grow rapidly after establishment, providing acceptable reproduction when the density and stocking levels are similar to those reported here.

Overstory hardwood retention within a shelter-wood pine stand will have the most significant impact on environmental conditions in the understory. Overstory hardwoods appear to suppress development of pine reproduction to a greater degree than an equivalent pine basal area, reflecting differences in the crown features between the two species groups. The limit for retaining hardwoods within a shelterwood pine stand appears to be fairly low. These early results suggest that 15 ft^2 per acre of hardwood basal area in a scattered distribution can be retained for at least the first few 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 ft^2 per acre of pines and 15 ft^2 per acre of hardwoods is equivalent to a pine overstory 60 ft^2 per acre, which is generally considered to provide an acceptable environment for the development of pine reproduction 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 reproduction, Grano (1961) found that the loss in pine milacre stocking was only 10 percent for a basal area removal of 3 1 ft^2 per acre and 16 percent for 42 ft^2 per acre.

The upper limit for acceptable overstory stocking has not been well established in even-aged reproduction cutting methods, probably because traditional guidelines call for overstory removal as soon as reproduction 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. For example, annual basal area growth in this study was about 0.75 ft^2 per acre for pines and 0.75 ft^2 per acre for hardwoods. Thus, the pine overstory treatment should take well over 20 years to reach a basal area of 75 ft^2 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 upper limit in 7 years when projected basal areas are 35 ft^2 per acre for pines and 20 ft^2 per acre for hardwoods (equivalent to a pine basal area of 35 + 2 X 20 = 75 ft^2 per acre). Of course, this prediction needs confirmation by the continued monitoring of overstory and understory dynamics in this study, but the general contrast between overstory treatments is clear-in 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 hardwood control treatments were low in intensity and cost. The chemical control treatment was restricted to the stumps of individual stems in the 1- to 5-in d.b.h. classes and, therefore, applied to only a fraction of the total hardwoods in the stand. The herbicide application effectively controlled the sprouting of some-but not all-species. Early results suggest that the chemical control treatment was not justified in the conditions tested here because it failed to substantially improve the amount, size, or overtopped status of shortleaf pine reproduction. Other conditions had more influence on the acceptable establishment of shortleaf pine reproduction, including the abundant pine seed production and the low initial levels of competing vegetation.

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This publication describes the development of pine and hardwood reproduction after shelterwood cutting in pine-hardwood stands. Results demonstrate the importance of overstory-understory relationships in reproduction cutting methods that retain overstory trees. However, the method of submerchantable hardwood control (manual versus chemical) may be unimportant if the pine seed production is good and the level of competing vegetation is low.

Keywords: Even-aged silviculture, natural regeneration, pine-hardwood stands, *Pinus echinata* Mill., shelterwood reproduction cutting method, site preparation.