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Shortleaf Pine and Mixed Hardwood Stands: Thirty-four Years After Regeneration with the Fell-and-burn Technique in the Southern Appalachian Mountains

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ABSTRACT

There has been considerable interest in developing management techniques for creating mixed shortleaf pine (*Pinus echinata*)–hardwood forests in the Southern Appalachian Mountains. This interest has increased in recent years due to the need to manage for more diverse and resilient forests, and to reestablish shortleaf pine as a dominant species throughout its native range. The fell-and-burn regeneration technique was developed in the 1980s as a low-cost method to establish planted pines among hardwood sprouts for regenerating mixed species stands. This study documented the success of the fell-and-burn technique for establishing shortleaf pine on moderately productive hardwood sites. Thirty-four years after planting shortleaf pine seedlings among hardwood sprouts, the pines had the largest diameter at breast height (d.b.h.), height, basal area, and volume. One study site, which was intermediate in soil moisture and fertility, had a greater number of hardwoods (particularly oaks) than a more productive site where pine was dominant. Results suggested that the fell-and-burn technique was successful for establishing shortleaf pine among hardwood sprouts, which may meet multiple economic and ecological forest management objectives.

Keywords: Fell-and-burn site preparation, mixed-species management, pine-hardwood mixtures, prescribed fire, regeneration, stand development.

INTRODUCTION

Historically, shortleaf pine (*Pinus echinata*) was a dominant and abundant overstory species throughout the Southern and Central United States, with the largest native range of any pine species in the Southeast. From the time of European settlement through the early 20th century, shortleaf pine became less abundant. The species was displaced by oaks (*Quercus* spp.) and other hardwoods by extensive timber harvesting, land clearing, wildfire followed by fire exclusion, and insect outbreaks (Hubbard and others 2004, Kabrick and others 2015).

In the 1980s and 1990s, managers of National forests in the Southern Appalachian Mountains were interested in planting pines among hardwood sprouts after clearcutting to improve stand productivity and value (Waldrop and Mohr 2012). The fell-and-burn regeneration technique was developed as a low-cost method to reduce the vigor of competition from hardwood sprouts following harvest while allowing for control of stocking and genetics of pine seedlings (Abercrombie and Sims 1986, Phillips and Abercrombie 1987). The fell-and-burn technique involves clearcutting a hardwood stand, felling residual hardwood stems in the spring when leaves are mostly developed, and site preparation burning in the summer to further target hardwood regeneration, followed by planting pine seedlings at a wide spacing (10 by 10 feet). Each step was designed to reduce competition from hardwood sprouts and allow pines the opportunity to establish and grow (Waldrop and Mohr 2012). These mixed-species stands allow for increased economic incentives by increasing the pine component of the stands. Ecological benefits may increase by providing greater species diversity, including wildlife.

Today, there is considerable interest in restoring shortleaf pine throughout much of its historic range (Kabrick and others 2007, Zhang and others 2012). The conversion of hardwood-dominated stands to mixed shortleaf pine-hardwood stands would increase the presence of shortleaf pine in the Appalachian Mountains and may result in increased ecological resilience and resistance to emerging threats to forest health, changes in management strategy, and a changing climate (Churchill and others 2013, Lake 2013). A return to more heterogeneous species mixtures may produce forests that are less susceptible to insect or disease problems (Kabrick and others 2008, 2015), including outbreaks by southern pine beetle (*Dendroctonus frontalis*). While these pine-hardwood ecosystems are limited in their extent, representing <5 percent of the Southern Appalachian landscape, their unique vegetation type provides important habitat for flora and fauna (Vose and others 1997). Additionally, the range and abundance of shortleaf pine are predicted to increase under a number of climate change scenarios (Iverson and others 2008), greatly increasing the need to understand methods of regeneration on sites where shortleaf pine has been excluded and where it may have the potential to be a key component of future forests.

In comparison to most southern yellow pines, shortleaf pine tends to grow slower in the early years after establishment (Lawson 1990), and competition from woody and nonwoody plants is highly detrimental to its growth and development (Dougherty and Lowery 1986, Jensen and others 2007, Lawson 1986, Lowery 1986). Shortleaf pine is slower to dominate a stand than loblolly pine (*Pinus taeda*), but can maintain dominance on most sites after it overtops competing vegetation. However, on good sites, shortleaf pine may be outcompeted by fast-growing species such as sweetgum (*Liquidambar styraciflua*) or red maple (*Acer rubrum*) (Cain and Yaussy 1983, 1984).

Long-term stand establishment after using the fell-and-burn technique has been evaluated for stands planted with loblolly pine (Waldrop 1997, Waldrop and Mohr 2012, Waldrop and others 1989), but not with shortleaf pine. Loblolly pine stands that were burned prior to planting had greater densities and greater volume of pines after 20 years than those that had not been burned. In contrast, unburned stands had greater densities and taller heights of hardwood species. Species dominance in both burned and unburned stands shifted from hardwood or hardwood-pine mixtures in year 6 (Waldrop 1997) to pine or pine-hardwood stands by year 20 (Waldrop and Mohr 2012). In this study, we evaluate the success of the fell-and-burn technique for establishing mixed shortleaf pine-hardwood forest stands 34 years after the technique was used to regenerate formerly hardwood-dominated stands.

METHODS

In 1985, Phillips and Abercrombie (1987) selected several sites on the Andrew Pickens Ranger District (Sumter National Forest) in Oconee County, SC for a study of shortleaf pine regeneration success. Sites included Sandy Ford, Whetstone, and Pine Mountain. Another site, Thrift's Ferry, was added to the current study to replace the Sandy Ford site because almost all pines at Sandy Ford had been killed by southern pine beetle in 2001. Thrift's Ferry had been harvested and regenerated by the same techniques and at the same time as the other study sites, and it was considered similar in site quality to Sandy Ford. Prior to harvest, all four study sites contained stands of mixed hardwoods. Site index for shortleaf pine was 69 feet (base age 50) and did not vary among the four sites. Site index for white oak (*Quercus alba*) did vary among sites, ranging from 59 feet at Thrift's Ferry to 70 feet at Pine Mountain. Soils were Typic Hapludults with soil solum depths ranging from 16 to 49 inches.

Stands were regenerated using the fell-and-burn technique beginning with a commercial clearcut in the winter of 1980–81, chainsaw felling of residual stems in the spring, a site preparation burn in the summer, and planting of genetically improved shortleaf pine 1-0 seedlings (10- by 10-foot spacing; 437 trees per acre) during the winter of 1981–82. Measurements to determine species composition, density (trees per acre), diameter at breast height (d.b.h.), and height were taken in 1985 (4 years following establishment) at Sandy Ford, Whetstone, and Pine Mountain (Phillips and Abercrombie 1987) and in 2015 at Thrift's Ferry, Whetstone, and Pine Mountain (34 years following establishment). In 1985, free-to-grow planted shortleaf pines (those receiving light from above) were tallied in each stand on six 52.5- by 82.0-foot plots arranged in a 2 by 3 matrix with the long axis running east and west along the contour (Phillips and Abercrombie 1987). Hardwoods were measured on three 10- by 120-foot strips spaced approximately 90 feet apart and arranged perpendicular to the contour of the slope. Basal diameter and total tree height were measured for each planted pine; species and total tree height were measured for each individual hardwood or tallest sprout in a clump (Phillips and Abercrombie 1987). Measurements in 2015 used the same plot arrangement, although the exact plot locations could not be found. Total height and d.b.h. were measured on every pine, hardwood, or dominant stem within a hardwood clump; height was estimated to the nearest 5 feet, and d.b.h. was measured with a tape.

Sawtimber cubic volume per ha for all species (>11.5 inches d.b.h.) was estimated to a 4-inch top using tables from Clark and Souter (1996). Pulpwood volume was estimated for pines between 4.5 and 11.5 inches d.b.h., and sawtimber was estimated for individuals >11.5 inches d.b.h. Hardwood volume estimates were for pulpwood only because no hardwoods were of sawtimber size.

To determine the differences between study sites on the Sumter National Forest, response variables (d.b.h., height, density, basal area, relative basal area, and volume) were summed by species at the plot level and analyzed using Analysis of Variance (ANOVA) based on stand averages. Relative basal area was determined as the total basal area for a species (or species group) divided by the total basal area for the plot and shown as a percentage. Where significant differences occurred, Student's T-tests were used to determine significant differences among sites. Data were analyzed using JMP®, Version 11, SAS Institute Inc., Cary, NC 1989–2007 or SAS® 9.1.3, SAS Institute Inc., Cary, NC. Data are reported as means. Any p-value ≤0.05 was considered evidence of a significant difference.

RESULTS

Shortleaf pine basal area ranged between 32 and 54 percent of the total stand basal area and had the largest means for density, d.b.h., height, and volume 34 years after stand establishment. Average shortleaf pine d.b.h. ranged from 6.1 to 7.6 inches on the three study sites with heights ranging from 59.4 to 71.2 feet (table 1). Red oaks (*Quercus rubra*) ranged in d.b.h. from 1.9 to 2.8 inches with heights between 20.7 and 33.1 feet. White oaks ranged from 2.3 to 2.8 inches d.b.h. and heights from 26.9 to 34.1 feet. Shortleaf pine densities ranged from 241 to 253 trees per acre, representing a survival of 53 to 56 percent of planted pines. Shortleaf pine basal area ranged from 57.2 to 91.6 square feet per acre (table 2). Density and basal area were significantly different between sites. Densities were higher at Thrift's Ferry (2,341 trees per acre) and Whetstone (2,079 trees per acre); however, basal area was largest at Pine Mountain (192.5 square feet per acre) and Thrift's Ferry (170.4 square feet per acre). Sandy Ford/Thrift's Ferry and Whetstone maintained a larger proportion of oak species than Pine Mountain from 1985 to 2015 (fig. 1). In 2015, the sites differed in their relative basal areas by species group (table 2). The proportion of hardwood species at Whetstone (30.4 percent) was comparable to Thrift's Ferry (23.3 percent), but significantly greater than that at Pine Mountain (18.0 percent). In contrast, Pine Mountain (82.0 percent) and Thrift's Ferry (76.7 percent) had the greatest proportion of pines. Thrift's Ferry had the greatest proportion of shortleaf pine, whereas Pine Mountain was dominated by Virginia pine. Whetstone had the greatest amount of oak species, and, in particular, those in the white oak group.

Total cubic-foot volume for pine species differed by site (table 3). Pine Mountain (4,195 cubic feet per acre) and Thrift's Ferry (3,787 cubic feet per acre) had more total volume than did Whetstone (2,462 cubic feet per acre). Thrift's Ferry had significantly more sawtimber (2,267 cubic feet per acre), and Pine Mountain had more pulpwood (3,133 cubic feet per acre) than the other sites. Total cubic volume for hardwoods was significantly greater at Pine Mountain (304 cubic feet per acre) and Whetstone (263 cubic feet per acre) than at Thrift's Ferry (89 cubic feet per acre) (table 4). Even though volumes of red oak and white oak appeared different, variability was high and differences were not statistically significant.

Table 1—Mean diameter at breast height, height, and density of species or species type recorded on the Sumter National Forest 34 growing seasons after establishment by the fell-and-burn technique

	Pine Mountain			Thrift's Ferry			Whetstone		
Species	**d.b.h.**	**Height**	**Density**	**d.b.h.**	**Height**	**Density**	**d.b.h.**	**Height**	**Density**
	inches	*feet*	*stems per acre*	*inches*	*feet*	*stems per acre*	*inches*	*feet*	*stems per acre*
Red maple	2.3	35.4	315	1.5	20.7	413	2.8	33.8	57
Hickories	0.8	10.5	36	0.8	11.2	88	1.1	13.5	62
Yellow-poplar	2.5	36.7	37	2.2	25.6	94	2.8	32.5	5
Other	1.3	15.7	643	1.5	16.4	957	1.5	17.7	1,102
Shortleaf pine	6.7	71.2	241	7.6	66.3	253	6.1	59.4	246
Pitch pine	2.8	22.0	2	4.4	43.6	3	6.4	56.4	7
Loblolly pine	9.5	80.1	2	16.9	88.6	17	10.6	75.1	20
White pine	0.0	0.0	0	1.6	15.4	111	3.3	29.2	57
Virginia pine	5.8	65.0	413	4.7	44.3	44	5.6	50.5	133
Red oaks	2.2	23.3	49	1.9	20.7	216	2.8	33.1	64
White oaks	2.4	28.5	37	2.3	26.9	142	2.8	34.1	324
Pines	6.1	67.3	658	6.1	51.8	428	5.9	53.8	464
Hardwoods	1.8	23.0	1,194	1.6	18.7	1,913	1.9	22.0	1,615

d.b.h. = diameter at breast height.

Table 2—Mean basal area and percent relative basal area of species or species group by site on the Sumter National Forest 34 growing seasons following the fell-and-burn regeneration technique

Species	Pine Mountain	Thrift's Ferry	Whetstone
	square feet per acre (% relative basal area)		
Maples	13.3 (6.9)	7.2 (4.3)	3.4 (2.1)
Hickories	0.2 (0.1)	0.5 (0.3)	0.5 (0.3)
Yellow-poplar	1.6 (0.8)	3.2 (1.9)	0.3 (0.2)
Other	12.1 (6.5)	16.5 (9.7)	19.7 (13.8)
Shortleaf pine	63.1 (32.4)	91.6 (53.6)	57.2 (36.9)
Pitch pine	0.1 (0.03)	0.4 (0.2)	1.6 (1.1)
White pine	0 (0)	4.1 (2.3)	6.5 (4.7)
Loblolly pine	0.8 (0.4)	28.1 (16.4)	13.4 (8.4)
Virginia pine	94.0 (49.1)	7.2 (4.1)	27.9 (18.5)
Red oaks	1.6 (0.8)	6.1 (3.7)	3.4 (2.3)
White oaks	5.6 (2.8)	5.6 (3.5)	17.3 (11.7)
Pines	158.1 (82.0)	131.4 (76.7)	151.0 (69.6)
Hardwoods	34.4 (18.0)	39.0 (23.3)	44.5 (30.4)

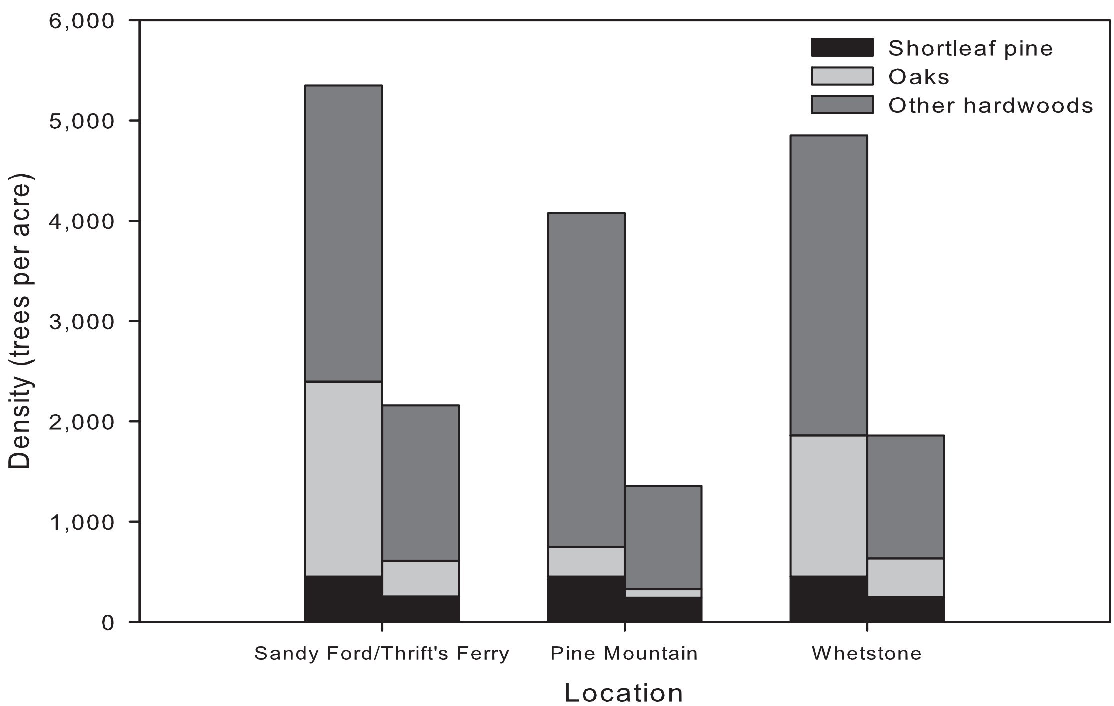

Figure 1—Mean density (trees per acre) of shortleaf pine, oak species, and other hardwoods at fell-and-burn sites on the Sumter National Forest surveyed in 1985 (left) and 2015 (right).

Table 3—Cubic foot volume of pine pulpwood (4.5–11.5 inches d.b.h.) and sawtimber (>11.5 inches d.b.h.) by site on the Sumter National Forest in 2015

Site	Pulpwood	Sawtimber	Total
		cubic feet per acre	
Pine Mountain	3,132.6 a	1,065.1 b	4,194.7 a
Thrift's Ferry	1,520.3 b	2,266.6 a	3,786.9 a
Whetstone	1,861.9 b	599.9 b	2,461.8 b

Volume estimates are derived from Clark and Souter (1996) to a 4-inch top.

Means followed by the same letter within a column are not significantly different at the 0.05 level.

d.b.h. = diameter at breast height.

Table 4—Cubic volume of hardwood pulpwood (>4.5 inches d.b.h.) by site at the Sumter National Forest in 2015

Site	Other	Red oaks	White oaks	Total
			cubic feet per acre	
Pine Mountain	234.6 a	5.4	64.0	304.1 a
Thrift's Ferry	24.7 b	34.4	29.6	88.9 b
Whetstone	67.0 b	21.0	120.3	263.0 ab

Volume estimates are derived from Clark and Souter (1996) to a 4-inch top.

Means followed by the same letter within a column are not significantly different at the 0.05 level.

d.b.h. = diameter at breast height.

DISCUSSION

Our study illustrates that the fell-and-burn technique was effective for establishing shortleaf pine on sites with moderate levels of soil fertility and moisture, where fast-growing hardwood sprouts were competitive and present at high densities. This regeneration system was an effective method for establishing shortleaf pine in formerly hardwood-dominated stands, especially on sites where hardwoods may be strong competitors during the slow early growth stages of shortleaf pine. On our sites, shortleaf pine had an advantage over the hardwoods after 34 years, being taller, with larger diameters, and occupying a considerable proportion of the total stand basal area even with large densities of hardwoods.

Site preparation burning prior to planting may have provided shortleaf pine an advantage throughout early stand development. Vose and others (1997) reported that the fell-and-burn technique had comparable results to stand-replacement wildfires for pine regeneration and for creating mixed-species stands. In comparison to wildfire, however, the fell-and-burn technique has several advantages, including greater control of the fire, harvesting of economically viable forest products, and the ability to control spacing, species, and genetics of planted pines (Vose and others 1997).

In a similar study on dry sites (site index 39 feet for oaks) in the Piedmont region of South Carolina, Waldrop and Mohr (2012) found that hardwoods were significantly taller in unburned plots than in burned plots 20 years after stand establishment using the fell-and-burn technique. However, the heights of loblolly pines were not affected by burning, and pine trees were approximately twice the height of the hardwood trees. Similarly, we found that shortleaf pine height was more than twice that of hardwoods, but the density of hardwoods was several times that of the pines and much higher than that recorded on the drier sites by Waldrop and Mohr (2012). Additionally, Waldrop and Mohr (2012) reported that burned sites had significantly fewer hardwoods than unburned sites in year 11, but the difference was less dramatic by year 20. Hardwood density ranged from 215 trees per acre in burned plots to 243 trees per acre in unburned plots. Although previous findings from loblolly pine-hardwood stands support our results that the fell-and-burn technique reduced the competitiveness of hardwoods, we found much greater hardwood density and volume on our sites. These differences may be attributed to greater site productivity in our mountain sites compared to Piedmont sites studied by Waldrop and Mohr (2012).

Our results suggest that site quality may affect species composition, dominance, and relative productivity following treatment. Pine Mountain was the most productive site of the three with higher basal area and the most pine pulpwood. However, Thrift's Ferry, which had the lowest site index, had the highest density and largest volume of pine sawtimber. Drier sites favor pines because hardwoods are more sensitive to site differences (Phillips and Abercrombie 1987), suggesting dry sites provide the best conditions for a mixture of species for multiple management objectives. Whetstone, which was moderate in site productivity, had a greater proportion of hardwood species, especially white oaks, which are desirable for timber and wildlife. The white oaks at Whetstone were larger in diameter and height than white oaks from the other sites, resulting in the largest amount of oak pulpwood. Intermediate sites may allow for increased yield over the stand rotation by allowing for mixed species products with multiple entries, such as removal and harvest of the pines for recruitment of oaks to the canopy. The wide initial spacing of planted pines in the fell-and-burn technique may allow enough light for an advance oak regeneration pool to develop that may be successfully released by pine thinning.

The most productive site in this study, Pine Mountain, had the largest proportion of red maple and the lowest proportion of oaks. Intermediate treatments may be necessary to favor shortleaf pines or hardwood species, such as oaks, on more productive sites because competition with more shade-tolerant species may be high. Frequent anthropogenic surface fires historically maintained pine-hardwood forest types (Abrams and others 1995, Stambaugh and others 2007), and a similar regime of prescribed burning may help to favor shortleaf pine-oak mixed stands. At the seedling stage, shortleaf pine is adapted to survive fire by sprouting from dormant buds formed on a basal crook (Clabo and Clatterbuck 2015). In addition, frequent burning may allow desirable oak species to develop while acting antagonistically to highly competitive mesophytic species, such as red maple and yellow-poplar (*Liriodendron tulipifera*) (Van Lear and Watt 1993). Recently, Kabrick and others (2015) reported that underplanting shortleaf pine in a partial overstory of hardwood did not adversely affect shortleaf pine survival during the first five growing seasons, allowing for the potential to manage for mixed species communities without complete canopy removal.

CONCLUSION

Although we are not able to directly compare effects of site preparation or productivity gradients within this study, our results demonstrate that the fell-and-burn technique was effective for establishing shortleaf pine-hardwood stands on moderately productive sites. In addition to a dominant component of shortleaf pine, the fell-and-burn technique also maintained a significant level of desirable hardwood species, particularly oaks, on the dry and intermediate sites. Because shortleaf pine is a weak early competitor in comparison to other southern yellow pines or fast-growing hardwood sprouts, its persistence and eventual dominance may require site-preparation burning to give the pines an advantage. Additional research is needed to determine how these stands will continue to develop through time and how to manage them as a mixed-woods community. This may require intermediate treatments such as thinning pines to favor oaks or controlling hardwoods to favor pines. However, these stands should maintain a component of all desirable species with no intermediate cutting. Prescribed burning should be considered to protect and maintain these stands as shortleaf pine-oak dominated forests.

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There has been considerable interest in developing management techniques for creating mixed shortleaf pine (*Pinus echinata*)–hardwood forests in the Southern Appalachian Mountains. This interest has increased in recent years due to the need to manage for more diverse and resilient forests, and to reestablish shortleaf pine as a dominant species throughout its native range. The fell-and-burn regeneration technique was developed in the 1980s as a low-cost method to establish planted pines among hardwood sprouts for regenerating mixed species stands. This study documented the success of the fell-and-burn technique for establishing shortleaf pine on moderately productive hardwood sites. Thirty-four years after planting shortleaf pine seedlings among hardwood sprouts, the pines had the largest diameter at breast height (d.b.h.), height, basal area, and volume. One study site, which was intermediate in soil moisture and fertility, had a greater number of hardwoods (particularly oaks) than a more productive site where pine was dominant. Results suggested that the fell-and-burn technique was successful for establishing shortleaf pine among hardwood sprouts, which may meet multiple economic and ecological forest management objectives.

Keywords: Fell-and-burn site preparation, mixed-species management, pine-hardwood mixtures, prescribed fire, regeneration, stand development.