REGENERATION DEVELOPMENT ACROSS A RANGE OF REPRODUCTION CUTTING METHODS IN SHORTLEAF PINE AND PINE-HARDWOOD STANDS IN THE INTERIOR HIGHLANDS

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Abstract—Density, milacre stocking, and height of shortleaf pine (*Pinus echinata* Mill.) regeneration under 13 reproduction cutting methods were measured after 5 growing seasons across a range of reproduction cutting treatments in shortleaf pine and pine-hardwood stands in the Interior Highlands of Arkansas and Oklahoma. A subset of the full database was used to suggest trends in the data to date. After five growing seasons, six of the treatments exceeded the minimum standards for regeneration success—the clearcutting treatment, two of the three shelterwood treatments, and three of the four single-tree selection treatments. The two seed-tree methods fell short in both pine regeneration density and pine milacre stocking, whereas the two group selection treatments and the unmanaged control fell short in both pine milacre stocking and height. Key questions over the next 5-year period are whether regeneration development can be maintained as residual overstory basal area continues to increase, and whether the 10-year cutting cycle harvest in the uneven-aged stands or the partial removal cut in the even-aged stands will cause unacceptable mortality in the current regeneration cohort.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.), the most widely distributed of the four major southern pines, reaches its ecological optimum in the Ouachita Mountains. In this region, the topography is characterized by long ridges running generally from east to west. South-facing slopes are dominated by pine and pine-hardwood stands, and the pine component consists exclusively of shortleaf pine. No other part of the country contains naturally regenerated stands in which shortleaf pine is the major, dominant, and only pine species over so large an area of pine-dominated landscapes.

There has been relatively little interest in the silviculture of natural stands dominated by shortleaf pine. Little is known about regenerating shortleaf pine with even-aged and uneven-aged reproduction cutting methods. However, interest in natural regeneration of shortleaf pine has increased with the shift in management philosophy away from clearcutting and planting on the Ouachita National Forest in the 1990s.

In this paper, we describe results of a variety of even-aged and uneven-aged high-forest reproduction cutting methods to establish and maintain shortleaf pine and pine-hardwood stands in the Ouachita Mountains and southern Boston Mountains of Arkansas and Oklahoma. Key silvicultural questions are (1) the early growth of seed-origin shortleaf pine versus sprout-origin hardwoods, (2) the effects of overstory hardwoods on regeneration development, and (3) the effects of residual basal area on pine and hardwood regeneration development. We present initial data from a subset of treatments, and we give suggestions for further analysis.

METHODS

Study Layout

The study layout was established as previously described (Guldin and others 1994). Fifty-two stands were included in the study. In each stand, 12 plots were assigned to the timber management zone (TMZ) where tree harvesting was permitted and 2 plots were installed in streamside management zones, where harvesting is excluded. All plot centers were located using geographic positioning systems, and were digitized on low-level orthogonally rectified aerial photos.

Reproduction Cutting Treatments

Even-aged and uneven-aged reproduction cutting methods was tested. Even-aged methods were the seed tree and shelterwood methods. Uneven-aged methods included both the single-tree selection and group selection methods. At least two variations of each method were tested—one in which primarily pines were retained in the residual overstory, and one in which both pines and hardwoods were retained. In addition, two control treatments were used—the clearcutting method and an unmanaged treatment. Table 1 lists the residual basal area target for pines and hardwoods in each treatment, and the site preparation and release treatments used in each treatment.

Site Preparation and Release Treatments

A subset of stands was subdivided into quarters to measure effects of site preparation and release (Table 1). One quarter remained untreated by either site preparation or release. A second quarter received two manual felling treatments—manual site preparation early in the first growing season in the late spring and early summer of 1994, and manual release early in the fifth growing season in the late spring and early summer of 1998. Manual felling was done using either machetes or chain saws. In a third quarter, chemical site preparation was imposed by applying triclopyr (Garlon®) to cut surfaces of vegetation prior to the first growing season in the late spring of 1994. In the fourth quarter, chemical release was conducted by applying triclopyr (Garlon®) as a cut surface application or a directed foliar spray immediately prior to the fifth growing season in the late spring and summer of 1998.

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Table 1—Reproduction cutting method treatments included in the phase II study in the Interior Highlands

Reproduction cutting methods	Site preparation/ release treatments[a] Q1	Q2	Q3	Q4	RBA Conifer	RBA Hardwood
					square feet per acre	
Clearcutting	C/N	C/N	C/N	C/N	0	2 – 5
Seed tree, pine	N/N	C/N	M/M	N/C	20	2 – 5
Seed tree, pine-hardwood	N/N	C/N	M/M	N/C	10	10
Shelterwood, pine	N/N	C/N	M/M	N/C	40	2 – 5
Shelterwood, pine-hardwood	N/N	C/N	M/M	N/C	30	10
Shelterwood, pine-hardwood	M/M	M/M	M/M	M/M	30	10
Group selection, pine	M/M	M/M	M/M	M/M	60	2 – 5
Group selection, pine-hardwood	M/M	M/M	M/M	M/M	50	10
Single-tree selection, pine	N/N	C/N	M/M	N/C	60	2 – 5
Single-tree selection, pine-hardwood	N/N	C/N	M/M	N/C	50	10
Single-tree selection, pine-hardwood	M/M	M/M	M/M	M/M	50	10
Single-tree selection, low impact	M/M	M/M	M/M	M/M	60	15
Unmanaged control	N/N	N/N	N/N	N/N	~100	~30

RBA = residual basal area; C = chemical; N = no treatment; M = manual felling.
[a] Site preparation/release treatment combinations are shown by quarter (Q1-Q4) to illustrate whether a given treatment was split or uniformly treated; split treatments were randomly assigned by quarter by stand.

Table 2—Measurements to date taken by the silviculture research group in the stand-level phase II study in the Interior Highlands

Schedule	Season	Data collected
Preharvest	Winter 1992–93	Overstory
Harvesting occurred	Summer 1993	None[a]
Postharvest year 0	Winter 1993–94	Overstory
Postharvest year 1	Winter 1994–95	Regeneration
Postharvest year 2	Winter 1995–96	Overstory
Postharvest year 3	Winter 1996–97	Regeneration
Postharvest year 4	Winter 1997–98	Overstory
Postharvest year 5	Winter 1998–99	Regeneration

[a] None taken during harvest.

In a second subset of treatments, competing vegetation in the entire stand was manually felled as described earlier (table 2). The purpose of this treatment was to promote uniform understory habitat conditions for studies of bird populations.

The group selection treatments and the controls were omitted from the split-plot site preparation and release comparison (table 1).

Measurements

Overstory vegetation (woody plants 3.6 inches in d.b.h. and larger) and regeneration (woody plants 3.5 inches in d.b.h. and smaller) were measured separately. Each measurement cycle required approximately 6 months of field work and was restricted to the dormant season, so overstory and regeneration measurements occurred on a 2-year cycle. Measurement cycles completed to date are shown in table 2. Measurement protocols for overstory and regeneration measurements have been published elsewhere (Guldin and others 1994) and are summarized later.

A nested sample was taken to measure the overstory. All woody plants 9.6 inches in d.b.h. and larger were sampled by species using variable-radius plots established using a prism with a basal area factor of 5.0 square feet per acre, and d.b.h. was recorded to the nearest 0.1 inch. After the harvest, all sample trees were tagged for remeasurement and the slope distance and slope percent from plot center to each tree were recorded. A measurement error of +5 feet was deliberately added to the formula used to calculate the horizontal limiting distance such that all trees up to and 5 feet past the exact limiting distance for the prism were sampled. The use of field data recorders and uploaded spreadsheet template data files allowed this calculation to be easily made in the field. In this way, borderline trees in the prism sample were included in or excluded from the sample by office computation rather than field technique.

All woody plants with d.b.h. between 3.6 and 9.5 inches inclusive were sampled by species on a 0.1-acre fixed-radius plot. The preharvest measurement was made by tallying these trees to the nearest 1-inch diameter class. After harvest, the d.b.h. of these was measured to the nearest 0.1-inch, and all sample trees were tagged.

The regeneration measurements were slightly modified from the original study design. Two separate samples—an inventory tally and a tagged tree tally—were taken. The inventory tally was designed to sample regeneration 1 year after the harvest, but was subsequently modified to sample the entire cohort of woody plants with d.b.h. ≤ 3.5 inches. Thus, in postharvest year 1, all woody plants between 3 inches in total height to > 4.5 feet in height but with a d.b.h. ≤ 0.5 inch were tallied on 6 milacres located within the 0.1-acre fixed radius plot. In postharvest year 3 and subsequently, all woody plants between 3 inches in height but with a d.b.h. ≤ 3.5 inches were tallied on the same 6 milacres.

The tagged tree measurement was designed to follow height and diameter growth of specific stems. Milacres were divided into four quadrats along cardinal directions. In postharvest year 1, the tagged tree sample was imposed on 2 milacres per plot; in postharvest year 3 and subsequently, the tagged tree tally was extended to all 6 milacres. During the first measurement, the tallest pine and the tallest hardwood, if present, per quadrat were tagged and measured for species identity, root-collar diameter, and total height. During remeasurement all previously tagged trees were remeasured; in addition, if a different pine or hardwood was taller than a previously tagged pine or hardwood, the new dominant was sampled and tagged.

ANALYSIS

A subset of stands based on rank within treatments was selected that would be representative of general trends in regeneration success from reproduction cutting methods. Results are summarized from only one of the four stands in each treatment. A broader analysis of the complete data set will be reported elsewhere.

The decision variable upon which the subset is based was milacre stocking after the fifth growing season. Thus, in all treatments except the clearcutting treatment, the four stands were ranked by percent milacre stocking in the pine component within the TMZ. The stand with the second-lowest milacre stocking was included in this subset to represent that treatment. The clearcut treatment was represented by the one stand in that treatment with the highest pine milacre stocking.

Milacre stocking was calculated as the proportion of the 72 milacres per stand stocked with at least one pine seedling. Regeneration density for both pine and desired hardwoods, defined as white oak (*Quercus alba* L.) and southern red oak (*Q. falcata* Michx.), was calculated as the sum of all pines or desired hardwoods on the 72 milacres per stand converted to a per-acre basis.

Pine height was calculated by averaging the height of all tagged pines after the fifth growing season. Thus, this variable represents the average height of the tallest pines in the regeneration cohort, not the average height of all pines in the regeneration cohort.

Acceptable standards for pine and hardwood regeneration density were set at 300 trees per acre in even-aged stands, and 200 trees per acre in uneven-aged stands (Baker and others 1996). These are the standards used by the Ouachita National Forest. If the trees are well spaced, the standards translate to 30 and 20 percent pine milacre stocking for even-aged stands and uneven-aged stands, respectively. Minimum acceptable height growth for pines is 0.5 feet per year; therefore, the third standard of acceptable height growth is whether seedlings exceed 2.5 feet in height after the fifth growing season.

RESULTS

Regeneration Density

In the even-aged treatments, acceptable regeneration density for shortleaf pine and for desired hardwoods is 300 trees

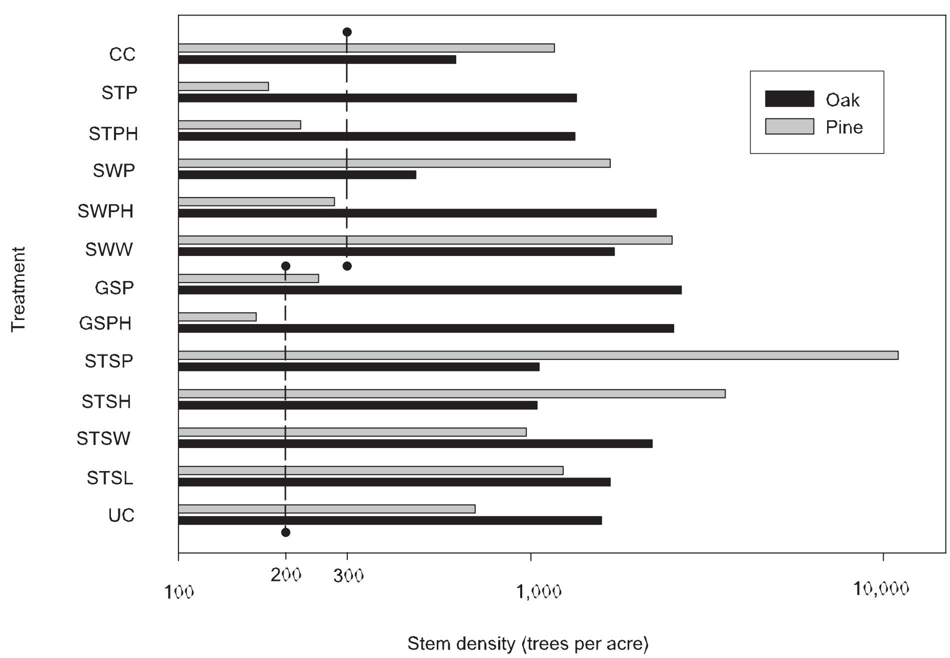

Figure 1—Density of regeneration, shortleaf pine, and combined white and southern red oaks after five growing seasons, by treatment (cf. table 1). Dashed vertical lines represent minimum acceptable standard for corresponding treatments.

per acre (fig. 1). The clearcut treatment supported more than three times this number of pines, and more than double the minimum number of desired hardwoods. The pine regeneration density was not surprising, because the clearcut was planted in the spring of 1994 with genetically improved 1-0 shortleaf pine seedlings on an 8-foot x 10-foot spacing (544 trees per acre). Scattered volunteer pine seedlings that seeded in naturally from adjacent stands boosted stocking. Virtually all of the white and southern red oaks are of stump sprout or seedling sprout origin.

Desired hardwood regeneration exceeded the minimum acceptable stocking in all even-aged seed tree and shelterwood treatments (fig. 2). Four treatments out of five had more than 1,000 stems per acre of desired hardwood regeneration.

In two of the three shelterwood treatments, pine regeneration exceeded the minimum acceptable density by between threefold and fourfold. Pine regeneration density was also greater here than in the clearcut stands. The third shelterwood treatment yielded just slightly less than the minimum acceptable density. Conversely, both seed-tree treatments fell well below the acceptable minimum density of pine regeneration.

The minimum acceptable regeneration density for shortleaf pine and for desired hardwoods in the uneven-aged treatments is 200 trees per acre. All uneven-aged treatments exceeded this minimum number in the desired hardwood component, varying between 1,000 and 2,000 stems per acre.

In the pine component, all of the single-tree selection treatments produced adequate pine regeneration density. Only one of the two group selection treatments yielded an acceptable number of pines. Stem density in the single-tree selection treatments varied from 800 to 10,000 trees per acre.

The unmanaged control treatment supports acceptable densities of pine and hardwood regeneration as well (fig. 1). More than 700 pines and 1,500 desired hardwood seedlings and saplings per acre are present.

Milacre Stocking

In the even-aged treatments, minimum acceptable milacre stocking of shortleaf pine is 30 percent. After the fifth growing season, milacre stocking of pine exceeded 60 percent in the clearcutting treatment (fig. 1). The unmanaged control, as expected, had the lowest pine milacre stocking of all treatments—< 10 percent.

In the even-aged seed tree and shelterwood stands, milacre stocking of shortleaf pine was much lower than in the clearcut stand. However, pine milacre stocking in two of the three shelterwood treatments exceeded the minimum of 30 percent, and the third was < 5 percent below the minimum. Both seed-tree stands had pine milacre stocking less than half the minimum acceptable stocking.

For the uneven-aged single tree and group selection treatments, minimum acceptable milacre stocking of pine is 20 percent (fig. 2). Three of the four single-tree selection treatments exceeded this minimum. The fourth, the low-impact single-tree selection, contained < 2 percent below the minimum. Neither of the group selection treatments contained more pine seedlings than the minimum.

Height of Shortleaf Pine Regeneration

In all treatments, acceptable development of dominant pines was judged by whether seedlings exceeded 2.5 feet in height after the fifth growing season. As with the other standards

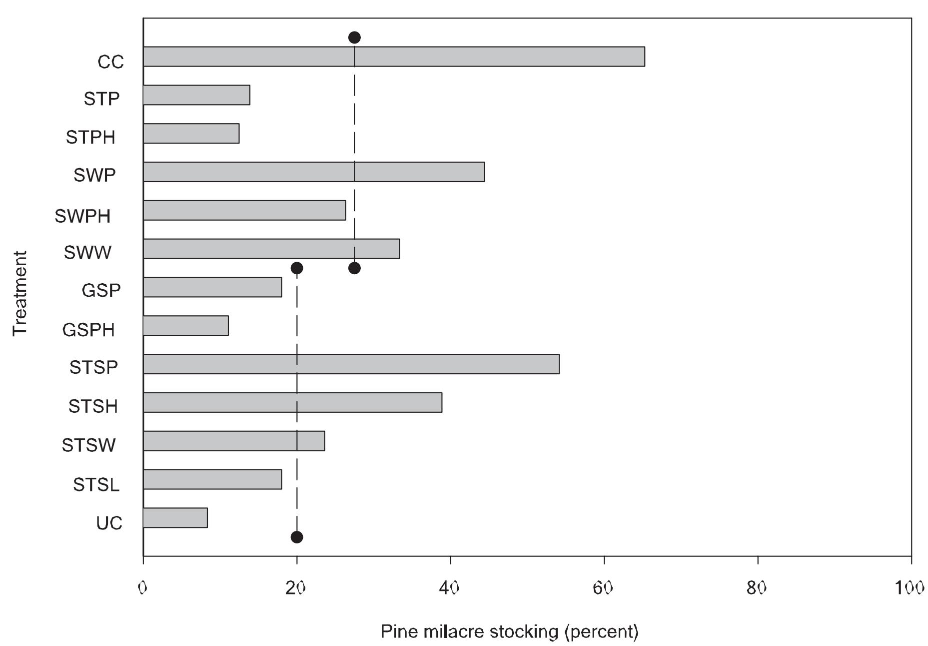

Figure 2—Milacre stocking, percent, for shortleaf pine regeneration by treatment (cf. table 1). Dashed vertical lines represent minimum acceptable standard for corresponding treatment.

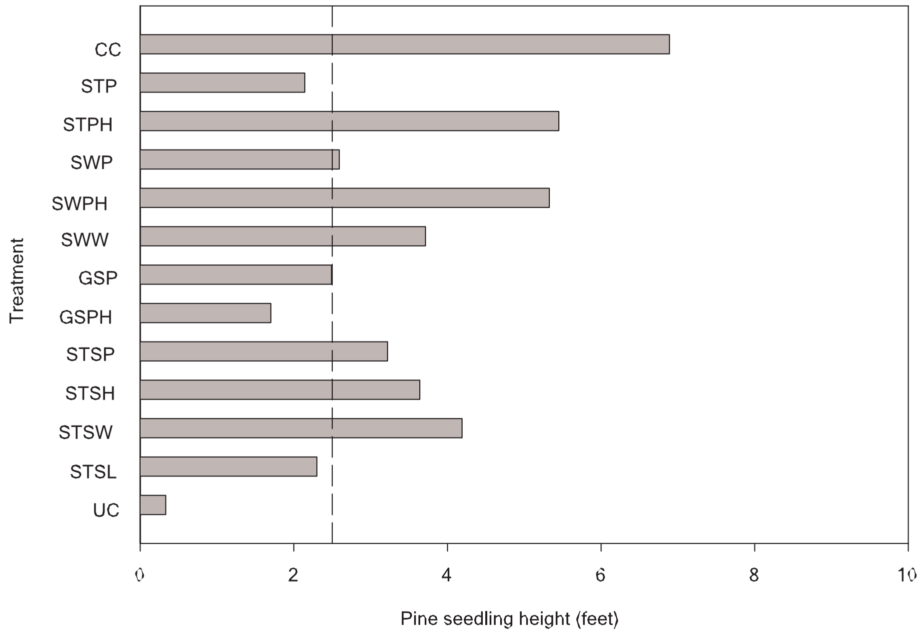

Figure 3—Height of dominant shortleaf pine saplings after five growing seasons by treatment (cf. table 1). Dotted vertical line represents minimum acceptable standard across all treatments.

of regeneration success, the clearcut treatment was best, with dominant pines exceeding 6 feet in height (fig. 3). Of the other five even-aged treatments, four exceeded the minimum standard, and two supported dominant pines whose average height exceeded 5 feet.

In the uneven-aged stands, the average height of dominant pines exceeded the minimum in three of the four single-tree selection stands, and was fractionally less than the minimum in one of the group selection stands (fig. 3). In all of the uneven-aged stands, the average height of dominant pines was < 5 feet after 5 years.

The average height of dominant pines in the unmanaged control stand was < 0.5 foot after five growing seasons. Seedlings in this treatment apparently can become established and can persist, but they grow very little.

DISCUSSION

Judging success of pine regeneration after five growing seasons requires consideration of three standards—acceptable density, acceptable stocking, and acceptable growth. As expected, the clearcut treatment has been most successful. Pine regeneration density exceeded 1,000 trees per acre, milacre stocking of 60 percent was double the minimum, and the height of dominant pines exceeded 6 feet after 5 years. These data all exceeded minimum standards by a comfortable margin.

However, several of the reproduction cutting treatments that rely on natural regeneration also exceeded all three standards. Specifically, two of the three shelterwood stands met or exceeded minimum standards; the third, which fell slightly below minimum in both regeneration density and milacre stocking, exceeded the other two in average dominant pine height.

Three of the four single-tree selection treatments also exceeded all three minimum standards, and the fourth, the low-impact single-tree selection stand, was only slightly below the minimum in both regeneration density and milacre stocking. The relatively high levels of overstory basal area in these single-tree selection stands was expected to hinder regeneration development, but this was apparently not the case over the first 5 years of the study. However, these stands are expected to grow approximately 2 square feet per acre of basal area annually. Thus, over the typical 10-year cutting cycle expected in these stands, the most critical years for overstory suppression of regeneration development are probably the second, rather than the first, 5-year period.

Between 1992 and 1996, about 60 percent of the even-aged reproduction cuts on the Ouachita National Forest were done using the seed-tree method; between 1992 and 1995, about one-fifth of the uneven-aged reproduction cuts on the same forest were done using group selection (Guldin and Loewenstein 1999). The data presented here suggest that these two treatments do not consistently exceeded minimum standards for regeneration establishment and development. Both seed-tree stands yielded less that the minimum standard in pine density and pine milacre stocking; both group selection treatments yielded less than the minimum standard in pine density and pine height growth.

A decision about whether a stand is successfully regenerated is commonly required on national forests during the first 5 years after harvest. These data raise a question about that standard, especially in uneven-aged stands. Overstory basal area is likely to reach a maximum during the last half of the cutting cycle rather than the first half. Seedling performance should be followed through the next cutting cycle harvest to determine whether regeneration development continues to be acceptable in the single-tree selection stands.

Before they can comfortably rely on natural regeneration, foresters need to know whether acceptable density and stocking of regeneration can be retained through the scheduled removal cut in the even-aged seed tree and shelterwood stands, and through the next cutting cycle in the uneven-aged stands. In this study, both are scheduled for the summer of 2003, the tenth growing season of this regeneration cohort. Ideally, this study should be continued beyond that point, so that these and other unresolved questions can be addressed.

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