GROWTH RESPONSE TO COMPETITION AND PRESCRIBED FIRE IN PLANTED SHORTLEAF PINE

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ABSTRACT

Shortleaf pine (*Pinus echinata*) is an economically and ecologically important species that was once prevalent across the Southeastern United States, and there is growing interest in its restoration throughout its former range. One challenge with restoring shortleaf pine is competition from hardwoods. This study used tree-ring analysis to study growth response of shortleaf pines planted following a 2002 tornado in two stands with different known histories of management activities, specifically prescribed burning and mechanical release, across a range of competition levels. Early release was effective in increasing radial growth of shortleaf pine in this study, and competition, especially from hardwoods, caused decreased annual growth. There was only minimal evidence for direct reductions in shortleaf growth following burning, and fire seemed to effectively control hardwood competition in the midstory. These findings provide insight into the roles of prescribed fire and hardwood competition on growth of planted shortleaf pine throughout its early life.

INTRODUCTION

Shortleaf pine (*Pinus echinata*) covered approximately 300,000 km^2 across what is now the Southeastern United States prior to European colonization (Anderson and others 2016) but has been reduced to approximately 25,000 km^2 currently, or less than 10 percent of the historical estimate (Oswalt 2012). Restoring shortleaf pine and shortleaf pine-oak (*Quercus* spp.) mixedwood forests is challenging due to issues with recruiting shortleaf pine from the forest understory to competitive positions in the midstory, and ultimately to the overstory. Although planting shortleaf pine seedlings can provide a solution to regeneration shortages caused by potential problems with seed production or germination, newly planted shortleaf pine seedlings do not compete well with hardwoods (Kabrick and others 2015), often because the hardwood stems have larger advance reproduction or have recently resprouted from an established root system.

Removing understory hardwoods can prove to be an effective release treatment for shortleaf pine (Brinkman and Smith 1968). In a study in Arkansas, a shortleaf pine stand with the hardwood understory removed had greater growth over 5 years than stands with the understory left intact (Bower and Ferguson 1968). In a similar study at the Sinkin Experimental Forest in Missouri, hardwood control increased shortleaf pine growth by 2 m^2/ha over 10 years (Rogers and Brinkman 1965).

Prescribed burning provides another option to suppress hardwood competition in understory and midstory layers. Properly timed prescribed fire may benefit shortleaf pine growth rates and recruitment into the midstory by top-killing less fire-tolerant hardwood species. For example, a study in the Ouachita National Forest examined changes in the fire regime over time using

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dendrochronological and fire scar evidence, and found changes in species composition of recruiting trees between the “European American settlement period,” with fire return interval of 3–7 years, and the “Fire Protection period,” with fire return intervals of 42 years, with the composition shifting from primarily shortleaf pine (85 percent) with more frequent fires, to primarily oaks (68 percent) and other hardwoods (31 percent) with the longer fire intervals (Flatley and others 2023). Similarly, in a 53-year study of frequently burned loblolly (*P. taeda*) and shortleaf pine woodlands in northern Florida, 1- to 2-year burn intervals maintained pine dominance, while hardwoods gained dominance in stands with a 3-year fire return interval (Robertson and others 2021). Based on these findings, the authors suggested selecting a fire-return interval aligned with the specific site conditions, land-use histories, and stand objectives (Robertson and others 2021). Once shortleaf pine stems are large enough that vulnerability to top-kill is low, repeated prescribed burning can be used as a maintenance treatment to limit the abundance of hardwood stems in the midstory and keep stand conditions in an open structure. In uneven-aged loblolly-shortleaf pine stands in southeastern Arkansas, burn intervals of 3, 6, and 9 years were compared with nonburned areas. While there was no difference in the basal area of the saplings [2.5–8.9 cm diameter at breast height (d.b.h.)] across treatments, there was significantly less sapling diversity in the 3-year burn interval than in the other treatments, which was explained by the elimination of fire-sensitive species (Cain and others 1998).

However, there remain challenges to using prescribed fire to control hardwoods and boost shortleaf pine growth. In pine-oak forests in the southern Appalachians, a single March burn reduced the basal area of fire-sensitive midstory hardwoods, but the density (stems per area) of these hardwoods increased due to prolific sprouting, suggesting that repeated burns were warranted (Elliott and Vose 2005). Furthermore, though reducing hardwood competition with prescribed burning can increase shortleaf pine growth, a recent study in southeast Oklahoma found that radial growth of shortleaf pine trees was reduced by 21–33 percent in the growing season following prescribed fire (Adhikari and others 2021), suggesting that fire may also directly negatively affect tree growth.

Improving our understanding of the effects of both prescribed burning and hardwood competition on shortleaf pine growth and overstory recruitment is important for management of this species. The objective of this study was to use tree-ring analysis to examine the radial growth of shortleaf pines in response to known silvicultural treatments and local competition levels. Our research questions were: 1) How does repeated prescribed burning affect stand development (structure and composition) following release of planted shortleaf pine? 2) How does shortleaf pine radial growth respond to release? 3) Does prescribed burning affect the radial growth of shortleaf pine? 4) Does the level and composition of local competition affect the radial growth of shortleaf pine?

METHODS

Study Site

The study was located in the Poplar Bluff Ranger District of the Mark Twain National Forest in southeastern Missouri. This study focused on two adjacent management units, separated by a gravel road, that were affected by a tornado in 2002 and salvaged in 2003. Scattered residual overstory trees consisted primarily of shortleaf pine and white oak (*Quercus alba*). A site preparation burn was conducted in both units in 2004, and bareroot shortleaf pine seedlings were planted in spring of 2005 at 3-m by 3-m spacing. A release treatment was completed in both units between June and December 2011. The release prescription was to cut any hardwood stems within 1.83 m of a shortleaf pine except those that were less than half the height of the shortleaf pine. In one of the two units, prescribed burns were conducted in March 2011, April 2013, March 2015, April 2018, and March 2021. The burned and nonburned units were approximately 5 ha and 7 ha, respectively.

Soil series for both units are mapped as predominately (93 percent) Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults), which are very deep, moderately well-drained soils (USDA NRCS 2017). The units are nearly level, with slopes of 1–8 percent. The average annual temperature from 2005 to 2021 was 14 °C and the average annual precipitation for the same period was 1,286 mm (NOAA 2022).

Experimental Design

In each of the two units, henceforth called burned and nonburned despite both having a site preparation burn, 30 shortleaf pine trees were selected as focal trees to quantify growth patterns in relation to the competitive environment. Around these trees the overstory and midstory basal area were measured, and understory stems that reached at least breast height were tallied.

Tree Selection and Overstory Sampling

In the summer of 2022, four or five parallel transects were established in each management unit, with sampling points set every 15 m for a total of 45 sampling points per unit. The closest overstory (d.b.h. ≥11.4 cm) shortleaf pine to each point was selected as a potential focal tree and d.b.h. was measured. All overstory trees within a 7.3-m radius [3x the average crown radius, as recommended by Lorimer (1983)] of the focal pine were also identified and d.b.h. recorded.

The level of local competition surrounding each potential focal tree was quantified using the following competition index (CI): $(\Sigma D_j)/D_i$, where D_j is the diameter of the competitor and D_i is the diameter of the focal tree (Lorimer 1983).

The competition index measured across the initial 45 potential focal trees for each unit ranged from 1.5 to 23.5, with fewer than 10 trees having CIs >15. From this range, 6 competition classes were established, with the goal of randomly selecting 5 focal trees from each stand per class for a total of 30 focal trees per stand covering a range of competition levels. The CI classes were <5; 5–7.5; ≥7.5–10; ≥10–12.5; ≥12.5–15; and >15. If a CI class did not have sufficient trees to select from, additional trees from the closest class were randomly selected. In the burned unit, the two highest competition classes had insufficient representation, so all available trees within the classes were used and an additional tree from each of the three smaller competition classes were used. In the nonburned unit, only three trees were included in the 12.5–15 CI class, so all three were used and one extra tree from the class immediately higher and lower were used.

Midstory and Understory Sampling

Within a 7.3-m radius of the 30 focal trees per unit, the midstory trees (d.b.h. 2.5–11.4 cm) were identified and d.b.h. was measured. The understory trees (≥1.37 m tall and <2.5 cm d.b.h.) were also identified and tallied by species within the same radius.

Tree Coring

Two cores were taken from each focal tree, as close to the base of the trees as possible. All tree cores were glued to wooden core mounts and sanded with increasingly fine (up to 1,200 grit) sandpaper. Images of each core were scanned at 2,400 dpi and imported into the CooRecorder software (Cybis Electronik & Data AB, Sweden) for demarking ring boundaries and measuring annual ring widths. The best core per tree was used for analysis. Criteria for selecting the best core included a core's proximity to or inclusion of the pith, the clarity of ring boundaries, and the absence of damage that interfered with ring-width measurements. The distance to pith was estimated in the CooRecorder software for each core used in analysis, and ring widths were converted to basal area increment (BAI) for analyses.

There are several methods for detecting release events using tree-ring data. Several of these are reviewed in Trotsiuk and others (2018). One early method is called radial growth averaging, which was first described by Lorimer (1985) and uses the procedure of averaging the radial growth over the 15 years preceding and following the potential release event and then calculating the percent growth change by subtracting the pre-event average from the postevent average and dividing that by the pre-event average. Lorimer (1985) defined an event as a major release if the percentage growth change was ≥100 percent and a defined a moderate release as a percentage growth change between 50 and 99 percent. The method was later modified by Nowacki and Abrams (1997) by using 10-year averages and expanding the definition of a moderate release to include growth percentage increases of ≥25 percent. Another method for detecting release is the absolute increase method developed by Fraver and White (2005). This method also uses 10-year averages but includes a species-specific threshold value rather than a percent. They recommend thresholds for several species, but for other species they suggested using the formula of 1.25 times the standard deviation of all absolute increases to calculate the threshold.

For this study, we modified the above methods to use an average of only 5 years prior to and following release because of the young age of these trees. To attempt to detect a release using the absolute increase method, we calculated the threshold value of 1.8 mm using the standard deviation method, because shortleaf pine was not a species included in Fraver and White (2005).

Data Analysis

Because this study compares two adjacent management units and does not have true replication at the stand level, the first research question regarding stand composition and repeated burning was addressed with descriptive statistics only. Composition for each unit was reported by grouping white oak species [white oak (*Quercus alba*) and post oak (*Q. stellata*)] and red oak species [scarlet oak (*Q. coccinea*), black (*Q. velutina*), blackjack (*Q. marilandica*), and northern red oak (*Q. rubra*)]. Hickories (*Carya* spp.) were also grouped, but not identified to the species level. Sumac species were predominately fragrant sumac (*Rhus aromatica*) with a smaller component of winged sumac (*R. copallinum*).

To address questions 2 and 3, regarding growth response to release and prescribed burning, a repeated measures analysis of variance (ANOVA) was used with ring width or BAI as the response variable, year as the within-subject variable, and treatment (burned versus nonburned) as the between-subject variable. Because repeated measures ANOVA requires listwise deletion of missing values (meaning any sample missing ring-width measurements for any year is deleted entirely from the dataset), analysis included only years with full replication, which began in 2011. The focal tree is the experimental unit for these analyses. To determine growth response to competition, a generalized linear model with a lognormal distribution and a logit link was used with the average ring width or BAI of 2019–2021 as the response variable and plot-level basal area, stocking, or competition index as fixed effects. Because the results of the repeated measures ANOVA showed separation starting in 2019, the years 2019–2021 were used to analyze competition.

RESULTS

Stand Level

In the nonburned area, the average overstory basal area was 15 m^2/ha and the average midstory basal area was 6 m^2/ha for a total of 21 m^2/ha. The mean number of understory stems (≥1.37 m tall) was 2,060 stems/ha. In the burned area the average overstory basal area was 12 m^2/ha and the average midstory basal area was 1.4 m^2/ha for a total of 13.4 m^2/ha. The average number of understory stems was 3,291 stems/ha. Species composition was similar in the overstory but differed in the midstory and understory (tables 1 and 2). The average d.b.h. of cored trees in the burned unit was 9.8 cm and the average d.b.h. of cored trees in the nonburned unit was 9.1 cm. All cored trees were considered part of the 2005 planting.

Table 1—Overstory and midstory species composition by percentage of basal area in the burned and nonburned management units

	Overstory		Midstory	
Species	Burned	Nonburned	Burned	Nonburned
Shortleaf pine	73	74	59	–
White oak species	12	12	12	19
Hickory species	11	4	6	17
Red oak species	4	8	10	21
Winged elm	–	–	–	13
Other	0	2	13	30

Table 2—Understory species composition by percentage of stems in the burned and nonburned management units

Species	Burned	Nonburned
Sumac species	48	–
Black cherry	21	4
Red oak species	14	8
Black gum	5	–
Hickory species	4	28
Winged elm	–	40
White oak species	–	8
Other	8	12

Annual Ring Width

Analysis of raw ring-width data revealed a significant effect of year (P <0.001) and a significant interaction between year and treatment (P <0.001) on ring width. Years in which treatments were significantly different included 2013 (P <0.001) with the nonburned greater than burned, and 2019 (P = 0.002), 2020 (P <0.001), and 2021 (P <0.001), with the burned greater than nonburned (fig. 1). Year differences within units were complex. In the burned unit, generally years after 2014 had greater ring widths than years before, with the exception of 2018 being similar to early years. The nonburned areas had fewer significant differences, with 2016 being significantly higher than some early years.

Analysis of BAI also revealed significant effects of year (P <0.001) and a significant interaction between year and treatment (P <0.001). Years in

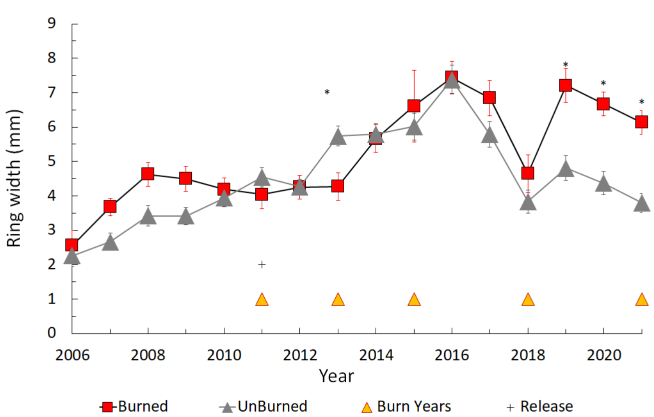

Figure 1—Average ring width for shortleaf pine tree cores taken from the burned and nonburned management units by year. *indicates years with significant treatment differences. Error bars are standard errors.

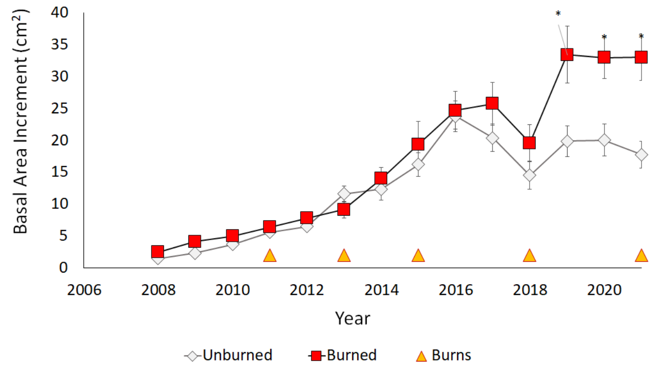

Figure 2—Average basal area increment for shortleaf pine tree cores taken from the burned and nonburned management units by year. *indicates years with significant treatment differences. Error bars are standard errors. A release occurred in 2011.

which BAI was greater in the burned unit than in the nonburned unit were 2019 (P = 0.012), 2020 (P = 0.003), and 2021 (P <0.001) (fig. 2). In both the burned and nonburned units, BAIs in later years were generally higher than in earlier years.

Effectiveness of Release

Using averages for the years 2006–2010 and 2012–2016 (omitting the release year 2011 in the averaging), the percentage of growth change for the nonburned unit was 69 percent, the burned unit was 38 percent, and combined was 52 percent, so there is evidence that the 2011 release was effective according to the 50 percent and 25 percent thresholds established by Lorimer (1985) and Nowaki and Abrams (1997). The differences between the 5-year post release average and the prerelease average were 2.38 mm in the nonburned unit, 1.65 mm in the burned unit, and 2.02 mm when data were combined, indicating a detectable release from the treatment in 2011 in the nonburned unit and when looking at the units together, according to the absolute increase method (Fraver and White 2005).

Both units showed a decline in growth from 2016 to 2018, then in 2019 the burned area had significantly greater ring widths for the remainder of the measurements. It is possible that the 2018 burn acted as a release from midstory competition in the burned unit, but with only 3 years following the 2018 burn, this was not calculated.

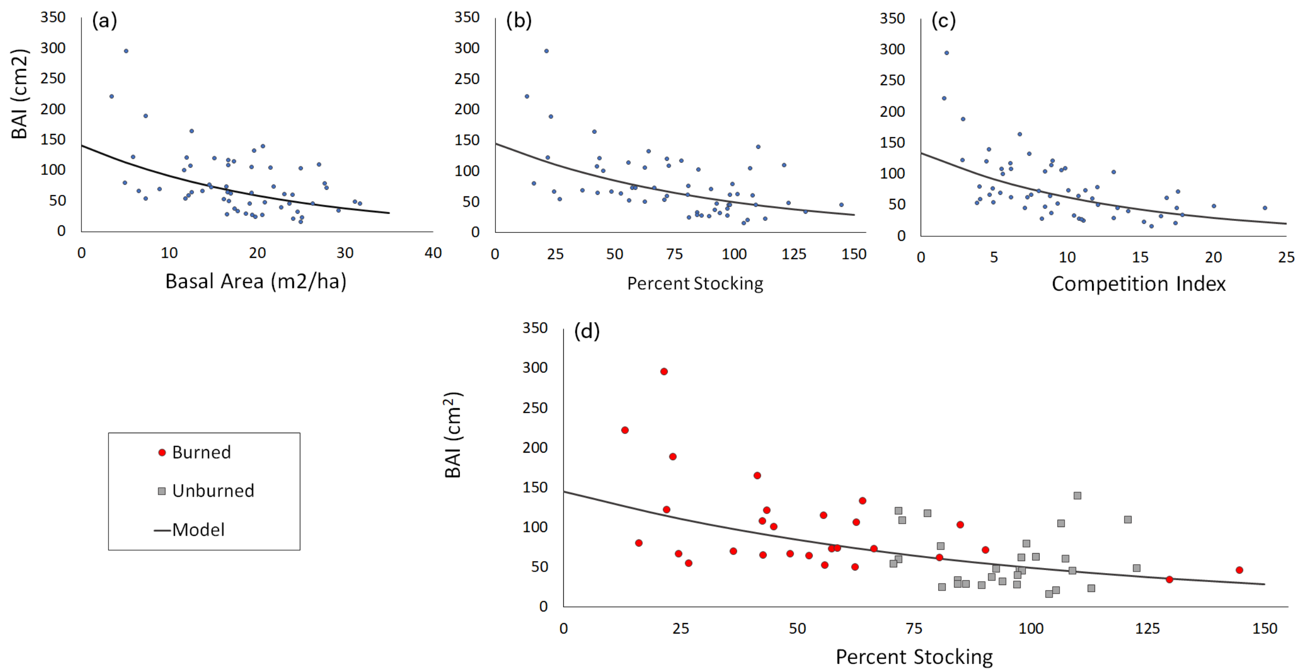

Figure 3—Cumulative basal area increment (BAI) from 2019 to 2021 across both burned and nonburned units by (a) basal area, (b) stocking, and (c) competition index. (d) BAI by stocking is shown again magnified with data points separated by unit.

Effects of Competition

The cumulative BAI from 2019 to 2021 was negatively correlated with basal area (*P* <0.001), stocking (*P* <0.001), and competition index (*P* <0.001) (fig. 3). The raw ring-width data averaged across the years 2019 to 2021 was also negatively correlated with basal area (*P* <0.001), stocking (*P* <0.001), and competition index (*P* <0.001).

Cumulative BAI for 2019–2021 was significantly correlated with basal area (*P* = 0.002) and the interaction between basal area and percentage of hardwood basal area (*P* <0.001) (fig. 4). This pattern was apparent for ring-width data averaged from 2019–2021 as well, with significant effects of basal area (*P* = 0.048) and the interaction between basal area and percent hardwoods (*P* = 0.018). There was not a significant interaction between stocking and percentage of hardwoods for either BAI (*P* = 0.210) or ring width (*P* = 0.068).

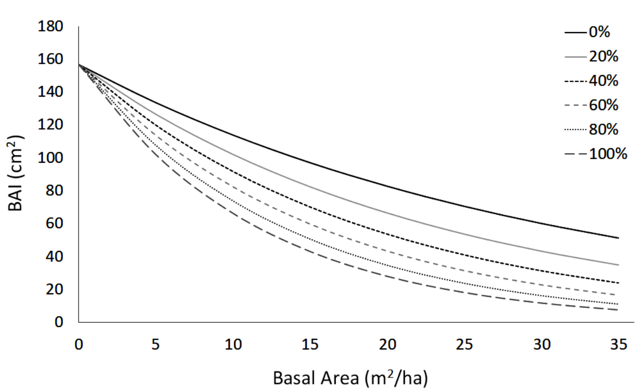

Figure 4—Cumulative basal area increment (BAI) from 2019 to 2021 across both burned and nonburned units by basal area and percentage of basal area composed of hardwoods.

DISCUSSION

This study had several findings about the relationships between prescribed burning and hardwood competition, and how both factors influence the growth of shortleaf pine. We found that the prescribed burning regime in this study altered midstory and understory composition and that the release treatment done in this study was moderately effective according to two different methods. We also found that competition reduced the radial growth of shortleaf pine while prescribed burning, in most cases, did not.

Our analysis of midstory and understory composition pointed to differences in the burned and nonburned units, with the burned unit having more shortleaf pine and fewer hardwoods in the midstory. Similar compositional changes have been seen in other studies (Cain and others 1998, Elliott and Vose 2005, Flatley and others 2023, Robertson and others 2021). In the Mark Twain tornado area, our results suggest that a 2- to 3-year fire return interval is suited for maintaining shortleaf dominance, but continued monitoring is needed to determine if this trend continues as the stand ages.

The release treatment took place in 2012, which was a hot, droughty year in Missouri. Carter County had the highest maximum growing season temperature for the period of 2000–2021 in 2012 (29.8 °C) as well as the lowest precipitation (401 mm) (NOAA 2022). This drought likely reduced shortleaf growth, so a potentially greater response to the 2012 release may have been possible were the release not immediately followed by drought. There is evidence that hot, dry conditions slow the growth of shortleaf pine. Grissino-Mayer and Butler (1993) found significant negative relationships between growth and temperature in April, June, July, August, and September. They also found significant positive relationships between growth and precipitation during May, June, and July. These same trends were observed when using seasonal averages of temperature and precipitation, and the strongest predictor of growth was growing season precipitation. In Oklahoma, on the western edge of shortleaf pine's range, Adhikari and others (2021) found that annual growth was positively correlated with growing season precipitation and negatively correlated with maximum summer temperature. They also found evidence that higher minimum temperatures the previous October correlate with higher growth and that trees growing in open savanna conditions were less sensitive to annual variation in precipitation than trees growing in closed forests. Using long-term data from the Missouri Ozark Forest Ecosystem Project, Stambaugh and Guyette (2004) found that shortleaf pine growth was sensitive to a 21-year drought cycle, and that growth was correlated with the minimum winter temperature prior to the growing season.

The effects of competition, especially from hardwoods, on shortleaf pine growth seen in this study are consistent with literature on pine and hardwood competition. In southeastern Arkansas, shortleaf pine and loblolly pine growth was examined in naturally regenerated stands with different types of competition control. From ages 5 to 13, pine diameter growth increased on plots with woody competition control compared with plots with only herbaceous competition control because of hardwood competition in the herbaceous control areas (Cain 1997). In the Pisgah National Forest, McNab (2022) found that shortleaf and pitch pines (*P. rigida*) planted in a clearcut hardwood stand were significantly taller when growing in groups of at least two pines than when surrounded by hardwood species. They concluded that the pine groups provided a buffer from interspecific competition, which was more detrimental than the intraspecific competition of pine groups (McNab 2022). The increased effects of hardwoods to growth reduction in this study were not seen when analyzing growth by stocking, as the stocking equations themselves account for the greater growing space required by hardwoods (Gingrich 1967, Rogers 1983). When predicting radial growth of shortleaf pine in response to competition, managers should use stocking measurements or account for the differential effects of hardwoods if using basal area measurements.

In this study, 2013 was the only year in which prescribed burning resulted in significantly lower growth in the burned unit, and only when analyzing raw ring-width data. This is somewhat consistent with the study by Adhikari and others (2021) in the western Ouachita Mountains, in which tree rings were analyzed in cores collected from shortleaf pine trees in oak-pine forest burned periodically since 1985. In areas burned on 2- or 3-year intervals, the radial growth in the year following fire was reduced by 21 to 33 percent. A reduction in growth following prescribed burning was not seen in the 4-year return interval stands, which the authors attributed to differences in fuel characteristics (Adhikari and others 2021). Both this study and Adhikari and others (2021) seem to indicate that fire behavior affects possible growth reductions in shortleaf. The 2013 burn was anecdotally described as being hot, and took place in April, a bit later than the typical dormant season burns in this unit. Further research on prescribed burning and radial growth reduction of shortleaf pine, including data on fire timing and behavior, would likely be useful to determine how and when prescribed burning could lead to growth reductions.

Overall, this study shows that repeated burning may change midstory composition by reducing fire-sensitive species and promoting shortleaf pine. One of the burn years in this study resulted in lower ring widths in the burned unit, while the others did not, indicating that factors such as burn conditions and fire behavior may mediate the effects of burning on shortleaf pine growth, but that burning does not necessarily reduce BAI. Local competition density reduced shortleaf pine radial growth in this study, and this was especially true for hardwood competition. Additionally, the hardwood midstory may have contributed to lower growth in the nonburned area in the later years of this study.

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