THE INFLUENCE FROM COMBINATIONS OF PRESCRIBED FIRE, HERBICIDE INJECTION, AND PARTIAL OVERSTORY REMOVAL ON RESTORATION OF NATURAL OAK STANDS IN THE ARKANSAS OZARKS

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Abstract—Two studies were conducted in the Springfield Plateau province of the Arkansas Ozarks from 2009 to 2014 incorporating the applied silvicultural methods proven beneficial to promote oak natural reproduction. The first study, River Hills, was a completely randomized design with treatments including: partial overstory removal to basal area 50 (BA50), partial overstory removal to basal area 50 plus mid-story removal (BA50+MR), and a non-harvest control (NHC). An additional treatment was applied in early 2013 involving a prescribed burn of the BA50 and BA50+MR treatments. Prior to the prescribed burn application, a significant difference was detected between initial versus year 3 total (all 3 height classes) oak seedlings per acre (SPA) measurements for all treatment (p = 0.003, 0.008, 0.007; Student's t-test, α = 0.05), associated with light availability. A prescribed fire conducted in year 4 had a negative impact on total oak SPA. The second study, Waugh Mountain, was a RCB, split plot design. Treatments included a partial overstory removal to basal area 50 (SW) and partial overstory removal to basal area 50 plus mid-story removal (SW+MR), with the split plot factor being either pre-harvest prescribed burn or no-burn. No significant differences were observed between initial and year 2 post-treatment total oak SPA. Significant differences were detected between initial and year 2 post-treatment oak SPA between 1 and 3 feet and greater than 3 feet in height.

INTRODUCTION

Oaks have been the predominant species in hardwood forests of the Arkansas Ozarks for thousands of years. The forests also included hickories (*Carya* spp.), ash (*Fraxinus* spp.), blackgum (*Nyssa sylvatica*), elm (*Ulnus* spp.), maple (*Acer* spp.), other hardwoods, and a component of shortleaf pine (*Pinus enchinata* L.), as stated by Foti (2004). Densification of hardwood stands within this region over the past century has resulted in reduced sunlight canopy penetration and species shifts to more shade tolerant species (Soucy and others 2004). The result from this management shift is an ongoing reduction in levels of oak regeneration in newly established stands, which could have significant impacts on the ecology and utilization of Ozark upland forests. Decades of research aimed at reversing these effects have provided methods for increasing oak reproduction abundance and size in naturally regenerated stands.

Previous studies have demonstrated the positive impacts prescribed fire, midstory removal, and shelterwood harvests can provide to establishing oak reproduction in naturally regenerated hardwoods (e.g. Loftis 1990 and 1993, Larsen and Johnson 1998, Brose and others 1998, Brose and others 2013, Cunningham 2011, and Cunningham 2015). Controlling non-oak competition and altering sunlight canopy penetration to the understory are primary factors impacted by these stand-level modifications. Brose and others 1998 and Brose and others 2013 emphasized the timing of prescribed burning and its subsequent benefit or lack thereof to oak reproduction. Cunningham 2011 and 2015 established sunlight conditions at the understory level associated with varying midstory and overstory densities. Here, we will expand on the results of Cunningham 2015, present results from an additional study and summarize our efforts to incorporate prescribed fire, midstory removal and partial overstory removal in naturally regenerated hardwood stands within the Arkansas Ozarks.

MATERIALS AND METHODS

The study sites are located in the dissected Springfield Plateau physiographic province in the Arkansas Ozarks. The predominant soils are Clarksville very cherty silt loam, 8 to 20 percent slopes and Clarksville very cherty silt loam 20 to 40 percent slopes. These soils are described as deep, somewhat excessively drained, low available water, low organic matter content, and strongly acidic (Ferguson and others 1982). The description provided is a general soil description based

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on broad ranges of slope positions. The areas selected for these studies were only on north aspects, which potentially had somewhat higher organic matter, higher moisture content, and generally considered more productive than ridge-tops and south facing slopes. Site indices for white oak, black oak, and northern red oak dominant and co-dominant trees were calculated from equations developed by Graney and Bower (1971). Site indices for oaks were 65 feet on upper slopes to 75 feet plus on lower slopes.

Study Design

The River Hills study was a completely randomized design, with three treatments and four replicates. Treatments included: 1) shelterwood harvest to BA 50 a^{-1} (BA50), 2) shelterwood harvest to BA 50 a^{-1} plus injection of non-oak stems between 1 and 5 inches DBH (BA50+MR) and 3) non-harvested control (NHC). A detailed description for the River Hills methodology was provided by Cunningham (2015). Three years of post-treatment data were collected, analyzed and presented in the original study (initial, year 1, year 2 and year 3 data). In spring 2013, a prescribed fire was conducted in the BA50 and BA50+MR treatments. The NHC treatment remained undisturbed. Post-burn oak reproduction measurements were obtained in the fall 2014, representing year 5 data presented here.

The Waugh Mountain study was a randomized complete block, split plot design. The study included two primary treatments: shelterwood harvest to residual BA 50 ft^2 a^{-1} (SW) or a residual BA 50 ft^2 a^{-1} plus midstory removal (SWI). Prescribed fire was a split plot factor providing two additional treatments: a SW treatment plus a burn (SW+B) or a SWI treatment plus a burn (SWI+B). The layout resulted in four treatments with three replicates. Mid-story removal treatments were applied in February 2012. Follow-up treatments were applied in July 2012. Mid-story removal was performed using herbicide injection. 0.03 ounces of an aqueous solution of 25 percent imazapyr and 75 percent water was injected for every three inches of diameter at breast height. Prescribed burn applications were conducted on burn plots in March 2012. A partial overstory harvest operation was applied to all treatments from September 2012 through March 2013. The target residual basal area was 50 ft^2 a^{-1}. Desirable residual tree characteristics were 1) oak species and 2) large vigorous crowns.

Each 2.5 acre treatment replicate contained nine 100th acre circular regeneration sample plots spaced on a 20 meter by 20 meter grid. Stand level reproduction measurements at each plot included species and height class (<1 feet, 1 to 3 feet, and >3feet). Over-story measurements were taken from one, fifth acre circular plot per replicate. Over-story measurements included species, DBH, merchantable height, and log grade. Mid-story measurements were taken from 1, 20th acre circular plot per replicate. Mid-story measurements included species and total height. Initial over-story, mid-story and understory measurements were taken in fall 2011.

Statistical Analyses

All statistical analyses were performed in SigmaPlot 11.0. Data were tested for normality and equal variances. When necessary, regeneration data were square root transformed to help meet required assumptions. For the River Hills data, regeneration responses were analyzed for treatment differences using analysis of variance (ANOVA). In the event that a square root transformation did not adequately fix assumption issues, a Kruskal-Wallace ANOVA on Ranks was performed (KW). Individual means separation was conducted using Student Newman-Kuels (SNK) tests. All tests were conducted at the alpha = 0.05 significance level. Waugh Mountain results were analyzed using a pairwise analysis of initial versus year 2 data (Student's t-test, α = 0.05).

RESULTS

River Hills

Year 5, or year 2 post-burn, means were 854 (± 141), 1,596 (± 625), 1,534 (± 540) oak seedlings per acre (SPA) for BA50, BA50+MR, and NHC, respectively (figs. 1A and 1B). No significant differences were detected for total oak SPA (p = 0.49) between treatments. No significant differences were detected for oak seedlings < 1ft. or 1 – 3 ft. between treatments (p = 0.16 [KW] and p = 0.19). A significant difference was detected between treatments for oak seedlings > 3 ft. (p = 0.007). A SNK test determined significant differences occurred between BA50 and BA50+MR versus NHC for oak seedlings > 3ft. BA50 and BA50+MR were similar for oak seedlings > 3 ft.

Reductions in oak SPA occurred for all treatments between year 3 and year 5 post-treatment data. Year 5 post-treatment oak SPA were 50, 48, and 54 percent lower than year 3 for BA50, BA50+MR, and NHC, respectively. A one-way analysis of variance for all years detected significant differences between years for total oak SPA (p = <0.001). A SNK analysis determined year 3 to differ significantly from all other years and year 5 to differ from initial and year 1. Initial through year 2 were determined to be similar for total oak SPA (fig. 2).

Waugh Mountain

Year 2 post-treatment means were 581 (± 179), 1,167 (± 372.6), 1,467 (± 775.7), 1,325 (± 444.4) total oak SPA for SW, SWI, SW+B, and SWI+B. These numbers represented a 66 reduction in oak SPA in the SW treatment. However, oak SPA increased 45 percent in the SWI treatment, 11.5 percent in the SW+B treatment

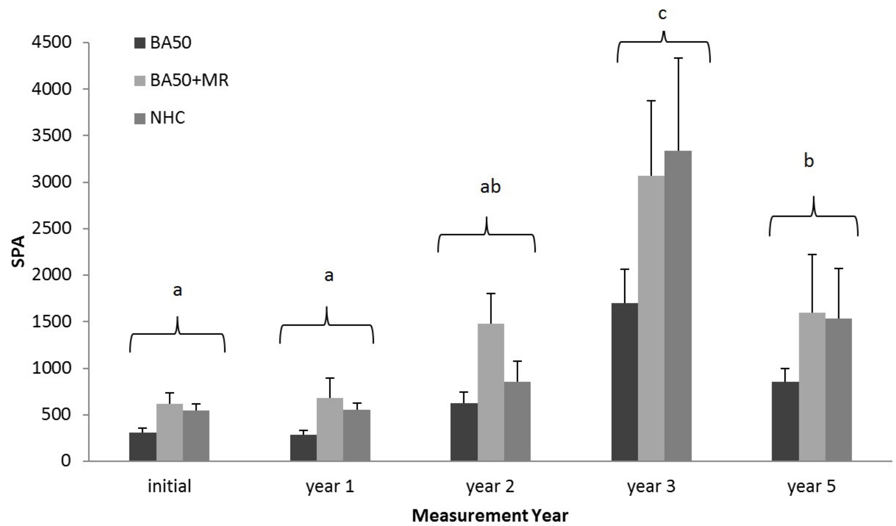

Figure 1A—Oak seedlings per acre by treatment by year (Means followed by same letter do not significantly differ, SNK, α = 0.05).

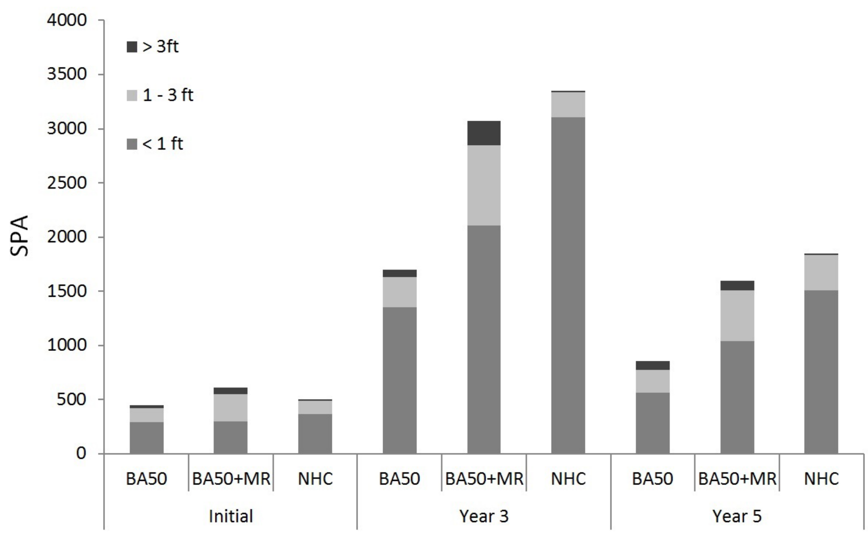

Figure 1B—Oak seedlings per acre by height class and treatment for initial, year 3 and year 5 post-treatment.

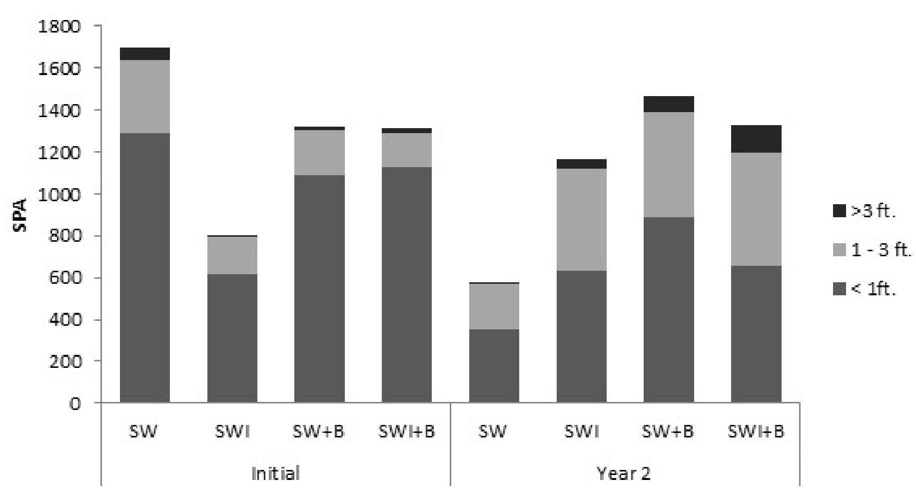

Figure 2—Oak SPA by Height Class for Waugh Mountain Initial Versus Year 2 Post-Treatment.

and 1 percent in the SWI+B treatment. No significant differences were detected between initial and year 2 values for total oak SPA by treatment (table 1).

Mean non-oak SPA < 1 foot in height decreased 72, 19, and 42 percent for SW, SW+B, and SWI+B, respectively. The SW+I experienced a 2 percent increase. Mean oak SPA 1 to 3 feet tall increased 177, 136, and 226 percent for SWI, SW+B, and SWI+B. However, oak SPA between 1 and 3 feet tall decreased 39 percent in the SW treatment. Mean oak SPA > 3 feet tall increased 1,106 (4 to 41 SPA), 425 (14 to 77) and 598 (18 to 129) percent for SWI, SW+B, and SWI+B treatments. The SW treatment experienced a 76 percent decline in oak SPA > 3 feet. No significant differences were observed between initial versus year 2 data by treatment for oak SPA < 1 ft. in height. A pairwise analysis detected significant differences between initial versus year 2 data for oak SPA 1 – 3 ft. and > 3 ft. for the SWI treatment ($p = 0.04$ and <0.001). No significant differences for oak SPA 1 – 3 ft. and > 3 ft. were observed for other treatments.

Year 2 post-treatment means were 4,793 (±710.5), 4,852 (±368.9), 4,437 (±747.6), and 5,625(±1,033.8) non-oak SPA for SW, SWI, SW+B, and SWI+B. These averages represented 36, 67, 7, and 120 percent increases for the respective treatments. There were no significant differences detected between initial and year 2 post-treatment average non-oak SPA for the SW and SW+B treatments. A pairwise analysis detected significant differences between initial and year 2 post-treatment average non-oak SPA for the SWI and SWI+B treatments (table 2).

A general increase occurred across most height classes for all treatments between initial versus year 2 non-oak SPA averages. Non-oak SPA less than 1 foot in height increased 59, 85, and 70.4 percent for SW, SWI and SWI+B treatments. However, SW+B experienced a 12 percent reduction in non-oak SPA less than 1 foot in height. Non-oak SPA from 1 to 3 feet tall increased 54, 50, and 59 percent for SW, SWI, and SW+B treatments. SWI+B experienced the highest change with a 301 percent increase for non-oak SPA between 1 and 3 feet tall. Non-oak SPA greater than 3 feet tall increased 45, 30, and 133 percent for SWI, SW+B, and SWI+B treatments. Non-oak SPA greater than 3 feet tall declined 40 percent in the SW treatment (fig. 3).

DISCUSSION

River Hills

Cunningham 2015 presented results from initial to year 3 post-treatment, demonstrating an increase in oak SPA for all treatments over the time period. Those results were significantly impacted by the resulting sunlight environments generated by the applied overstory and/or midstory treatment combination and a topographical effect. The continued results presented here described the impact of a prescribed fire conducted prior to the

Table 1—Initial Versus Year 2 Post-Treatment Oak SPA Analysis

Treatment	Initial	SE	Year 2	SE	p-value
SW	1,696	654.0	581	179	0.17
SWI	800	197.6	1,167	372.6	0.43
SW+B	1,316	481.9	1,467	775.7	0.78
SWI+B	1,311	429.9	1,325	444.4	0.98

SE = ± 1 standard error

Table 2—Mean Non-oak SPA comparisons for Initial versus Year 2 Values

Treatment	Initial	SE	Year 2	SE	p-value
SW	3,515	735.8	4,793	710.5	0.30
SWI	2,893	430.4	4,852	368.9	0.03
SW+B	4,122	205.3	4,437	747.6	0.71
SWI+B	2,559	155.2	5,625	1,033.8	0.04

SE = ± 1 standard error

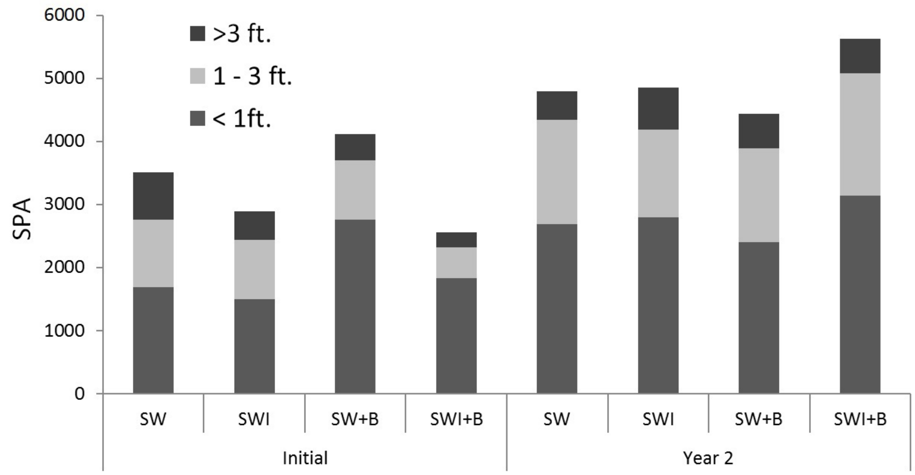

Figure 3—Initial Versus Year 2 Non-oak SPA by Height Class for the Waugh Mountain Study.

year 4 (2013) growing season. The results presented represented year 5 overall or year 2 post-burn data. Brose and others (2013) suggested that fires conducted several years after a stand disturbance often generated positive results in oak seedling abundance and were more effective than pre-harvest preparatory burns. The results from this study did not coincide with these findings. Oak SPA declined for all treatments between year 3 and year 5.

The authors believe there are several causative factors taking place. First, the NHC treatment was not burned and therefore fire had no effect on the reduction in oak SPA. The reduction in oak SPA in the NHC treatment was most likely a response to the natural flux of oak reproduction established from the bumper acorn crop of 2011 and the impacts of inadequate sunlight environments for those new germinates to perpetuate through time. However, low sunlight could not be a primary causative factor for BA50 or BA50+MR. In these treatments, where sunlight environments were at a minimum adequate for oak seedling survival and development (except for lower slope positions in BA50), the prescribed fire was likely a causative factor in the decline of oak SPA between year 3 and year 5. An analysis of the data suggests that the influx of new seedlings in year 3, followed by fire in the following dormant season resulted in seedling mortality of those new seedlings, returning oak SPA to near year 3 values. However, it should be further noted that year 3 was a year of excessive drought and the flux of new seedlings were stressed and not high-vigor in many cases. Thus additional factors may have also impacted the year 5 results.

Year 5 data did demonstrate that the sunlight environments established in the initial treatments were still having impact, with the mid-story removal treatments having the most oak reproduction in the taller height classes. Furthermore, visual observations of oak reproduction in BA50 and BA50+MR in year 5 suggest that these seedlings are physiologically active, have good leaf area indices, and are vigorous. The authors believe year 6 data will show a strong rebound in oak reproduction in BA50 and BA50+MR and predict a continued decline in oak SPA in the NHC.

Waugh Mountain

Statistically there were no differences between initial and year 2 values for any treatment in total oak SPA. The shelterwood only treatment (SW) served as the control treatment and did demonstrate expected and notable results. The SW treatment experienced a significant decline in oak SPA, 66 percent, which was the largest of any treatment applied. These reductions were likely attributable to inadequate sunlight environments from continued shading by residual midstory competition in the shelterwood only treatment.

When midstory removal was added to the shelterwood treatment (SWI) a different oak seedling response was observed. Oak SPA increased by 45 percent in the SWI treatment from 800 SPA to 1,167 SPA. This result suggests that the optimal sunlight conditions created by reducing midstory level competition positively impacted oak seedling abundance.

When prescribed fire alone was added to the shelterwood harvest (SW+B), oak seedling abundance increased slightly by 11 percent from 1,316 SPA to 1,467 SPA. A reduction occurred in seedlings < 1 foot in height likely due to seedlings moving into the taller height classes and possibly some mortality from the disturbance from harvesting and burning. While variation between replicates prevented significant differences in data analysis, notable increases in seedling height occurred. The increases in height were likely a function of seedling sprouts from the burn treatment.

When midstory removal and prescribed fire were coupled with a shelterwood harvest (SWI+B), total oak SPA increased slightly. However, an appreciable increase in oak SPA in heights between 1 and 3 feet and greater than 3 feet occurred. This treatment had the greatest impact on the combination of survival and growth. The associated sunlight environment was viewed as the primary factor in this treatment. The apparent increase in seedling growth was likely a response from seedling sprouting in post-burn conditions, as in the SW+B treatment.

CONCLUSIONS

These two studies demonstrated the importance of creating optimal sunlight conditions to promote oak reproduction survival and development. The River Hills study demonstrated the impact of inadequate sunlight conditions in undisturbed stand conditions. Even with a significant flux of new oak reproduction appearing in year 3, evidence of that effect being short lived was observed in year 5. At both study locations, a shelterwood only harvest, with no additional treatments had limited impacts on oak reproduction abundance and growth. The areas in the shelterwood harvest where conditions were favorable did promote oak reproduction. The areas where the midstory remained intact remained inadequate sunlight environments for oak reproduction survival and development. Furthermore, midstory removal combined with a shelterwood harvest created the most uniform and favorable sunlight conditions for oak reproduction survival and development.

Prescribed fire appeared beneficial in the Waugh Mountain study, with appreciable increases in oak seedling survival and development. However, fire appeared to have negative effects on oak seedling survival at the river hills study. As stated, this negative effect could have been caused by the presence of new seedlings established prior to the burn application. In these two studies, a preparatory burn prior to midstory and overstory manipulation appeared to be more beneficial than a post-treatment burn. These results help supplement our current understanding of prescribed fire in oak regeneration. In application, forest managers should gain an understanding for positive and negative factors associated with prescribed fire in regard to their potential impact on oak regeneration success. Timing of prescribed fire applications to match existing stand and reproduction conditions is important to prescribed fire having beneficial effects on oak regeneration efforts.

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