FIRST YEAR RESPONSE OF OAK NATURAL REGENERATION TO A SHELTERWOOD HARVEST AND MIDSTORY COMPETITION CONTROL IN THE ARKANSAS OZARKS

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ABSTRACT

A study evaluating the response of oak reproduction to a shelterwood harvest and midstory competition control in an upland hardwood stand within the Ozark Highlands of Arkansas is being conducted. The study site is located in the dissected Springfield Plateau physiographic region on the University of Arkansas – Division of Agriculture Livestock and Forestry Research Station near Batesville, AR. Five-acre treatment plots have been established within a 140 acre shelterwood harvest on north-facing slopes (SI 65 - 75 for oaks) in a 110 year old upland hardwood stand. The overstory is dominated by white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and northern red oak (*Quercus rubra* L.). Treatments include: 1) shelterwood harvest to basal area (BA) 50 $ft^2 a^{-1}$ (BA50); 2) shelterwood harvest to BA 50 plus injection of undesirable stems greater than 1inch DBH (BA50+MR); and 3) non-harvested/ control treatment (NHC). For BA50 and BA50+MR, post-treatment basal areas ranged from 45 to 55 $ft^2 a^{-1}$, resulting in approximately a 55 percent reduction in over-story density. The NHC remained at initial basal area levels (~ 94 $ft^2 a^{-1}$). The mean post-treatment mid-story density for BA50 was 157.5 TPA, resulting in approximately a 51 percent reduction from initial mid-story density from harvest damage. The BA50+MR mid-story trees were near 100 percent removed from chemical injection treatments (~ 310 TPA). NHC mid-story densities were approximately the same as initial stand conditions. Mean mid-day photosynthetic photon flux densities (PPFDs) following treatment applications were 476.0 (± 75.3, α=0.05), 640.8 (± 180.3, α=0.05) and 62.5(± 60.0, α=0.05) µmol photons $m^2 s^{-1}$, respectively for BA50, BA50+MR, and NHC.

INTRODUCTION

Throughout the hardwood forests of North America, regenerating oak stands on productive upland sites presents a major problem to resource managers (Brose et al. 1998). The physiological and morphological adaptations of oak seedlings often narrow the environmental conditions in which they survive and grow. A basic assumption is that success in survival and growth is influenced by: 1) microclimate and edaphic factors, 2) morphological and physiological characteristics of a particular species, and 3) interaction between the two (Hodges and Gardiner 1993). Understanding these relationships is important to understanding management strategies for perpetuating oaks into new forests.

Mature, undisturbed hardwood stands typically do not have enough sunlight reaching the understory for the development of oak seedlings into the mid and upper canopies. Canham et al. (1990) found closed canopy hardwood forests to exhibit understory light levels from 0.4 to 2.5 percent of total available sunlight. Also, 48 to 69 percent of PAR transmittance occurs in sunflecks with 4 to 11 minute duration. Low understory light levels in hardwood stands may be the most limiting factor to the establishment and growth of oak regeneration (Hodges and Gardiner 1993). Battaglia et al. (2000) stated that environmental factors such as light and soil moisture may have independent or interacting influence on hardwood seedling survival and growth. Quero et al. (2008) found that irradiance levels have greater impact on oak seedling growth than water supply. Increases in sunlight aid in promoting both the successful establishment and subsequent growth of oak reproduction in hardwood stands. However, too much light in the initial stages of development may hinder oak seedlings by favoring faster growing, more shade intolerant, tree species and herbaceous vegetation (Hodges and Janzen 1986). Hodges and Gardener (1993) suggested that sufficient sunlight levels for growth and survival for cherrybark oak (*Quercus pagoda* Raf.) occurred at 27 percent of total available PAR and optimal growth conditions occur at 53 percent of total available PAR.

Sources for hardwood regeneration include: seedlings, seedling sprouts, and stump sprouts. When present prior to harvest, these sources are known as advanced reproduction (Rogers et al. 1993). The level of partial overstory removal may affect the amount of advance reproduction present following harvesting activity as it impacts both the amount of site disturbance and the resulting available sunlight. Shelterwood harvests may present the most flexible alternative to naturally regenerating desirable species such as oaks. A shelterwood harvest is a management system that promotes a standing crop of regeneration through a series of partial removals of the overstory (Smith et al. 1996). An alternate version of the classical approach to

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shelterwood harvests may be required for the desirable oak species on the more productive sites. Combining herbicide treatments and/or prescribed fire along with the shelterwood has been evaluated by many researchers (Hicks et al. 2001). Although there are no universal prescriptions for the hardwood regeneration problem, modified shelterwood systems that remove canopy and sub-canopy individuals prior to overstory removal to increase light reaching the ground can increase seedling dominance and survival for desirable species such as the oaks (Loftis 1993). This study attempts to further supplement our knowledge of oak natural regeneration by evaluating understory light levels and hardwood regeneration response to two modified shelterwood methods.

MATERIALS AND METHODS

The study site is located in the Ozark Mountains of Arkansas, within the dissected Springfield Plateau physiographic province. The predominant soils are listed as Clarksville very cherty silt loam, 20 to 40 percent slopes and Clarksville very cherty silt loam, 8 to 20 percent slopes. These soils are described as deep, somewhat excessively drained, low available water, low organic matter content, and strongly acidic (Ferguson et al. 1982). It should be noted that the description provided is a general soil description based on broad ranges of slope positions. The areas selected for this study were only on north aspects, which potentially have somewhat higher organic matter, higher moisture content, and are 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 determined from equations developed by Graney and Bower (1971). Oak site indices ranged from 65 to 75 feet, depending on slope position. Initial over-story mean basal area of treatment replicates was 93.8 $ft^2\ a^{-1}$ (± 8.5 $ft^2\ a^{-1}$), representing a fully stocked to slightly overstocked stand. Initial over-story species composition was dominated by approximately 75 percent oak species. Initial mean mid-story density was 310 trees per acre (TPA) and dominated by non-oak, shade tolerant species. Mean understory (regeneration source) density included 475 oak seedlings per acre (SPA) (± 147 SPA) and 2,532 non-oak seedlings per acre (± 366 SPA). Species composition in the under-story was dominated by shade tolerant species. Red maple, winged elm, and hickory comprised 48 percent of understory, while oaks, collectively, comprised 15 percent.

The study utilizes two primary treatments that incorporate two shelterwood methods to potentially generate an adequate to optimum environment for mid-tolerant oak seedling establishment and development. A third treatment is a control, where no stand manipulation has occurred. Treatments include: 1) shelterwood harvest to BA 50 (BA50); 2) shelterwood harvest to BA 50 plus injection of undesirable stems greater than 1inch DBH (BA50+MR); and 3) non-harvested/ control treatment (NHC). Mid-story removal treatments were applied from November 2008 to February 2009. Follow-up treatments were applied in July 2009. Non-oak species were removed using herbicide injection. One milliliter of an aqueous solution of 25 percent imazapyr and 75 percent water was injected for every three inches of circumference around tree trunks. The mechanical thinning operation was applied to the BA50 and BA50+MR from October 2009 through March 2010. The target residual basal area was 50 $ft^2\ a^{-1}$. Desirable residual tree characteristics were well spaced oak species with large vigorous crowns.

EXPERIMENTAL LAYOUT AND FIELD MEASUREMENTS

The experimental design is a randomized complete block (RCB). However, a physical constraint on randomization exists. The BA50 and BA50+MR are blocked and replicated into four blocks within the harvested area, while NHC replicates are located adjacent to the harvest area. This design was necessary to fit geographical constraints and to reduce the potential for bias between harvested and non-harvested treatments, potentially having significant impacts on data quality. The tradeoff is that the control replicates are not truly blocked with BA50 and BA50+MR. The author feels the modified design does not jeopardize confidence in results. 1) The treatment replicates are all in relatively close proximity, and 2) appreciable homogeneity existed among site and initial stand conditions.

Each treatment within a block contains twelve 1/100 acre circular regeneration sample plots spaced on a grid along the slope gradient. Regeneration measurements at each plot included species and height class (<1 feet, 1 to 3 feet, and >3feet). Over-story measurements were taken from two (one upper slope and one lower slope) fifth acre circular plots. Over-story measurements included species, DBH, merchantable height, log grade, damage, and number of epicormic branches. Mid-story measurements were taken from 2, 1/20 acre circular plots. Mid-story measurements included species and total height. Initial over-story, mid-story and understory measurements were taken in the summer of 2009.

Photosynthetic Photon Flux Density (PPFD) was measured at each of the twelve regeneration plots per replicate. PPFD was measured at plot center using a quantum sensor attached to a Mini-PAM 2000 (WALZ, Inc.). Mini-PAM readings were calibrated against a Li-COR quantum sensor for accuracy. The sensor was mounted to a leveled tripod at each measurement point. Plot center light measurements were taken in September 2010. PPFD measurements were taken under mostly sunny conditions.

STATISTICAL ANALYSES

All statistical analyses were performed in SAS 9.2. Normality tests were performed through the PROC UNIVARIATE procedure utilizing the Shapiro-Wilks W-test. Sunlight level and regeneration response were analyzed for treatment differences using analysis of variance (ANOVA) using PROC GLM. Individual means separation was conducted with Student Newman-Kuels SNK tests. All tests were run at the $\alpha = 0.05$ level.

RESULTS

Treatment applications had appreciable impact on residual over-story and mid-story conditions. For the BA50 and BA50+MR, post-treatment basal areas ranged from 45 to 55 square feet/acre, resulting in approximately a 55 percent reduction in over-story density. The NHC remained at initial basal area levels (~ 93.8 $ft^2\ a^{-1}$). The BA50 mid-story density was approximately 125 TPA for upper slope plots and 190 TPA for lower slope plots. The mean post-treatment, mid-story density for BA50 was 157.5 TPA, resulting in approximately a 51 percent reduction from initial mid-story density. The BA50+MR mid-story trees were approximately 100 percent removed (~ 310 TPA). The NHC mid-story densities were approximately the same as initial stand conditions.

IRRADIANCE

September 2010 plot center mean understory light levels were 476.0, 640.8 and 62.5 $\mu mol\ m^2\ s^{-1}$ for BA50, BA50+MR, and NHC, respectively. A one-way analysis of variance determined significant differences to exist, with an F-Value of 44.10 ($P < 0.0003$) for treatment effects. A SNK means analysis determined significant differences to exist between all three treatments (Figure 1). BA50 mean PPFD values for slope positions 1 – 4 were 131.1, 449.8, 514.8, and 808.0 $\mu mol\ m^2\ s^{-1}$, respectively. Significant differences among rows for plot center PPFD measurements for BA50 were determined to exist, with an F-Value of 5.65 ($P = 0.0186$). Significant differences were determined between slope position 1 versus slope positions 2, 3, and 4. Also, slope position 4 significantly differed from slope positions 1, 2, and 3. No differences existed between rows 2 and 3 (Figure 2). BA50+MR mean PPFD values for slope positions 1 – 4 were 377.0, 740.5, 768.5, and 675.6 $\mu mol\ m^2\ s^{-1}$. A one-way analysis of variance for treatment effects found no significant differences to exist, with an F-Value of 2.95 ($P = 0.09$). NHC mean PPFD values for slope positions 1 – 4 were 21.9, 108, 31, and 75 $\mu mol\ m^2\ s^{-1}$. No significant differences were determined to exist for NHC slope positions, with an F-Value of 2.95 ($P = 0.10$) (Figure 2).

REGENERATION

No statistical difference occurred between initial and year 1 species composition among treatments. Year 1, post harvest, mean oak SPA were 260.4, 682.6, and 552.0 SPA for BA50, BA50+MR, and NHC, respectively. The percent change in mean oak SPA was -1.6, 10.3, and 0.7 percent for BA50, BA50+MR, and NHC, respectively. Year 1, post harvest, mean non-oak SPA were 2244.8, 2400.4, 2406.3 SPA for BA50, BA50+MR, and NHC, respectively. The percent change in mean non-oak SPA was -9.5, -13.5, and -0.3 percent for BA50, BA50+MR, and NHC, respectively (Figure 3 and 4).

Year 1, mean oak SPA for BA50 were 129.2, 118.8, and 12.5 SPA for height classes 1, 2, and 3, respectively. Height class 1 experienced a loss in oak SPA, while height classes 2 and 3 experienced a slight increase for BA50 oak reproduction. Year 1, mean non-oak SPA for BA50 were 553.1, 978.1, and 713.5 SPA for height classes 1, 2 and 3, respectively. Height class 1 and 3 experienced a loss of non-oak SPA, while height class 2 exhibited an increase in SPA (Figure 3 and 4). Mean oak SPA for BA50+MR were 378.6, 265.7, and 38.3 SPA for height classes 1, 2, and 3, respectively. Height classes 1 and 2 experienced an increase of oak SPA, while height class 3 experienced a slight decrease for BA50+MR oaks. Year 1, mean non-oak SPA for BA50+MR were 568.9, 1,125.4, and 706.1 SPA for height classes 1, 2 and 3, respectively. Height classes 1 and 3 experienced a loss in SPA, while height class 2 exhibited an increase (Figure 3 and 4). Mean oak SPA for NHC were 385.4, 154.2, and 12.5 SPA for height classes 1, 2, and 3, respectively. Height classes experienced negligible changes in oak SPA. Year 1, mean non-oak SPA for NHC were 572.9, 879.2, and 954.2 SPA for height classes 1, 2, and 3, respectively. Height classes also experienced negligible changes in non-oak SPA for NHC (Figure 3 and 4).

DISCUSSION

In the BA50, a portion of the mid-story was inadvertently removed during the overstory harvest operation. The result was that approximately one-third to one-half (depending on slope position) of mid-story trees were either snapped off near ground level or removed by the mechanical operation. The mid-story component represents the key difference between the BA50 and BA50+MR. Approximately 100 percent of the mid-story trees were removed from the BA50+MR and none were removed from the NHC. Mid-story trees that were killed had positive impacts on understory light levels. However, trees that were snapped off by the mechanical operation have a high sprout potential and will certainly remain as competition for oak reproduction. Additionally, there existed a gradient from lower slope to upper slope damage intensity to mid-story trees in the BA50. The result is a low to high understory light level gradient from lower slope to upper slope for BA50 (Figure 2). The BA50+MR differed in that mid-story stems were deadened, thus removed equally from lower to upper slope positions. The result is a higher intensity, more uniform canopy transmittance pattern across the slope (Figure 2) and little to no chance of stump sprout competition from deadened mid-story trees. Thus far in the study, understory light levels in BA50+MR most closely mimic those suggested for mid-tolerant oak species development.

Harvest damage also appeared to reduce seedling abundance for non-oak species in both treatments 1 and 2. Figure 3 illustrates the changes for non-oaks by height class. The author feels the primary harvesting impacts to non-oaks was experienced in height class 3. The reduction in non-oak SPA for height class one is potentially a combined result of harvest damage and influx from height class 1 into height class 2 (generated by the increased light environment). There appeared to be little negative harvest impact on oak seedling abundance (Figure 3). BA50 exhibited little change in oak SPA. The BA50+MR experienced an influx of height class 1 oak seedlings (primarily *Q. alba*). The BA50+MR also experienced an increase in height class 2 SPA, potentially a function of the improved light conditions. Additional growing seasons will be required to fully evaluate seedling abundance among treatments.

CONCLUSIONS

Initial data indicates that a shelterwood harvest alone (BA50) created somewhat variable sunlight conditions at ground level, with only a portion of its area exhibiting potentially adequate sunlight for oak seedling development. Year 1 results suggest that a modified shelterwood, combining partial overstory and complete mid-story removal, generate adequate (potentially optimal) sunlight conditions for oak seedling growth and survival in the Ozark uplands of Arkansas. Additional analyses will be performed in future growing seasons to more fully evaluate the treatment effects on oak abundance and competitive position.

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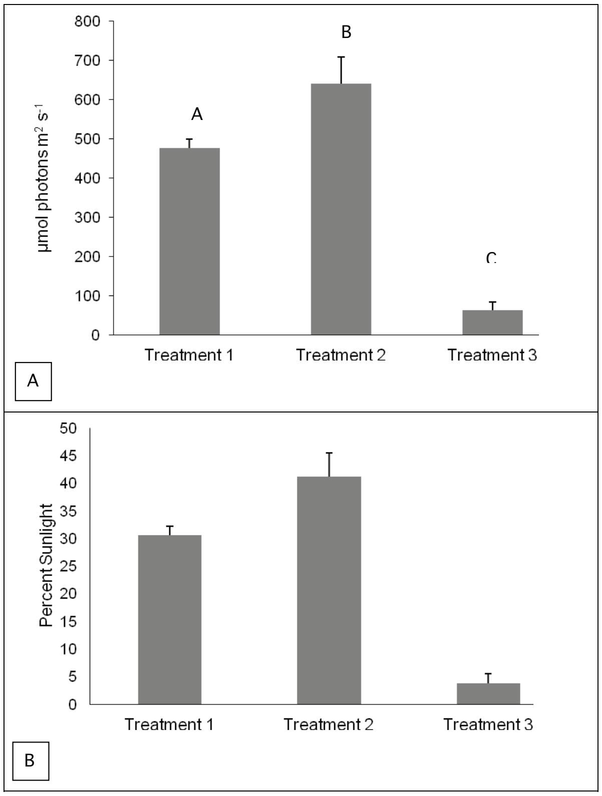

Figure 1—A) Plot center PPFD values by treatment for September 2010. B) Plot center PPFD values by topographic position and treatment. (Means followed by same letter do not significantly differ, SNK Pr > F ≤ 0.05)

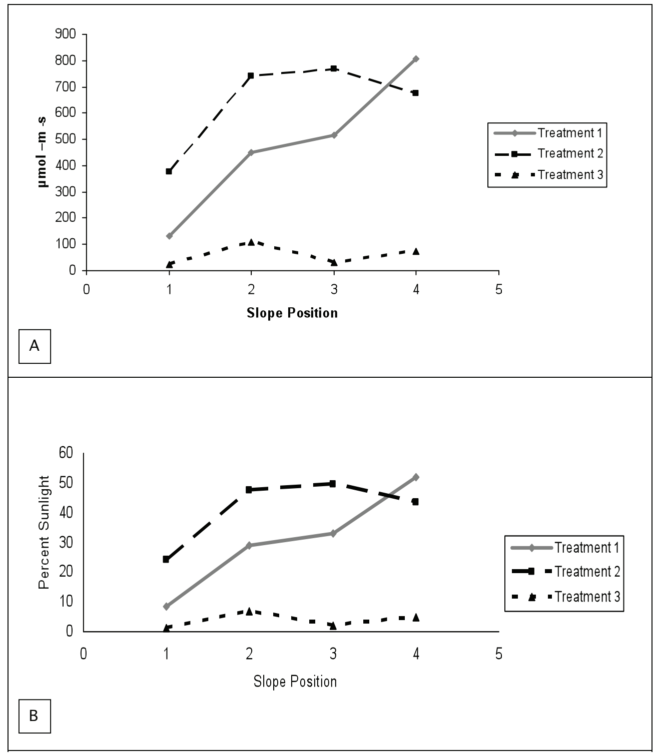

Figure 2—A) Plot center PPFD values by treatment for September 2010. B) Plot center PPFD values by topographic position and treatment.

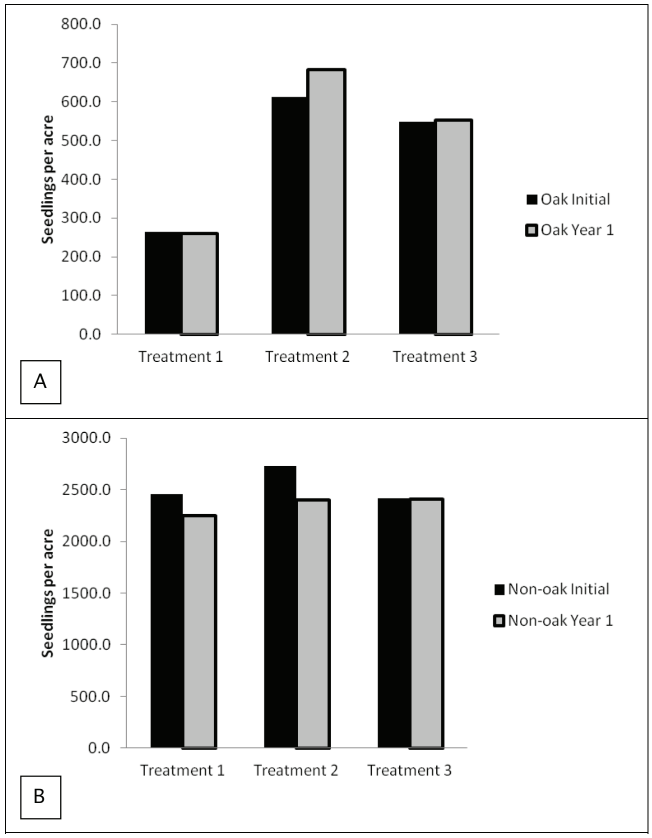

Figure 3—A) SPA initial and year 1 measurements for oaks. B) SPA initial and year 1 measurements for non-oaks.

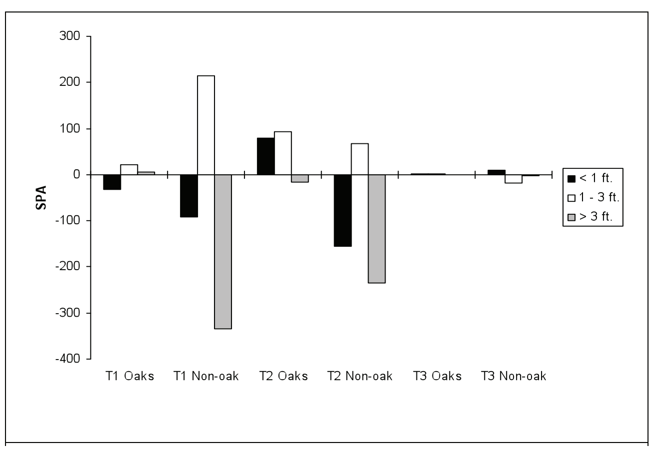

Figure 4—Change in oak and non-oak seedlings per acre (SPA) by height class and treatment between initial and year 1 measurements.