THIRD-YEAR RESPONSE OF OAK NATURAL REPRODUCTION TO A SHELTERWOOD HARVEST AND MIDSTORY COMPETITION CONTROL IN THE ARKANSAS OZARKS

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Abstract--A study evaluating the response of oak natural reproduction to a shelterwood harvest and midstory competition control in an upland hardwood stand within the Ozark Highlands of Arkansas was conducted. The study site was 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 were established within a 140-acre shelterwood harvest on north-facing slopes (site indices 65 to 75 for oaks) in a 110-year-old upland hardwood stand. The overstory was dominated by white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), and northern red oak (*Q. rubra* L.). Treatments include: (1) shelterwood harvest to 50 square feet per acre (BA50); (2) shelterwood harvest to 50 square feet per acre plus injection of non-oak midstory trees (1 to 5 inches d.b.h.; BA50+MR); and (3) non-harvested control (NHC). Initial mean oak seedlings per acre (SPA) were 308 (± 49.8); 613 (± 123.8); and 548 (± 72.0) for BA50, BA50+MR, and NHC, respectively. Year 3 post-treatment mean oak SPAs were 1,698 (± 365); 3,070 (± 807.8); and 3,340 (± 990.3), respectively. A significant difference was detected between initial versus year 3 values for all three treatments ($p = 0.003$, 0.008, and 0.007 respectively; student's t-test, $\alpha = 0.05$). No differences in total oak SPA were detected between treatments within year 3. Significant differences were detected between initial and year 3 oak SPA by height class for BA50 and BA50+MR. BA50+MR exhibited the greatest changes in oak seedling height growth.

INTRODUCTION

Throughout the hardwood forests of North America, regenerating oak stands on productive upland sites presents a major problem to resource managers (Brose and others 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. Most hardwood stands do not have adequate sunlight penetration through the upper canopy for the development of oak seedlings. Undisturbed, “closed” canopies often result in sunlight canopy penetration to the ground level of less than 10 percent (Canham and others 1990, Cunningham and others 2011) Low understory light levels in hardwood stands may be the most limiting factor to the establishment and growth of oak reproduction (Hodges and Gardiner 1993). Battaglia and others (2000) stated that environmental factors such as light and soil moisture may have independent or interacting influence on hardwood seedling survival and growth. Quero and others (2008) found that irradiance levels have greater impact on seedling growth than water supply.

An increase of sunlight aids in promoting both the successful establishment and subsequent growth of advance 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) detected that sufficient sunlight levels for growth and survival for cherrybark oak (*Q. pagoda* Raf.), under controlled conditions, occurred at 27 percent of total available photosynthetically active radiation (PAR) and optimal growth conditions occur at 53 percent of total available PAR. Recent advances in applied research for oak natural regeneration have established combinations of partial overstory harvests and midstory competition control to improve environmental conditions for developing oak reproduction (Cunningham and others 2011; Larsen and Johnson 1998; Loftis 1990, 1993). Sources for hardwood regeneration include seedlings, seedling sprouts, and stump sprouts. Seedlings present prior to harvest are known as advance reproduction (Rogers and others 1993). The level of partial overstory removal may affect the amount of advance

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reproduction present following harvesting activity as it impacts both the amount of site disturbance and resulting available sunlight.

Shelterwood harvests may present the most flexible option for naturally regenerating desirable species such as oaks. A shelterwood harvest is a management system that promotes a standing crop of reproduction through a series of partial removals of the overstory (Smith and others 1996). An alternate version of the classical approach to shelterwood harvests may be required for desirable oak species on more productive sites. Combining herbicide treatments and/or prescribed fire along with the shelterwood has been evaluated by many researchers (Hicks and others 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 forest floor can increase seedling dominance and survival for desirable species such as oaks. This study attempts to further supplement our knowledge of oak natural regeneration by evaluating irradiance effects and hardwood reproduction response to two shelterwood methods.

MATERIALS AND METHODS

The study site is 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. 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 on broad ranges of slope positions. The areas selected for this study were only on north aspects, which potentially had 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 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

Three treatments with four replicates were incorporated into a completely randomized design. Treatments included: (1) shelterwood harvest to basal area (BA) 50 (BA50); (2) shelterwood harvest to BA 50 plus injection of non-oak stems between 1 and 5 inches diameter at breast height (d.b.h.) (BA50+MR); and (3) non-harvested control (NHC). Midstory removal treatments were applied from November 2008 to February 2009. Follow-up treatments were applied in July 2009. Midstory removal was performed using herbicide injection. A 0.03-ounce aqueous solution of 25 percent imazapyr and 75 percent water was injected for every 3 inches of diameter around tree trunks. A partial overstory harvest operation was applied to the BA50 and BA50+MR from October 2009 through March 2010. The target residual basal area was 50 square feet per acre. Desirable residual tree characteristics were: (1) oak species and (2) large vigorous crowns.

Each treatment replicate contained twelve 0.01-acre circular regeneration sample plots spaced on a grid along the slope gradient. Stand-level reproduction measurements at each plot included species and height class (< 1 foot, 1 to 3 feet, and > 3 feet). Overstory measurements were taken from two (one upper slope and one lower slope) 0.20-acre circular plots. Overstory measurements included species, d.b.h., merchantable height, log grade, damage, and number of epicormic branches. Midstory measurements were taken from two 0.05-acre circular plots. Midstory measurements included species and total height. Initial overstory, midstory and understory measurements were taken in summer 2009.

Photosynthetic Photon Flux Density (PPFD) was measured at each of the 12 regeneration plots per replicate. PPFD was measured at plot center using a microquantum sensor attached to a Mini-PAM 2000 (WALZ, Inc.). Mini-PAM light readings were calibrated against an additional quantum light sensor (Delta OHM LP 471, ƛ400 to 700 nm) for accuracy. The sensor was mounted to a leveled tripod at each measurement point. Plot center light measurements were taken in September of each growing season.

Statistical Analyses

All statistical analyses were performed in SAS 9.2 (SAS Inc., Cary, NC). Normality tests were performed through the PROC UNIVARIATE procedure utilizing the Shapiro-Wilks W-test. Data were also tested for equal variances. When necessary, regeneration data were square root transformed to meet required assumptions. Sunlight level and regeneration response were analyzed for treatment differences using analysis of variance (ANOVA) using PROC GLM. Individual means separation was conducted using Student Newman-Kuels (SNK) tests.

RESULTS

Initial overstory mean BA of treatment replicates was 93.8 square feet per acre (± 8.5 square feet), representing a fully stocked to slightly overstocked stand. Initial overstory species composition was dominated by approximately 75 percent oak species. Initial mean midstory density was 310 trees per acre (TPA) and dominated by non-oak, shade tolerant species. An appreciable portion of the midstory consisted of large crowned flowering dogwood (*Cornus florida* L.). Mean understory density included 475 oak seedlings per acre (SPA) (± 147) and 2,532 non-oak SPA (± 366). Species composition in the understory was dominated by shade-tolerant species. Red maple (*Acer rubrum* L.), winged elm (*Ulmus alata* Michx.), and hickory (*Carya* spp.) comprised 48 percent of understory, while oaks comprised 15 percent.

Treatment applications had appreciable impact on residual overstory and midstory conditions. For the BA50 and BA50+MR, post-treatment BAs ranged from 45 to 55 square feet per acre, resulting in approximately a 55 percent reduction in overstory density. The NHC remained at initial BA levels (approximately 93.8 square feet per acre). The BA50 midstory density was approximately 125 TPA for upper-slope plots and 190 TPA for lower-slope plots. The mean post-treatment, midstory density for BA50 was 157.5 TPA, resulting in approximately a 51 percent reduction from initial midstory density. The BA50+MR midstory trees were approximately 100 percent removed (approximately 310 TPA). The NHC midstory densities were approximately the same as initial stand conditions.

Irradiance

Mean mid-day PPFDs following treatment applications were 507, 744.5 and 72.1 μmol m^{-2} s^{-1}, respectively for BA50, BA50+MR, and NHC (fig. 1a). Sunlight canopy penetration to ground level was 28, 42, and 5 percent of full sunlight for BA50, BA50+MR, and NHC, respectively. A one-way ANOVA detected significant differences to exist ($p = 0.003$) for treatment effects. A SNK means analysis detected significant differences to exist between all three treatments. Sunlight levels increased from lower slope to upper slope positions for all treatments (fig. 1b). A significant difference ($p = 0.02$) was detected between upper slope (527.2 μmol m^{-2} s^{-1}) and lower slope (355.3 μmol m^{-2} s^{-1}).

Regeneration

Year 3 mean oak SPA for BA50, BA50+MR, and NHC were 1,698; 3,070; and 3,340, respectively (fig. 2a). Final oak SPA numbers represented an increase from initial numbers of 1,389; 2,456; and 2,792 for BA50, BA50+MR, and NHC, respectively (table 1). Paired t-test comparisons detected a significant difference between initial versus year 3 oak SPA for BA50, BA50+MR, and NHC ($p = 0.003$, 0.008, and 0.007, student's t-test, $\alpha = 0.05$). A one-way ANOVA for year by treatment detected significant differences between years (square root transformed; $p < 0.001$). SNK means separation procedure detected significant differences between year 3 versus year 2, year 1, and initial oak SPA and year 2 versus year 1 and initial oak SPA. No differences were detected between year 1 and initial oak SPA. A one-way ANOVA established differences among treatments across years (square root transformed; $p = 0.003$). A SNK means analysis detected significant differences between year 3 BA50+MR and NHC versus all treatments by year.

Year 3, mean oak SPA for BA50 were 1,354; 279; and 65 for height classes 1, 2, and 3, respectively. This was an increase of 1,062; 148; and 38 over initial values for height classes 1, 2, and 3. Paired t-test detected significant differences between year 3 versus initial oak SPA for all three height classes in BA50 (square root transformed; $p = 0.01$, 0.04, and 0.007, $\alpha = 0.05$). Year 3 mean oak SPA for BA50+MR were 2,105; 746; and 218 for height classes 1, 2, and 3, respectively. This was an increase of 1,807; 492; and 158 over initial values for BA50+MR oak SPA (fig. 3). Paired t-test detected significant differences for all height classes between initial and year 3 values (square root transformed; $p = 0.04$, 0.03, and 0.04, $\alpha = 0.05$).

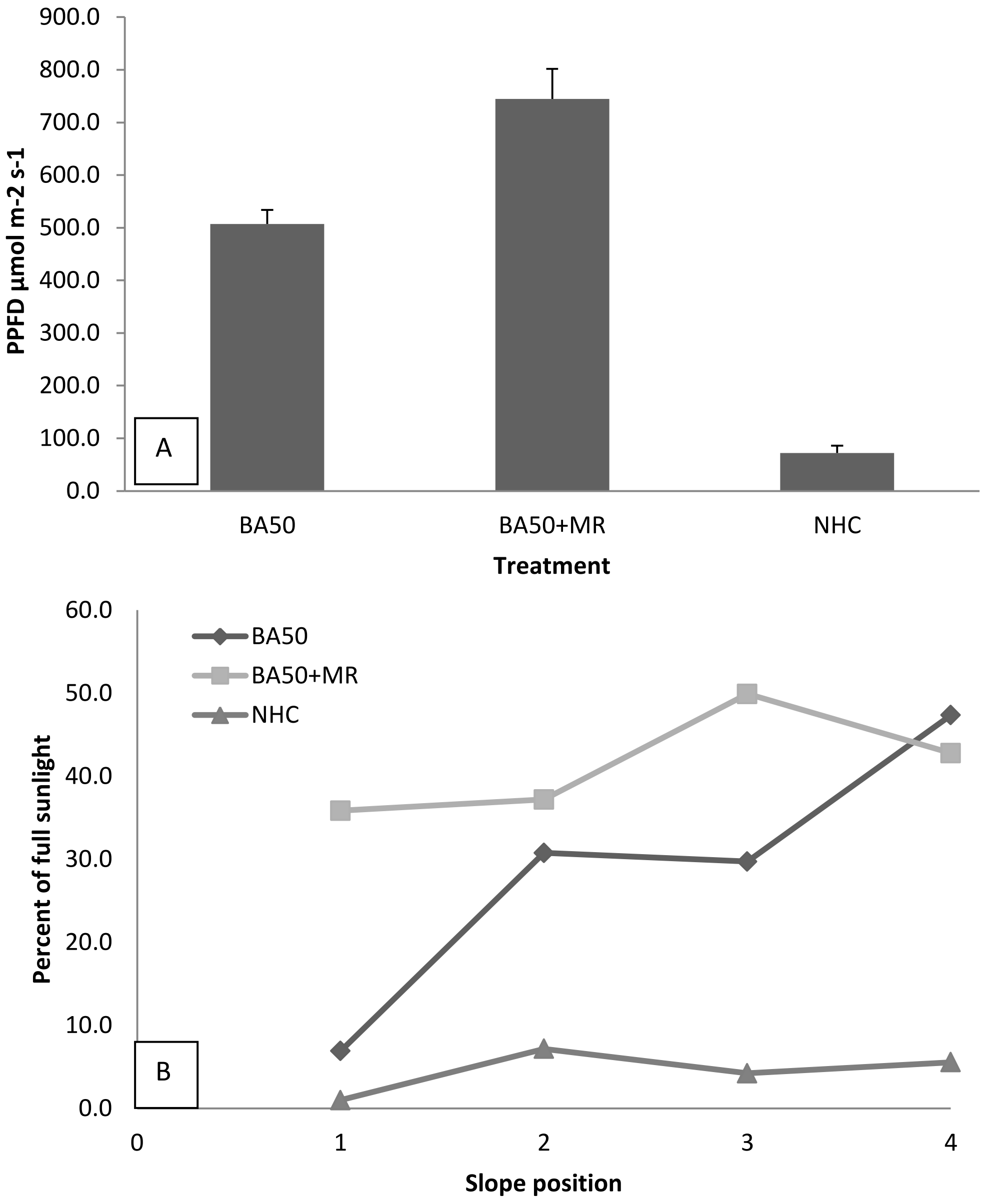

Figure 1--(A) Sunlight levels at ground level by treatment, and (B) sunlight levels at ground level by topographic position and treatment (means followed by same letter do not significantly differ at α = 0.05 using Student Newman-Kuels test

Table 1--Year 3 post-treatment versus initial oak seedlings per acre by treatment and height class. Numbers in brackets are ± SE; p values for paired t-tests at α = 0.05 are in parentheses

	BA50		BA50+MR		NHC	
Height class	Initial	Final	Initial	Final	Initial	Final
	seedlings per acre					
1	292 [59]	1,354 [367] (0.01)	298 [98]	2,105 [724] (0.04)	367 [73]	3,109 [1,018] (0.07)
2	131 [22]	279 [68] (0.04)	254 [61]	746 [164] (0.03)	119 [29]	227 [48] (0.11)
3	27 [3]	65 [34] (0.007)	60 [23]	218 [57] (0.04)	6 [4]	4 [4] (0.82)

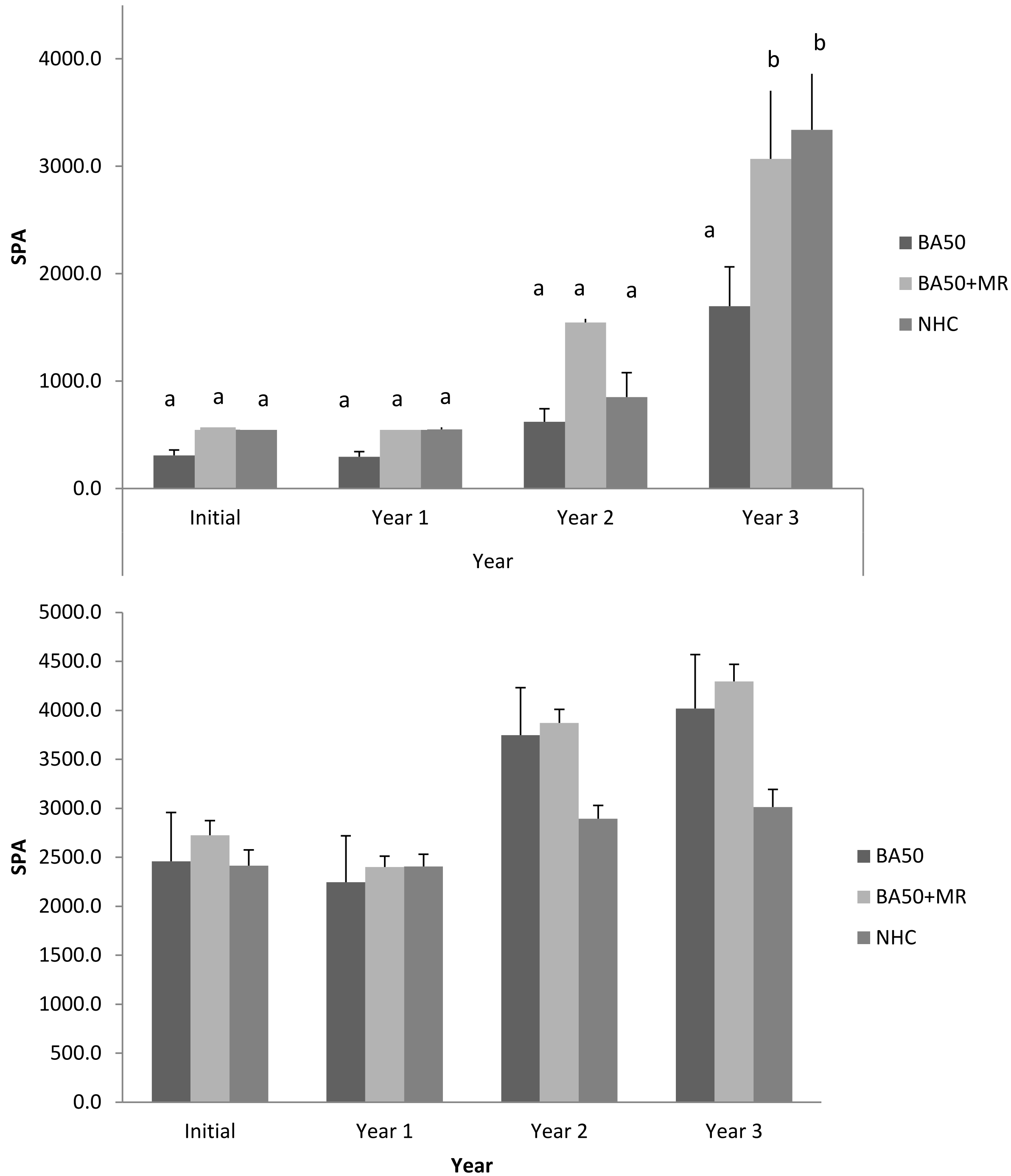

Figure 2--(A) Oak seedlings per acre by treatment by year, and (B) non-oak seedlings per acre by treatment by year (means followed by same letter do not significantly differ at $\alpha = 0.05$ using Student Newman-Kuels test.

Year 3 mean oak SPA for NHC were 3,109; 227; and 4 for height classes 1, 2, and 3, respectively. This was a change of 2,742; 108; and -2 oak SPA for height class 1, 2, and 3 in the NHC treatment. There were no significant differences found between initial versus year 3 oak SPA by height class for the NHC treatment.

Year 3 post-harvest mean non-oak SPA were 4,018; 4,296; and 3,013 for BA50, BA50+MR, and NHC treatments, respectively (fig. 2b). This was an increase in mean non-oak SPA of 1,560; 1,570; and 599 for BA50, BA50+MR, and NHC treatments, respectively. Primary non-oak species were winged elm, red maple, black cherry *(Prunus serotina* Ehrh.*),* blackgum *(Nyssa sylvatica* Marsh.*),* hickory species, and flowering dogwood. Year 3 mean non-oak SPA for BA50 were 671; 1,256; and 2,091 for height classes 1, 2 and 3, respectively. Year 3 mean non-oak SPA for BA50+MR were 892; 1,556; and 1,848 for height classes 1, 2 and 3, respectively. Year 3, mean non-oak SPA for NHC were 928; 1,130; and 955 for height classes 1, 2, and 3, respectively.

DISCUSSION

Sunlight canopy penetration to the ground level was significantly impacted by treatment. BA50+MR provided 14 percent more sunlight than BA50 and 37 percent more sunlight than the NHC treatment. BA50+MR provided light levels in the optimal range for oak seedling establishment and growth. Non-oak midstory removal in BA50+MR helped establish uniform light conditions from lower slope to upper slope. BA50 provided adequate light levels for oak seedling development. However, there was a gradient in sunlight levels from lower slope to upper slope in BA50. This effect was attributed to harvest damage to midstory trees. This resulted in areas where light conditions ranged from optimal to adequate to inadequate for oak seedling development within BA50. Sunlight levels remained inadequate for oak seedling development across all slope positions in the undisturbed stand conditions present in the NHC treatment.

Oak reproduction was also significantly impacted by treatment applications. BA50+MR provided the greatest increase in oak reproduction abundance coupled with height growth. BA50+MR increased oak reproduction in height classes 2 and 3 by 193 and 263 percent. This increase was greater than BA50, which exhibited increases of 112 and 140 percent for height class 2 and 3 oaks. The NHC treatment did have a 90 percent increase in oak reproduction in height class 2 but exhibited a 33 percent decline in height class 3. Increases in height classes 2 and 3 are of great importance because these are the seedlings that have potential to become “free to grow” and contribute to future stand stocking through recruitment into the overstory.

The NHC treatment did provide a glimpse into seedling flux in undisturbed hardwood stands. Oak reproduction remained somewhat constant from initial through year 2 post-treatment abundance numbers. However, year 3 post-treatment abundance values spiked for NHC with a total of 3,109 oak SPA, which was an increase of 2,258 oak SPA over the previous season and the highest of any treatment in year 3. The increase was attributable to a heavy white oak acorn crop observed in fall 2011 (year 2). Conventional wisdom dictates that the majority of these seedlings will not persist into the future if stand conditions remain constant.

An additional question arose as to why the influx of new seedlings was not as substantial in harvested treatments versus the NHC. The author attributes this phenomenon to two factors: (1) environmental conditions and (2) competition from non-oak competitors. Year 3 was a season with extreme temperatures and severe drought in the region. With the capacity of upland sites in the Springfield Plateau region to become very dry, the harvest areas were exposed to higher sunlight levels and temperatures compared to the NHC treatment.

Also, while partial overstory harvests and midstory removal demonstrated improved sunlight conditions for oak seedling development, there remains significant competition from non-oak reproduction, suggesting additional competition control operations such as prescribed burning, could be a beneficial additional treatment to those presented in this study.

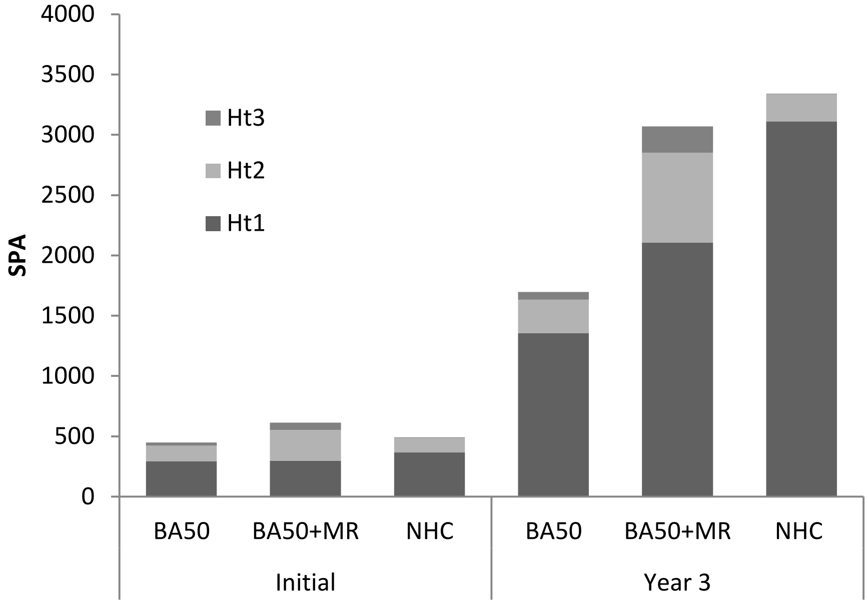

Figure 3--Oak seedlings per acre by height class and treatment for initial versus year 3 post-treatment.

CONCLUSIONS

Undisturbed stand conditions did not allow growth of oak reproduction into taller height classes, keeping them in a poor position to compete with other species. A shelterwood harvest alone (BA50) created variable sunlight conditions at ground level, with only a portion of its area exhibiting adequate sunlight for oak seedling growth and survival. Year 3 results show that a modified shelterwood, combining partial overstory and non-oak midstory removal, generated optimal sunlight conditions for oak seedling development. While the partial overstory removal coupled with midstory removal created conditions beneficial to oak seedling development, non-oak species in these environments remain strong competitors. Additional treatments, such as prescribed burning, could benefit oak reproduction.

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