THE CONUNDRUM OF CREATING UNDERSTORY LIGHT CONDITIONS CONDUCIVE TO PROMOTING OAK REPRODUCTION: MIDSTORY HERBICIDE AND PRESCRIBED FIRE TREATMENTS

Callie Jo Schweitzer and Daniel C. Dey[1]

Abstract--Challenges remain to regenerating oak (*Quercus* spp.) in eastern upland hardwood forests. It is well established that to be competitive, advance oak reproduction must be of sufficient size to respond favorably upon release. We also know altering the understory light regime, through reductions in stand stocking, basal area, or canopy cover, promotes the growth and competitiveness of small oak advance reproduction. Reductions in stand density can be accomplished by herbicide treatment of the existing midstory, prescribed fire, or harvesting. We found midstory herbicide treatment resulted in an ephemeral increase in light, from < 1 percent of full sunlight pretreatment to 15 to 20 percent post-treatment. This increase in light levels dissipated after three growing seasons. Oak seedlings responded to increased light levels but so did both sugar maple (*Acer saccharum* L.) and yellow-poplar (*Liridendron tulipifera* L.). One and two prescribed fires, implemented on a 3-year-return interval, resulted in 12 percent of full sunlight, compared to 8 percent pre-burn. Conversely, a one-time thin to 50 BA (basal area in square feet per acre) resulted in 50 percent full sun following the initial thin and burn and 37 percent after the second burn. Because these fires were repeated on a 3-year interval, the increase in light was sustained over time compared to the thin only. However, much of the growing space was occupied by aggressive red maple (*Acer rubru*m L.) sprouts after the prescribed burning.

INTRODUCTION

Maintaining or enhancing the oak (*Quercus* spp.) component in upland hardwood forests of the Cumberland Plateau and associated highlands has been a goal for generations of silviculturists. We have learned that appropriate prescriptions are site-specific and driven by the concurrent response of the oak and its competitors. Changes in cover and light are transient and will alter vegetation response, including seedling recruitment (Chiang and others 2005, Iverson and others 2004). Two prescriptions have been touted to create the desired understory conditions to promote oak, including enhanced light and reduced numbers of competitive stems: the use of an herbicide to deaden midstory non-oak species and prescribed fire. Both prescriptions have challenges in their application.

For example, herbicide use is often restricted on National Forest lands due to the public's lack of knowledge and understanding of this treatment. Further, the use of herbicide can be costly for a private landowner, as this treatment is completely non-commercial. Oak survival and growth benefit from the removal of the midstory (Janzen and Hodges 1987, Lhotka and Loewenstein 2008, Lockhart and others 2000, Loftis 1990, Lorimer and others 1994, Miller and others 2006, Motsinger and others 2010, Stringer 2005) but on productive sites, the pulse of increased light reaching the understory is ephemeral (Schweitzer and Dey 2011). Private landowners often are swayed by prescriptions that are promoted to enhance wildlife. Wang and others (2006) found that the habitat created following the deadening of the midstory in upland hardwood forests in the Mid-Cumberland Plateau was positively correlated with the use of the dead stems by bark-foraging and cavity-nesting birds. On the same sites, Felix and others (2010) found that treatments where midstory trees were deadened with herbicide had no effect on either biophysical parameters or egg mass number of amphibians. Similar treatments had no negative effect on terrestrial salamander abundance or demographics (Knapp and others 2003) or on herpetofaunal abundance, richness, or diversity (Cantrell and others 2013).

Prescribed fire in southeastern upland hardwood forests is primarily practiced on public lands, where costs and liabilities are subsidized. Fire has been promoted as a tool that will restore the oak component to upland hardwood forests (Albrecht and McCarthy 2006, Dey and Hartman 2005, Hutchinson and others 2005, Moser and others 2006 Nyland and others 1983, Van Lear and Waldrop 1989). Results from most studies suggest that prescribed burning alone, without additional disturbances involving overstory tree harvesting, will not significantly promote oak

[1]Research Forester, USDA Forest Service, Southern Research Station, Huntsville, AL 35801; and Research Forester, USDA Forest Service, Northern Research Station, Columbia, MO 65211.

Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

reproduction over the short-term (Blankenship and Arthur 2006, Hutchinson and others 2005, Signell and others 2005). Some have shown that large reductions in canopy cover followed by prescribed fire facilitated regeneration of desirable oak species (Albrecht and McCarthy 2006, Brose 2010, Brose and others 1999). A more detailed ecological understanding of the life stages of the oak genus may allow prescribed fire to be applied as a tool following a life-history gradient to enhance or sustain this species (Arthur and others 2012). Additional concerns on subsequent degrade to residual trees following fire is also receiving renewed, heightened attention (Dey and Schweitzer, in press; Smith and Sutherland 1999; Stambaugh and Guyette 2008). Fire has been documented to be beneficial to certain wildlife species. Herpetofaunal response to fire disturbance has been found to be mixed, with negligible or ephemerally positive impacts on amphibians and positive or non-measurable impacts for reptiles (Sutton and others 2013). Studies of avian communities have found prescribed fire to have no discernible impact on breeding bird composition or total population levels (Aquilani and others 2000, Artman and others 2001, Saab and others 2004).

The objectives of this study were to use results from an herbicide-midstory treatment and a prescribed fire treatment in two common Mid-Cumberland Plateau forest ecosystems, the Plateau tabletop and the Plateau slope or escarpment, to examine: (1) the temporal response of light in the understory, and (2) the response of the oak reproduction to ascertain how these prescriptions are meeting target management goals.

METHODS

Study Areas

The 180,000-acre Bankhead National Forest (BNF), in north-central Alabama, is in the Cumberland Plateau Section of the Appalachian Plateaus physiographical province (Fenneman 1938), and study stands are more specifically characterized by the Strongly Dissected Plateau subregion of the Southern Cumberland Plateau, within the Southern Appalachian Highlands (Smalley 1979). These are Plateau tabletop sites. Base age 50 site indices for loblolly pine (*Pinus taeda* L.), red oaks [northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Munchh.), and southern red oak (*Q. falcata* Michx.)], and white oaks [white oak (*Q. alba* L.) and chestnut oak (*Q. prinus* L.)] are 75 feet, 65 feet, and 65 feet, respectively (Smalley 1979). Soils are loamy, formed in residuum weathered from sandstones and conglomerates (Smalley 1979). Climate of the region is temperate with mild winters and moderately hot summers with a mean temperature of 55.4 ^{o}F and mean precipitation of 59 inches (Smalley 1979). Study stands were located on broad, flat ridges with elevations ranging from 720 to 1,220 feet above sea level. The BNF, established by proclamation in 1914, has a long history of repeated logging and soil erosion caused by poor farming practices during the Depression era. Study stands were representative of this history, with non-managed loblolly pine planted 25 to 45 years ago and substantial hardwood encroachment. There were three pine species, dominated by loblolly pine at 87 percent of the total basal area (BA), with a smaller portion of Virginia pine (*P. virginiana* Mill.) and shortleaf pine (*P. echinata* Mill.). Other species included upland oaks (chestnut oak, white oak, northern red oak, scarlet oak, black oak and southern red oak) representing 7 percent of stand BA, yellow-poplar (*Liriodendron tulipifera* L.) at 6 percent of BA, and red maple (*Acer rubrum* L.) at 2 percent of BA. Understory vegetation included flowering dogwood (*Cornus florida* L.), bigleaf magnolia (*Magnolia macrophylla* Michx.), and sourwood (*Oxydendrum arboretum* DC).

The second study area was located in Jackson County, northeastern Alabama, within the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman 1938). The site encompasses strongly dissected margins and sides of the plateau and represents Mid-Plateau escarpment sites. Slopes range from 15 to 30 percent. Upland oak site index is 75 to 80, and yellow-poplar site index is 100 [base age 50 years, Smalley Landtype 16, plateau escarpment and upper sandstone slopes and benches-north aspect (Smalley 1982)]. The area is characterized by steep slopes dissecting the Plateau surface and draining to the Tennessee River. Soils are shallow to deep, stony and gravelly loam or clay, well-drained, and formed in colluvium from those on the Plateau top (Smalley 1982). We conducted our study at two separate sites. One site with one block of treatments was located on a south, southwest-facing slope of Miller Mountain with a mean elevation of 1,600 feet. The second site was located on a north-facing slope at Jack Gap, with two blocks: one at 1,200 feet and one at 1,562 feet elevation. Dominant canopy tree species on both sites included *Quercus*, with black oak, northern red oak, white oak, and chestnut oak comprising 46 percent of pretreatment BA. Hickory (*Carya* spp.) accounted for 15 percent of the pretreatment BA, while sugar maple (*A. saccharum* Marsh.) was 13 percent and yellow-poplar 9 percent. Common understory species included flowering dogwood, eastern redbud (*Cercis canadensis* L.), and sourwood.

Study Design

The BNF study employed a randomized complete block design with a 3 by 3 factorial treatment arrangement and four replications of each treatment. For this study, we are only considering six of the total treatments: two residual basal area treatments (heavy thin leaving 50 square feet per acre and an untreated control) with three prescribed burn frequencies: frequent burns every 3 years (stands have received two burns to date), infrequent burns every 9 years (stands have received one burn to date), and an unburned control. Each treatment was replicated 4 times, for a total of 24 treatment stands. Stand size ranged from 22 to 46 acres. Treatments are representative of management practices described in the BNF's Forest Health and Restoration Project for restoring oak forests and woodlands (USDA Forest Service 2003).

Criteria for stand selection were based on species composition, stand size, and stand age. Treatment stands were at least 22 acres in size with basal areas ranging from 122 to 132 square feet per acre (table 1). Commercial thinning was conducted by marking from below smaller trees or trees that appeared diseased or damaged; canopy trees were also removed to meet target residual basal areas. Hardwoods were preferentially retained. Thinning treatments were completed prior to the initiation of the burning treatments (thinning conducted from June through December). Prescribed burning was conducted during the dormant season (January through March) using backing fires and strip head fires to ensure that only surface fire occurred.

The study design for the Jackson County study was a randomized complete block, with three replications of five treatments. Only two treatments are considered for this analysis. Each site (block) comprised one replication of five treatments established along the slope contour. Treatments were randomly assigned to 10-acre areas within each replicated block. Pretreatment basal areas ranged between 101 to 116 square feet per acre (table 2).

For the midstory herbicide treatment, Arsenal® (active ingredient imazapyr, BASF Corporation, Florham Park, N.J.) was used to deaden the midstory. Rates of application were within the range recommended by the manufacturer. Watered solutions were made in the laboratory, and trees received application via waist-level hatchet wounds using a small, handheld sprayer. One incision was made per 2.5 inch of diameter, and each incision received approximately 0.15 fluid ounces of solution. Herbicide treatments were completed in autumn 2001, prior to leaf fall. The goal was to minimize the creation of overstory canopy gaps while removing 25 percent of the basal area in the stand midstory. All injected trees were in lower canopy positions, reducing the creation of canopy gaps. All oak, ash (*Fraxinus americana* L.) and persimmon (*Diospyros virginiana* L.) stems were excluded from treatment. Three control stands were left untreated.

Field Techniques

On all study sites, we established five 0.2-acre vegetation measurement plots in each treatment stand and measured plots prior to and one growing season after treatment implementation, and again 4 to 8 years post-treatment. All plot centers were permanently marked with rebar, flagging, and GPS coordinates. We permanently tagged all trees > 5.6 inches diameter at breast height (d.b.h.) with aluminum tags. Tree distance and azimuth to plot center were

Table 1--Cumberland Plateau tabletop stands, basal area (BA in square feet per acre) and stems per acre (SPA) of trees ≥ 5.6 inches d.b.h. for six treatments, at times pre (prior to treatment), post1 (first growing season post-treatment) and post2 (first growing season post second burn or 4 years post thin and first burn)[a]

Treatment	Burn	Pre BA	Pre SPA	Post1 BA	Post1 SPA	Post2 BA	Post2 SPA
No harvest	None	131.7	265	137.5a	264a	147.3a	269a
No harvest	One	123.1	381	127.1a	275a	137.0a	277a
No harvest	Two	121.8	318	130.2a	317a	146.2a	333a
Thin to 50 BA	None	132.0	296	50.6b	86b	59.3b	90b
Thin to 50 BA	One	132.0	300	49.5b	86b	57.0b	87b
Thin to 50 BA	Two	127.5	278	50.0b	84b	56.7b	86b
p-value		0.4134	0.7131	0.0001	0.0001	0.0001	0.0001

[a]Columns containing different letters indicate significant differences at α = 0.05.

Table 2--Cumberland Plateau escarpment stands, basal area (BA in square feet per acre) and stems per acre (SPA) of trees ≥ 5.6 inches d.b.h. for five treatments at times pre (prior to treatment), post1 (first growing season post-treatment) and post2 (fourth growing season post-treatment). Treatments are control (no harvest or herbicide) and midstory herbicide treatment

Treatment	Pre BA	Pre SPA	Post1 BA	Post1 SPA	Post2 BA	Post2 SPA
Control	101.2	331	100.6	325	110.7	335
Herbicide	116.3	372	114.6	271	122.8	245
p-value	0.4668	0.4081	0.4441	0.02314	0.5002	0.2266

recorded, and we measured and recorded tree species and d.b.h. (diameter tape, to the nearest 0.1 inch). Reproduction was sampled on 0.01-acre circular plots around the same plot center. Seedlings were tallied by species in each reproduction plot by 1-foot height classes, up to 4.5-feet tall. Canopy cover was estimated using a hand-held spherical densitometer, with five measurements obtained at each plot, one 10 feet from plot center in each cardinal direction and one at plot center. Photosynthetically active radiation was measured using two synchronized ceptometers (AccuPar LP-80, Decagon Devices, Pullman, CA). One ceptometer was placed in full sunlight, and the second ceptometer was used to record light in each stand along pre-designated transects.

RESULTS AND DISCUSSION

Jackson County Midstory Herbicide Treatment

The majority of the targeted trees removed in the herbicide treatment were occupying a midstory position. To document the targeted tree response in the herbicide treatment, additional tree data were recorded for all trees 1.5 inches d.b.h. and greater on the Jackson County sites.

An average of 381 stems per acre (SPA) were treated with the herbicide, and their average d.b.h. was 2.9 inches. The BA of trees 1.5 inches d.b.h. and larger for the herbicide treatment was reduced from 115.9 square feet per acre to 86.1 square feet per acre, meeting the targeted 75 percent BA retention. Following treatment, the canopy tree BA (represented by trees > 5.6 inches d.b.h.) was not different from the control stands (table 2).

Table 3 gives the percent of full sunlight received in the understory for the month of August, for one, four and eight growing seasons post-treatment. The percent of canopy cover is also given in table 3. Only during the first growing season post-treatment was the amount of light reaching the understory in the herbicide treatment significantly greater than controls, 16.5 percent compared to 8 percent of full sunlight. By the second post-treatment growing season, light was 10 percent of full sunlight, and remained around this level for eight growing seasons post-treatment. There was no difference in the amount of overstory canopy cover, as the herbicide treatment targeted midstory trees only.

Table 3--Percentage of full sunlight received and canopy cover in the control and midstory deadened with herbicide treatments over eight growing seasons, for the month of August, Cumberland Plateau escarpment stands

	---2001 (pretreatment)---		---------2002----------		----------2004---------		----------2009---------	
	full sun	canopy cover	full sun	canopy cover	full sun	canopy cover	full sun	canopy cover
	--*percent*--							
Control	n/a[a]	99.7	8.0	96.8	3.0	98.8	5.2	97.5
Herbicide	n/a	98.3	16.5	94.6	6.3	96.2	8.3	93.4

[a]n/a = no pretreatment (2001) data collected.

The response of the reproduction cohort was assessed by looking at all oaks, yellow-poplar, sugar maple, and all other species combined. Oak in the reproduction stratrum were primarily black and white oaks, with lesser representation of northern red, scarlet and chestnut oaks. The other species category included a host of species: ash (*Fraxinus* spp. L.), basswood (*Tilia americana* L.), American beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* March.), elm (*Ulmus* spp. L.), flowering dogwood, hickory (*Carya* spp.) and sassafras [*Sassafras albidum* (Nutt.) Nees]. The number of oaks in control stands did not change over time, while the number of small oak seedlings, up to 1 foot in height, decreased appreciatively in the herbicide treatment, from 1,523 to 1,142 SPA (table 4 and fig. 1). This decrease was countered by a concurrent increase in the SPA of oak in all other size classes, as oaks increased 400 SPA in the 1- to 2-foot size class, 62 SPA in the 2- to 3-foot size class, and 10 SPA in the 3- to 4.5-foot size class (table 4 and fig. 1). Following the herbicide treatment, the number of yellow-poplar seedlings also increased, from 52 to 1,599 SPA, but after eight growing seasons this number consistently declined as the amount of light dissipated. However, the number of sugar maple stems in the three largest size categories increased, with changes of 282, 271, and 62 SPA for the 1- to 2-foot, 2- to 3-foot, and 3- to 4.5-foot height categories, respectively. Interestingly, the number of sugar maple in the understory also increased in the control stands, with a positive change of 305, 48, and 10 SPA in the same size categories, respectively.

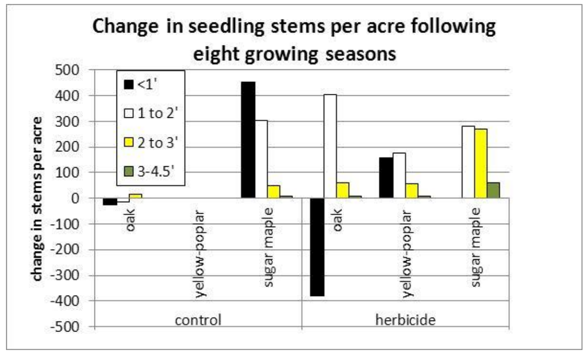

Figure 1--The change in stems per acre of oak, yellow-poplar, and sugar maple seedlings by four height classes, for Cumberland Plateau escarpment stands under untreated (control) and herbicide (removal of midstory trees using herbicide) prescriptions after eight growing seasons.

Bankhead National Forest Thinning and Burning Treatments

The BNF stand basal area and stems per acre are given in table 1. Pretreatment stand BA was dominated by loblolly pine, which accounted for 87 percent of the BA and 85 percent of the SPA. The thin to 50 BA was successfully implemented, with the majority of the removed BA comprised of pine. The prescribed burning had no effect on overstory composition and structure ($P = 0.6697$), and there were no burn by thinning interactions ($P = 0.7040$). The percent of total BA and SPA for upland oaks was 7 and 8 percent, for yellow-poplar 6 and 5 percent, and for both red maple and black cherry, 2 and 3 percent, respectively.

The percent of full sunlight received in each of the six treatments is shown in figures 2 and 3.

Table 4--Cumberland Plateau escarpment stands regeneration data, in stems per acre, by four height size classes, for all oak combined, yellow-poplar, sugar maple, and all other species combined. Year 2001 is pretreatment data

Oak	Control	2001	776	129	14	5
		2004	486	29	0	0
		2009	752	114	29	5
	Herbicide	2001	1,523	29	0	0
		2004	995	76	24	10
		2009	1,142	433	62	10
Yellow-poplar	Control	2001	0	0	0	0
		2004	205	0	0	0
		2009	0	0	0	0
	Herbicide	2001	52	10	5	0
		2004	1,599	243	5	5
		2009	209	186	62	10
Sugar maple	Control	2001	1,057	119	29	19
		2004	857	224	52	24
		2009	1,509	424	76	29
	Herbicide	2001	1,485	143	71	76
		2004	1,157	362	62	38
		2009	1,485	1,157	343	138
Other species	Control	2001	3,446	1,228	505	190
		2004	3,027	1,228	443	257
		2009	4,022	1,918	724	367
	Herbicide	2001	3,975	981	257	205
		2004	3,108	962	386	176
		2009	3,451	3,046	1,333	752

Stands that were not subjected to burning or thinning had the lowest light levels. Thinning to 50 BA resulted in at least 50 percent of full sun, compared to an average of 20 percent pre-thin. The amount of sunlight in stands that have received two burns was three times that of pre-burn levels, while the light was twice that of the pre-burn level for stands receiving only one burn. All three unthinned treatments showed light levels below 14 percent regardless of burn treatment. Pretreatment canopy cover ranged from 91.3 to 96.3 percent. Burning did not affect the canopy cover while thinning reduced canopy cover from 93 to 66 percent. After four growing seasons, the canopy cover increased to 83.3, 82.9 and 82.4 percent for the thin with no-burn, thin with one burn, and thin with two burn treatments, respectively.

The reproduction cohort was dominated by stems < 1-foot tall, with an average of 4,239 SPA in this size class among the six treatments (table 5). Small red maple seedlings (those < 1-foot tall) comprised 46 percent of the total in this size class pretreatment. Oaks were dominated by chestnut oak (29 percent of all oak regeneration tallied), white oak (26 percent), southern red oak (15 percent), and scarlet oak (14 percent). Other species of oaks tallied in the reproduction cohort included black oak, northern red oak, and post oak. Sixty-seven percent of the oak reproduction was < 1-foot tall.

Following the first treatment (thinning, burning or a combination), the oak and red maple both responded. Thinning alone increased the SPA of oak in all the larger size classes, and after four growing seasons there were 80 SPA of oak 3- to

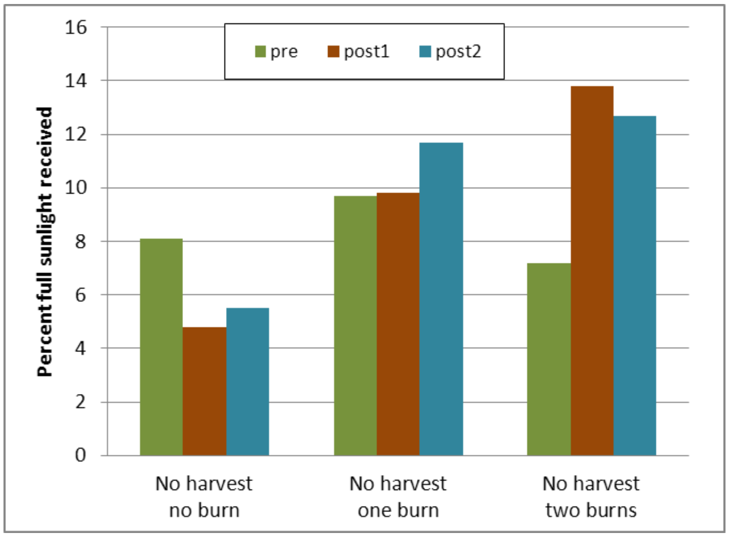

Figure 2--Percent of full sunlight received at 4.5 feet above the forest floor for Cumberland Plateau tabletop stands under three treatments. Stands were not thinned and were subjected to none, one, or two burns. Burns were conducted during the dormant season. Post1 light measurements taken in August of the first growing season and post2 measurements taken in August of the fourth growing season.

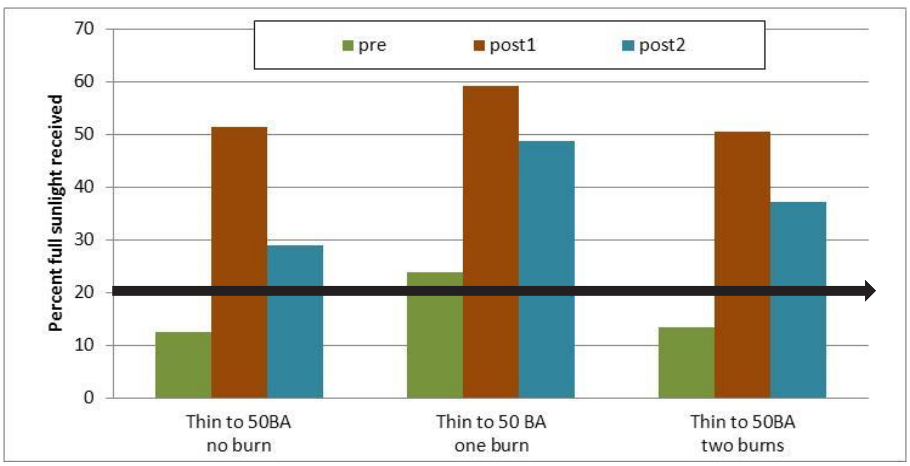

Figure 3--Percent of full sunlight received at 4.5 feet above the forest floor for Cumberland Plateau tabletop stands under three treatments. Stands were thinned to 50 square feet per acre residual basal area and were subjected to none, one, or two burns. Thinning was done in the growing season prior to the burn; burns were conducted during the dormant season. Post1 light measurements were taken in August of the first growing season, and post2 measurements were taken in August of the fourth growing season. The arrow represents the reported needed threshold of light for encouraging oak seedling growth.

4.5-feet tall (tables 5 and 6). Four growing seasons after just a single prescribed burn, oak seedlings increased by 300 SPA in the 2- to 3-foot height class; this increase was only 63 SPA when stands received two burns. Thinning alone also increased oak that was 3- to 4.5-feet tall (by 20 SPA to 80 SPA total), while there was a decline of 10 SPA following one burn and a gain of only 2 SPA in this size class after two burns. However, in concert with the increase in oak reproduction, red maple seedlings also increased in response to the thinning and burning. Red maple seedlings were lost from the < 1-foot height class following each burn. Subsequent recruitment was found in the next height class, as red maple seedlings increased by about 500 SPA in the 2- to 3-foot height class after one burn, and added about 400 SPA after two. However, a larger change was noted in the 3- to 4.5-foot height class, where red maple

Table 5--Cumberland Plateau tabletop stands regeneration data, in stems per acre, by four height size classes, for all oaks combined and red maple, for six treatments. BA is basal area in square feet per acre

	----------Treatment---------		----------------------------Seedling height class----------------------------			
Species	Harvest	Burn	Up to 1 foot	1 to 2 feet	2 to 3 feet	3 to 4.5 feet
Oak	No harvest	None	690	230	55	40
	No harvest	One	625	150	25	10
	No harvest	Two	800	235	40	0
	Thin to 50 BA	None	575	130	105	30
	Thin to 50 BA	One	845	475	155	80
	Thin to 50 BA	Two	500	163	64	46
Red maple	No harvest	None	1,975	165	110	45
	No harvest	One	2,155	240	155	75
	No harvest	Two	1,835	280	115	75
	Thin to 50 BA	None	2,160	90	40	35
	Thin to 50 BA	One	1,830	325	275	170
	Thin to 50 BA	Two	1,655	340	95	95

Table 6--Cumberland Plateau tabletop stands change in stems per acre (SPA) of seedlings by four height size classes for six treatments. Time at post1 is the first growing season post thin and first burn; time at post 2 is the first growing season post second burn (4 years post thin and first burn). BA is basal area in square feet per acre

	--------Treatment--------			------------------------Seedling height class-------------------------			
Species	Harvest	Burn	Time	Up to 1 foot	1 to 2 feet	2 to 3 feet	3 to 4.5 feet
Oak	No harvest	None	Post1	-20	-35	10	25
			Post2	20	-5	5	15
	No harvest	One	Post1	40	0	0	-5
			Post2	45	25	50	15
	No harvest	One	Post1	235	-45	-15	10
		Two	Post2	385	-30	-5	5
	Thin to 50 BA	None	Post1	26	163	30	86
			Post2	-80	68	35	20
	Thin to 50 BA	One	Post1	270	305	180	50
			Post2	285	405	300	-10
	Thin to 50 BA	One	Post1	-140	60	62	35
		Two	Post2	-272	17	63	2
Red maple	No harvest	None	Post1	-525	35	-40	15
			Post2	-280	165	-20	-15
	No harvest	One	Post1	-552	772	520	60
			Post2	65	370	285	45
	No harvest	One	Post1	66	475	266	52
		Two	Post2	401	531	351	32
	Thin to 50 BA	None	Post1	-1,540	555	500	240
			Post2	-1,185	245	175	130
	Thin to 50 BA	One	Post1	-770	890	490	175
			Post2	-795	1,150	495	55
	Thin to 50 BA	One	Post1	-889	791	573	112
		Two	Post2	-1,149	336	393	152

seedlings increased by 152 SPA to 247 SPA after two burns and added 55 SPA to total 225 large seedlings after one burn.

On more productive sites such as those found on the Cumberland Plateau escarpment, the outcome of reducing the midstory using an herbicide to increase light and allow small oak advance reproduction to grow into a more competitive position was questionable. Others have found mixed results with this prescription (Dillaway and others 2007, Gordon and others 1995, Harmer and others 2005, Janzen and Hodges 1987, Lhotka and Lowenstein 2008, Lockhart and others 2000, Loftis 1990, Lorimer and others 1994, Stringer 2005). We were able to non-commercially kill the midstory and allow an ephemeral increase in light compared to control stand conditions (Schweitzer and Dey 2011). However, the amount of light never exceeded the 20 percent threshold commonly reported in the literature as the minimal amount needed to promote oak seedling growth (Dey and others 2012, Gardiner and Hodges 1998, Gottschalk 1994, Lhotka and Lowenstein 2008, Lockhart and others 2000, Loftis 1990, Lorimer and others 1994, Motsinger and others 2010, Parker and Dey 2008, Stringer 2005). Although small oak seedlings did respond and increase SPA in the next larger height class, there was a concurrent initial response by a shade-intolerant competitor, yellow-poplar, which germinated from seed in the seed bank, with almost 1,600 seedlings per acre appearing in the second growing season post-treatment.

Additionally, the small sugar maple, those 1 to 2 inches in diameter that were not treated, also responded and soon occupied the midstory position. A compensatory increase in the larger size classes of the sugar maple reproduction also contributed to the competition for light in the understory. Sugar maple seedlings were being recruited in all size classes, in both the control and the herbicide treated stands. The canopy of these stands was dominated by sugar maple, and sugar maple was ranked first in importance value prior to any treatment (Schweitzer and Dey 2011); the importance of sugar maple dropped slightly post-herbicide treatment but was on the increase after eight growing seasons. We are not finding a notable reduction of sugar maple densities, suggesting vigorous sugar maple establishment and recruitment, unlike that found by others (Belden and Pallardy 2009, Pallardy and others 1988, Rochow 1972).

Success of this treatment will be gauged once the overstory trees are removed in the final phase of this prescription.

Combining reduced stand density prescriptions with prescribed burning to control competing vegetation has shown promise on certain sites (Albrecht and McCarthy 2006; Brose 2010; Dey and Hartman 2005; Iverson and others 2004, 2008). For those sites on the Cumberland Plateau escarpment, site characteristics may be prohibitive to the implementation of prescribed fire. Cumberland Plateau tabletop sites are more conducive to this treatment, mainly due to topography. With no stand density reduction, light levels remained below 14 percent, although following burning, there was an increase from 7 to 14 percent. Following one prescribed fire without any stand density reduction, SPA of oak seedlings in the larger size classes decreased; after two burns the response remained similar, although there was an increase of approximately 400 SPA in the smallest size class. Conversely, the effect on red maple, the primary oak competitor in these systems, was pronounced, with substantial recruitment and increases in all size classes. The fires implemented thus far have been done in January or February and are characterized as low intensity. Others have found that dormant season fires may have limited impact on light levels while encouraging sprouting of competitors (Alexander and others 2008, Green and others 2010, Hutchinson and others 2005).

Reducing stand density to 50 BA resulted in light levels increasing above the 20 percent level; burning after thinning did not impact understory light levels. On these more xeric sites, oak reproduction was abundant, but primarily < 1-foot tall. Four growing seasons post thin and one burn, oak seedlings in the 2- to 3-foot height classes increased by 700 SPA, while the same sized red maple seedlings increased by 1,600 SPA. In the largest size class, 3- to 4.5-foot tall, red maple SPA outnumbered oak seedlings by 155 SPA. Adding another burn did not change these relationships, with red maple seedlings outnumbering oak in all size classes, with 200 more SPA in the largest class. Resprouting of red maple has been noted by others following prescribed burns (Arthur and others 2012, Dey and Hartman 2005, Waldrop and others 1992), and managers are increasingly aware that using fire in hardwood systems must be more targeted

(Alexander and others 2008, Arthur and others 2012, Green and others 2010).

Research on regenerating oak has resulted in several prescriptions aimed solely at that goal. However, applying these prescriptions on a stand level and obtaining results found at plot-scale has been problematic. Managers need tools such as shelterwood harvests, thinning, and prescribed burning that can be implemented with biological and economical efficiency. Obtaining results that are predictable has remained elusive for stands located on the Mid- and Southern Cumberland Plateau. We have learned that on more productive sites, such as those on the Plateau escarpment, the increase in light levels following a midstory herbicide treatment is ephemeral. Tweaking of the prescription to target the smaller sugar maple (1 to 3 inches d.b.h.) may allow for a less transient light response as those trees would be removed and would not occupy the newly created growing space. However, removing those stems may change stand density in a manner that would enhance germination and growth of yellow-poplar. On these productive sites, light levels may not be high enough to sustain the yellow-poplar, but their competitiveness under these conditions must be taken into account. Using prescribed fire without stand density reduction was not conducive to increasing light or the number of competitive oaks. Reducing stand density alone on more xeric Plateau tabletop sites increased oak reproduction numbers; red maple also increased. Adding fire did not control the red maple competition. Changes in this prescription may include burning at the end of the dormant season/beginning of the growing season, with the expectancy of more intense fires. The conundrum remains on both mesic and xeric sites, where the intent is to reduce stand density and increase available light in the understory in order to develop competitive oak reproduction without provoking competitive species.

ACKNOWLEDGMENTS

The authors wish to thank those who contributed to the implementation of the study, data collection and management, and general assistance: Ryan Sisk, Nathan Brown, Matthew Zerbil, Nancy Bastin, USDA Forest Service, Southern Research Station; Greg Janzen, Stevenson Land Company; Allison Cochran, Kerry Clark and other employees, Bankhead National Forest; and Yong Wang, Alabama A&M University.

LITERATURE CITED

Albrecht, M.A.; McCarthy, B.C. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. Forest Ecology and Management. 226: 88-103.

Alexander, H.D.; Arthur, M.A.; Loftis, D.L.; Green, S.R. 2008. Survival and growth of upland oak and co-occurring competitor seedlings following a single and repeated prescribed fires. Forest Ecology and Management. 256: 1021-1030.

Aquilani, S.M.; LeBlanc, D.C.; Morrell, T.E. 2000. Effects of prescribed surface fires on ground- and shrub-nesting neotropical migratory birds in a mature Indiana oak forest, USA. Natural Areas Journal. 20: 317-324.

Arthur, M.A.; Alexander, H.D.; Dey, D.C. [and others]. 2012. Refining the oak-fire hypothesis for management of oak-dominated forests of the eastern United States. Journal of Forestry. 110(5): 257-266.

Artman, V.L.; Sutherland, E.K.; Downhower, D.F. 2001. Prescribed burning to restore mixed-oak communities in southern Ohio: effects on breeding-bird populations. Conservation Biology. 15: 1423-1434.

Belden, A.C.; Pallardy, S.G. 2009. Successional trends and apparent *Acer saccharum* regeneration failure in an oak-hickory forest in central Missouri, USA. Plant Ecology. 204: 305-322.

Blankenship, B.A.; Arthur, M.A. 2006. Stand structure over 9 years in burned and fire-excluded oak stands on the Cumberland Plateau, Kentucky. Forest Ecology and Management. 225: 134-145.

Brose, P.H. 2010. Long-term effects of single prescribed fires on hardwood regeneration in oak shelterwood stands. Forest Ecology and Management. 260: 1516-1524.

Brose, P.; Van Lear, D.; Cooper, R. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecology and Management. 113: 125-141.

Cantrell, A.; Wang, Y.; Schweitzer, C.; Greenberg, C. 2013. Short-term response of herpetofaunal to oak regeneration treatments on the Mid-Cumberland Plateau of southern Tennessee. Forest Ecology and Management. 295: 239-247.

Chiang, J.-M.; Arthur, M.A.; Blankenship, B.A. 2005. The effect of prescribed fire on gap fraction in an oak forest understory on the Cumberland Plateau. Journal of the Torrey Botanical Society. 132: 432-441.

Dey, D.C.; Gardiner, E.S.; Schweitzer, C.J. [and others]. 2012. Underplanting to sustain future stocking of oak (*Quercus*) in temperate deciduous forests. New Forests. 43(5-6): 955-978.

Dey, D.C.; Hartman, G. 2005. Returning fire to Ozark highland forest ecosystems: effects on advance reproduction. Forest Ecology and Management. 217: 37-53.

Dey, D.C.; Schweitzer, C.J. [In press]. Timing fire to minimize oak damage in managing oak ecosystems. In: Holley, A.G.; Haywood, J.D.; Connor, K.F., eds. Proceedings of the 17th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-xx. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station.

Dillaway, D.N.; Stringer, J.W.; Rieske, L.K. 2007. Light availability influences root carbohydrates, and potentially vigor, in white oak advance regeneration. Forest Ecology and Management. 250: 227-233.

Felix, Z.; Wang, Y.; Schweitzer, C. 2010. Effects of experimental canopy manipulation on amphibian egg deposition. Journal of Wildlife Management. 74(3): 496-503.

Fenneman, N.M. 1938. Physiography of eastern United States. New York: McGraw-Hill. 714 p.

Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108: 127-131.

Gordon, A.M.; Simpson, J.A.; Williams, P.A. 1995. Six-year response of red oak seedlings planted under a shelterwood in central Ontario. Canadian Journal of Forest Research. 25(4): 603-613.

Gottschalk, K.W. 1994. Shade, leaf growth and crown development of *Quercus rubra*, *Quercus velutina*, *Prunus serotina* and *Acer rubrum* seedlings. Tree Physiology. 14: 735-749.

Green, S.R.; Arthur, M.A.; Blankenship, B.A. 2010. Oak and red maple seedling survival and growth following periodic prescribed fire on xeric ridgetops on the Cumberland Plateau. Forest Ecology and Management. 259: 2256-2266.

Harmer, R.; Boswell, R.; Robertson, M. 2005. Survival and growth of tree seedlings in relation to change in the ground flora during natural regeneration of an oak shelterwood. Forestry. 78(1): 21-32.

Hutchinson, T.F.; Sutherland, E.K.; Yaussy, D.A. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. Forest Ecology and Management. 218: 210-228.

Iverson, L.R.; Hutchinson, T.F.; Prasad, A.M.; Peters, M.P. 2008. Thinning, fire, and oak regeneration across a heterogeneous landscape in the eastern U.S.:7-year results. Forest Ecology and Management. 255: 3035-3050.

Iverson, L.R.; Prasad, A.M.; Hutchinson, T.D. [and others]. 2004. Fire and thinning in an Ohio oak forest: grid-based analyses of fire behavior, environmental conditions, and tree regeneration across a topographic moisture gradient. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 190-197.

Janzen, G.C.; Hodges, J.D. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understory vegetation. Gen. Tech. Rep. SO-54. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Research Station: 273-278.

Knapp, S.M.; Haas, C.A.; Harpole, D.N.; Kirkpatrick, R.L. 2003. Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. Conservation Biology. 17: 752-762.

Lhotka, J.M.; Lowenstein, E.F. 2008. Effect of midstory removal on understory light availability and the 2-year response of underplanted cherrybark oak seedlings. Southern Journal of Applied Forestry. 33(4): 171-177.

Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 24: 45-50.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. Forest Science. 36(4): 917-929.

Lorimer, C.G.; Chapman, J.W.; Lanbert, W.D. 1994. Tall understory vegetation as a factor in the poor development of oak seedlings beneath mature stands. Journal of Ecology. 82(2): 227-237.

Miller, G.W.; Kochenderfer, J.N.; Fekedulegn, D.B. 2006. Influence of individual reserve trees on nearby reproduction in two-aged Appalachian hardwood stands. Forest Ecology and Management. 224: 241-251.

Moser, W.K.; Hansen, M.; McWilliams, W.; Sheffield, R. 2006. Oak composition and structure in the eastern United States. In: Dickinson, M.B., ed. Fire in eastern oak forests: delivering science to land managers. Proceedings of a conference. Gen. Tech. Rep. NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 49-61.

Motsinger, J.R.; Kabrick, J.M.; Dey, D.C. [and others]. 2010. Effect of midstory and understory removal on the establishment and development of natural and artificial pin-oak advance reproduction in bottomland forests. New Forests. 38: 195-213.

Nyland, R.D.; Abrahamson, L.P.; Adams, K.B. 1983. Use of prescribed fire for regenerating red and white oak in New York. In: America's hardwood forests - opportunities unlimited: proceedings of the 1982 Society of American Foresters national convention. Washington, DC: Society of American Foresters: 163-167.

Pallardy, S.G.; Nigh, T.A.; Garrett, H.E. 1988. Changes in forest composition in central Missouri: 1968-1982. American Midland Naturalist. 120: 380-390.

Parker, W.C.; Dey, D.C. 2008. Influence of overstory density on ecophysiology of red oak (*Quercus rubra*) and sugar maple (*Acer saccharum*) seedlings in central Ontario shelterwoods. Tree Physiology. 28: 797-804.

Rochow, J.J. 1972. A vegetational description of a mid-Missouri forest using gradient analysis techniques. American Midland Naturalist. 87: 377-396.

Saab, V.A.; Dudley, J.; Thompson, W.L. 2004. Factors influencing occupancy of nest cavities in recently burned forests. Condor. 106: 20-36.

Schweitzer, C.J.; Dey, D.C. 2011. Forest structure, composition, and tree diversity response to a gradient of regeneration harvests in the mid-Cumberland Plateau escarpment region, USA. Forest Ecology and Management. 262: 1729-1741.

Signell, S.A.; Abrams, M.D.; Hovis, J.C.; Henry, S.W. 2005. Impact of multiple fires on stand structure and tree regeneration in central Appalachian oak forests. Forest Ecology and Management. 218: 146-158.

Smalley, G.W. 1979. Classification and evaluation of forest sites on the Southern Cumberland Plateau. Gen. Tech. Rep. SO-23. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 59 p.

Smalley, G.W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans: U.S. Department of Agriculture Forest Service, Southern Research Experiment Station. 58 p.

Smith, K.T.; Sutherland, E.K. 1999. Fire-scar formation and compartmentalization in oak. Canadian Journal of Forest Research. 29: 166-171.

Stambaugh, M.; Guyette, R. 2008. Prescribed fire effects on the wood quality of three common oaks in the Ozark region, *Q. coccinea, Q. velutina, Q. alba*. Jefferson City, MO: Missouri Department of Conservation. 23 p.

Stringer, J. 2005. Oak shelterwood: how to apply the system to stimulate oak regeneration. Forest Landowner. 64: 27-29.

Sutton, W.B.; Wang, Y.; Schweitzer, C.J.; Steen, D.A. 2013. Amphibian and reptile response to thinning and prescribed burning in mixed pine-hardwood forests of northwestern Alabama, USA. Forest Ecology and Management. 295: 213-227.

USDA Forest Service. 2003. Final environmental impact statement, forest health and restoration project, National Forests in Alabama, Bankhead National Forest. Manage. Bull. R8-MB-110B. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 353 p.

Van Lear, D.H.; Waldrop, T.A. 1989. History, uses, and effects of fire in the Appalachians. Gen. Tech. Rep. SE-54. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 24 p.

Waldrop, T.A.; White, D.L.; Jones, S.M. 1992. Fire regimes for pine-grassland communities in the southeastern United States. Forest Ecology and Management. 47: 195-210.

Wang, Y.; Schweitzer, C.J.; Lesak, A.A. 2006. Response of avian bark foragers and cavity nesters to the regeneration treatments in the oak-hickory forests of north Alabama. In: Connor, K.F., ed. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 363-366.