

# RECRUITING OAK USING MIDSTORY HERBICIDE SHELTERWOOD PRESCRIPTIONS IN CUMBERLAND PLATEAU FORESTS IN ALABAMA, TENNESSEE, AND KENTUCKY

Callie J. Schweitzer



**Abstract**—I examined the implementation of a midstory herbicide treatment as the first phase in a two-phase shelterwood prescription in upland hardwood stands in Alabama, Tennessee, and Kentucky. The initial prescription for all three sites was similar: use herbicide to reduce the density of the midstory, allowing increased light to the established oak (*Quercus* spp.) reproduction. The goal was to increase understory light to at least 20 percent of full sun to promote oak seedling growth and recruitment over other species. Light was increased, but ephemeral and not to the 20-percent full sun goal. Densities of large oak seedlings [ $>4$  feet in height up to 1.5 inches diameter at breast height (dbh)] increased only on the Kentucky site, which had the most advance oak reproduction of all three sites prior to treatment. Response of competitors, including shade-tolerant sugar maple (*Acer saccharum* Marsh.), intolerant yellow-poplar (*Liriodendron tulipifera* L.), and ubiquitous red maple (*A. rubrum* L.), also responded. Treating small stems ( $<1$  inch dbh) and other tending treatments prior to overstory may be warranted to maintain oak.

## INTRODUCTION

The idea of applying the two-phase shelterwood method to recruit oak (*Quercus* spp.) reproduction into larger, competitive size classes, followed by release, is not new. In the southern upland hardwood forests, one original mention of using shelterwood prescriptions came as a result of Frothingham's (1917) study, from which he concluded that total clearing or clearing with reserves was needed for an immediate start in the shape of stocked stands of desirable species composition. He recognized the need to control light to recruit oaks into competitive positions, and recommended thinning where white oak (*Q. alba* L.) was found overtopped by black (*Q. velutina* Lamark) and scarlet oak (*Q. coccinea* Muench.). Shelterwood cutting and selection cutting were also considered, but little thought was given to present or future management of young growth or to the reproduction status and composition. From this study came the origins of managing for desired species by altering light regimes.

For researchers who have devoted careers to studying oak, an original and fundamental reference is work conducted by Clarence Korstian (1927). His earliest work was a cooperative project between the U.S. Department of Agriculture Forest Service Appalachian Forest Experiment Station and the School of Forestry at Yale. He began by saying “. . . there is little information

available upon the seed and seedling characteristics of the American oaks” (p. 7). Research by both the Forest Service Appalachian and Northeastern Forest Experiment Stations indicated that American chestnut [*Castanea dentata* (Marsh.) Borkh.] was being replaced by stands more highly stocked with various species of oak (Korstian and Stickel 1927, Leffelman and Hawley 1925). Korstian (1927) recommended natural reproduction of oak by partial harvesting or a two- or three-cut shelterwood method. His conclusions were complemented by those of Leffelman and Hawley (1925), whose work in Connecticut hardwoods also concluded that the desired reproduction (oaks) originates prior to the regeneration harvest, and was assisted in its development under shelterwood prescriptions.

Downs and McQuilkin (1944), in a seminal paper, focused on defining silviculture prescriptions for sustaining oak stands using ‘quantitative evidence,’ with emphasis on the reproduction cohort. Seeding habits, seed fate, and the amount of seed needed for adequate restocking were quantified for northern red (*Q. rubra* L.), black, scarlet, white, and chestnut oak (*Q. prinus* L.), and cutting methods were described to enhance seedling growth. They found that some form of partial cutting benefited oak reproduction as litter and canopy cover retarded acorn desiccation, partial shade lent to sapling recruitment, and oak seed sources from

Author information: Callie J. Schweitzer, Research Forester, Southern Research Station, USDA Forest Service, Huntsville, AL 35801.

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trees with healthy, well-developed crowns were plentiful. They referenced partial-cutting systems, including shelterwood and selective cutting.

In 1961, Carvell and Tryon detailed the response of oak under various environmental factors in an inclusive examination of influences to oak regeneration (Carvell and Tryon 1961). They showed that oak reproduction was best on drier sites and thus more easily maintained on those sites as opposed to moister exposures, in which myriad factors increased the competition for light, including more competition from herbaceous vegetation, shrubs, and tolerant tree species, and denser overhead canopies. The amount of sunlight in the understory was the driving factor in oak seedling abundance and subsequent recruitment into the larger size classes. They concluded that the ability of oak reproduction to persist was more related to environmental conditions than its ability to become established, as overstory seed sources were abundant and understory conditions were not retarding germination. Finally, they suggested a series of thinnings during the last years of a stand's rotation to get light to the small seedlings, allowing those seedlings to grow into a more competitive position, prior to overstory removal.

Tall (4.5 feet in height) oak reproduction was shown to have a high potential to compete successfully in a new stand (Sander 1972). To grow seedlings into larger size classes, Sander (1979) prescribed a shelterwood system in which the overstory density was reduced to not <60 percent, and understory stems larger than the oaks were selectively herbicided, followed by a 10-year growth period. Overstory removal was to be done when the stand had 430 stems per acre (SPA) of oak >4.5 feet tall (Sander 1979). In shelterwood prescriptions examined by McGee (1975) and Loftis (1983), the first cut to residual basal areas of 66 square feet per acre or 33 square feet per acre, followed 15 years later by all overstory stem removal, resulted in the same species composition as clearcutting. Loftis (1983) suggested an initial phase I reduction of density to be minimal to prevent high sunlight levels and stimulation of yellow-poplar (*Liriodendron tulipifera* L.) germination and growth, coupled with an herbicide treatment targeting midstory stratum trees to prevent their resprouting after final harvest. A combination of the shelterwood method with site preparation to control understory competition and allow oak to grow before complete overstory removal was also proposed (Johnson and others 1989). Essentially this work evolved into the two-phase shelterwood prescription, in which 20 percent of the basal area is reduced from below using herbicides 10 years prior to final harvest, to enhance growth of oak over other woody competitors (Dey 1996, Kass and Boyette 1998, Loftis 1990a, Lorimer and others 1994, Parker and Dey 2008, Schlesinger and others 1993, Schuler and Miller 1995).

Recruiting oak in the regeneration process has become the focus of much oak-hardwood silviculture. In upland hardwood systems in the eastern United States, there remains sufficient seed source (sexually mature oak trees) to provide seed for germination and establishment. The challenge now is to introduce a series of disturbances that will favor environmental conditions, especially light, conducive to oak growth response, over competing trees. This is essentially the shelterwood prescription touted to regenerate oaks that is still under examination today (Brose and others 2008; Craig and others 2014; Hutchinson and others 2016; Janzen and Hodges 1987; Lockhart and others 2000; Loftis 1990b; Miller and others 2014, 2017; Parrott and others 2012; Schweitzer and Dey 2011, 2017) and that was first proposed by Leffelman and Hawley (1925) and Korstian (1927).

I examined the implementation of the midstory herbicide as the first phase in a two-phase shelterwood in upland hardwood stands in Alabama, Tennessee, and Kentucky. The initial prescription for all three sites was similar: use herbicide to reduce the density of the midstory, allowing increased light to the established oak reproduction. The goal was to recruit the small oak reproduction into larger sizes classes enhancing their competitive status at the time of residual overstory removal. This paper reviews the initial response of the reproduction for all three sites, gives response following phase II for the Alabama sites, and details changes in the prescription for both the Tennessee and Kentucky sites based on preliminary results.

## SITES AND METHODS

All three study locations were within the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman 1938), and each site had three to six replications, with stand sizes from 10 to 36 acres. All sites had replicated control stands. The Alabama study was conducted in mature upland hardwood forested sites located at the southern end of the mid-Cumberland Plateau in northeastern Jackson County, AL, on State lands managed by the Alabama Department of Natural Resources and Conservation. The area was classed into the Cliff section of the Cumberland Plateau in the Mixed Mesophytic Forest region by Braun (1950) and the Eastern Broadleaf Forest (Oceanic) province and Northern Cumberland Plateau section by Bailey (1995). The area is characterized by steep slopes dissecting the plateau surface and draining to the Tennessee River. Stands were located on the escarpment between 1,245 and 1,667 feet elevation. Upland oak site index was 75 to 80 feet, and yellow-poplar site index was 100 feet (base age 50 years) (Smalley 1982). 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). Climate of the region is temperate with mild winters and



moderately hot summers; mean annual temperature is 55 °F, and mean annual precipitation is 59 inches (Smalley 1982).

The midstory-herbicide shelterwood prescription was implemented in two phases. The phase I goal was to retain 75 percent of the basal area by removing midstory stems. In 2001, the stands were treated using an herbicide (Arsenal®, active ingredient imazapyr) by means of the tree injection technique to deaden the midstory. Rates of application were within the range recommended by the manufacturer. Aqueous solutions were made in the laboratory, and then trees received application via waist-level hatchet wounds using a small, handheld sprayer. One incision was made per 3 inches of diameter, and each incision received approximately 0.15 fluid ounce of solution. Herbicide treatments were completed in autumn 2001, before 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 [diameter at breast height (dbh) range of 1.5 to 10.5 inches; average dbh of treated stems was 2.9 inches], reducing the creation of canopy gaps.

Stands on average had 120.6 square feet per acre of basal area and 320 stems per acre for all stems >1.5 inches dbh. Canopies were dominated by oaks (black, northern red, white, and chestnut), yellow-poplar, hickories (*Carya* spp.), and sugar maple (*Acer saccharum* Marsh.), with a lesser proportion of ash (*Fraxinus* spp.) and blackgum (*Nyssa sylvatica* Marsh.) (Schweitzer and Dey 2011). Depending on the site, dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* DC.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), and eastern redbud (*Cercis canadensis* L.) were common understory species. Herbicide was applied to 202 SPA of trees ≥1.5–10.5 inches dbh. Basal area removed in this treatment was 19.4 square feet per acre, or 16.1 percent of the total. Nine species were targeted in the herbicide treatment. *A. rubrum* L. was the primary species for removal (56 SPA treated), followed by sugar maple (53 SPA treated) and blackgum (40 SPA treated).

Phase II was implemented in 2010 after eight growing seasons. Phase II was the release or final harvest. Merchantable trees, primarily those ≥5.5 inches dbh, were removed through chainsaw felling and grapple skidding (Schweitzer and Dey 2017).

The Tennessee study site was located on the mid-Cumberland Plateau in Grundy County, in southern Tennessee, on private timber industry lands managed by Stevenson Land Company. The elevation of the site is approximately 1,279–1,804 feet above sea level. The site is just east of the Eastern Highland rim in a true plateau with strongly dissected margins (Smalley 1982), and in the Cliff section of Mixed Mesophytic Forest region

(Braun 1950). The site index is 75–80 feet for upland oak and 100 feet for yellow-poplar (Smalley 1982). Soil is deep and well drained, consisting of 30–75 percent rocky slopes on the escarpment and classified as Bouldin series, a stony loam formed in colluviums weathered from interbedded sandstone, siltstone, and shale (U.S. Department of Agriculture Natural Resources Conservation Service 2007). The climate is characterized by long, hot summers while winters are mild and short (Smalley 1982). The average date of last freeze is in mid-April, and the average date of the first freeze occurs in mid- to late October. The annual precipitation average is approximately 50 inches.

Midstory trees (1.0–11.0 inches dbh) were deadened using a triclopyr herbicide solution (Garlon® 3A) injected using the hack and squirt method. Rates and application instructions were as described by the label: the herbicide was diluted with water and applied at 0.03 ounce (1 ml) per cut, with one cut per inch of diameter. The initial treatment in 2008 did not kill targeted midstory trees and was successfully reapplied in the fall/winter of 2009. Small stems (1.0–1.5 inches dbh) were severed or scraped with a hatchet and the cut surface treated.

The dominant overstory trees at the site include yellow-poplar, sugar maple, white oak, pignut hickory (*Carya glabra* Sweet), and northern red oak (Cantrell and others 2013). The stands on average had a basal area of 119.7 square feet per acre and a density of 306 SPA (trees >1.5 inches dbh). Herbicided trees totaled 207 SPA, averaging 3.6 inches dbh. After treatment, there were 182 residual SPA; deadened basal area totaled 12.3 square feet per acre. The majority of the treated trees were sugar maple (89 SPA), followed by 8 SPA of blackgum, 5 SPA of red maple, and 5 SPA of basswood (*Tilia glabra* Vent.). Remaining treated stems (2 or 3 SPA) were beech (*Fagus grandifolia* Ehrh.), black locust (*Robinia pseudoacacia* L.), eastern red bud, flowering dogwood, pignut hickory, red hickory (*C. ovalis* Sarg.), sassafras [*Sassafras albidum* (Nutt.) Nees.], and red maple.

The Kentucky study area is located on the Cold Hill Area of the London Ranger District of the Daniel Boone National Forest (DBNF), under federal jurisdiction. The treatment stands are described by Smalley (1986) as the Rugged Eastern Area of the Northern Cumberland Plateau, with mixed oak and oak-hickory forest communities mingled with mixed mesophytic forests (Braun 1950). All treatment stands were located on broad ridges. Soils on the study sites are predominantly silt loams belonging to the Latham, Shelocta, and Whitley soil series (Smalley 1986). Site indices for upland oaks are 50–65 feet on subxeric sites (McNab and others 2002, Smalley 1986). Treatment stands were relatively similar prior to treatment and uniform within stand boundaries, and are best described as upland hardwood forests dominated by oak species. The stands have



been subjected to various silvicultural treatments, including harvesting and prescribed burning, since the National Forest acquired the land, but the stands are representative of fully stocked upland hardwood forests on the Cumberland Plateau.

An herbicide was used to remove the midstory, with treatment applied between October 2008 and March 2009. Undesirable tree species <3 inches dbh were treated with a thin line basal bark treatment using triclopyr ester (Garlon® 4). Trees >3 inches dbh in the midstories and understories were treated with a stem injection method using triclopyr amine (Garlon® 3A). Application rates followed labeling directions.

The forest type on the study sites predominantly comprised white oak, scarlet oak, black oak, and red maple. For all stems with dbh  $\geq 1.5$  inches, basal area changed from 100.0 square feet per acre pretreatment to 85.8 square feet per acre posttreatment, and SPA changed from 333 pretreatment to 139 posttreatment. We herbicide-treated, on average, 176 SPA that had an average dbh of 3.0 inches and a range of dbh of 1.6 to 9.1 inches. Of the 176 SPA treated with herbicide, 106 were red maple, 13 were yellow-poplar, and the rest included blackgum, sourwood, sassafras, bigleaf magnolia (*Magnolia macrophylla* Michx.), and serviceberry [*Amelanchier aborea* (Michx. f. Fern.)]. The residual stands comprised primarily oaks, hickories, and red maple, with a lesser component of shortleaf pine (*Pinus echinata* Mill.), yellow-poplar, sourwood, and flowering dogwood (Schweitzer and others 2011).

### Field Techniques

Prior to treatment, measurement plots were systematically located in each treatment area. Plot centers were permanently marked with a 2-foot piece of reinforcing steel, and GPS coordinates were recorded. Using the plot center, all trees were monumented (distance and azimuth measured and recorded from plot center, each tree tagged with a numbered aluminum tag) and species and dbh recorded. Each site differed slightly with regard to overstory and midstory survey plot size, but all plots were fixed radius circular plots. The Alabama site had concentric plots of 0.2 acre for overstory (>5.6 inches dbh) and 0.025 acre for midstory ( $\geq 1.5$  inches dbh). The Tennessee site's overstory plots were 0.125 acre and midstory plots were 0.02 acre; plots were also concentric. The Kentucky site used one 0.1-acre plot for both overstory and midstory trees. For the reproduction, all woody vegetation was sampled on 0.01-acre circular plots, located at plot center for Alabama and Tennessee sites, and offset 14 feet from plot center in Kentucky. All reproduction was tallied by species by 1-foot height classes up to 4.5 feet tall; large seedlings were recorded as those >4.5 feet tall up to 1.5 inches dbh. Trees >1.5 inches dbh were tallied by

diameter. Reproduction tallies were truncated at 25 for each species on each plot.

To determine how much of full sunlight was penetrating the canopy and reaching the seedling layer through the residual stand structure, I measured photosynthetically active radiation ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ ) in the understory and compared those values to measurements taken simultaneously in full sunlight. I used two AccuPar Linear Par Ceptometers, Model PAR-80 (Decagon Devices Inc., Pullman, WA). Measurements with one ceptometer were taken at 4.5 feet above the forest floor at each plot center and along transects equally dissecting each plot. Measurements with the second ceptometer were taken in completely open conditions adjacent to each stand. By matching two simultaneous readings, I could take into account some variation caused by changes in cloud cover. 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.

## RESULTS

### Canopy Cover and Understory Light

Canopy cover for the Alabama site was 99.8 percent pretreatment, and slowly declined to 94.0 percent eight growing seasons posttreatment (fig. 1). The percent of full sunlight reaching the forest floor was not measured pretreatment for this site; however, in the first two growing seasons posttreatment, the measured light was 16.7 and 17.1 percent, compared to 8 and 6.4 percent for control stands. By the third growing season, understory light was 6.2 percent, and ranged from 6.2 to 10.0 percent during the next 5 years of measurement. These same trends, with an initial but ephemeral increase in light coupled with a slight decrease in canopy cover, were also found for the Tennessee and Kentucky sites (fig. 1). Light measurements on the Kentucky site for the control stands showed that light was <5 percent of full ambient light under these closed canopies (Grayson and others 2012).

### Reproduction Composition and Structure

On the Alabama site, the reproduction cohort had 32 species and averaged 9,214 SPA (table 1). Seventy-six percent of the stems were  $\leq 1$  foot tall, 19 percent were >1 foot to 4.5 feet tall, and 4 percent were >4.5 feet tall-1.5 inches dbh. For all reproduction sizes, 22.1 percent were sugar maple, 19.5 percent were oaks [black, chinkapin (*Q. muehlenbergii* Englem.), chestnut, northern red, white], 9.4 percent were red maple, 4 percent were hickories [mockernut (*C. tomentosa* Nutt.), red, shagbark (*C. ovata* K. Koch.)], 2.9 percent were ash, and 1 percent were yellow-poplar. The 46 percent of species in the other category included future canopy species such as beech, blackgum, cucumber tree (*M. acuminata* L.),



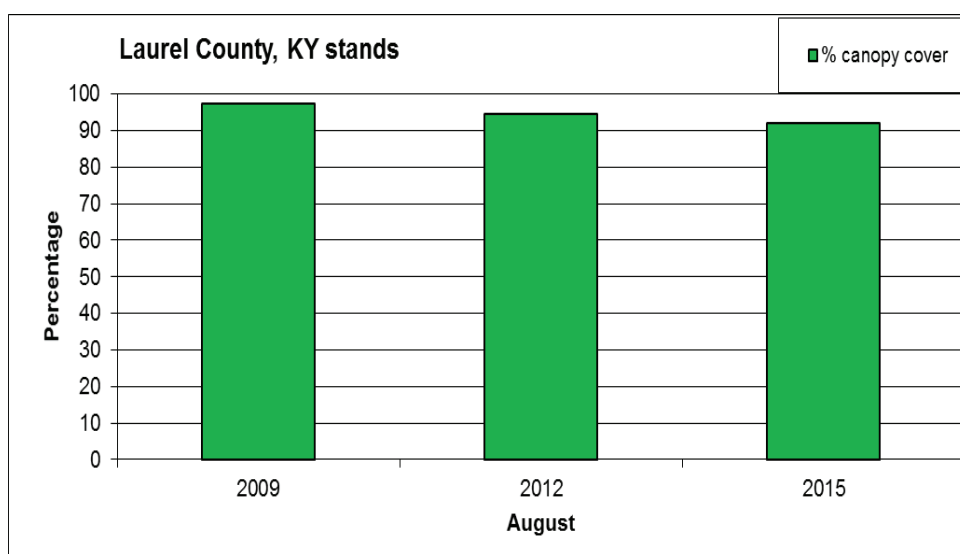
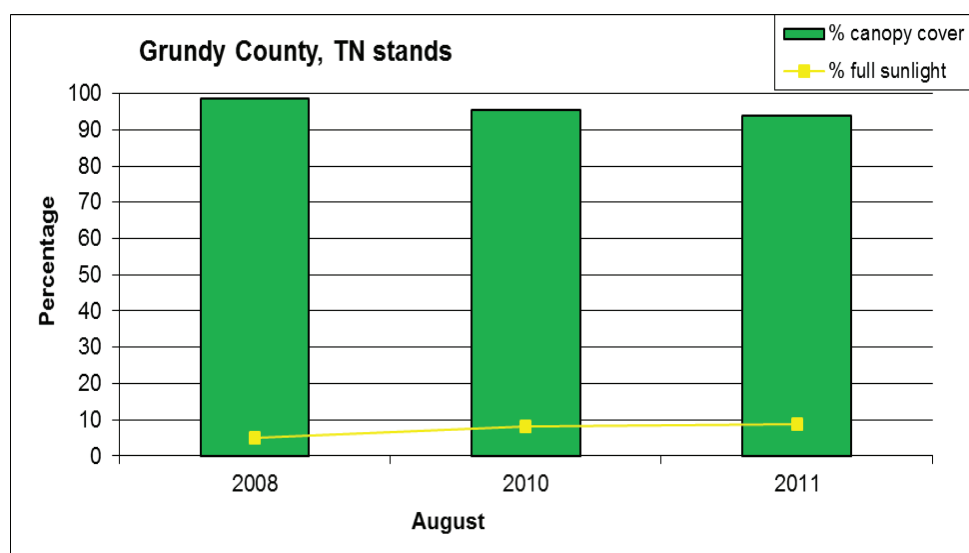
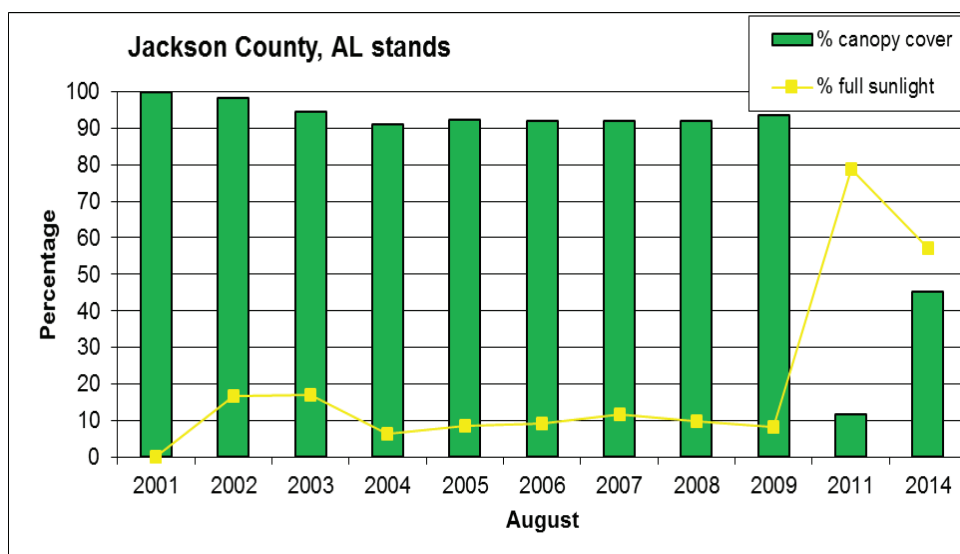


Figure 1—Percent canopy cover and understory light measured in August for three sites subjected to a midstory herbicide shelterwood treatment; no light was recorded for the Kentucky site. The first bar for each graph represents pretreatment levels.



**Table 1—Stems per acre of reproduction by species and size class for pretreatment (pre) and 5 years following a midstory herbicide shelterwood treatment (post) for stands in Jackson County, AL**

|               | <1 ft |       | 1–4.5 ft |       | 4.5 ft–1.5 in dbh |      | Total |        |
|---------------|-------|-------|----------|-------|-------------------|------|-------|--------|
|               | Pre   | Post  | Pre      | Post  | Pre               | Post | Pre   | Post   |
| All spp.      | 7,038 | 6,319 | 1,776    | 3,352 | 400               | 729  | 9,214 | 10,400 |
| Oak spp.      | 1,524 | 748   | 29       | 105   | 0                 | 0    | 1,552 | 852    |
| Yellow-poplar | 52    | 943   | 14       | 524   | 0                 | 43   | 67    | 1,510  |
| Ash           | 181   | 724   | 33       | 119   | 14                | 10   | 229   | 852    |
| Hickory spp.  | 333   | 295   | 24       | 24    | 5                 | 5    | 362   | 324    |
| Sugar maple   | 1,486 | 1,495 | 290      | 429   | 110               | 133  | 1,886 | 2,057  |
| Red maple     | 805   | 881   | 52       | 138   | 10                | 10   | 867   | 1,029  |
| Other spp.    | 2,657 | 1,233 | 1,333    | 2,014 | 262               | 529  | 4,252 | 3,776  |

sassafras, and sourwood, and midstory stratum species including blackhaw (*Viburnum prunifolium* L.), Carolina buckthorn, eastern hophornbeam (*Ostrya virginiana* K. Koch.), eastern redbud, flowering dogwood, *Viburnum* species, and *Vaccinium* species. These species dominated all size classes and were 65–78 percent of the >1-foot tallies. Pretreatment oaks were 1,524 SPA, and 21.7 percent of these oaks were in the <1-foot-tall height class. There were 29 SPA of oak in the >1-foot to ≤2-feet size class, and none in any other size class. On the Alabama sites, sugar maple reproduction was prevalent in all size classes, with 1,486 SPA in the <1-foot size class, 290 SPA in the >1-foot to 4.5-feet class, and 110 SPA >4.5 feet tall up to 1.5 inches dbh (table 1).

After five growing seasons post-midstory herbicide, the shift in the reproduction cohort was pronounced, and for most species there was recruitment into larger size classes (table 1). Yellow-poplar had the largest increase of 1,443 SPA, representing a 13 percent change in the proportion of the total density. All size classes of yellow-poplar accrued seedlings and represented 14.5 percent of the regeneration cohort. Ash seedlings also increased to 8.2 percent of the cohort, and SPA increased in all size classes. Sugar maple seedlings continued to comprise a significant component of the seedling pool, representing 9.8 percent of the total seedling density and 18 percent of the largest size class. Sugar maple seedlings in the >3–4.5-feet size class declined by 33 SPA, as these stems recruited into the next and largest size class, which increased from 110 to 133 SPA. Oak seedling densities declined by 700 SPA; the majority of this loss was in the <1-foot-tall size class, and there was recruitment of oak into the >1-foot to ≤2-feet and >2-feet to ≤3-feet size classes. No oak recruited into the largest size class.

Phase II on the Alabama site was implemented in 2010 after eight growing seasons. Phase II was the release

or final harvest. Merchantable trees, primarily those ≥5.5 inches dbh, were removed through chainsaw felling and grapple skidding. After the harvest, the stands had 14.5 square feet per acre of basal area and 19 SPA. Four years after the final harvest, the species composition of larger stems in the stands was scant; only two species, eastern redbud and ash, provided any structure for stems >1.5 inches. The species of residual stems after the final harvest were red hickory, beech, ash, black cherry (*Prunus serotina* Ehrh.), and black locust. The red hickory was the largest diameter tallied at 11.5 inches dbh; the other stems were all ≤4.0 inches dbh. Four years after the final harvest, total oak densities were 914 SPA. Thirty-three percent of total oak stems were in the largest size class, which represented a change from none before treatment to 300 SPA following four growing seasons after the final harvest. In 2014, yellow-poplar had the greatest number of SPA in the largest seedling size class at 995 SPA. In 2009, just prior to overstory removal, there were 500 SPA of yellow-poplar, with a gradient of stems across the seedling size classes; 42 percent were in the ≤1-foot-tall size class, 37 percent were >1 foot to ≤2 feet tall, 12 percent were >2 feet to ≤3 feet tall, and 9 percent were >3 feet to ≤1.5 inches dbh. In 2014, we found no differences for yellow-poplar tallies between the midstory shelterwood treatment and the clearcut (cut in 2010 also). In the clearcut, 75 percent of the total 2,376 SPA of yellow-poplar were in the largest seedling size class, and in shelterwood, 50 percent of the 1,986 SPA were in the largest size class (Schweitzer and Dey 2017).

Reproduction species richness for the Tennessee location included 41 species; oaks included black, chinkapin, chestnut, northern red, scarlet, and white oak. Hickories included bitternut (*C. cordiformis* K. Koch.), pignut, red, shagbark, and mockernut, and the site had similar ‘other’ canopy species and midstory species to the Alabama site. The reproduction in the



Tennessee stands was dominated by sugar maple, which represented 29.9 percent of the cohort. Sugar maple densities were 2,639 SPA, with 1,291 <1 foot tall, 437 ≥1 foot tall to 4.5 feet tall, and 369 SPA 4.5 feet tall to 1.5 inches dbh (table 2). There were few stems in the larger size classes of any other species except those grouped in the other category. Ash seedling densities totaled 1,007, with the majority in the smallest size class (863 SPA), 134 SPA >1 foot to 4.5 feet tall, and 10 SPA in the largest size class. Oaks were greatest in the smallest size class at 646 SPA, with 60 SPA >1 foot to ≤3 feet tall. There were no oaks in the larger seedling size classes.

After only two growing seasons, the largest change in the portion of total seedling densities by species was for yellow-poplar, which increased 3.1 percent. Yellow-poplar densities increased from 27 to 324 SPA, with the largest increase in the smallest size class (from 3 SPA

pretreatment to 297 posttreatment) and a concurrent increase from 5 to 12 SPA in the largest size class (table 2). The reproduction cohort remained dominated by sugar maple, which increased by 1,304 SPA in the smallest size class, but decreased by 259 SPA in the largest size class. Oak total seedling densities declined from 706 to 608 SPA; however only the smallest sizes declined, with recruitment of these stems into larger size classes. Oak seedling classes >3 feet to 4.5 feet tall and 4.5 feet-1.5 inches dbh each had 3 SPA accrual.

Stands on the DBNF in Kentucky had 38 species tallied in the understory, with 6 oaks [white, scarlet, southern red (*Q. falcata* Michx.), chestnut, northern red, and black] and 2 hickories (pignut and mockernut). The regeneration cohort was dominated by red maple (3,957 SPA, 31.2 percent of the total) and oaks (2,753 SPA, 21.5 percent of the total). Red maple seedlings were dominant across all size classes (table 3). Oak



**Table 2—Stems per acre of reproduction by species and size class for pretreatment (pre) and 2 years following a midstory herbicide shelterwood treatment (post) for stands in Grundy County, TN**

|               | <1 ft |       | 1–4.5 ft |       | 4.5 ft–1.5 in dbh |      | Total |       |
|---------------|-------|-------|----------|-------|-------------------|------|-------|-------|
|               | Pre   | Post  | Pre      | Post  | Pre               | Post | Pre   | Post  |
| All spp.      | 4,798 | 5,860 | 1,642    | 2,953 | 633               | 359  | 7,027 | 9,172 |
| Oak spp.      | 646   | 543   | 60       | 62    | 0                 | 3    | 706   | 608   |
| Yellow-poplar | 3     | 297   | 18       | 15    | 5                 | 12   | 27    | 324   |
| Ash           | 863   | 1,027 | 134      | 220   | 10                | 22   | 1,007 | 1,269 |
| Hickory spp.  | 426   | 554   | 50       | 65    | 2                 | 2    | 478   | 621   |
| Sugar maple   | 1,291 | 1,595 | 438      | 1,189 | 369               | 110  | 2,098 | 2,894 |
| Red maple     | 140   | 180   | 60       | 167   | 2                 | 0    | 202   | 347   |
| Other spp.    | 1,428 | 1,663 | 965      | 1,234 | 245               | 210  | 2,639 | 3,108 |

**Table 3—Stems per acre of reproduction by species and size class for pretreatment (pre) and 5 years following a midstory herbicide shelterwood treatment (post) for stands in Laurel County, TN**

|               | <1 ft |        | 1–4.5 ft |       | 4.5 ft–1.5 in dbh |       | Total  |        |
|---------------|-------|--------|----------|-------|-------------------|-------|--------|--------|
|               | Pre   | Post   | Pre      | Post  | Pre               | Post  | Pre    | Post   |
| All spp.      | 7,973 | 17,060 | 3,633    | 0     | 1,080             | 2,428 | 12,687 | 26,111 |
| Oak spp.      | 2,077 | 2,821  | 613      | 556   | 43                | 163   | 2,733  | 4,179  |
| Yellow-poplar | 200   | 77     | 120      | 3,260 | 67                | 117   | 387    | 256    |
| Ash           | 27    | 17     | 13       | 63    | 3                 | 10    | 43     | 47     |
| Hickory spp.  | 467   | 456    | 447      | 20    | 120               | 220   | 1,033  | 1,232  |
| Sugar maple   | 0     | 0      | 0        | 1,528 | 0                 | 0     | 0      | 0      |
| Red maple     | 2,187 | 11,245 | 1,277    | 0     | 493               | 1,375 | 3,957  | 15,881 |
| Other spp.    | 3,017 | 2,444  | 1,163    | 6,623 | 353               | 543   | 4,533  | 4,515  |

seedlings were highest in the smallest size class (2,077 SPA), but oaks were well distributed across all seedling size classes, and there were 614 SPA of oaks >1 foot to 4.5 feet tall and 43 SPA in the largest size class. Hickory reproduction was 8 percent of the cohort, with seedlings distributed among all size classes. Ash seedlings were scant and small, and there was no sugar maple on this site.

After five growing seasons, red maple seedlings increased by 29.6 percent, with an increase of 882 SPA in the largest size class. Red maple seedlings dominated all size classes and doubled or more in their densities in each size class (table 3). The remaining non-oak and oak groups also increased (table 3). Oaks increased across all size classes, and recruitment of oak into the largest seedling sizes was 120 SPA, resulting in a total of 163 SPA of large oak seedlings; the next largest size, >3 feet to 4.5 feet tall, also increased, from 37 to 180 SPA. Yellow-poplar seedling densities declined across all sizes, and hickories increased across all sizes, with the greatest increase for hickories in the largest seedling sizes.

## DISCUSSION

The midstory oak shelterwood prescription is predicated on altering light in the understory to create conditions more conducive to oak growth and subsequent recruitment into larger seedling size classes over other co-occurring species. For most stands, where oak remains in the overstory, oak reproduction exists, although it is small in stature and low in density. Because sites differ greatly in their understory species composition, primarily due to inherent site characteristics and past stand disturbance regimes, the response of the oak, coupled with the concurrent response of competing woody vegetation, will differ. Oak is easier to regenerate on xeric than mesic sites (Carvell and Tryon 1961, Weitzman and Trimble 1957), and the range of light conditions favorable to oak seedling growth is narrower on mesic sites (Hodges and Gardiner 1993).

It has been well-established that light is the primary driver in the oak recruitment conundrum, and that an increase in understory light up to at least 20 percent of full sunlight is imperative. This is the minimum level and was a goal for these studies because of the concern over stimulating yellow-poplar with any increase in light. Kramer and Decker (1944) and Ferrell (1953) were early reporters of the need to increase light in the understory to promote oak; their collective recommendations were to increase light up to one-third of full sunlight. Suggestions to increase light during the last years of rotation were made by Downs and McQuilken (1944), Weitzman and Trimble (1957), Scholz and DeVriend (1957), Tryon and Carvell (1958), and McGee (1975). Light availability in studies of midstory removal at phase I of a shelterwood prescription have been reported at

10–20 percent of full sun (Dey and others 2012, Lhotka and Loewenstein 2009, Lorimer and others 1994, Miller and others 2004, Schweitzer and Dey 2011). Gottschalk (1985) identified the optimal range of light to grow understory oak at 40-percent reduction of basal area with an increased understory light of 20 percent, with a caveat of caution that the use of a midstory shelterwood was not promising to favor oak over black cherry and red maple. Ostrom and Loewenstein (2006) removed the midstory in a mesic Piedmont forest in Georgia and found that light only increased to 10 percent of full sunlight, and midstory removal in a bottomland hardwood forest in Missouri increased light to 15 percent (Motsinger and others 2010). In Kentucky, understory light evaluated immediately after midstory herbicide treatment was 10 percent of full light, and was 14 percent 7 years later (Parrott and others 2012). Also in Kentucky, a removal of 20 percent of the basal area from below in an upland hardwood stand resulted in an increase of light from 4 to 18.5 percent of full sunlight (Craig and others 2014).

The challenge is altering light enough to stimulate growth, but not so much that shade-intolerant, or other, species respond more favorably than oak. This response is dependent on the species composition and competitive status within each stand.

Deadening the midstory allowed an ephemeral increase in light to the understory. Overstory canopy cover was not changed, but growing space was created in the midstory stratum. On the Alabama site, competition was from shade-intolerant yellow-poplar, which came in as new seedlings, and shade-intolerant sugar maple. The response of yellow-poplar to high light conditions was one driver behind using a midstory shelterwood to promote oak (Beck and Hooper 1986; Loftis 1978, 1983, 1990a). Because the understory sugar maple that was <1.5 inches dbh was not treated, these residual stems took full advantage of the opened growing space and quickly occupied the midstory (Schweitzer and Dey 2015). Hutchinson and others (2016) also found that lack of herbicide treatment for small shade-tolerant species (blackgum and sourwood) resulted in their impediment to oak response. This compensatory increase in the larger size class of sugar maple, or other shade-tolerant species, contributed to the competition for light in the understory. As with Hutchinson and others' study (2016) germination and establishment of yellow-poplar seedlings also occurred, but on the Alabama site by the 9<sup>th</sup> growing season, they began to decline from a high of 18 percent of the total reproduction cohort to 4 percent. Tolerant sugar maple soon shaded out less tolerant ash and yellow-poplar seedlings (Sander and Williamson 1957) and increased most under heavy crown cover (Hannah 1991). However, there were 40 SPA of large yellow-poplar seedlings at the time of overstory removal. Prior to overstory removal in phase II, there were



250 SPA of sugar maple in the largest size class and only 7 oaks. The competition from both yellow-poplar and sugar maple most likely deterred oak from recruiting into greater numbers into the largest size class (Schweitzer and Dey 2016).

The Tennessee study was implemented after the Alabama site, and the prescription was slightly altered to treat more of the smaller understory sugar maple. Tweaking the prescription to target the smaller sugar maple (1–3 inches dbh) may facilitate a less transient light response as these trees would be removed and thus unable to occupy any newly created growing space. On productive sites, however, caution is needed as this may enhance germination and growth of yellow-poplar. On these productive sites, light levels in the understory may not be high enough to sustain the yellow-poplar, but their competitiveness under these conditions must be considered. Although the increase in understory light was small, recruitment into larger size classes was found for all species, and sugar maple once again dominated the reproduction cohort. This dense population of sugar maple will essentially shade the understory and prevent the recruitment of oak into larger sizes.

In Kentucky, the sites were slightly different, located more on xeric, broad ridges. These sites had the greatest potential for recruiting oak because of lower site quality (Carvell and Tryon 1961) and high densities of oak reproduction. The treatment did not increase light above a threshold 20 percent of full sunlight level (Grayson and others 2012). However, there was an increase in the density and proportion of larger seedlings for oak, hickory, and red maple. Other studies on similar sites in Kentucky have found that red maple can be competitive with oaks after some disturbance (Arthur and others 1997, Lhotka 2012, Tift and Fajvan 1999), and Parrott and others (2012) found red maple comprised 57 percent of the reproduction stems and were most abundant in larger size classes 7 years after a midstory treatment. In order to maintain the stocking of oak, the Kentucky study stands will receive a site preparation herbicide treatment prior to overstory removal (Clatterbuck and Armel 2011, Hutchinson and others 2016). A shelterwood with reserves regeneration harvest retaining 10 to 15 square feet per acre basal area is scheduled for phase II. Pre-harvest site preparation via herbicide treatment of the red maple stems will be implemented 2 years prior to the harvest. Herbicide (imazapyr) will be applied to the cut surface of red maple stems using a backpack sprayer or spray bottles.

## CONCLUSION

Regeneration success cannot be determined until after the parent stand has been removed. Under most stand conditions, oak reproduction lacks adequacy in size and number, and intense manipulation will be required

to recruit oak into larger size classes and promote the highest probability of retaining oak dominance in the next stand. Competition and differential growth rates among species in mixed species stands drive future stand composition. The theory of shade tolerance predicts that growth of species with differing tolerances must intersect at some point of moderate light intensity. The midstory shelterwood prescription using herbicide to deaden midstory trees is predicated on finding this optimal point. Removing trees from the lower (mid) canopy layers as the first phase will provide favorable light conditions to grow and recruit oak into larger sizes. Timing this treatment with a good acorn crop increases the potential for recruitment. Consideration of lingering small shade-tolerant species must be done and if a threat of their recruitment is present, those small stems should be also be treated along with midstory stems. Depending on site conditions and species composition, a 5- to 10-year growth response period should be allowed, reproduction status assessed, and a cleaning of undesirable stems performed if warranted. The number and size of desirable oak stems are dependent on site and ownership goals, but error given towards larger and more being better. A final overstory removal to release oak is imperative to complete the process.

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