FIRST-YEAR EFFECTS OF SHELTERWOOD CUTTING, WILDLIFE THINNING, AND PRESCRIBED BURNING ON OAK REGENERATION AND COMPETITORS IN TENNESSEE OAK-HICKORY FORESTS

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Abstract—Oak regeneration has declined significantly over the past century in many regions of the United States. Prescribed burning, herbicides, and cutting are all potentially viable methods of favoring oak regeneration by removing competitors, but evaluation of these methods in all regions of the Eastern United States is incomplete. We compared effects of four treatments on oak regeneration and competitors: Shelterwood cutting, wildlife thinning using herbicide, wildlife thinning using herbicide combined with prescribed burning, and prescribed burning with no overstory treatment. Light, soil moisture, herbs, shrubs, woody reproduction, and overstory structure were measured to quantify treatment effects. Shelterwood harvests and wildlife thinnings significantly increased light availability and reduced overstory and midstory cover. Prescribed fire significantly increased the density of oak seedlings and sprouts < 10 cm tall. Prescribed fire also reduced the density of red maple regeneration, but significantly increased the density of sassafras and yellow-poplar regeneration.

INTRODUCTION

Eighty-nine percent of Tennessee's 14.1 million acres of forestland is classified as hardwood forest with 45 percent of the hardwood timber volume comprised of oak (*Quercus* spp.) (Schweitzer 2000). Nationally, oak ecosystems occupy 114 million acres and provide habitat for more than 75 associated tree species and 230 species of wildlife (Rogers and others 1993). Certain oak species form a cornerstone of the forest products industry in Tennessee and the remainder of the United States. In addition to oak timber, oak ecosystems provide a number of recreation opportunities, including bird watching, hunting, hiking, and camping. The net economic impact of oak ecosystems is difficult to estimate but exceeds that of oak timber alone.

Due to the high ecological and economic importance of oak, the current failure of oak species to regenerate across the Eastern United States has attracted considerable attention. It is widely held that oak regeneration failures represent a prominent silvicultural problem (Van Lear 1990). Upland oak species are generally favored by disturbance such as periodic fire (Abrams 1992), and much of the oak-dominated forest we have today developed following disturbances such as clearing land for agriculture, burning, and logging in the late 19th and early 20th centuries (Clark 1993, Crow 1988). As oak stands originating after these disturbances have matured and developed dense canopies, species such as maple (*Acer* spp.) and beech (*Fagus* spp.) that are more shade tolerant and fire intolerant than oak have begun to dominate the understory and middlestory (Abrams 1992). Complete canopy removal tends to release these tolerant species and hasten the replacement of oak. Yellow-poplar (*Liriodendron tulipifera*) is also less tolerant of fire than oak and can be a significant competitor in large openings created by harvests (Loftis 1990). Past research suggests that oak regeneration failures are more common on high-quality sites where competitors such as yellow-poplar and red maple (*A. rubrum*) have a competitive advantage over oaks (Oak 1993). Oak regeneration is often more successful on poor-quality sites, where large root systems and other adaptations to drought give oak the advantage over these competitors (Abrams 1990).

The effects of most disturbances in the forest, including fire, are to increase light availability, reduce competition, and increase the growing space for oaks. Although oaks are intermediate in tolerance of shade, prolonged shading can lead to seedling mortality (Crow 1988). Carvell and Tryon (1961) indicated that of all the environmental factors at a particular site, light intensity was most strongly correlated with the density of oak seedlings, and that oak regeneration was more abundant on disturbed sites than undisturbed sites. Other factors, such as soil moisture and nutrient levels, can also significantly impact seedling establishment (Crow 1988).

A wide range of mechanical, chemical, and prescribed burning methods are available for removing overstory and middlestory stems to reduce competition and increase the survival and growth of oak in the understory. Shelterwood and shelterwood-burn techniques for facilitating the regeneration of oak species have been investigated and show promise (Brose and others 1999, Keyser and others 1996, Loftis 1990). Several studies have indicated that prescribed fire is a valuable tool for controlling less fire-tolerant competitors (Barnes and Van Lear 1998, Huddle and Pallardy 1999). An alternative method to overstory removal via harvesting is the use of herbicides. The girdling and treating of individual trees with herbicides reduces competitive effects of the overstory and midstory vegetation layers, without the level of soil disturbance associated with logging. Herbicides, when applied as recommended by the manufacturer, generally do not have significant effects on the environment and efficiently increase light and growing space for vegetation (Morrison and Meslow 1983).

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In 2001, we examined the initial, first-year effects of several potentially interacting factors on oak regeneration in a study designed to compare the effectiveness of shelterwood cutting, wildlife thinning using herbicide, wildlife thinning using herbicide combined with prescribed burning, and prescribed burning alone for improving oak regeneration and wildlife habitat.

Specific objectives of this research were to (1) evaluate the effectiveness of shelterwood cutting and wildlife thinning with herbicide for increasing oak regeneration success; (2) test the hypothesis that prescribed fire enhances the positive effects of these treatments on oak regeneration; and (3) establish the impact of all treatment combinations on potential competitors of regenerating oaks.

METHODS

Study Area

This study was conducted at Chuck Swan State Forest and Wildlife Management Area in eastern Tennessee, a 9,700-ha peninsula in Norris Lake co-managed by the Tennessee Division of Forestry and the Tennessee Wildlife Resources Agency for timber production and recreation such as hunting, hiking, and wildlife viewing.

The primary cover type of Chuck Swan is mixed hardwoods. Predominant species include white oak (*Q. alba*), chestnut oak (*Q. montana*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), blackgum (*Nyssa sylvatica*), red maple, and yellow-poplar. The terrain of Chuck Swan is hilly with elevations ranging from 305 m to over 488 m above sea level. Temperatures on the area range from a yearly average high of 20.4 °C to a yearly average low of 7.9 °C. The area receives approximately 1193.8 mm of rain per year (NCDC 2001). Soils were Ultisols of three series: Fullerton, Bodine, and Clarksville (Soil Survey Division 2002).

Four 9.7-ha stands on moderately productive sites were delineated for study. Site index was approximately 20 m for oak at base age 50 (Personal communication. Darren Bailey. 2002. Forester, Chuck Swan State Forest, 3476 Sharps Chapel Road, Sharps Chapel, TN 37866). All study sites were located on northwest aspects, with slopes averaging 24 to 30 percent. All stands were comprised of mixed (oak-hickory) hardwoods with a small component of pine.

Treatments

Five different treatments and a control were implemented for this study. The treatments were a prescribed burn alone with no overstory treatment, shelterwood harvest unburned, shelterwood harvest with prescribed burning, wildlife thinning using herbicides, and wildlife thinning using herbicides combined with prescribed burning. The shelterwood-burn treatment (Brose and others 1999) will be burned in 2005 and is currently incomplete. Each treatment was randomly assigned to a 0.81-ha cell. Two cells in each stand received each treatment. The shelterwood-cutting treatment was assigned to four cells in each stand, with two cells scheduled to be burned in 2005 to complete the shelterwood-burn treatment. The data from the two shelterwood treatments were analyzed separately to maintain a balanced design, although no significant differences between these treatments were expected.

The wildlife thinnings were designed to enhance habitat and food production for wildlife with no timber production concerns considered. Trees that were marked to be treated were species of lesser benefit to wildlife, such as red maple and yellow-poplar. A target residual basal area of 11.5 m^2 per ha was established. In cases where overstory oaks occurred in high density, some oaks had to be treated to achieve the target basal area. Trees selected for removal were treated with Garlon 3A® after they were either girdled with a chainsaw or hatchet, or felled. As recommended by the manufacturer's representative, Garlon 3A® was applied in a 50/50 mixture with water to treat all cut surfaces on girdled trees and stumps. No trees or debris were removed from the site. All stands were treated in late February to early March 2001.

Prescribed burning was conducted on the uncut-burn and wildlife thinning with prescribed burning treatments in April 2001. No precipitation occurred within 3 days of the burn in any stand. The average high temperature during the burns was 25 °C and the average low was 10 °C. Relative humidity on the burn days averaged 54 to 66 percent. Fire intensity was estimated based on average flame lengths. Flame lengths for most burned areas averaged 1 m.

The shelterwood harvests were completed between June 19 and July 20, 2001. Timber marking was carried out based on timber production and regeneration goals. The goal of the harvest was to have a residual basal area of approximately 11.5 m^2 per ha. Trees that were left were of good quality, as vigorous as possible, and of good form. Whenever possible, oak stems were left as residual stems. Species removed included American beech (*Fagus grandifolia*), red maple, sassafras (*Sassafras albidum*), and hickory (*Carya* spp.). Harvesting was completed by a contract logging crew.

Measurements

Pre- and posttreatment data were collected in August and September 2000 and 2001, respectively. Three permanent sampling plots were established within each 0.81-ha treatment cell. To prevent edge effect and measurement overlap, each plot was at least 30.5m from the cell edge and at least 30.5 m from another plot.

Herb species and cover were recorded in each sampling plot using a line-intercept method. Three transects, each 11.3 m long, were established radially around plot center on bearings of 0, 120, and 240 degrees. A measuring tape was stretched along the length of each transect. Wherever an herbaceous plant intersected the tape, its coverage of the tape was recorded to the nearest centimeter for calculation of percent cover. Woody regeneration was tallied using a 3.6-m radius circular plot. Within this plot, all woody stems 140 cm tall and shorter were counted. The count was organized by species and height class. Two height classes were used: stems less than 10 cm tall, and those 10 cm to 140 cm tall. Woody saplings were tallied within a 5.7-m radius circular plot. All woody stems greater than 140 cm tall and up to 11.4 cm in diameter at breast height (d.b.h.) were tallied. The data were collected by species.

Overstory tree data were obtained within an 11.3-m radius circular plot. Tree diameter and species were recorded for trees larger than 11.4 cm in d.b.h. Overstory basal area was calculated from the diameter measurements of overstory trees.

Canopy cover was estimated with a handheld spherical densiometer (Forest Densiometers Inc., Bartlesville, OK) in 2001. Readings were taken at points 5.6 m from plot center in each of the four cardinal directions. Four measurements were taken at each of these four sampling points, one in each cardinal direction. This method resulted in a total of 16 measurements per plot.

Measurements of photosynthetically active radiation (PAR), the wavelength increment of light that plants use to conduct photosynthesis, were taken with an AccuPAR Ceptometer (Decagon Devices Inc.; Pullman, WA). Measurements were taken in September 2001 along the same three transects used for herbaceous measurements. Measurements were taken at plot center and at the midpoint and endpoint of each transect. Two measurements were taken at each point. One measurement was taken at 32.5 cm above the ground to measure light at the level of small seedlings and herbs. The other measurement was taken at approximately 100 cm above ground to measure light at the sapling and shrub level. Seven measurements were taken at each sampling plot for each height, resulting in a total of 21 samples in each treatment cell. Reference measurements were taken in the open just before and after sampling in the stands to calculate percent full PAR at each measurement point. Light measurements were taken on cloudless days from 10:00 a.m. until 2:00 p.m. to minimize effects of low-sun angles.

Soil-moisture measurements were collected over 2 days in October 2001. No measurable precipitation had occurred within 4 days of the measurements. Percent volumetric soil moisture was measured using a Trase TDR soil-moisture probe (Soil Moisture Equipment Corp; Goleta, CA). One measurement was taken at each plot center, totaling three per treatment cell.

Data Analysis

Means for each plot were calculated and analyzed using Analysis of Variance General Linear Model (GLM) procedure; (SAS Institute 2000). Class variables used were stand and treatment. The GLM procedure tested for differences between stands and treatments using the stand-treatment interaction as an error term to account for variation between stands with $\alpha = 0.05$. Means were separated using Tukey's mean separation technique with $\alpha = 0.05$. Data found to be nonnormal in distribution were transformed by taking natural logarithms. Means presented in the results are calculated from the raw data.

RESULTS

As expected, significant differences in canopy cover were detected among treatments ($P = 0.0001$) (fig. 1). Increased overstory removal decreased canopy cover. Prescribed burning also affected canopy cover, either by further

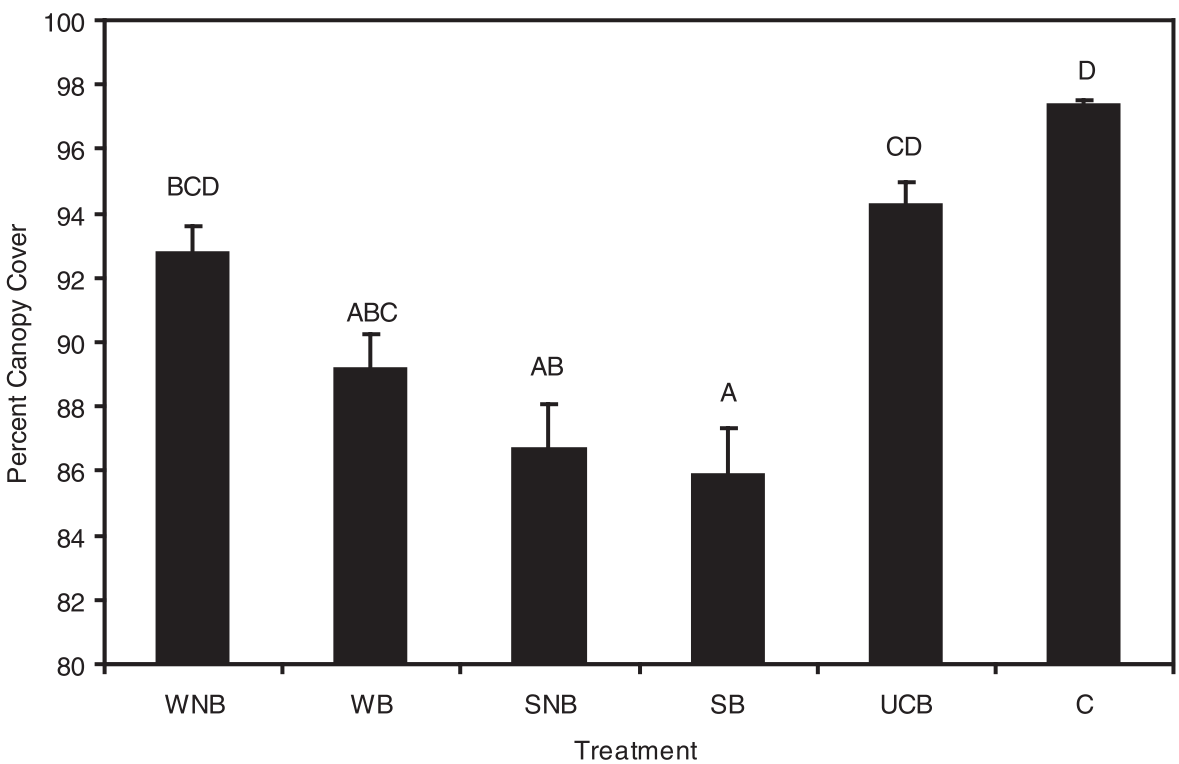

Figure 1—Percent canopy cover by treatment. Error bars represent one standard error beyond the mean. Means with similar letters are not significantly different. If no letters are present for a particular set of means, no statistically significant separation was found. SB = Shelterwood Cut Designated to be Burned; SNB = Shelterwood Cut Designated to Remain Unburned; WB = Wildlife Thinning Prescribed Burned; WNB = Wildlife Thinning Unburned; UCB = Uncut Prescribed Burned; C = Control.

reducing levels of cover when combined with the herbicide treatments or by reducing cover to a lesser degree when used alone.

Significant differences in PAR levels at 100 cm above the ground were detected between treatments (*P* = 0.0001) (fig. 2). The control had significantly lower PAR availability than all other treatments. Any cell that received a treatment exhibited increased levels of light (PAR) availability over the control. A similar pattern occurred in measurements taken at 30.5 cm above the ground, although these PAR levels were slightly lower than PAR at 100 cm above the ground across all treatments. Differences in PAR availability at 30.5 cm between treatments were very significant (*P* = 0.0001). The control had significantly lower PAR at this height than any other treatment except the uncut burned treatment. The uncut burned treatment had significantly lower light levels than the shelterwood treatment designated for burning. Any treatment involving overstory removal increased light (PAR) availability.

There were no significant differences in percent soil moisture between treatments (*P* = 0.2264). Mean percent soil moisture ranged from 12.8 to 16.03 percent.

Density of chestnut oak regeneration under 10 cm tall differed significantly among treatments (*P* = 0.0334) (table 1). Tukey's mean separation showed that the prescribed burned wildlife thinning had significantly more chestnut oak stems per ha than the shelterwood cut not to be burned. The raw means indicated that the control and the uncut burned areas had more chestnut oak stems than the prescribed burned wildlife thinning. There were no significant differences in the density of chestnut oak regeneration over 10 cm tall between treatments (*P* = 0.1011).

Red oaks, including northern red (*Q. rubra*), black, and scarlet oaks, were analyzed as a group. The number of red oak stems per ha less than 10 cm tall did not significantly differ between treatments (*P* = 0.1795) (table 1). The means, though not significantly different, indicate differences between the burned and unburned treatments, with more stems less than 10 cm tall occurring in burned areas. No significant differences between treatments (*P* = 0.1511) were found in the number of red oak stems per ha over 10 cm tall. However, fewer red oak stems over 10 cm tall were found in treatments involving prescribed burning. The shelterwood treatments also exhibited some loss of red oak stems greater than 10 cm tall.

No significant differences between treatments were found in white oak stems per ha less than 10 cm tall (*P* = 0.0964) (table 1). However, the means indicate that nearly 9 times more white oak stems under 10 cm tall were present in prescribed burned treatments than in unburned treatment. Between treatment differences in white oak stems per ha over 10 cm tall were marginally significant (*P* = 0.0529). The unburned wildlife thinning had significantly more white oak stems over 10 cm tall than the prescribed burned wildlife thinning. Burning significantly reduced the density of white oak stems greater than 10 cm tall.

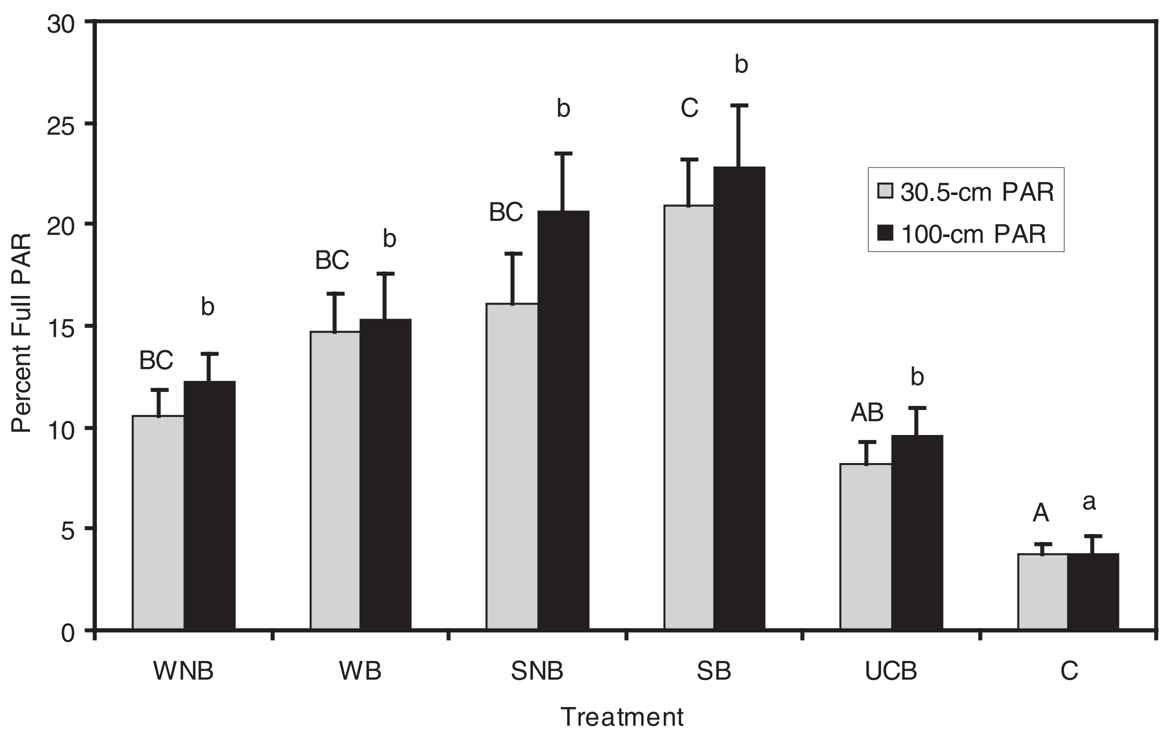

Figure 2—Percent full PAR by treatment. Error bars, significant differences, and treatment codes as in figure 1. Lower case letters were used for 1 m PAR and capital letters were used for 30.5 cm PAR.

Table 1—Mean density of woody regeneration under 1.4 m tall per ha by treatment and species

Species	Height	Treatment C	UCB	WNB	WB	SNB	SB
	cm						
Chestnut Oak	10-140	16 237	3 174	10 913	6 317	4 330	4 586
	< 10	3 286ab	4 484ab	2 395ab	2 600a	921b	1 986ab
Red Oaks	10-140	1 290	2 918	3 686	1 054	983	2 293
	< 10	235	1 065	461	543	123	512
White Oak	10-140	1 003ab	532ab	1 463a	430b	829ab	543ab
	< 10	184	5 242	584	6 849	113	778
Red Maple	10-140	31 583	17 752	29 464	15 428	23 905	20 291
	< 10	21 222	16 155	26 648	11 538	13 657	15 418
Sassafras	10-140	2 027	8 835	4 505	21 386	1 904	2 867
	< 10	717	23 086	829	47 912	737	2 631
Yellow-Poplar	10-140	410	1 884	1 014	3 634	1 044	942
	< 10	184a	31 664a	635ab	25 860a	307b	225ab

C = control; UCB = uncut prescribed burned; WNB = wildlife thinning unburned; WB = wildlife thinning prescribed burned; SNB = shelterwood cut designated to remain unburned; SB = shelterwood cut designated to be burned.
Densities with the same letters are not significantly different between treatments. If no letters are present, no statistically significant differences were found.

Before and after treatments, oak saplings greater than 140 cm tall but less than 11.4 cm in d.b.h. were exceedingly rare and highly variable in distribution across the study area, which precluded statistical analysis of the density of oak in this size class. The virtual absence of large oak saplings highlights the lack of oak regeneration success in the area.

Two of the major competitors of oak regeneration, yellow-poplar and sassafras, showed posttreatment increases in the density of stems under 10 cm tall (table 1). Significant posttreatment differences were detected in the density of yellow-poplar stems per ha under 10 cm tall ($P = 0.0041$). The prescribed burned wildlife thinning and the uncut burned treatment had significantly more yellow-poplar stems under 10 cm tall than the shelterwood cut to remain unburned and the control. This increase far exceeded the number of yellow-poplar stems present before burning that could have produced post burn sprouts. Thus, prescribed burning significantly increased yellow-poplar density. Density of yellow-poplar stems over 10 cm tall differed significantly between treatments ($P = 0.0279$). Tukey's mean separation did not find any differences, however, between treatments. Pre- and posttreatment means indicate prescribed burning increased the density of yellow-poplar in this size class as well. The uncut burned treatment and prescribed burned wildlife thinning had significantly more sassafras stems less than 10 cm tall than in any other treatment. Posttreatment differences in sassafras stems per ha greater than 10 cm tall were marginally significant ($P = 0.0553$). Sassafras over 10 cm tall was most abundant in prescribed burned treatments.

Red maple regeneration under 10 cm tall did not significantly differ between treatments ($P = 0.0879$) (table 1). However, means indicate that any treatment involving site disturbance or prescribed burning reduced red maple density relative to pretreatment densities, whereas red maple density in the control increased. Differences in red maple stem density over 10 cm tall between treatments were also not significantly different ($P = 0.1769$). However, a reduction in the density of red maple greater than 10 cm tall can be observed in the prescribed-burned and shelterwood-cut treatments in contrast to the control when comparing pre- and posttreatment means.

No significant differences in percent cover of herbs were found between treatments ($P = 0.0929$) (fig. 3). Mean herb cover of sampling plots ranged from 2.29 to 8.30 percent. Similarly, no significant differences were detected in the number of herbaceous species per plot between treatments ($P = 0.1774$). No new exotic plants were found. However, two new species colonized some of the treatment areas. Pokeweed-(*Phytolacca americana*) colonized areas where the soil had been disturbed by logging machines and fireweed (*Erechtites hieracifolia*) primarily colonized cells that were prescribed burned, though some individuals also appeared in the shelterwood-treatment cells.

SUMMARY AND CONCLUSIONS

The first objective of the research was to evaluate and compare the effectiveness of the shelterwood harvests and wildlife thinnings in terms of their ability to increase the success of oak regeneration. It was difficult to detect significant differences in the density of oak regeneration due to high variability in the distribution of oak stems within and between stands. In addition, the short period of time between treatment installation and measurement of the stands makes it difficult to arrive at definitive conclusions. However, patterns can be detected, and both treatments reduced the number of oak stems over 10 cm tall and generally increased the number of oak stems under 10 cm tall. Individuals in the 10-cm and taller size class were top-killed by fire and cutting, and sprouts from these individuals

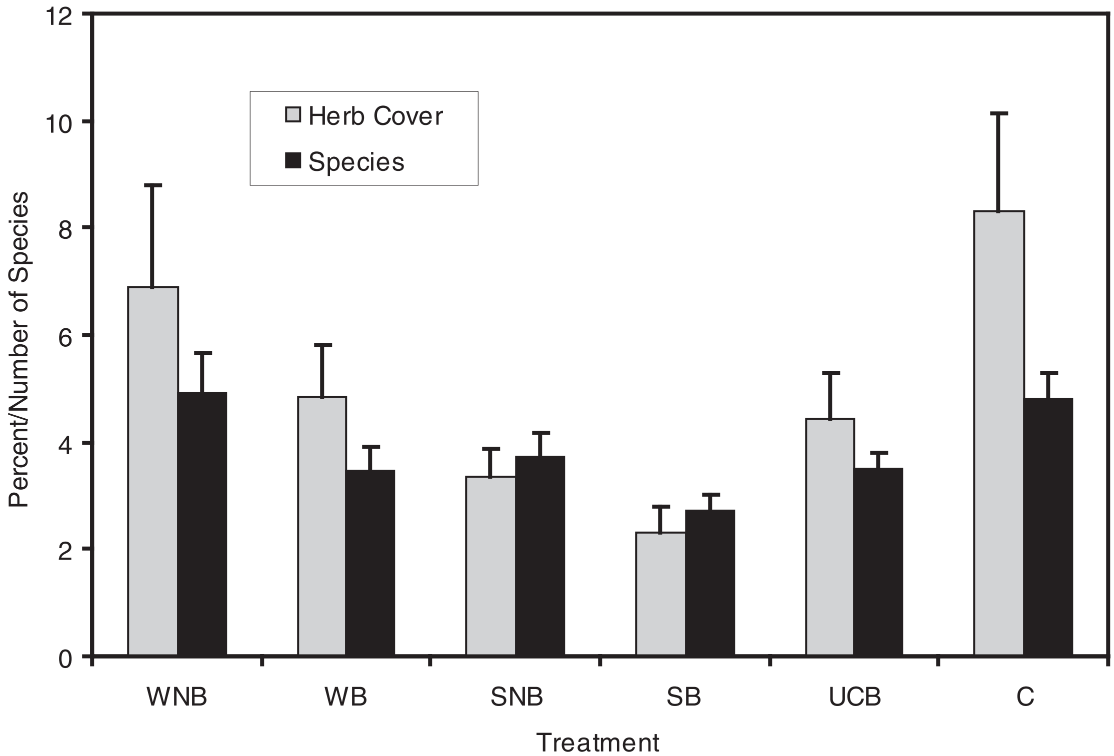

Figure 3—Percent cover of herbs and number of herb species per measurement plot by treatment. Error bars, significant differences, and treatment codes as in figure 1.

entered the smaller size class, leading to an increase in stems under 10 cm tall without any new seedling establishment. One exception was the increase in the density of white oak stems under 10 cm tall in the wildlife thinning combined with prescribed burning treatment. There was a greater increase in the smaller size class than can be accounted for by the decrease in the 10-cm and taller size class, suggesting a flush of new seedling establishment. Both of the treatments significantly increased understory light availability by reducing canopy cover. Increased light availability has been demonstrated to increase the growth and survival of oak regeneration (e.g., Beck 1970, Buckley and others 1998). The wildlife thinning treatments increased light availability relative to the uncut areas but not as substantially as the shelterwood cutting. Overstory removal by either method significantly increased PAR availability. In contrast, none of the treatments significantly affected measured soil-moisture levels. It is possible that other site factors (e.g., subsurface hydrology) not measured in this study played a more important role in influencing soil moisture than the treatments.

Prescribed burning significantly affected the distribution of oak regeneration over size classes. Oaks in the large seedling class, those over 10 cm tall but less than 140 cm tall, were significantly reduced due to top-killing by the fires. Stems less than 10 cm tall were significantly increased with burning. This increase in oak stems can be attributed to two sources: some new seedling establishment (white oaks) and new oak sprouts from oak regeneration that was top killed in the fire. The prescribed burned wildlife thinning treatment exhibited greater PAR levels than the unburned wildlife thinning. When combined with the wildlife thinning treatment, burning further reduced the midstory structure to allow more light to reach the seedling level. White oak stem density less than 10 cm tall significantly increased with wildlife thinning combined with prescribed fire. Thus, prescribed fire enhanced the effects of the wildlife thinning.

Both overstory removal treatments and prescribed burning had mixed results on woody competitors of oak. Prescribed burning likely increased competition between oaks and yellow-poplar and sassafras. However, prescribed fire reduced competition from red maple in all regeneration-size classes. The increase in yellow-poplar and sassafras likely occurred from seed already in the soil prior to the treatments and from sprouting. Prescribed burning, combined with overstory removal, provided the seedbed and increase in light necessary for germination and sprouting. We believe subsequent fires may be needed on a fairly frequent interval to reduce the number of yellow-poplar and sassafras stems. Provided there is a sufficient fuel load, burning can be carried out on intervals as little as every 2 to 3 years to reduce competition while not harming the oak stems. Subsequent fires should reduce the ratio of these competitors to oaks. An alternative would be to wait 3 to 5 years for these competitors to develop before burning, as outlined in the shelterwood-burn technique recommended by Brose and others (1999). Completion of the shelterwood-burn treatment in 2005 will allow comparison of the effects of fire in the first growing season and 4 years after shelterwood cutting on the sites.

Based on their effects on PAR and certain competitors such as red maple, shelterwood cuts, wildlife thinnings, and prescribed fire should benefit oak regeneration on the study sites. Long-term monitoring of the development of oak and potential competitors on the sites is necessary and planned.

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