CHANGES TO OAK WOODLAND STAND STRUCTURE AND GROUND FLORA COMPOSITION CAUSED BY THINNING AND BURNING

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Abstract.—Our objective was to quantify the cumulative effects of prescribed burning and thinning on forest stocking and species composition at a woodland restoration experiment site in the Ozark Highlands of Missouri. Our study used four treatments (burn, harvest, harvest and burn, control) on three slope position and aspect combinations (south, north, ridge) replicated in three complete blocks. Harvested stands were thinned from below to 40 percent residual stocking. Two prescribed fires were applied to both burn and harvest-burn treatment units in a 5-year period. Results reflect changes that have taken place over a 6-year period, from pretreatment conditions to 1 year after the last fire. In this period, there was a 10-percent reduction in the stocking in burned stands compared to control and a 6-percent reduction in harvested and burned stands compared to harvested stands. Compared to the control, percentage ground cover of woodland indicators was seven times greater in burned stands, six times greater in harvested stands, and 22 percent greater in harvested and burned stands. There was no significant ($P > 0.05$) interaction between aspect and treatment on stocking or ground flora cover. This study indicated that silvicultural treatments do achieve various goals that are common to managers who aim to restore woodland communities.

INTRODUCTION

Woodland communities are characterized by open midstories and understories and dense ground flora composed of forbs, grasses, sedges, and shrubs (Nelson 2005, Nuzzo 1986, Taft 2009). They once were common in the western Central Hardwoods Region and prairie-forest transition zone, where low-intensity fires occurred frequently (Guyette et al. 2002, Taft 2009). In the absence of fire, many of the oak (*Quercus* spp.) woodland ecosystems throughout much of the Midwest have succeeded to compositions and structures resembling those of mature oak forests (Johnson et al. 2009, Nowacki and Abrams 2008). In some oak ecosystems, mesophytic vegetation is replacing fire-dependent species at a rapid rate (Ladd 1991, Nowacki and Abrams 2008). Shifts in species composition and structure within woodland communities could jeopardize the biotic diversity, wildlife habitat, and ecosystem processes that occur in each environment (Peterson and Reich 2001, Shifley et al. 2006). These changes are deemed undesirable by many managers of state and private lands, many of whom have restoration objectives for their forests.

There is increasing interest in restoring the structure and composition of oak woodlands (Ladd 1991, Peterson and Reich 2001). Prescribed fire is considered an important woodland restoration tool (Nowacki and Abrams 2008, Taft 2009) largely for two reasons. Fire was the ecosystem process that maintained oak woodlands in the past, and it reduces stand density, particularly by removing fire-sensitive species in the understory and thereby increasing the sunlight reaching the

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Table 1.—Density, basal area, and stocking (Gingrich 1967) for all treatments[a]

	Trees per acre			Basal area (ft^2/acre)			Stocking (Percent)		
	2001	2003	2006	2001	2003	2006	2001	2003	2006
Burn	370.2	262.2	213.3	104.8	99.5	95.9	94.1	86.4	81.9
Control	350.6	317.5	303.5	107.3	105.6	111.5	94.7	92.1	95.9
Harvest	338.3	81.7	80.8	112.3	52.1	52.9	93.8	42.9	43.3
Harvest-Burn	370.7	55.7	52.8	105.1	37.8	40.4	94.1	31.1	32.9

[a] Data for 2001 were collected pretreatment, data for 2003 were collected after timber harvests and the first prescribed fire, and data for 2006 were collected after the second prescribed fire.

ground (Hutchinson et al. 2005, Johnson et al. 2009). Much has been written about how the use of prescribed fire modifies forest structure and favors oak regeneration, especially in mesic ecosystems, where regenerating oaks has remained an important problem (Arthur et al. 1998, Dey and Hartman 2005, Hutchinson et al. 2005). However, fewer studies have measured the effects of both fire and commercial overstory harvests (Albrecht and McCarthy 2006, Brose et al. 1999) on forest structure and ground flora composition on upland sites at a landscape scale.

The objectives of this study were to examine the effects of prescribed fire, thinning, and their interactions with slope position and aspect on forest structure and ground flora species composition. Stand structure was evaluated based on changes in the diameter distribution and overall stocking by diameter. Ground flora species composition was evaluated based on changes in the cover of forbs, legumes, graminoids, shrubs, vines, and woody seedlings in the understory.

STUDY AREA

This project was conducted in southeastern Missouri at Logan Creek Conservation Area (CA) and Clearwater Creek CA, which are managed by the Missouri Department of Conservation. When the study was initiated, the sites were fully stocked and composed primarily of oak-hickory and oak-pine forest types (Table 1). No management or documented fire had been recorded for at least 40 years. Sites were within the Black River oak-pine woodland/forest hills landtype association, characterized by steep hillslopes consisting mainly of cherty, low-base soils and occupied by second-growth forests (Nigh and Schroeder 2002).

METHODS

Study Design and Treatments

This study is designed so that four treatments are applied across three slope position and aspect combinations: north-facing slopes (aspect 315º to 45º), ridge tops (slopes <8 percent), and south-facing slopes (aspect 135º to 225º). Treatments were prescribed fire (burn), commercial thinning (harvest), their combination (harvest-burn), and control. Treatments were paired by slope and aspect to create twelve 5-acre units (hereafter “treatment units”) per block. Three complete blocks were initially established: two at Clearwater Creek CA and one at Logan Creek CA, each approximately 60 acres in area. Due to unsuitable weather conditions, however, some of the burn units in block three were not treated on schedule. Consequently block three was not included in our analyses.

Table 2.—Observed parameters for fire behavior averaged across blocks one and two

	Treatment	Rate of spread		Fireline intensity		Flame height
		Nelson[a]	Byram[b]	Nelson[a]	Byram[b]	
		---------------ft/min---------------		----------BTU/ft/sec----------		inches
1st fire	Burn	2.4	1.2	43	22	20
	Harvest-burn	3.6	1.9	76	41	24
2nd fire	Burn	Not determined	Not determined	28	14	15
	Harvest-burn	Not determined	Not determined	72	40	18

[a] Based on an equation by Nelson (1986).
[b] Based on an equation by Byram (1959).

Timber harvests occurred during summer and early fall 2002, before the first burn. Harvesting reduced stand density to 40 percent stocking (Gingrich 1967) by thinning from below. However, to achieve stocking goals, some dominant and codominant trees were removed. Preferred trees for retention were white oak (*Quercus alba* L.) and shortleaf pine (*Pinus echinata* Mill.) because of these two species' fire tolerance. Prescribed fires were applied during spring for burn and harvest-burn units in 2003 and 2005. Each burn was executed by using the ring fire method, while burning the ridges at the same time. Fire behavior parameters are included in Table 2.

Fire Behavior Measurements

Fire behavior was characterized by using passive fire behavior sampling techniques, passive flame height sensors, and rate of spread (ROS) clocks. Flame height data were collected by using passive flame height sensors, which were placed in the three overstory plots within each stand. Passive flame height was measured by using 12 strands of cotton string treated with fire-retardant, which were suspended between 2 wires, one at fuel bed height and the other approximately 7 feet above the fuel bed (Kolaks 2004). Additionally, trained observers used visual aids to determine flame-tilt angle as the fire front passed through the flame height sensors.

Estimated average and maximum flame lengths were derived by averaging flame heights, recording the tallest flame height logged by the series of sensors, and then applying the flame tilt angle. In the same plots, five ROS clocks were inserted with one at plot center and one at 50 feet in each cardinal or sub-cardinal direction (Kolaks et al. 2005). Rate of spread and direction were calculated by using at least three measurements from the buried ROS clocks or the average of all the triangle combinations, if more than three clocks activated and worked properly (Kolaks 2004, Simard et al. 1984).

Vegetation Sampling

Permanent plots were established during summer along a transect following the contour of the slope that is approximately 700 feet long. This transect contained both woody and herbaceous vegetation plots. All trees ≥1.5 inches in diameter at breast height (d.b.h.) were inventoried in three 0.33-acre circular plots randomly located along transects within each treatment unit. All trees and shrubs >3.3 feet tall and <1.5 inches d.b.h. were inventoried in fifteen 0.002-acre circular subplots randomly located along transects within each treatment unit. Trees ≤3.3 feet tall, ground flora, and vines were sampled in thirty 3.28 feet by 3.28 feet quadrats that were randomly located along transects within each treatment unit. Within each quadrat all live herbaceous plants and tree seedlings were identified to species and cover was estimated to the nearest percent. Post-treatment understory data were collected in the same plots and quadrats in summer 2003 and again in summer 2005 (i.e., during the first growing season after harvest and/or prescribed fire was applied). Data for trees and shrubs > 3.3 feet tall were collected during the dormant season following the understory data collection (i.e., winter 2003-2004 and winter 2005-2006).

Data Analysis

We used the general linear models procedure (Proc GLM, SAS version 9.1, SAS Institute, Cary, NC) to examine the effects of treatment (burn, harvest, harvest-burn, or control) and slope position and aspect (north-facing slope, ridge, south-facing slope) and the interaction between treatment and slope aspect. The error term was the block*treatment*slope aspect interaction. Response variables were the change in percentage stocking (post-treatment – pretreatment) by diameter size class for woody vegetation and the change in percentage cover of ground flora by forbs, legumes, graminoids, shrubs, vines, and woody seedlings in the understory. Post-treatment included the sampling period following the second burn. We limited our analysis to blocks one and two because they were burned two times during the study period. The vegetation data for 2003 (after one burn) were examined but not included in the analysis. To test for significant effects ($\alpha = 0.05$), we compared means by using Fisher's least significant difference test.

RESULTS

Changes in Overstory Structure

Prior to treatment, the average stocking for all stands was greater than 94 percent and sawtimber (>10.5 inches d.b.h.) accounted for the majority of stocking (Table 1). The two prescribed burns caused only minor reductions in the overall stocking (Table 3). There was a 10-percent stocking reduction in the burn treatment compared to control and only a 6-percent reduction in the harvest-burn treatment compared to the harvest treatment. Most of the reductions due to the prescribed fire were in small tree sizes (1.5 to 5.4 inches d.b.h.) and greater differences occurred between the control and the burn treatment than between the harvest and the harvest-burn treatments (Table 3). When sampled in 2006, density (trees per acre) was reduced twice as much in burn treatments as in control, and five times as much in harvest and harvest-burn treatments as in control (Fig. 1). We found no significant differences among slope position and aspect combinations or with their interactions with treatment.

Table 3.—Changes in level of percentage stocking (pre- to post-treatment)[a]

Size class (d.b.h.)	Control	Burn	Harvest	Harvest-Burn
Small trees (1.5 - 5.4 inches)	-2.4 a	-9.3 b	-11.9 bc	-17.7 c
Small poles (5.5 - 8.4 inches)	0.57 a	-4.3 b	-8.0 c	-9.0 c
Large poles (8.5 - 10.4 inches)	-0.89 a	-2.3 a	-5.7 b	-5.7 b
Saw timber (>10.5 inches)	7.2 a	6.1 a	-30.2 b	-25.6 b
Total	4.5 a	-9.8 a	-55.9 b	-58.0 b

[a]Post-treatment data were collected one year after the last prescribed fire in 2005. Within rows, values followed by a different letter indicate significant differences (P < 0.05).

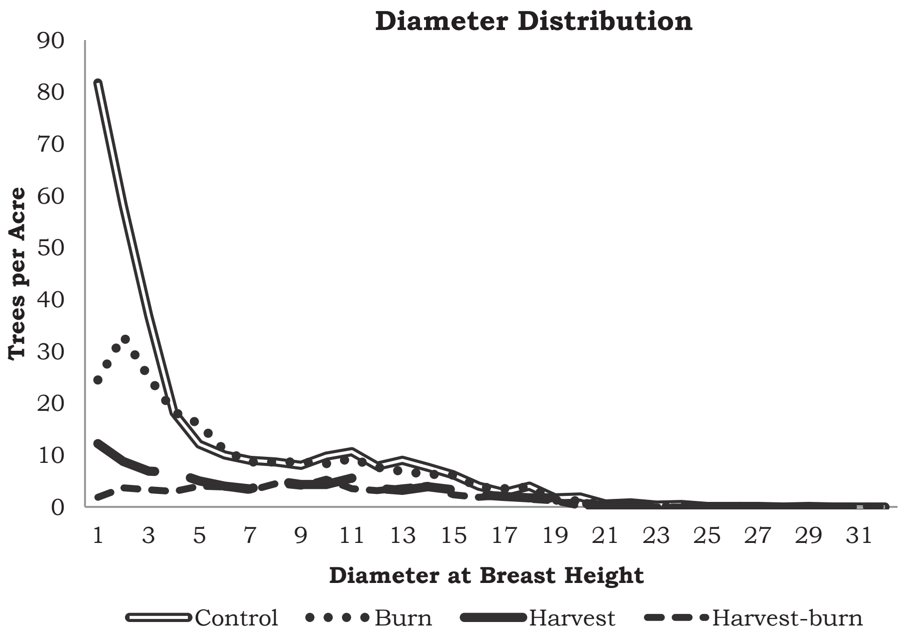

Figure 1.—Diameter distributions in inches for trees after treatment.

Changes in Ground Flora and Understory

Forb cover increased in the burn and harvest-burn treatments (Fig. 2a), indicating that the fire was a primary influence. Harvesting alone had little effect on forb cover and the change in cover was not significantly different from that of the control. Graminoid cover including grasses, sedges, and rushes increased in all treatments except for control (Fig. 2b). As with forbs, the harvest-burn treatment resulted in the greatest increase in percentage cover of graminoids (3.6%); however, this physiognomic group showed the smallest range of coverage variation between treatments. For legumes, the burn treatment had the greatest nominal increase in percentage coverage (3.7%); however, this increase was not significant (Fig. 2c).

The harvest and harvest-burn treatments increased the cover of shrubs and vines (Fig. 2d, e) but the changes were less for these life forms than for the others when compared to their non-burned analogs (i.e., burn vs. control and harvest-burn vs. harvest). The greatest change in percentage cover of any physiognomic life form within a treatment was that of woody species in control plots, which decreased by 15.9 percent but remained unchanged in the other treatments (Fig. 2f). This decrease in the control was caused by the mortality of seedling cohorts established after heavy seed crops that did not persist under a fully stocked canopy. As with changes to structure, slope position and aspect had no significant effect on the changes in the coverage of these life forms.

We grouped the ground flora into a "woodland indicators" category by using a species list of legumes, forbs, and graminoids common to Ozark Highlands woodlands created by field staff of the Missouri Department of Conservation (Table 4). Percentage cover of woodland indicators increased in the burn and harvest treatments compared to control with the greatest increases occurring in the harvest-burn treatment (Fig. 3).

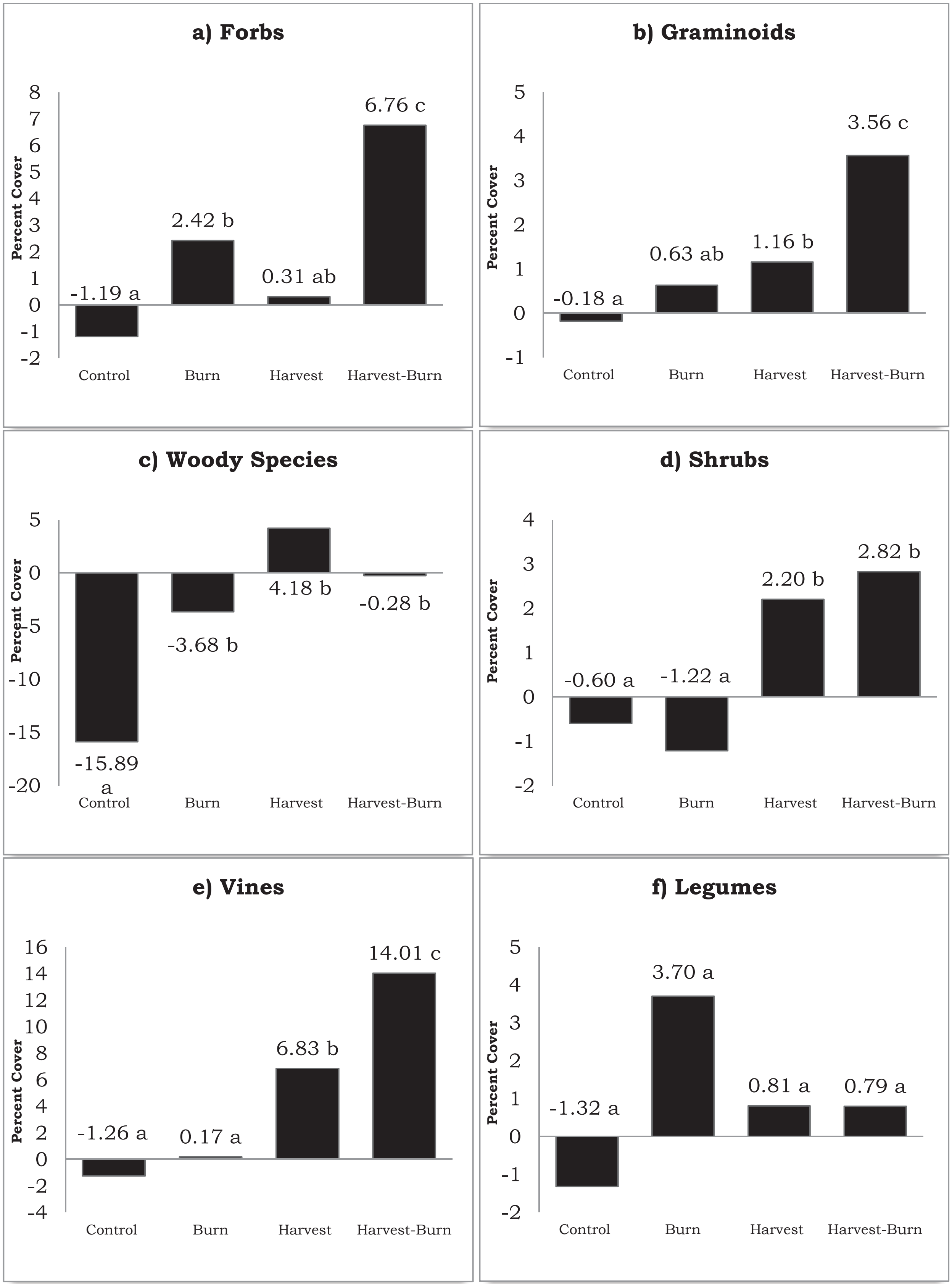

Figure 2.—Changes in percentage coverage of six physiognomic life forms. Values followed by a different letter indicate significant differences ($P < 0.05$).

Table 4.—Woodland indicator species[a] used in understory vegetation sampling

Andropogon gerardii	*Ionactis linariifolius*	*Silphium terebinthinaceum*
Asclepias tuberosa	*Lespedeza hirta*	*Solidago hispida*
Aureolaria grandiflora	*Lespedeza procumbens*	*Solidago petiolaris*
Babtisia bracteata	*Lespedeza violacea*	*Solidago radula*
Blephilia ciliata	*Lespedeza virginica*	*Solidago rigida*
Ceanothus americanus	*Liatris aspera*	*Solidago speciosa*
Comandra umbellata	*Liatris squarrosa*	*Solidago ulmifolia*
Coreopsis palmata	*Lithospermum canescens*	*Sorghastrum nutans*
Cunila origanoides	*Monarda bradburiana*	*Symphyotrichum anomalum*
Dalea purpurea	*Orbexilum pedunculatum*	*Symphyotrichum oolentangiense*
Desmodium rotundifolium	*Parthenium integrifolium*	*Symphyotrichum patens*
Echinacea pallida	*Phlox pilosa*	*Symphyotrichum turbinellum*
Eryngium yuccifolium	*Pycnanthemum tenuifolium*	*Taenidia integerrima*
Euphorbia corollata	*Schizachyrium scoparium*	*Tephrosia virginiana*
Gentiana alba	*Silene regia*	*Verbesina helianthoides*
Gillenia stipulata	*Silene stellata*	*Viola pedata*
Helianthus hirsutus	*Silphium integrifolium*	

[a]Woodland indicator species are herbaceous plants that produce flowers and seeds during the summer months, and are adapted to ecosystems where light penetration is relatively high. These species, often associated with prairie and savanna ecosystems, indicate stand density has remained sufficiently low to allow sunlight to reach the ground vegetation.

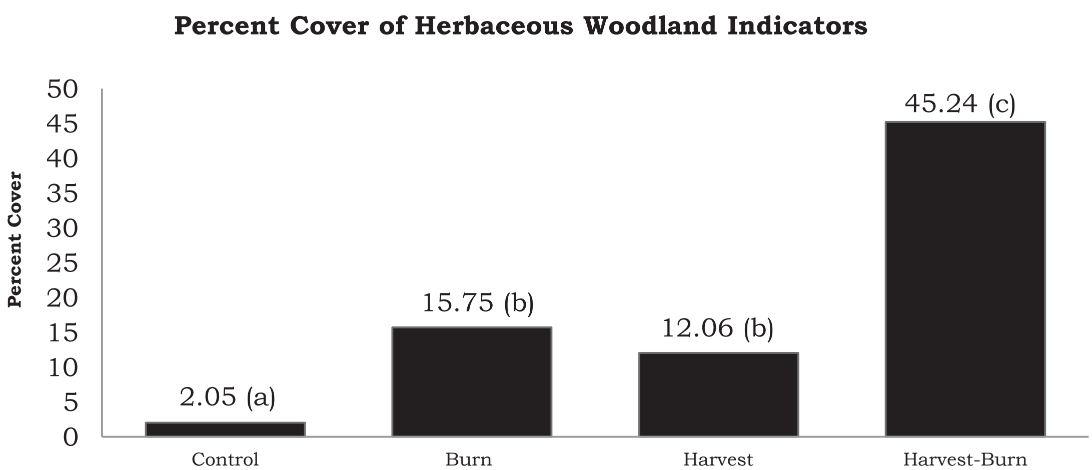

Figure 3.—Percentage coverage of woodland indicator species (see Table 4) following treatment. Values followed by a different letter indicate significant differences (P < 0.05).

DISCUSSION

The transition from what once were open-canopied oak woodland ecosystems to the present-day dense oak forest throughout the Ozarks is well documented (Ladd 1991, Nuzzo 1986). Fire suppression is thought to have facilitated increases in woody components of a stand, especially in small-diameter stems (Albrecht and McCarthy 2006, Arthur et al. 1998, Hutchinson et al. 2005, Nowacki and Abrams 2008, Peterson and Reich 2001). Our results showed that the two prescribed fires applied during a 3-year period significantly reduced stocking of small trees compared to control conditions although overall stocking decreases attributable to the burning were minor (Table 3). In stands that were harvested before burning, stocking reductions attributable to prescribed fire were smaller, mainly because the thinning was applied from below, targeting first the size classes of trees most vulnerable to mortality caused by fire (Dey and Hartman 2005).

The larger size classes of trees in our study were mostly unaffected by the prescribed fire, a result also reported by others (Albrecht and McCarthy 2006, Arthur et al. 1998, Hutchinson et al. 2005, Johnson et al. 2009). Larger-diameter trees are much less vulnerable to mortality caused by fire, allowing most of the canopy dominant and codominant trees to persist in the overstory (Brose et al. 1998, Dey and Hartman 2005, Taft 2009). This differential susceptibility to fire based upon tree diameter is thought to have led to the development of woodland structure characterized by the presence of “open-grown” large trees with a wide-spreading canopy and a relatively sparse understory and midstory (Nelson 1995, Taft 2009).

Despite only minor reductions in stocking, the two prescribed fires significantly increased the abundance of forbs, legumes, and graminoids (Fig. 2a, b, f), as well as woodland indicator species (Table 4, Fig. 3). The response of woodland indicators to the prescribed fire was about the same as in the harvest treatment, where overstory stocking was reduced to about 40 percent. This result suggests that the effects of prescribed fire were not limited to simply increasing the amount of sunlight reaching the understory. Fire reduces competition by woody species and removes some or all of the thick layers of leaf litter that can inhibit the germination of some of the woodland indicator ground flora (Nelson 2005, Stambaugh et al. 2006). In our study sites, Kolaks et al. (2004) reported that the first prescribed fire consumed more than 97 percent of the leaf litter, perhaps creating favorable conditions for herbaceous plant germination. Increasing sunlight to the ground layer played an important role in increasing the cover of woodland indicators. We found that the combination of thinning the canopy and applying fire caused the greatest response in the woodland indicators, increasing their cover three times compared to burn only, almost four times compared to harvest only, and more than 20 times compared to control.

Relative to control and burn treatments, the percentage cover of woody species, shrubs, and vines increased where stands were harvested or harvested and burned. This is an important finding considering that a dense layer of woody plants may inhibit the development of a diverse herbaceous layer. In fact, the establishment of woody seedlings, seedling sprouts, and stump sprouts may become a problem for managing the herbaceous ground flora in stands that were thinned to low stocking levels and where the fire-free interval is several years long (Taft 2009). Our data suggest that the high shade from these remaining canopy trees in the burn treatment may have helped to slow or inhibit the cover of understory woody vegetation and promoted the development of herbaceous ground flora.

It is important to recognize that these results represent the changes that have taken place during a relatively short time following the application of treatments. Forest and woodland vegetation is dynamic and rapid changes in the cover of the understory are anticipated. Thus woodland management should be considered a continuous process requiring the application of prescribed fire and possibly thinning treatments on a regular basis to prevent the woody cover from becoming dominant in the midstory and understory layers (Albrecht and McCarthy 2006, Arthur et al. 1998, Brose et al. 1998, Johnson et al. 2009). Future work in this study will focus on the dynamic nature of restored woodlands and on the changes that take place during fire-free intervals.

It is also important to recognize that at some point in time, management actions may be necessary to ensure trees can be recruited into the overstory to replace those that die or that are harvested. These actions may require creating canopy openings by harvesting some or all of the overstory and by maintaining fire-free intervals to allow seedlings to grow large enough to survive when the prescribed fire regime is reinstituted. Although beyond the scope of this study, recruiting seedlings in managed woodlands is an important consideration if sustaining the composition and structure of the overstories of these unique ecosystems is a management objective.

CONCLUSIONS

The application of prescribed fire for restoring and managing woodlands was found to cause minor changes to forest structure primarily by reducing the stocking of trees <5 inches d.b.h. Despite these minor changes, the prescribed fire significantly increased the cover of forbs, graminoids, and other plant species considered indicators of woodland composition. The effect of prescribed fire on woodland indicators was about the same as thinning stands to 40 percent stocking, underscoring the important effects of prescribed fire for maintaining woodland composition. However, harvesting alone also increased the cover of woody regeneration, shrubs, and vines – lifeforms that can prohibit the development of herbaceous plants in woodlands. The greatest response of the ground flora, particularly woodland indicator plants, occurred with the combination of harvesting and prescribed burning. This result suggests that increased sunlight to the ground layer, the removal of leaf litter, and the reduction of woody competition are the most beneficial to woodland plants. However, it is likely that the density of woody reproduction will rapidly increase under low overstory stocking if fire is not applied on a frequent basis.

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