

INTRODUCTION

Fire in the Ozark Highlands was historically used by Native Americans (Guyette and others 2002). Early European settlers continued to burn the landscape to manage livestock forage. In the late 1800s, people began to harvest timber, cutting first pine trees and later oak (Flader 2008). Woodlands eventually succeeded to forests and pine-oak compositions gave way to hardwood-dominated forests as frequent fires and pine logging promoted hardwood regeneration (Record 1910, Sasseen 2003). In the 1930s, fires began being suppressed throughout this area. In the absence of fire, woodlands became forests in structure with the increase in tree density and development of subcanopies. The current oak forest health problems occurring in the Missouri Ozark Highlands are also believed to be related to this long-term fire suppression, shift in species composition, and increased tree density (Hartman and Heumann 2003, Kabrick and others 2008, Shifley and others 2006). Therefore, prescribed fires were reintroduced to restore the oak woodland ecosystem where it occurred historically and to mitigate current health problems that are plaguing oak forests, such as widespread outbreaks of oak decline (Fan and others 2008, Kabrick and others 2008, Spetich and He 2008).

The Chilton Creek Prescribed Burning Project (CCPBP) was initiated by The Nature Conservancy (TNC) in 1996 to study the effects of different fire regimes on promoting the diversity of native species and ecosystem

restoration in the Ozark Highlands (Hartman and Heumann 2003). The CCPBP study site is a 1000-ha forest tract that includes one annual burning unit and four random burning units with about a 4-year fire return interval. The primary objectives of the research project were to (1) compare the structural and compositional characteristics of unburned and burned upland oak forests using repeated measures data with treatments ranging from no fire to 8 years of annual burning, and (2) develop indicators, indices, or both that predict the impact of fire treatments on forest size structure and species composition and evaluate the influence of ecological land type (ELT) on forest response.

METHODS

Structural and compositional data

In total, 250 0.2-ha permanent plots were installed over the five burning units to monitor the change in forest vegetation. In each plot, overstory trees ≥ 11.5 cm diameter at breast height (d.b.h.) were measured. Midstory trees with d.b.h. less than 11 cm and more than 3.8 cm were measured in four 0.02-ha subplots that were nested within each 0.2-ha plot. Understory trees with d.b.h. less than 3.8 cm were measured in a 0.004-ha subplot that was located in the center of each 0.02-ha subplot. Coverage of herbaceous vegetation and tree seedlings were estimated in four 1-m² quadrants that were located 6.7 m from the subplot centers at 45°, 135°, 225°, and 315° azimuths. Tree species, d.b.h., crown class, status (dead or live), and d.b.h. per height class (for seedlings and saplings) were recorded or measured.

CHAPTER 8.

Effects of Prescribed Fire on Upland Oak Forest Ecosystems in Missouri Ozarks

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Data inventory was performed in 1997 (before treatments), and in 2001 and 2007. In addition, corresponding data from 70 0.2-ha plots on the adjacent Missouri Ozark Forest Ecosystem Project (MOFEP) site 9 (measured in 1998, 2002, and 2006) (Shifley and Brookshire 2000) were included to evaluate changes in vegetation where no burning or timber harvesting occurred.

Prescribed burning

All units were burned in the spring of 1998 to initiate the process of restoring fire. Thereafter, units were burned during the dormant season (usually in March and April) on a randomly selected 1- to 4-year return interval basis, with the exception of Kelly North management unit, which was burned annually. Average total fuel loads ranged from 9.6 to 13.2 mt/ha for any given burn year, and herbaceous and litter fuels accounted for much (40 to 60 percent) of the total tonnage. Air temperatures during most burns were between 16 and 24 °C; winds, in general, were less than 7 km/hour; and relative humidity ranged from 33 to 44 percent. Flame lengths were highly variable but often were in the range of 0.3 to 0.9 m. Rates of spread were also variable, but the fire front usually moved at a rate of 59 to 317 m/hour. Fire temperatures were highest at the fuel surface (ground level), reaching 121 to 316 °C.

Advance reproduction data

To monitor the response of advance regeneration to the prescribed burning, 26 of the 250 permanent plots were randomly located throughout the five burn units. Individual stems

of advance regeneration in a plot were sampled from within a 25.2-m radius of each sampling point. Each stem was permanently marked with a wire stake and metal numbered tag. More than 3,000 stems of various sizes were marked within the 26 plots. Information on species, stem basal diameter 2.5 cm above the ground, total height, d.b.h. (if existing), status (live or dead), and sprout condition (the number of sprouts and the height of the tallest sprout) were recorded. Initial stem measurements were conducted in the fall of 1997, before the first burn. Stems were measured again in 1998, 1999, 2001, and 2007 as the prescribed burn treatments were implemented.

Forest structural and compositional changes under different fire treatments

Forest composition on the MOFEP and CCPBP sites is a mixture of 50 tree species; however, only a relatively few species are dominant. Eight major tree species (based on importance values [IV])—black oak (23.6 percent), scarlet oak (21.3 percent), white oak (21.2 percent), shortleaf pine (9.0 percent), post oak (6.3 percent), black hickory (4.3 percent), pignut hickory (4.0 percent), and mockernut hickory (4.0 percent)—account for nearly 94 percent of the overstory species. The rest (more than 40 species) are minor species that are sporadically distributed in the forests with an IV of mostly less than 0.2 percent (Shifley and others 2006). Potential forest structural and compositional changes following the fire treatment were evaluated using these major species. Furthermore, it was statistically difficult

to analyze the fire effects at the species level due to the extreme unbalance in sample size (e.g., too small or large sample sizes, missing values). For this reason, the eight major species were further grouped into four functional species groups based on their dominance and bioecological characteristics: white oak group (white oak, post oak), red oak group (black oak, scarlet oak), hickory group (black, pignut, and mockernut hickory), and shortleaf pine. All minor species were grouped into a single group (i.e., the fifth group labeled as other species). This grouping scheme improved the power of statistical analyses and facilitated the explanation of results in analyzing forest- and stand-level compositional changes. All trees were classified into three categories based on the d.b.h. to evaluate forest structural change under different fire treatments: overstory (d.b.h. > 11.5 cm), midstory (3.8 cm < d.b.h. ≤ 11.5 cm), and understory (d.b.h. ≤ 3.8 cm, but height > 1 m). Relative changes in basal area or stem density (for understory) were used in multivariate analysis of variance (MANOVA). The plots under the annual fire, random fire, and no fire regimes were randomly classified into three groups (replicates). Relative changes in basal area or stem density after the fire treatments (i.e., after 4 and 10 years) were calculated as the difference in basal area or stem density between pretreatment and the reinventory years divided by the basal area or stem density of the pretreatment inventory, which ranged from -2.0 to 4.0 for the CCPBP experiment.

Responses of advance reproduction to fire

To better understand the effects of external factors on advance regeneration after 10 years of burn treatments, the relationship between mortality of advance regeneration and a suite of potential contributing factors was examined. These factors, including fire regimes (treatments), slope, aspect, ELT, stem basal diameter, total height, and species, were analyzed using a nonparametric classification and regression tree (CART) approach (Fan and others 2006). The CART model results indicated that total height and basal diameter are the key factors affecting the mortality rate of the species groups after a long (10-year in this study) period of repeated burns. The logistic regression was then employed to develop the species-specific mortality model for those species with a large sample of advance reproduction stems (> 100). After testing the different combinations of total height and basal diameter, it was finally found that a morphological variable, the ratio of total height to the square of the basal diameter, best predicted the stem mortality probability across most species selected. The Hosmer-Lemeshow test was used to evaluate the performance of the logistic regression model. The logistic regression model was:

$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 * HBR)}} \quad (1)$$

where

HBR = total height/(basal diameter).

RESULTS AND DISCUSSION

Structural and compositional change

Total overstory basal areas increased rapidly in both burning units but remained relatively stable in the no-burn unit (MOFEP site 9) from 1997 to 2007 (fig. 8.1). White oak basal areas increased under all treatments, indicating that fire did not change the overstory white oak growth pattern during the 10-year treatment interval. Red oak basal areas increased in both burning units, but decreased in the no-burn unit, suggesting that fire may have a positive influence on the survival or growth of overstory red oak trees in this area, or it is possible that the sites on the CCPBP property were either slightly younger in age than the MOFEP forests or that they had a different management history that left them with lower stocking (fig. 8.1) at the beginning of this study. Under lower stocking, there would be resources to support increases in stand basal area and density in the CCPBP forests compared with the MOFEP stands that were more fully stocked to begin with. Red oaks in the overstory on the CCPBP site had more opportunity to grow in diameter and increase in basal area than at the MOFEP sites. No management disturbances had occurred within 40 years of the initiation of the MOFEP study (Shifley and Brookshire 2000). In contrast, the CCPBP property had been owned by private timber companies until 1991, when it was acquired by TNC. The date of the last timber harvest on the property is unknown, but it is quite possible that it occurred closer to the initiation of this study than was the case on the MOFEP study site, thus explaining the lower initial stand basal area on the CCPBP site.

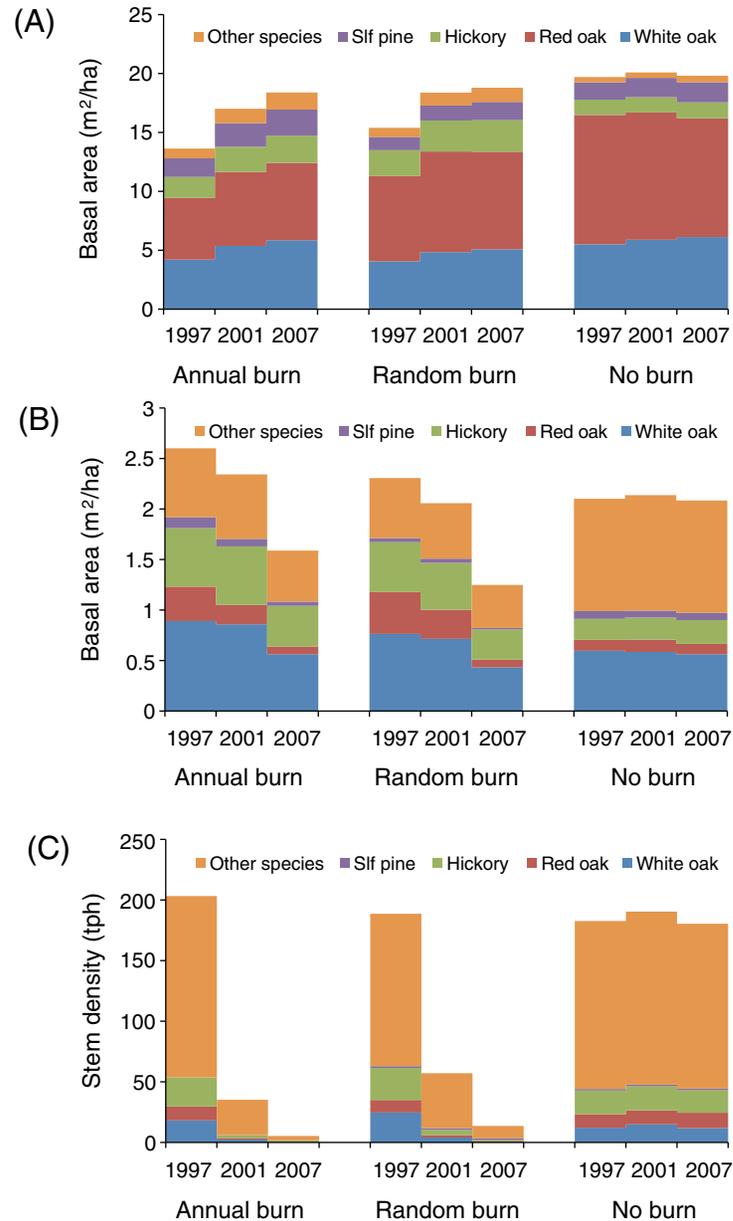


Figure 8.1—Structural and compositional change of oak forests under different fire treatments: (A) overstory, (B) midstory, and (C) understory.

Declines in red oak basal area on the no-burn sites may be related to oak decline, which has been occurring throughout the Ozark Highlands (Fan and others 2008, Kabrick and others 2008, Shifley and others 2006, Spetich and He 2008). Red oaks with low annual diameter growth rates, intermediate and suppressed trees in high-density stands, medium-sized dominant trees in high-density stands, and large-diameter dominant red oak trees are at higher risk of dying from oak decline (Shifley and others 2006). Initial stand basal areas on the no-burn MOFEP sites averaged 20 m²/ha, which was higher than that on the CCPBP burn treatments, where basal area ranged from 14 to 15 m²/ha. Changes in density of other species were minor. Hickory basal areas did not change in the no-burn treatment but increased slightly in the two burning treatments. Shortleaf pine basal areas increased slightly in the annual burn treatment but did not change in the no-burn and random burning treatments. Other species basal areas increased slightly under all three treatments.

The MANOVA model indicated significant fire effects ($p < 0.05$) on the relative changes in overstory basal area for both overall and individual species groups in 2001 and 2007. The relative change of overall basal area in overstory by year 2001 was 2.3, 19.5, and 15.3 percent, respectively, and by year 2007 was -7.9, 12.6, and -5.5 percent, respectively, for the unburned control, annual fire, and random fire treatments. The relative increases in basal area for the annual fire and random fire treatments were significantly higher than for the unburned control treatment in both 2001 and 2007. The

annual fire treatment caused a significantly higher relative change in basal area than the random fire treatment in both 2001 and 2007. The increase in relative change of basal area by species groups for the annual fire and random fire treatments was three to four times larger than and significantly different from that for the unburned control treatment ($p < 0.05$). In 2001, the relative changes in basal area for the individual species groups ranged from -0.7 to 10.2 percent under the unburned control treatment, 11.3 to 31.7 percent under the annual fire treatment, and 12.4 to 32.1 percent under the random fire treatment. In 2007, the relative changes in basal area for the individual species groups ranged from -8.6 to 19.6 percent under the unburned control treatment, 16.9 to 49.0 percent under the annual fire treatment, and 13.8 to 44.0 percent under the random fire treatment. These findings are confounded because the two fire treatments occurred on sites of initially lower stand basal area that affected the potential for increases in basal area during the course of this study.

Midstory basal areas showed a different trend from changes in the overstory (fig. 8.1). During the period 1997 to 2007, total midstory basal area continually decreased for the annual and random fire treatments but remained stable for the unburned control treatment. The decrease in midstory basal area occurred in all five species groups. The MANOVA model indicated significant fire effects ($p < 0.05$) on the relative change of total midstory basal area in both 2001 and 2007. The relative change of total midstory basal area by year 2001 was 2.4,

-12.9, and -15.5 percent, respectively, and by year 2007 was -0.2, -41.1, and -49.0 percent, respectively, for the unburned control, annual fire, and random fire treatments. The decreases in total midstory basal area for the annual fire and random fire treatments were significantly higher than for the unburned control treatment in both 2001 and 2007, but no significant differences were observed between the two fire treatments. For the individual species groups, the MANOVA model indicated that fire treatments had a significant effect on the relative change in midstory basal areas of all species groups, except for shortleaf pine and white oak in 2001, and of all species groups, except for shortleaf pine, in 2007 compared with the control. Much variability was apparent in the relative changes in the basal area among the fire treatments by species. The red oak group (79 and 82 percent for annual and random burn treatments, respectively) and shortleaf pine (58 and 65 percent for annual and random burn treatments, respectively) experienced the largest reductions.

The patterns of stem density change in the understory were similar to the midstory, except that the reduction was much greater for the annual and random fire treatments (fig. 8.1). The stem density on the burned sites was extremely low after 10 years; following the fire treatments, stem density dropped to less than 20 trees/ha for the annual and random fire treatments. The MANOVA model indicated significant fire effects ($p < 0.05$) on the relative (percent) change in stem density in the understory for all species combined

and by individual species and groups in 2001 and 2007. By year 2001, the relative change of stem density in the understory for the unburned control, annual fire, and random fire treatments was 2.8, -83.5, and -74.3 percent, respectively, and was -3.2, -97.0, and -94.1 percent, respectively, by year 2007. Both fire treatments significantly decreased the relative change in stem density in the understory, but no differences in the fire effects were observed between these two fire treatments. In 2007, the MANOVA model indicated no fire effects on the relative change in understory stem density of shortleaf pine. With the exception of shortleaf pine in 2007, both fire treatments significantly decreased the relative change in understory stem density, but no differences in the fire effects were observed between these two fire treatments.

Responses of advance reproduction to fire

Exploratory analyses indicated that, as the number of prescribed fires increased, species, initial total stem height, and stem basal diameter became increasingly important determinants of mortality and height growth, whereas burning treatment (annual vs. random burn), slope, aspect, ELT, and overstory stocking were not statistically significant by 2007. The simple logistic regression models depicted the impact of initial stem size on mortality of advance reproduction. Interestingly, for several of the major associated species such as hickories (pignut, black, mockernut), blackgum, sassafras, and winged elm, the estimated coefficients for *HBR* were not statistically significant, indicating mortality was less affected by the ratio. For

the oaks, shortleaf pine, flowering dogwood, and the minor species as a whole, however, the *HBR* ratio was a significant determinant of mortality. For these species, *HBR* consistently performed better than initial basal diameter, total height, or a combination of both variables included in the model. In the logistic regression models, oaks, hickories, sassafras, and winged elm had relatively low intercepts compared with shortleaf pine, flowering dogwood, blackgum, and other minor species, suggesting relatively lower mortality in these species as the ratio of stem height to the square of stem basal diameter decreases. The slope of the logistic curves for oaks was steeper than for other associate species, except for shortleaf pine, suggesting that oak mortality was more strongly affected by the *HBR* ratio.

HBR is a synthetic parameter derived from the relationship between total height and basal diameter. Basal diameter has been shown to be highly correlated with the size of root systems, especially in oak species (Canadell and Roda 1991, Dey and Parker 1997), and thus *HBR* essentially represents the allocation of biomass and carbohydrate between aboveground and belowground tree components (high *HBR* indicating lower relative belowground allocation, or vice versa). The resultant logistic regression models could be used to predict the mortality of existing advance reproduction prior to the application of multiple fires. After examining the models, we tentatively classified the species into four groups based on their relative slopes and intercepts in the logistic models. These groupings were: (1) species with low intercepts

and low slopes representative of black and pignut hickories, sassafras, and winged elm; (2) species with low intercepts and high slopes typical of various oaks and mockernut hickory; (3) species with high intercepts and slopes such as shortleaf pine and flowering dogwood; and (4) species with high intercepts but low slopes such as blackgum and other minor species as a whole. These groupings may represent different functional strategies for tolerating (e.g., vegetative sprouting in species such as oaks, hickories, sassafras, and winged elm) or avoiding (e.g., thick bark in species such as shortleaf pine) fire mortality, or they may indicate a lack of ability to persist in environments of multiple and frequent fires, i.e., the most fire-sensitive and inherently vulnerable species such as flowering dogwood (Dey and Hartman 2005). Species with low slopes and low intercepts, such as hickories, are more resistant to fire-induced mortality, whereas species with high slopes and high intercepts, such as shortleaf pine, are vulnerable to fire. Most oak species have low intercepts and relatively high slopes, indicating that oaks with larger basal diameter will have lower mortality rates but advance reproduction in the smaller size classes is moderately sensitive to fire-induced mortality. This is because oaks have a conservative and effective strategy for persisting in a frequent fire environment. They preferentially allocate biomass to their root system (Dey and Hartman 2005, Dey and Jensen 2002, Johnson and others 2009), which does two things: (1) the belowground plant tissues are insulated from the fire's heat and thus more likely to survive the fire, and (2) the

belowground carbohydrate stores provide energy to fuel rapid growth of new vegetative shoots following topkill.

CONCLUSIONS

Ten years after initiating burning, fire had little impact on the overstory, but it was effective in reducing the midstory basal area by > 40 percent and the understory basal area by > 90 percent. No significant differences in the understory and midstory basal area were observed between annual and random fire treatments. The net effect on stand structure was similar under either annual or random fire treatments. Thus, the restoration of closed woodland structure does not require annual burning when more than 14 m²/ha of overstory basal area exists. Overstory basal area was able to increase under a frequent-to-annual fire regime to levels approaching that observed in unburned mature forests. Frequent fire does not add to overstory mortality above what was observed in the control forests, and it may even provide a benefit to the growth and survival of maturing red oak species. There was a subtle but ecologically significant increase in white oak in the overstory of burned and unburned forests. White oaks are more shade tolerant than any of the red oak species, and they dominate in the midstory size class, which supplies recruitment into the overstory when canopy gaps form stochastically in the overstory. Increased dominance of oaks in the fire treatments were associated with increased diameter growth rates in the white oak group tree growth and reduced mortality in red oak group. The

increase in overstory basal area following the fire treatments was attributed to (1) ingrowth of midstory stems, (2) reduction of overstory mortality, and (3) growth of overstory trees. The difference in relative change of overstory basal area between the annual and random fire treatments was statistically significant for all species combined in 2001 and 2007, with the annual fire treatment having larger increases, but the significance varied for different species groups and inventory years.

The effect of fire treatments on the advance regeneration has become less and less significant over time based on CART analysis. After 10 years of fire treatments, basal diameter and total height were identified as the two most important contributing factors related to species-specific stem mortality. A new morphological variable, *HBR*—the ratio of the total height to the square of basal diameter—was found to be statistically significantly related to the tree mortality rate for most of the species. The logistic regression models for selected species using the morphological variable did a good job of predicting mortality based on the initial stem size of advance regeneration. These logistic regression models can be useful tools for comparing and quantifying species' responses to fires. The logistic regression analysis indicated that advance regeneration of oaks and hickories was favored more by frequent burning compared with other species, such as flowering dogwood and blackgum, as indicated by the higher intercept values in the logistic models. Fires historically occurred frequently in the Ozark forests. Use of low-intensity prescribed

fire to restore oak woodlands in the Ozarks is effective in managing ecosystem structure and composition. Prescribed burning can be used without aggravating forest health problems, or it may even reduce the risk of threats such as oak decline by favoring white oak growth and dominance and improving red oak vigor. Timber harvesting or thinning may be needed in combination with low-intensity, dormant-season burns to reduce overstory density if open woodland or savanna structures are desired.

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