FIRE SCARS AND TREE VIGOR FOLLOWING PRESCRIBED FIRES IN MISSOURI OZARK UPLAND FORESTS

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Abstract.—The goal of our project was to examine basal fire scars caused by prescribed fires and tree vigor in upland forests of the Missouri Ozarks. Fire scar data were collected in 100 plots from black oak (*Quercus velutina* Lam.), scarlet oak (*Q. coccinea* Muench.), Shumard oak (*Q. shumardii* Buckl.), post oak (*Q. stellata* Wangenh.), white oak (*Q. alba* L.), hickories (*Carya* spp. Nutt.), and shortleaf pine (*Pinus echinata* Mill.). Crown dimensions were measured in 99 plots for scarlet oak and black oak, and crown dimensions were converted to crown and tree vigor index values. Fire scar data for scarlet oak and Shumard oak were grouped into a red oak species group because of similar bark characteristics (i.e., fire tolerance) between the two species and a small sample size for Shumard oak. Results indicate large fire scars and more frequent scarring on southwest-facing slopes for individual species groups. For all species groups, scar frequency and scar height were positively correlated with stem-bark char height, a proxy for fire intensity. Red oaks were the most sensitive species group to scarring, and shortleaf pine and post oak were the most fire-resistant. Tree vigor index values indicated that black oak vigor was lower in unburned plots and crown vigor index indicated that scarlet oak vigor was lower in burned plots. The relationship between fire intensity, aspect, and species composition are important factors to consider when using prescribed fire.

INTRODUCTION

Prescribed fire is an effective tool to achieve specific ecosystem goals (Vose 2000). In Missouri, public agencies are using prescribed fire to restore glade, savanna, and woodland communities and to reduce hazardous fuel loads. A consequence of using prescribed fire is the potential to damage timber resources caused by heat-related cambial injury and subsequent scarring. High-intensity prescribed fires may also cause scorch in overstory hardwoods, thereby negatively affecting crown health (Brose and Van Lear 1999).

Many studies have used stem-bark char height as a postfire predictor of tree mortality in conifers (Dixon and others 1984, Regelbrugge and Conrad 1993, Menges and Deyrup 2001, Beverly and Martell 2003, Keyser and others 2006) and eastern hardwoods (Loomis 1973, Regelbrugge and Smith 1994). Low-intensity prescribed fires in eastern oak-dominated forests do not cause high rates of overstory mortality but can injure trees and cause subsequent basal scarring (Wendel and Smith 1986, Franklin and others 2003). Fire-caused scars in central hardwoods are a serious problem when managing timber resources, in part because of subsequent invasion by insects and fungal pathogens and the loss of timber volume (Berry and Beaton 1972, Loomis 1973). Postfire injury models have used bole blackening and stem-bark char height as important predictors of basal injuries in hardwoods (Loomis 1973, Simard and others 1986). Jenkins and others (1997) used landscape variables to predict fire scar frequency following a wildfire in northern Arkansas.

Evidence of fire impacts on crown conditions is most apparent in conifer-dominated stands, where intense crown damage leads to reduced diameter growth or high mortality rates (Peterson and Arbaugh 1986, Henning and Dickmann 1996, Stephens and Finney 2002, Kobziar and others 2006). Little research

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exists on the effects of fire on crown conditions in oak-hickory forests. Brose and Van Lear (1999) studied prescribed fire in an oak-dominated shelterwood and found spring and summer fires decreased the proportion of oaks with healthy crowns. They also reported that fire damage to other hardwoods manifested as declining crown conditions. Tree crown conditions have recently been used as indicators of forest health (U.S. Department of Agriculture 2005, Zarnoch and others 2004) and individual tree health (Starkey and Guldin 2004), and examining crown conditions in oak-dominated stands managed with prescribed fire can provide insight into fire impacts on forest health.

STUDY AREA

The study sites are located in upland forests across the Missouri Ozark Highlands. Data were collected from public and private lands across three ecological subsections (ES): the Current River Hills ES, the White River Hills ES, and the Meramec River Hills ES (Nigh and Schroeder 2002). Study sites include: Caney Mountain Conservation Area in the White River Hills ES; Pea Ridge Conservation Area in the Meramec River Hills ES; and Peck Ranch Conservation Area, Clearwater Lake Conservation Area, Logan Creek Conservation Area, Mule Mountain in Rocky Creek Conservation Area, Ozark National Scenic Riverways, and The Nature Conservancy's Chilton Creek Management Area in the Current River Hills ES.

The Ozark Highlands is characterized as hilly to rugged lands with relatively thin, rocky soils. The pre-EuroAmerican settlement vegetation in the uplands was a mosaic of mixed-oak and pine-oak woodlands and forests (Batek and others 1999). The current upland forests are dominated by white oak (*Quercus alba* L.), scarlet oak (*Q. coccinea* Muench.), and black oak (*Q. velutina* Lam.), with minor representations from hickories (*Carya* spp. Nutt.) and shortleaf pine (*Pinus echinata* Mill.). The range of scarlet oak does not extend into the White River Hills study area, but Shumard oak (*Q. shumardii* Buckl.) was relatively common throughout the area. Current management objectives in the study area include using prescribed fire to restore oak and pine-oak woodlands, including reducing woody undergrowth, stimulating native grasses and forbs, and reducing litter depths (Nelson 2005).

METHODS

Within each study area, burn units were selected for sampling. A burn unit is defined as an area surrounded by firebreaks and managed with prescribed fire. Twenty-two burn units were sampled from three ecological subsections: one unit in the Meramec River Hills, three units in the White River Hills, and 18 units in the Current River Hills. Each burn unit can be characterized as an upland oak- or pine-oak dominated forest matrix with glade inclusions and woodland intergrades. Burn units ranged in area from 10 ha to 660 ha. Each burn unit had at least one dormant season prescribed fire in the last 5 years. In each burn unit, transects were established along the slope of the hill in forested areas with an oak-dominated overstory. The number of transects per burn unit varied according to the size of the burn unit.

Sampling occurred in 20-m radius plots located along each transect. Transects were stratified by slope position (upper slope, middle slope, lower slope). Plots were systematically located within each slope position and were at least 40 m from forest edge and no less than 75 m from other plots. If a plot location did not contain at least 15 oaks greater than 10 cm diameter at breast height (d.b.h.), then the plot was relocated to the closest point that met this requirement. Plots per transect ranged from two (no middle slope position sampled) to three (all three slope positions sampled) based on the length of the hill. A total of 100 plots were sampled across the study area. Plots were equally sampled on northeast- (316°-135°) and southwest-facing (136°-315°) slopes. Glades, woodlands, and forests with high levels of fire-caused overstory mortality were not sampled.

The aspect of each plot was recorded by measuring the direction of the slope at plot center. A plot-level mean stem-bark char height was determined for each plot. Bark char refers to any blackening of stem bark due to fire. Field observations noted that shortleaf pine bark char was consistently higher than bark char on hardwoods, and therefore shortleaf pine bark char was not included in the plot-level calculation. Plots were subdivided into one-third subplots and a mean maximum bark char height on hardwoods was calculated from at least two char measurements in each one-third subplot.

For trees greater than 10 cm d.b.h., the three largest fire scars were measured for white oak, scarlet oak, Shumard oak, black oak, post oak (*Q. stellata* Wangenh.), hickories, and shortleaf pine. We included fire scar data for scarlet oak and Shumard oak in a red oak species group because the species have similar bark characteristics (i.e. fire tolerance) and we had only a small sample size for Shumard oak. Scar measurements included scar height and width at scar midpoint. The frequency of scarring per plot was recorded for all trees greater than 10 cm d.b.h. for the same six species groups.

Tree height (H), crown radius (CR), live crown ratio (LCR), crown density (CD), and d.b.h. were recorded for up to four randomly selected black oak and scarlet oak overstory trees in plots occurring in the Current River Hills. Crown density is defined as the amount of crown branches, foliage and reproductive structures that block light through the crown (Zarnoch and others 2004). Crown density was estimated by ocular assessment using a crown density-foliage transparency card from the 3.0 phase 3 field guide—crown: measurements and sampling (USDA Forest Service 2005). Black oak was also sampled from plots in the White River Hills.

For a direct comparison of tree vigor in unburned and burned areas, five stands not managed with fire were sampled. Stands were selected based on two criteria: 1) similar physiognomy (i.e., overstory species composition, stand structure) as burned areas; and 2) close proximity to burned areas. Transects and plots were established in unburned areas in the same manner as in burned areas. In each plot crown measurements were recorded for overstory black oaks and scarlet oaks. A total of 68 burn plots and 31 unburned plots were inventoried for sample tree measurements.

Crown surface area (CSA) for each individual sample tree was calculated based on the assumption that the crown surface is approximated by a parabaloid (Zarnoch 2004). Stem surface area (SSA) was calculated by assuming the bole of the tree was equal to the surface area of a cone using tree height (m), d.b.h. (cm), and an adjustment coefficient (Whittaker and Woodwell 1967). Two measures of tree vigor, crown surface index (CSI) and tree vigor index (TVI), were calculated using CSA and SSA (Voelker 2004):

Eq. 1. $SSA = ((\pi \times d.b.h. \times H) / 2) \times c$

Eq. 2. $CSI = CSA \times (1 - LCR)$

Eq. 3. $TVI = CSI / SSA$

where c = 1.268, an adjustment coefficient for scarlet oak from Whittaker and Woodwell (1967). Calculations for this study assume the adjustment coefficient for scarlet oak is the same for black oak (Voelker 2004).

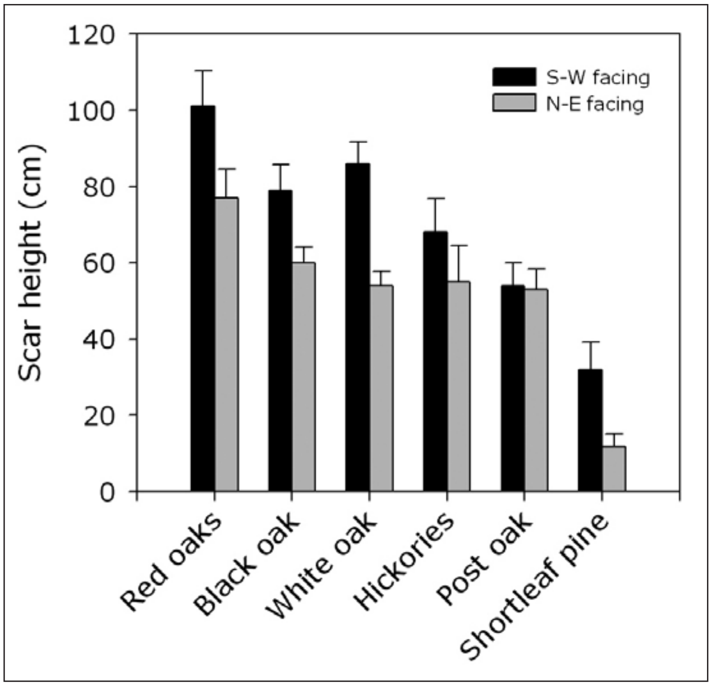

Figure 1.—Mean maximum scar height on southwest- and northeast-facing slopes for six tree species groups.

Analysis

Plot-level mean maximum scar height was determined for each species group. Scar frequencies at each plot were converted to a percentage of trees scarred for each species and for all selected species groups combined. Mean scar height and percent trees scarred were determined for each species on northeast and southwest-facing slopes.

Scar heights were normalized by calculating the natural logarithm of the mean. Scar percentages were normalized using Bartlett's arcsine transformation (Zar 1999). Aspect was transformed to a linear scale following Beers and others (1966). Multiple regression analysis was used to model scar height and scar percentage with respect to bark char height and aspect. For each model, char height was added and retained if its p-value was less than $\alpha = 0.05$. Aspect was then added to the model and retained if its p-value was less than $\alpha = 0.05$. The small sample size precluded regression analysis for shortleaf pine.

Mean CSI and TVI were determined for black oak and scarlet oak at each plot where overstory sample trees were measured. The effect of burning on CSI and TVI was tested for both black and scarlet oak using a mixed-model analysis of variance ($\alpha = 0.05$), where treatment (burned or unburned) is the fixed effect and unit (unburned stand or burn unit) is the random effect.

RESULTS

Mean scar height for each species group was higher on exposed versus protected slopes (Fig. 1). Overall, red oaks had the greatest scar heights and shortleaf pine had the lowest scar heights on both northeast-facing and southwest-facing slopes. Percent of trees scarred was highest for each species and all species groups combined on exposed slopes (Fig. 2). Red oaks and black oak had the highest percentage of trees scarred on exposed slopes, and shortleaf pine had the lowest scar percentage on exposed and protected slopes.

Multiple regression analysis revealed that bark char height was a weak to moderate predictor of mean scar height for all six species groups. Predictions from the model indicated red oaks to be the most sensitive

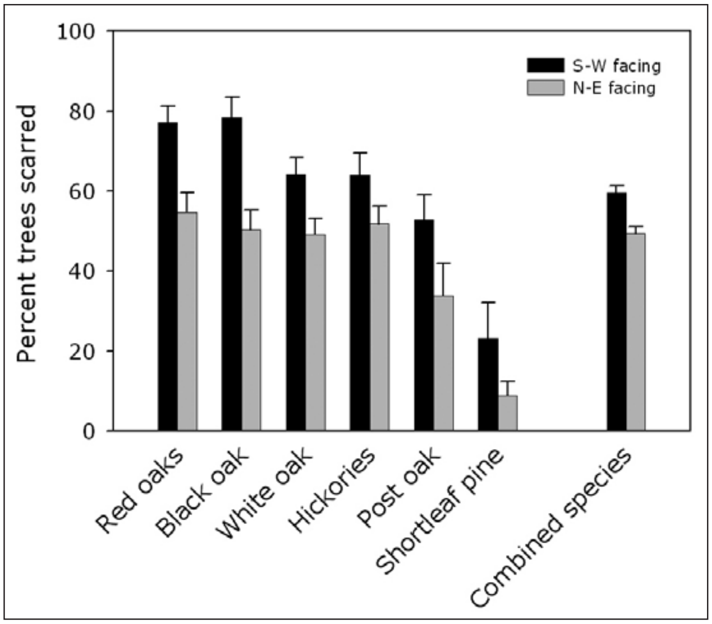

Figure 2.—Percent of trees scarred on southwest- and northeast-facing slopes for six species groups and combined species.

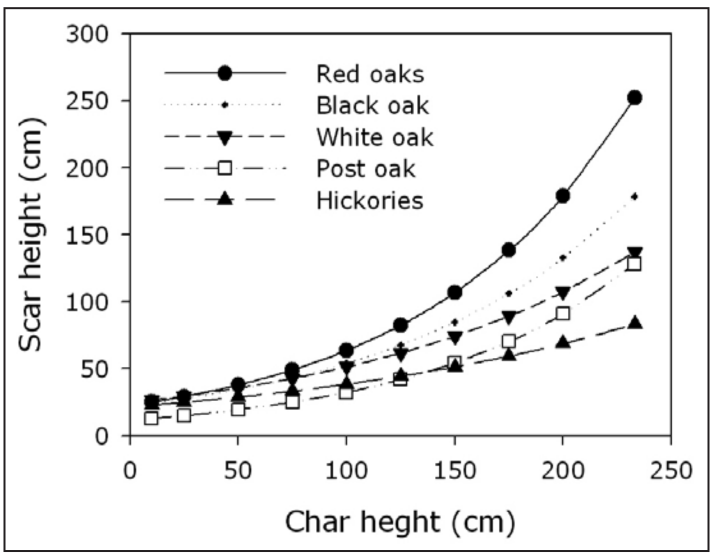

Figure 3.—Predicted scar height for five species groups based on stem-bark char height on hardwoods.

to scarring, followed by black oak and white oak, and post oak and hickories (Fig. 3). Aspect was a weak predictor of scar height for white oak and post oak (Table 1). For percentage trees scarred, stem-bark char height was a weak to moderate predictor for each species. Aspect was a weak predictor of percent trees scarred for red oaks, white oak, and all species groups combined (Table 2).

For overstory sample trees, mean d.b.h. and tree heights (H) were higher in unburned sites for scarlet and black oak (Table 3). CSA and CR were higher in unburned plots for scarlet oak, but black oak showed little differences in CSA and CR between burned and unburned plots. There was no difference in the CSI of black oak in burned and unburned plots, but scarlet oak had a lower CSI in burned plots ($F_{1,18} = 5.58$, $p < 0.03$) (Table 3). There was no difference for the tree vigor index (TVI) of scarlet oak, but TVI of black oak was lower in unburned areas ($F_{1,27} = 5.82$, $p < 0.04$)(Table 3).

Table 1.—Summary of multiple regression analysis for mean maximum scar heights of five Missouri tree species groups

Species	No. plots	Predictors	R^2	p-value
Red oaks[1]	82	char[2]	0.46	<0.001
Black oak	69	char	0.41	<0.001
White oak	93	char, aspect[3]	0.32	<0.001
Post oak	40	char, aspect	0.44	<0.001
Hickories	67	char	0.18	<0.001

[1]Red oaks include scarlet oak and Shumard oak
[2]Char = mean maximum bark char height (m) within a plot
[3]Aspect = transformed aspect (Beers and others 1966)

Table 2.—Summary of multiple regression analysis for percentage of trees scarred for five tree species groups and combined species

Species	No. plots	Predictors	R^2	p-value
Red oaks[1]	88	char[2], aspect[3]	0.37	<.001
Black oak	79	char	0.25	<.001
White oak	97	char, aspect	0.32	<.001
Post oak	57	char	0.30	<.001
Hickories	73	char	0.16	<.001
Combined species	100	char, aspect	0.30	<.001

[1]Red oaks include scarlet oak and Shumard oak
[2]Char = mean maximum bark char height (m) within a plot
[3]Aspect = transformed aspect (Beers and others 1966)

Table 3.—Mean and standard error (in parentheses) for variables measured for overstory scarlet oak and black oak. Different letters represent within-species differences between CSI and TVI in burned and unburned areas.

	Scarlet oak		Black oak	
	Burned	Unburned	Burned	Unburned
d.b.h. (cm)	33.0 (7.6)	38.6 (9.9)	33.6 (8.1)	36.4 (8.1)
H (m)	20.2 (3.2)	24.9 (3.3)	20.2 (2.8)	22.0 (3.0)
CR (m)	4.0 (0.9)	4.4 (1.3)	3.6 (0.9)	3.4 (0.8)
CSA (m^2)	68.0 (33.2)	86.4 (37.7)	55.3 (22.2)	52.5 (21.6)
CSI[a]	66.3 A (5.3)	94.3 B (10.6)	57.3 (4.4)	55.1 (2.9)
TVI[a]	4.5 (0.2)	4.6 (0.1)	3.5 A (0.2)	3.9 B (0.1)

H = total tree height; CR = average crown radius; CSA = crown surface area; CSI = crown surface index; TVI = tree vigor index.
[a]Values derived from measured variables

DISCUSSION

Based on the scar height and percent trees scarred results, species could be ranked according to sensitivity to scarring:

red oaks > black oak = white oak > post oak = hickories > shortleaf pine

These results are similar to other studies examining fire damage in hardwoods. Harmon (1984) found tree survival from a low-intensity surface fire increased with increasing bark thickness, and ranking fire sensitivity based on his bark thickness findings revealed scarlet oak as the most fire-sensitive and shortleaf pine as the least fire-sensitive of the species we examined. Regelbrugge and Smith (1994) found scarlet oak was the least fire-resistant of the oaks they examined. Studies in the Missouri Ozarks found scarlet oak as the most sensitive species to scarring, followed by white oak, black oak, hickories, and post oak (Burns 1955, Paulsell 1957).

Stem-bark char height has long been used to predict postfire mortality, but few studies have used it to predict fire injuries. Only two studies were found that used stem-bark char as an important predictor of fire injuries. Stem-bark char was used to predict scar height and scar width in Missouri oaks and hickories (Loomis 1973) and to predict percent circumference killed in northern hardwoods (Simard and others 1986). Our findings concluded that stem-bark char is an effective postfire variable for assessing scar heights and percent trees scarred in Missouri oaks and hickories.

Aspect determines solar radiation exposure on a slope, which in turn affects air temperature and fuel moisture levels. These factors contribute to fire intensity, and thus fire temperatures are higher on more exposed southwest and southeast slopes than on protected northeast facing slopes (Schwemlein and Williams 2006). Although char height is an approximate indicator of fire intensity, our results support the findings of Jenkins and others (1997) that aspect needs to be included in postfire injury models to capture a more complete effect of fire intensity.

Black oak is considered a relatively fire-tolerant species due to its relatively thick bark (Harmon 1984). Thicker bark can insulate the cambium from fire-caused injury and prevent injury-related crown dieback. The CSI for black oak was not different between burned and unburned areas, but the higher TVI in burned areas reflects the capacity for black oaks in prescribed fire stands to support a crown with less stem surface area than black oaks in unburned stands. It is possible that black oaks are able to better compete with other species for crown space in burned areas.

The lower CSI of scarlet oak in burned areas supports other research showing that fire decreased the proportion of oaks with healthy crowns (Brose and Van Lear 1999). Scarlet oaks are the most fire-sensitive oak species in Missouri and we expected them to have reduced crown vigor in burned stands. Overall TVI of scarlet oak was not different in burned and unburned areas. The lack of difference could be explained by the metric used to express tree vigor, which relied on weighting the CSI by the SSA, and scarlet oaks in unburned areas had a higher mean SSA due to larger mean diameters and tree heights.

It is unclear why scarlet oak and black oak had higher mean diameters and heights in unburned areas. Although the basal area in burned (21.5 ± 6.1 m^2 per ha) and unburned areas (21.4 ± 5.3 m^2 per ha) is nearly identical, it is possible that the unburned areas we selected for study sites were of higher site quality and higher productivity than burned areas targeted for woodland restoration and prescribed fire management. Although care was taken to ensure unburned areas sampled had similar forest structure and composition as burned areas sampled, it is possible that differences in environmental conditions between burned and unburned areas led to spurious results.

Based on these findings, resource managers using prescribed fire may improve the likelihood of satisfying the management objectives by realizing the consequences of prescribed burning. Postfire impacts such as scarring are dependent not only on fire intensity, but also on species composition and aspect. After a relatively intense fire, stands dominated by scarlet oak or Shumard oak will have more large fire scars than stands dominated by shortleaf pine and post oak. Under normal fire conditions, trees on southwest-facing slopes will be at higher risk for scarring than trees on northeast-facing slopes. Managers using prescribed fire must take into account the relationship between fire intensity, aspect, and species composition.

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