EFFECTS OF LONG-TERM PRESCRIBED BURNING ON TIMBER VALUE IN HARDWOOD FORESTS OF THE MISSOURI OZARKS

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Abstract.—Prescribed fire is commonly used for restoring and managing oak woodlands but raises concern over the risk of value loss to timber products. We used a long-term prescribed burning study to quantify standing timber volume and stumpage value, fire scar presence and size, and timber value loss in comparison to unburned stands. Three study treatments were initiated in 1949: annual burning (Annual; 1-year fire return interval), periodic burning (Periodic; 4-year fire return interval), and no burning (Control). In 2013, we measured the diameter at breast height (d.b.h.) and merchantable height of each overstory tree of sawtimber size (≥ 9.5 inches d.b.h.), from which standing volume and stumpage value were calculated. We measured the dimensions of each fire scar that was present and determined percent value loss based on previously published equations. We found that 4.8 percent of the overstory trees were scarred in the Annual plots compared to 54.8 percent in Periodic plots. At the stand level, percent value loss from fire damage was estimated to be less than 1 percent on Annual plots and less than 3 percent on Periodic plots. However, the stumpage values of Annual plots and Periodic plots were 29.9 percent and 34.3 percent lower than that of the Control plots, respectively, due to lower standing volume and greater prevalence of low-value species (i.e., post oak [*Quercus stellata* Wangenh.]). These results suggest that long-term, frequent prescribed burning affects stand-level timber value primarily through effects on stand structure and composition rather than fire damage.

INTRODUCTION

The restoration of oak woodlands has become an important management objective for many public and private landowners in the Central Hardwoods Forest region (Kabrick et al. 2014). In comparison to forests, woodlands are characterized by lower stocking, higher light levels beneath the canopy, relatively open midstory layers, and greater abundance of herbaceous vegetation in the ground layer (Hanberry et al. 2014a, Nelson 2004). Motivation for woodland restoration is driven, in part, by evidence that woodlands were more common on the landscape historically than they are today (Batek et al. 1999, Hanberry et al. 2014b, Nuzzo 1986), as well as recognition of the high levels of floristic diversity (Knapp et al. 2015, Peterson and Reich 2008) and unique wildlife habitats (Reidy et al. 2014, Starbuck et al. 2015) associated with these ecosystems.

The structure and composition of oak woodlands can be maintained with frequent, low-intensity surface fires (Kabrick et al. 2014), which were an important historical disturbance in the region (Guyette et al. 2002). Frequent fire kills or top kills small-diameter woody vegetation (Dey and Hartman 2005, Hutchinson et al. 2005b, Waldrop et al. 1992) and thus creates open stand structure (Knapp et al. 2015). Greater growing space and light availability at the forest floor and the reduction in litter depth by consumption from burning provide opportunities for herbaceous plants to establish and flourish in frequent-fire ecosystems (Hiers et al. 2007, Veldman et al. 2014). As a result, the richness, diversity, and abundance of herbaceous vegetation have been

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found to increase following prescribed burning in oak woodlands (Hutchinson et al. 2005a, Kinkead et al. 2013).

Although the probability of direct woody stem mortality due to fire decreases as stem diameter increases, prescribed burning can have complex and long-lasting effects on individual trees. Damage to cambial tissue from prescribed burning commonly results in scar formation on the lower portion of tree boles (Guyette and Stambaugh 2004, Shigo 1984), which can lead to fungal infection and the development of decay (Smith and Sutherland 1999). The likelihood of fire damage and subsequent scar formation is variable and is affected by factors such as fire intensity, tree size, and tree species (Dey and Schweitzer 2015, Guyette and Stambaugh 2004). Moreover, fire-induced defects may increase in size through time or following additional fires (McEwan et al. 2007), resulting in potentially negative impacts on timber value (Loomis 1974, Marschall et al. 2014).

Land managers are commonly challenged with balancing multiple objectives, some of which may not be compatible (Bradford and D'Amato 2012). Throughout the eastern United States, uncertainty and concern exist regarding how the use of prescribed fire may affect timber value in hardwood forests. A recent study from the Missouri Ozarks quantified value loss of fire scarred red oaks and reported that much of the damage was located in slab material cut away at the mill, with an average product value loss of 10.3 percent among fire-scarred butt logs (Marschall et al. 2014). However, longer-term prescribed burning (i.e., multiple decades) in forests may also affect timber values by changing the structure (e.g., tree density or standing volume) and composition at the stand level.

A long-term (>60 year) prescribed burning study provides the opportunity to assess effects of fire on timber quality and value. Our specific objectives were to: (1) determine effects of long-term burning at different intervals on standing timber volume; (2) determine effects of long-term burning at different intervals on scar presence and scar size; and (3) estimate timber value loss after more than 60 years of prescribed burning due to stand-level effects (i.e., structure and composition) and individual tree effects (i.e., damage from scarring).

METHODS

This study was established in 1949 at the University Forest Conservation Area in the Ozark Highlands of southeastern Missouri. Soils were moderately well-drained, upland silt loams with a fragipan at moderate depth (Graves 1984) and slopes of 3 to 8 percent in the study area. Since the study was initiated, mean annual temperature has been 57 °F and mean annual precipitation has been 44.5 inches. The study used a randomized complete block design with two blocks (replicates) located approximately 1 mile apart. Both blocks have six study plots, each measuring 131.2 feet × 131.2 feet with a 32.8 foot buffer around all sides. A prescribed fire treatment of unburned control (Control), annual burning (Annual; 1-year fire return interval), or periodic burning (Periodic; 4-year fire return interval) were randomly assigned to plots, resulting in two plots of each treatment per block. All burns were conducted between March and May, and all units that were to be burned in a given year were typically burned on the same day. Fire behavior records kept since 1997 indicate that burns were of low to moderate intensity with generally good consumption of hardwood litter fuels. The most recent burns occurred in Periodic plots in 2012 for one block and 2013 for the other block.

In summer 2013, all overstory trees of sawtimber size (≥ 9.5 inches diameter at breast height [d.b.h.]) were tagged. Species, d.b.h., and merchantable height were recorded for each tree. We determined merchantable height of each tree to the nearest full 4-foot length by measuring the height to the first fork or by calculating the height to an 8-inch diameter inside bark (d.i.b.), assuming a Girard form class of 78. Standing volume was calculated for white oak (*Quercus alba*), post oak (*Q. stellata*), red oaks (*Q. coccinea, Q. falcata, Q. velutina*), hickories (*Carya glabra, C. texana, C. tomentosa*), and for all species together using International ¼-inch log rule. Although there were other species present (e.g., *Cornus florida, Nyssa sylvatica, Ulmus alata*), they did not contribute merchantable volume. We determined standing stumpage value by applying recent Missouri timber prices (Morris and Treiman 2015) (Table 1) to each tree in the study and calculating stumpage value at the stand level. White oak and post oak were analyzed separately because of the difference in stumpage price between the species.

Table 1.—Timber stumpage prices for January-March, 2015, published by Missouri Department of Conservation (Morris and Treiman 2015)

Species group	Stumpage price per board foot
Hickories	$0.21
Post oak	$0.13
Red oaks	$0.29
White oaks	$0.26
Mixed hardwoods	$0.22

The presence of external damage was noted for each tree in the burned plots only, and the height, width (at the widest point), and depth of each wound (fire scar) were recorded. We assumed that each wound encountered below breast height (4.5 feet) was due to fire damage. We calculated scar volume as the product of scar height, width, and depth, and the proportion of the circumference of each tree that was scarred (circumference ratio) was calculated as scar width divided by tree circumference at breast height. We calculated the estimated timber value loss to the butt log using equations developed from red oaks by Marschall et al. (2014):

$$PVL = 0.51 + (13.5 * FDI) \quad (1)$$

$$FDI = \frac{(SH * SD)}{TBA} \quad (2)$$

Where

PVL = percent value loss to the butt log,

FDI = Fire damage index,

SH = scar height (inches),

SD = scar depth (inches), and

TBA = tree basal area (inches^2).

We summarized data at the stand level within each block (i.e., the experimental unit was two plots per treatment in each block). We calculated the number of trees per acre, the basal area (square feet per acre), volume (board feet per acre), and stumpage value ($ per acre) by species group for all trees ≥9.5 inches d.b.h. Variables that described scar size (scar width, scar height, scar depth, scar volume) and scar ratios (circumference ratio, FDI) were calculated at the treatment level using only scarred trees (mean per tree) and using all trees (mean per acre). We applied the calculated PVL to each butt log and then determined the value loss for the entire merchantable stem.

We used mixed-model analysis of variance to test for treatment effects on stand-level response variables, with block included as a random effect. Pair-wise comparisons among treatments were tested using Fisher's protected Least Significant Different (LSD). Because fire scars were only present on Annual and Periodic treatments, we used t-tests to compare scar size, scar ratio variables, and percent value loss. Analyses on scar size and ratios were conducted using only scarred trees (mean per tree) and using all trees (mean per acre). Treatment effects were determined to be statistical significance when $p < 0.05$.

RESULTS

There were no significant treatment effects on the number of trees per acre, basal area per acre, merchantable volume per acre, quadratic mean diameter (QMD), or standing stumpage for any species group or for all trees combined (Table 2), although there were too few hickories and white oaks for statistical analysis of QMD. Although not statistically significant, merchantable volume ranged from less than 6,000 board feet per acre in the Periodic plots to greater than 7,000 board feet per acre in the Control plots. Red oaks contributed the majority of the volume in the Control plots (56 percent standing volume), and post oaks dominated volume in the Annual (62 percent standing volume) and Periodic plots (60 percent standing volume).

Table 2.—Means and one standard error (SE) for number of trees per acre, quadratic mean diameter, basal area, merchantable volume, and stumpage value by treatment for each species group tested, and p-values from ANOVA tests for treatment effects

	Control		Annual		Periodic		
Species group	Mean	SE	Mean	SE	Mean	SE	p-value
			Trees per acre				
Hickories	5.69	5.69	0.63	0.63	0.00	0.00	--[a]
Post oak	33.53	5.69	48.08	6.33	46.82	26.57	0.685
Red oaks	27.84	0.00	17.71	0.00	12.65	11.39	0.420
White oaks	3.16	1.90	3.16	3.16	1.27	1.27	0.809
Total	70.22	1.90	69.59	2.53	60.73	16.45	0.765
			Quadratic mean diameter (inches)				
Hickories	12.44	--	10.43	--	--	--	--
Post oak	13.52	0.01	13.52	0.30	13.98	1.34	0.897
Red oaks	16.65	0.37	14.70	0.83	17.17	0.75	0.218
White oaks	15.10	0.41	16.97	--	16.88	--	--
Total	14.85	0.22	14.00	0.26	14.83	1.95	0.848
			Basal area (square feet per acre)				
Hickories	4.80	4.80	0.38	0.38	0.00	0.00	--
Post oak	33.42	5.73	48.25	8.41	44.97	19.06	0.450
Red oaks	42.12	1.85	20.93	2.36	21.97	20.11	0.491
White oaks	4.06	2.58	4.97	4.97	1.97	1.97	0.832
Total	84.41	0.20	74.52	5.44	68.91	0.92	0.116
			Volume (board feet per acre)				
Hickories	367.30	367.30	25.51	25.51	0.00	0.00	--
Post oak	2539.06	337.99	3984.11	909.07	3510.23	1382.42	0.335
Red oaks	4172.66	233.04	1886.17	299.36	2132.91	1952.62	0.456
White oaks	349.18	203.60	491.12	491.12	178.32	178.32	0.810
Total	7428.21	0.13	6386.91	691.80	5821.46	391.89	0.241
			Stumpage value ($ per acre)				
Hickories	77.13	77.13	5.36	5.36	0.00	0.00	--
Post oak	330.08	43.94	517.23	118.86	456.34	179.75	0.337
Red oaks	1210.06	67.58	546.99	86.81	618.52	566.24	0.456
White oaks	90.79	52.93	127.69	127.69	46.36	46.36	0.810
Total	1708.06	18.54	1197.27	72.62	1121.22	340.14	0.284

[a]-- indicates sample size too small.

Table 3.—Means and one standard error (SE) for percentage of trees scarred and scar width, height, and depth measurements by treatment for the most common species groups, and p-values from t-tests for treatment effects. Sample sizes (n) represent all trees for percentage of trees scarred and only scarred trees for the scar characteristics.

	Annual			Periodic			
Species group	n	Mean	SE	n	Mean	SE	p-value
			Trees scarred (percent)				
Post oak	71	5.83	1.07	71	47.95	22.95	0.207
Red oaks	27	5.00	5.00	20	73.68	26.32	0.122
All trees	104	4.77	0.69	93	54.78	17.64	0.214
			Scar width (inches)				
Post oak	4	4.82	2.26	42	7.35	0.26	0.383
Red oaks	1	4.33	4.33	10	4.23	3.12	0.986
All trees	5	5.84	1.25	54	7.30	0.03	0.451
			Scar height (inches)				
Post oak	4	18.25	9.78	42	10.69	4.39	0.554
Red oaks	1	20.89	20.89	10	8.10	6.21	0.617
All trees	5	20.54	12.07	54	13.08	1.24	0.602
			Scar depth (inches)				
Post oak	4	1.62	1.03	42	1.86	0.11	0.843
Red oaks	1	7.34	7.34	10	0.64	0.37	0.458
All trees	5	3.63	3.04	54	1.48	0.18	0.553

Although the percentage of trees scarred was not significantly different between burn treatments, 54.8 percent of the trees were scarred in Periodic plots and 4.8 percent of the trees were scarred in Annual plots (Table 3). When analyzing only trees with fire scars, scar size measurements were not significantly different between treatments (Table 3). Mean scar volume was high in the Annual plots due to one red oak with a particularly large scar, which resulted in high variability between blocks (Fig. 1). Averaged at the stand level, however, scar size and scar ratios decreased in Annual plots due to the low number of trees that were scarred, resulting in <1.0 percent of total tree circumference being scarred in Annual plots compared to 9.8 percent in Periodic plots.

Percent value loss due to fire damage was low in both treatments. For trees with scars, the butt logs in Annual plots had an average value loss of 9.0 percent compared to 3.2 percent value loss in Periodic plots, although this was not significantly different (Fig. 2). However, at the stand level (analyzing all trees) the value loss was 0.5 percent in the Annual plots compared to 2.0 percent in the Periodic plots. The butt log commonly made up the majority of merchantable volume in the trees on these sites; however, the percent value loss was nearly halved when accounting for the value of the entire merchantable tree rather than only the butt log (Fig. 2).

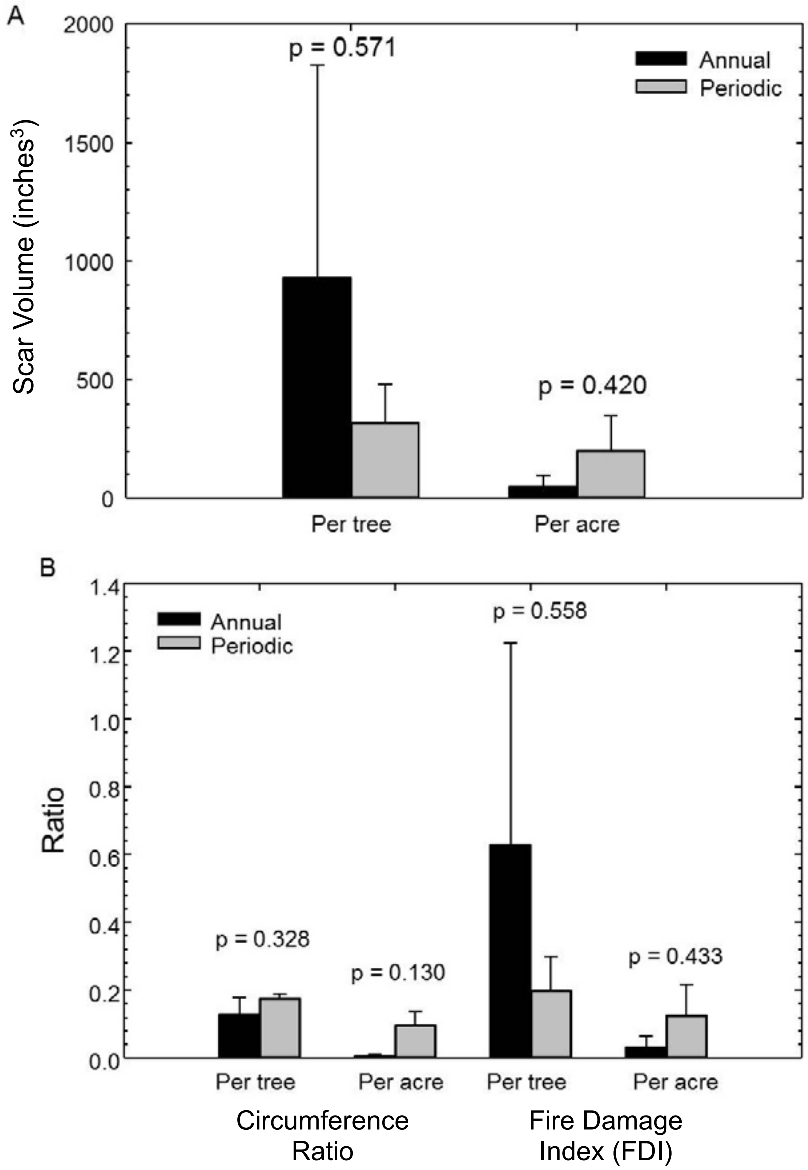

Figure 1.—Means and one standard error (error bars) for (A) scar volume, and (B) the proportion of tree circumference scarred and the Fire damage index. Each variable was calculated at the tree level (using only scarred trees) and at the stand level (using all trees), and p-values are from t-tests comparing burn treatments for each test.

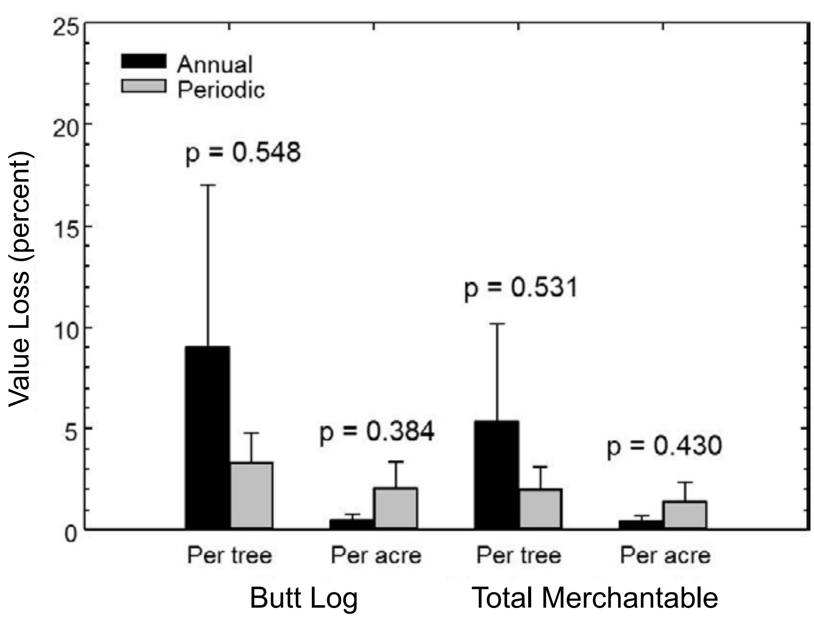

Figure 2.—Means and one standard error (error bars) for percent value loss of the butt log and of the total merchantable volume. Each variable was calculated at the tree level (using only scarred trees) and at the stand level (using all trees), and p-values are from t-tests comparing burn treatments for each test.

DISCUSSION

Our results showed no statistical effects of the burn treatments on stand structure. In a previous publication from this study, Knapp et al. (2015) reported that the burn treatments reduced stand basal area compared to the unburned control when considering trees >4 inches d.b.h. Because the probability of fire-induced mortality decreases as tree size increases (Dey and Hartman 2005), analyzing only sawtimber trees ≥ 9.5 inches d.b.h. in the current study likely reduced the impact of treatment effects. With no evidence of ingrowth of new trees into the canopy of burned plots (data not shown), the apparent shift in composition to post oak dominance on burned plots reflects the lower fire tolerance of mature red oak trees. It is not yet clear how the reduction in small-diameter stems previously reported (Knapp et al. 2015) would affect stand development and the prospect of future timber production with continued fire management.

For trees that were scarred, there was little indication that damage differed between the two burn treatments based on scar dimensions and tree size. However, few trees were scarred in the Annual plots but more than half the trees were scarred in the Periodic plots, resulting in relatively little damage at the stand level in the Annual plots. After the first 8 years of this study, Paulsell (1957) reported that 25 percent of trees on Annual plots and 40 percent of trees on Periodic plots had fire scars. It is likely that fire intensity differed between the treatments. Hardwood litter was the primary fuel type, and we measured greater litter fuel loads in Periodic plots (3.23 tons per acre) than in Annual plots (2.04 tons per acre), which followed patterns commonly observed with time-since-fire in Central Hardwood forests (Stambaugh et al. 2006). The likelihood of damage and the degree of damage from fire are both related to fire intensity (Abbot and Loneragan 1983, Bova and Dickinson 2005, Smith and Sutherland 1999). As a result, the higher fuel loads in Periodic plots likely resulted in greater fire intensity, and consequently more damage, despite lower fire frequency.

Our results indicated that value loss due to damage from prescribed burning was low for both treatments. Marschall et al. (2014) found that fire scar heights <20 inches, similar to those observed in our study, resulted in little value loss to red oak butt logs in the Missouri Ozarks. In contrast, the stumpage value of Annual plots ($1197 per acre) and Periodic plots ($1121 per acre) were 29.9 percent and 34.3 percent less than the unburned Control stumpage value ($1708 per acre) (Fig. 3). This difference was due to the higher volume and the value of red oak ($0.29 per board foot) on Control plots compared to post oak ($0.13 per board foot) on the burned plots.

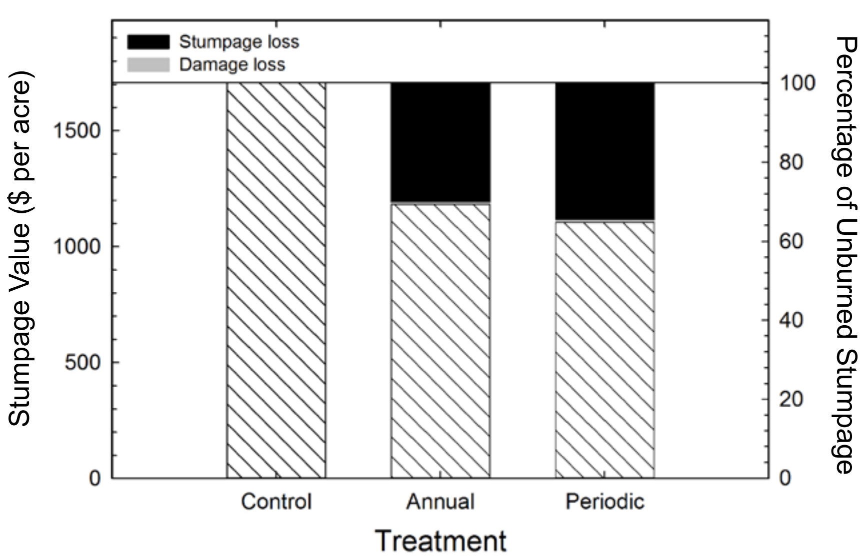

Figure 3.—Stumpage value (dollars per acre on left axis and percentage on right axis) for each treatment (hatched bars). The difference in value between each burned treatment and the control ($1708.06 stumpage value per acre) is attributed to changes in composition/structure (stumpage loss; black bars) and to scarring (damage loss; grey bars).

This study offers unique insight into the long-term effects of repeated prescribed burning on tree damage and potential value loss, despite several shortcomings. For example, statistical inference was constrained by replication in only two blocks. In addition, we applied the equations developed by Marschall et al. (2014) to estimate tree damage and value loss but recognize that the equations were developed for red oaks and for trees with no longer than 15 years of fire history. It is not clear how the development of damage would differ over longer timescales; for example, it is possible that trees in our study had internal damage or rot that was not accounted for by the models. Instances of past damage (see Paulsell 1957) may have healed over and not been identified as external scars in the current study (Smith and Sutherland 1999).

Despite these shortcomings, there were several important findings. The effects of long-term, frequent prescribed burning on stand density and composition may result in greater losses in timber value than value loss associated with fire scars on sawtimber trees. During the transition from forest to woodland structure, tree scarring from low- to moderate-intensity fires may cause relatively small decreases in standing sawtimber value. Over a period of decades, burning results in open-structured woodland conditions with an increased dominance of fire tolerant tree species, such as post oaks. Thus, decisions regarding where to target woodland restoration should consider both the existing stand composition and the overall management objectives. However, changes in stand-level value loss associated with stand density and species changes are highly dependent on value differences among species. Future changes in red oak versus post oak markets could have large influences on value losses or gains. These results may differ further when fire intensities exceed those of our study or in stands that contain trees with higher (e.g., stave, veneer) or lower (e.g., firewood, blocking) value potential.

ACKNOWLEDGMENTS

Funding for this work was provided by Research Council Grant URC 13-081, Office of Research, University of Missouri. We thank David Bourscheidt and Michael Hullinger for field assistance and are grateful for the support of the Missouri Department of Conservation, specifically Mark Pelton and Steve Orchard, and the hospitality of Marie Obourn.

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