Survival of major overstory oak trees under three fire treatments

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Introduction

The historical oak woodland-savanna complex in Missouri Ozark Highlands, shaped by frequent low-intensity surface fires, has largely been replaced by high-density oak-hickory forests. Over seventy years of fire suppression combined with altered grazing regimes have resulted in increased dominance of white oak (*Quercus alba*) and other more shade tolerant species in the region (Dey and Hartman, 2005; Kabrick et al. 2008). The Chilton Creek Prescribe Burning Project (CCPBP) was initiated in 1996 by The Nature Conservancy to study the effects of prescribed fire on woodland restoration in the Missouri Ozark Highlands. The objective of this study was to quantify the survival probability of four major oak species by three overstory size classes. This information will be helpful in projecting future trends in upland oak forest structure and composition as prescribed burning continues in the CCPBP site.

Methods

Overstory dbh was measured by species on 314 plots – 70 plots from the Missouri Ozark Forest Ecosystem Project (MOFEP) site 8 and 244 plots from the CCPBP. Data were collected in1997 prior to the initiation of burning treatments in 1998. Remeasurements occurred in 2001 and 2007. The CCPBP, implemented in the 1,000 ha Chilton Creek site, contains five burning units with varying burn cycles (Table 1). Site 8 of the MOFEP study, which is adjacent to Chilton Creek, was used as a no-burn control for comparing fire treatment effects on oak-hickory forest structure and composition.

To understand changes in overstory oak dominance, survival analysis of four major overstory oak species: black oak (*Q. velutina*), white oak, scarlet oak (*Q. coccinea*) and post oak (*Q. stellata*) was conducted. Overstory tree survival status (live or dead) in the CCPBP was right censored at three intervals: 1997 (pre-fire), 2001 and 2007 (4 and 10-years following the fire treatments, respectively). A survival distribution function (SDF) is used to describe the lifetimes of overstory oak trees. The SDF evaluated at any given time is the probability that an individual tree will have a lifetime exceeding that, as follows:

$$S(t) = \Pr(T > t)$$

where, T is the lifetime of a single overstory tree and $S(t)$ is the probability that a single tree survives beyond time t. The Kaplan-Meier (product limit) method was used to estimate individual tree survival rates at a given inventory time as:

$$\hat{S}(t_i) = \prod_{j=1}^{i}\left(1-\frac{d_j}{n_j}\right)$$

where t_i (i =1,2,3) represents inventory year 1997, 2001, and 2007, respectively; n_i and d_i are the number of surviving trees at inventory year t_i and the trees died during the inventory period by t_i. As reported in recent studies (e.g., Fan et al. 2006), tree size/vigor is significantly correlated to individual tree survival. Changes in overstory dbh distributions at the three inventory years, overstory trees are grouped into three dbh (in 1997) classes: dbh≤25cm; 25cm<dbh≤45cm; and dbh>45cm based on Fan's classification and regression tree (CART) analysis. The log-rank test was conducted separately to test the difference in survival rate of overstory trees under the annual, random and no fire treatments for four oak species and three size (dbh) classes.

Table 1: Schedule of prescribed burns conducted at Chilton Creek during the dormant season in each of the management burn unit attributes

Burn unit	Plot (n)	Dormant season fire									
		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Kelly South	43	X		X	X			X			
Kelly North	63	X	X	X	X	X	X	X	X	X	X
Chilton South	78	X	X	X			X				X
Chilton North	44	X				X		X			X
Chilton East	22	X				X	X			X	
MOFEP S8	70										

Results and Discussion

The diameter distribution of white oak (Figure 1) shows that the density of trees <20 cm dbh decreased over ten years under all treatments. In the 20 to 30 cm dbh class, tree density in the random fire and annual fire treatment increased, while density of trees >30cm dbh was not obviously affected by the treatments. The change in density of the largest trees was slight and probably due to factors other than fire. Results from the survival analysis (Figure 2) show that large white oak trees (dbh≥45cm) were not significantly affected by fire treatment (p = 0.34). The random fire treatment significantly decreased the survival probability of small trees (dbh <25cm) (p = 0.0034); however, the survival probability of white oak in all dbh classes was greater than 90% over the 10 years regardless of fire treatments.

Post oak diameter distributions (Figure 3) were similar to white oak except under the random fire treatment. Initial stem density of small post oaks (dbh<25cm) was in most cases much lower than for white oak. Similar to white oak, larger post oaks (dbh >45cm) showed no significant differences in survival probability among the fire treatments. There were significant survival differences among treatments according to the log-rank test, where the p-value was 0.04 for trees with diameters ranging from 25cm to 45cm dbh, and 0.0003 for trees <25cm dbh (Figure 4). The annual fire treatment killed fewer small trees (dbh<25cm) than the random and no fire (control) treatments. Mortality of middle-sized (25cm≤dbh<45cm) trees in the control treatment was significantly higher than under the annual and random fire treatments.

Scarlet oak and black oak had similar diameter distributions (Figures 5 and 7) and survival probabilities (Figures 6 and 8). The density of small trees (dbh<20cm) decreased over the ten years under all fire treatments. Both annual and random fire treatments increased the density of middle-sized trees. Survival probabilities of small scarlet and black oak were much lower than for white and post oak. Survival probability of scarlet oak over 10 years of fire treatments was 70%, and black oak survival probability was approximately 60%. These values are much lower than the survival probabilities of white oak (>90%) and post oak (>80%). For small-sized trees of both black and scarlet oak, there were no significant differences among treatments. For the middle-sized trees, survival probability in either fire treatment was higher than in the control treatment. The annual fire and random fire treatments significantly increased survival probabilities of these species (p < 0.0001). Larger trees, again, showed no significant differences among treatments.

Even though the life test results for small-sized trees showed statistically significant differences among treatments for white oak and post oak, we cannot conclude that treatment effects exist on small size trees, because the variation in density of small-sized trees was large for these species. For example, density of white oak (dbh <15cm) ranged from 20 to 30 trees per hectare (TPH) in the no-fire treatment, but densities ranged from 30 to 50 TPH in the annual and random fire treatments. The density of post oak (dbh<15 cm) ranged from 20 to 25 TPH in the no-fire treatment, 30 to 45 TPH in the annual fire treatment, and about 10 TPH in the random fire treatment. The average density of mid-sized trees (25 to 45cm dbh) of all four species was approximately 10 TPH (Figures 1, 3, 5, and 7). Lorimer (1985) reported that black oak was more resistant to fire than white oak based on bark thickness. It might be concluded that fire does have positive effects on the survival of mid-sized black oak, scarlet oak, and post oak, and to a certain extent mitigates mortality caused by decline. This could explain why the decrease in stem density and basal area of red oak group species in the annual and random fire treatments was lower than that within the control treatment.

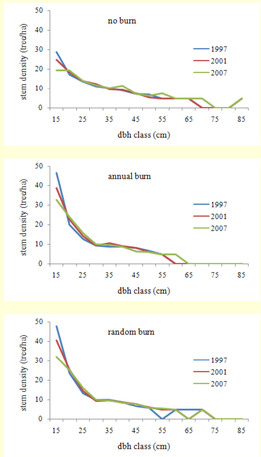

Figure 1. White oak overstory trees (dbh≥11.5cm) dbh distribution before fire treatment (1997) and after fire treatments (2001 and 2007)

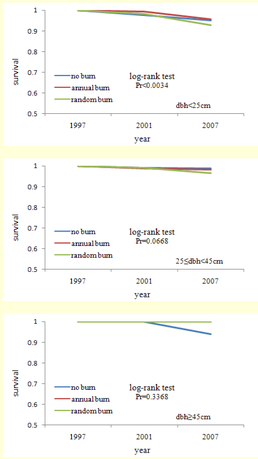

Figure 2. Survival of white oak overstory trees (dbh≥11.5cm) by fire treatment and dbh class after three and ten years' initial prescribed fire (2001 and 2007)

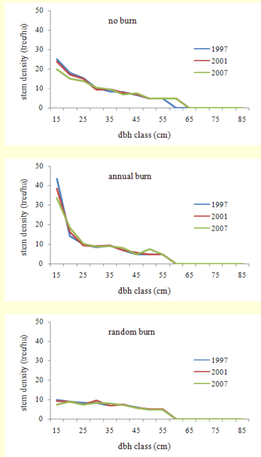

Figure 3. Post oak overstory trees (dbh≥11.5cm) dbh distribution before fire treatment (1997) and after fire treatments (2001 and 2007)

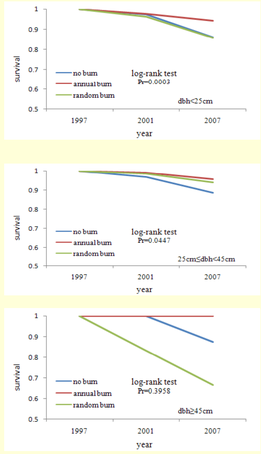

Figure 4. Survival of post oak overstory trees (dbh≥11.5) by fire treatment and dbh class after three and ten years' initial prescribed fire (2001 and 2007)

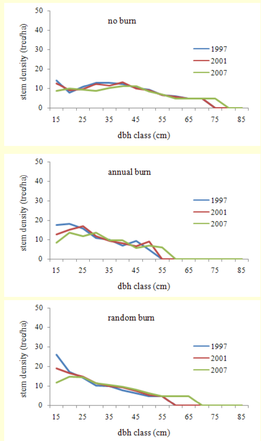

Figure 5. Scarlet oak overstory trees (dbh≥11.5cm) dbh distribution before fire treatment (1997) and after fire treatments (2001 and 2007)

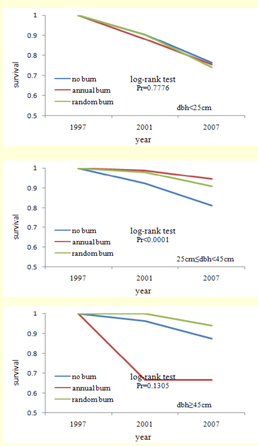

Figure 6. Survival of scarlet oak overstory trees (dbh≥11.5) by fire treatment and dbh class after three and ten years' initial prescribed fire (2001 and 2007)

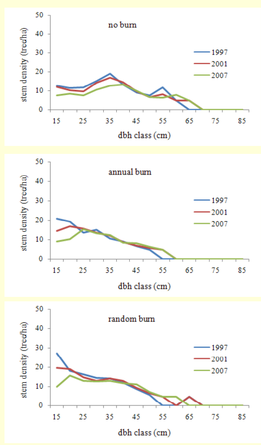

Figure 7. Black oak overstory trees (dbh≥11.5cm) dbh distribution before fire treatment (1997) and after fire treatments (2001 and 2007)

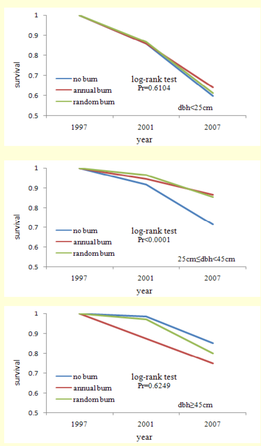

Figure 8. Survival of black oak overstory trees (dbh≥11.5) by fire treatment and dbh class after three and ten years' initial prescribed fire (2001 and 2007)

Major references

Dey, D.C., George Hartman. 2005. Returning fire to Ozark Highland forest ecosystems: Effects on advance regeneration.Forest Ecology and Mangement. 217 (2005) 37-53.

Kabrick, J.M.; Zenner, E.K.; Dey, D.C.; Gwaze, D.; Jensen, R.G. 2008. Using ecological land types to examine landscape-scale oak regeneration dynamics. Forest Ecology and Management. 255: 3051-3062.