

## Indirect Estimates of the Effect of Fire on Tree Mortality in a Temperate Managed Forest

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### Abstract

Indirect estimates of fire on canopy and juvenile tree mortality were recorded in the temperate managed forest of Cuivre River State Park. Number and proportion of standing dead and alive trees were recorded, as well as fallen logs in unburned and burned sites (two and four fire events). Density of juvenile tree was the smallest in the four burning sites compared to the unburned and two burning sites suggesting an increase in young tree mortality with fire events. Proportion of dead to alive trees was on average also highest for the juvenile trees in the four burning site (67%) supporting the notion of increased mortality for younger trees. On the other hand, canopy tree mortality, as expected, appears to be independent of the burning events, although sample sizes are relatively small. The amount of dead biomass also increased with fire events, being the diameter of tree logs and branches on the forest floor similar for all treatments. Effects of fire might be cumulative and start being significant after four burning events. The inadequacies of taking a static approach to a dynamic process to estimate tree mortality are discussed.

### Introduction

Prescribed burning is a common practice in many temperate regions to favor survival of early to mid-pioneer tree species (Taft et al. 1995). This burning practice is believed to maintain a species composition similar to that occurring since the early establishment of humans in the region. In eastern USA for example, fire exclusion in this century has facilitated the invasion of most oak understories by later successional species (Abrams 1996). Burning operates directly on forest structure and composition by differential mortality of plant species. Fire kills most of the maples (*Acer* spp.), and has little effect on the oaks (*Quercus* spp.) which can resprout more readily following fire (Huddle and Pallardy 1996). Fire also operates indirectly by opening the canopy allowing the oaks to grow and outcompete the more shade-tolerant species.

Since the prescribed burnings are done in portions of the forest, we can expect different effects at large and local scales. Within a given part of the forest, the frequency of disturbance events (fire in this case) is probably influencing the local diversity. Following Connell (1978) the highest diversity might be maintained at intermediate levels of disturbance, thus, a given frequency of fire events should maintain the highest

diversity. However, disturbance is also known to increase the invasibility of communities posing an important problem for conservation management (Hobbs and Huenneke 1992). Also at a local scale, the burning is releasing nutrients which are known to affect productivity and hence diversity. Although the relationship nutrient-diversity is empirically known the actual mechanism is not well understood (Rozenzweig 1995). Continuous burning could be detrimental if the loss of nutrients by leaching is higher than those captured by the regenerating vegetation. Finally, at a large scale, the different fire regimes in various parts of the managed forests introduces patch dynamics to the landscape, so the total diversity of the community is distributed among the different patches, allowing extinctions and recolonizations in each patch through time.

Field observations in the burned and unburned areas at Cuivre River forest suggested that a) tree mortality occurs while the tree is standing; b) tree gap influence minimal due to the small size of the trees and an open canopy, and, c) the dead biomass and debris (dead standing trees, number of branches on the forest ground, etc.) increase with the number of burning events. Based on these observations, we addressed the following question in an attempt to better understand the dynamics of these managed forests: 1) What size classes of trees (canopy and juvenile ) are more affected by burning the forest?; and, 2) What is the effect of fire on the distribution of dead biomass (i.e., standing dead trees, dead logs, branches, etc.) compared to an unburned forest?

We addressed these questions in three forest patches where two of them had undergone two and four prescribed burns respectively, and the remaining was unburned. The working hypothesis put forward were: a) that an increase in mortality for the smaller sizes of trees is expected with an increase in fire events (i.e., number of dead standing trees should be higher in burned patches) ; b) that canopy tree mortality should be independent of fire (i.e., number of dead standing tree should be constant across unburned and managed forests); and, c) A proportional increase in dead biomass related to the number of fire treatments (i.e., the number of fallen branches and logs found on the forest floor should increase with the number of fire events).

## **Methods**

The forest studied is within Cuivre River State Park, located in eastern central Missouri. The vegetation occurring park includes bottomland forests, upland deciduous hardwoods, prairies, pond marshes, limestone bluff communities and regenerating second growth. The study was conducted in the upland deciduous hardwood forest that is a forest in regeneration itself. Most of the former oak-grassland vegetation had already been replaced by pasture for cattle grazing by the beginning of the century. Since the state manages the park, tree regeneration has occurred forming a more closed canopy compared to the oak-grassland, with an increasing abundance of maple.

The management treatments considered were unburned, burned two times, and burned four times. On average, a two year period separates each burning treatment. Three transects of 50x4 m in each site (= 600 m<sup>2</sup> per treatment) were defined at random, trying

to control for slope and distance from the main road. The variables recorded were number and diameter of dead trees grouped into canopy ( $x_1 \geq 20$  cm dbh.) and juvenile ( $5 \text{ cm dbh} < x_2 < 20$  cm dbh) categories, number of alive trees in the canopy and juvenile, and, number and diameter of fallen wood.

Analysis were performed using single factor ANOVA with management treatment as the main effect (unburned, burned twice, and burned four times) to test for overall differences of canopy and juvenile tree densities, proportion of dead vs. alive trees and size of fallen logs. Post-ANOVA analyses were performed using the Tukey  $q$  test for mean differences when necessary (Sokal and Rohlf 1995).

## Results

Juvenile alive trees were the most abundant tree class found in the unburned and 2 burning sites, but not in the 4 burning site (means = 12.33, 17.67 and 2.33 respectively) (Table 1, figure 2). Means were not significantly different among the unburned and 2 burning treatments, but were significant among them and the 4 burning treatment ( $F=20.97$ ,  $p < 0.01$ , Tukey test  $q=3.396$ ,  $p < 0.10$ ). This result supports the first prediction of increased tree mortality with more burning events. In addition, canopy alive trees and dead canopy trees were not significantly different among treatments ( $F=1.03$ ,  $F=3.0$  respectively,  $p > 0.05$ , Table 1, figures 1 and 2). This result supports the second prediction, that adult trees should show a mortality independent of fire events. However, juvenile dead trees did not differ significantly among treatments ( $F=0.52$ ,  $p < 0.05$ ) which contradicts the result obtained for alive juvenile trees but reveals a trend when proportions are compared (see below).

The greatest proportion of dead trees was found for juvenile individuals in the four burning site, where 67% of the juvenile trees were dead compared to a 22% and 4% of the no burning and two burning sites (Figure 3). Despite this high value, none of the proportion values were significantly different from each other in the canopy category ( $F=1.70$ ,  $p > 0.05$ ) or juvenile category ( $F=2.62$ ,  $p > 0.05$ ) (Figure 2).

The dead material found on the forest ground (logs and branches) showed no significant differences in size as measured by diameter; but means, standard deviations and range of the data are strikingly similar (Table 2). However, the number of fallen logs increased with the number of times the site was burned indicating that fire increases the amount of dead biomass in the forest, affecting a particular size of branch or tree (ranges in table 2). In the same way, the abundance of dead material showed no significant differences among treatments, although the pattern is similar to biomass size (Table 3). The average number of logs and branches increases with fire events, but the overlapping of variances make this result not significant ( $F=1.71$ ,  $p > 0.05$ ). These findings do suggest a trend relating the amount of dead biomass in positive relation to the number of fire events (third prediction), but with the data available this trend can not be taken for granted.

Results for the sizes of canopy and juvenile dead and alive trees indicate that the sample for dead canopy trees is an underestimate of the true values, thus no analysis is possible (Table 4). Juvenile tree size is better represented in the sample, although differences were not significant ( $F=1.3, p > 0.05$ ) and the sample was highly unbalanced with only two individuals for the two burning site (Table 5).

## Discussion

The predictions about increased juvenile mortality under a higher fire treatment, and an independence of established trees to the fire, are supported with the available data. However, the effects are noticeable at the 4 burning site only, and not when unburned and sites with two burnings were compared. Sites with two burnings had the highest abundances of juvenile trees (Figure 2) but they were not significantly higher from the site with no burnings. One might argue that a moderate fire regime might release some nutrients to the forest and increase light availability. Nutrients and light promotes the regeneration in smaller classes, but increase mortality after some threshold in repeated number of burnings. Nonetheless, the fire also consumes small trees, so the differential effect of the treatment is not possible to assess without monitoring.

Proportion of dead/alive trees (Figure 3) also supports the idea of increased mortality for younger trees with more fire treatments. The dead/alive ratios are very low indicating little effect for both categories (canopy and juvenile) in the control and the two burning treatment. This proportion increases up to 67% for juvenile trees subject to four burning treatments although differences are not significant. Two factors may account for this result. First, the density of juvenile trees by itself may vary by different reasons (e.g., soil moisture, age of the patch, disturbance other than fire, etc.). Thus, we do not know if we are founding differences in abundances and proportions caused only by fire, but also caused by a pattern in the spatial distribution that we do not know. Second, the high value of the proportion of juvenile tree mortality also has a very wide variance (Figure 2). This raises the idea if the fire is introducing more heterogeneity to the forest community. the heterogeneity might increase with a few prescribed burnings and then decrease, because of a detrimental effect of extended burning. Also, mortality, from our perspective is random or highly heterogeneous (because we are not monitoring) and fire is highly variable in intensity and direction.

The tree community was under-represented in the 600 m<sup>2</sup> plots, as shown by the blank entries in table 4. Hence, the support of the prediction that adult tree mortality is independent of fire, should be taken with reserve. Also, we have the problem that we can not attribute all the death of the trees to the fire, but to the interaction of senescence and pathogens that by themselves have their own dynamics.

The pattern showed by the size of the logs on the ground which are highly similar in size and variance (table 2) but increase with the numbers of fire events, suggests that fire does affect certain range of young trees and has a cumulative effect. This range might go from seedlings (which are destroyed) to saplings in the range of 5 cm to 15 cm which are the ones that remain after the burnings. Again, a bigger sample size is required to

assess if the pattern is significant or is only the result of the spatial heterogeneity in tree distribution (i.e., uneven tree density at the different sites). However, besides more sampling, actual measurements of biomass volumes (diameter of logs and branches times length) are required to confirm this pattern.

To improve this study, mortality rates should be recorded before and after fire events, including control plots to monitor temporal variation in tree mortality regardless of fire effects. It is also very important to distinguish among species and to use more finely subdivided tree classes. At least for adult tree mortality, the sampling area should increase. Finally, it is important to measure the actual release of nutrients over time and increase in light availability, to relate them to species diversity and abundance under a certain number of prescribed burnings..

## **Conclusions**

The data available supports the notion that fire does increase mortality of small tree classes and increases the amount of dead biomass. Mortality of canopy trees is apparently independent of fire, although more sampling is required to confirm this idea. Fire can be introducing many effects in the community besides increasing mortality, by enhancing the spatial heterogeneity of the environment. Fire effects may also be noticeable from four burning events onwards. However, long term effects of prescribed burnings should be monitored. The small sample size and a static approach to a dynamic process, limit the generality of the above conclusions.

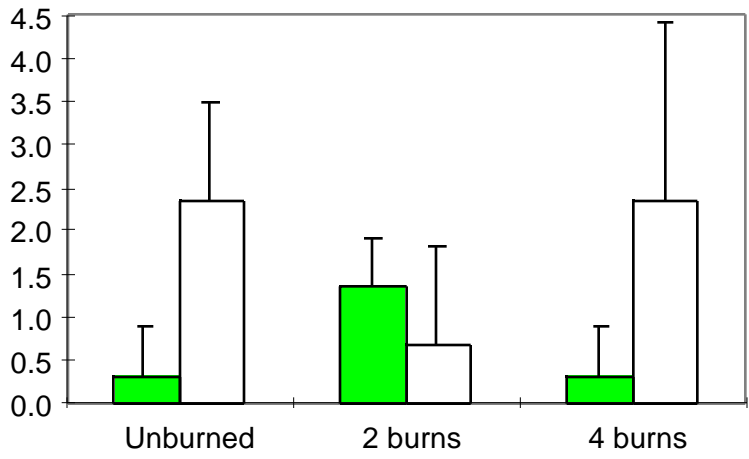
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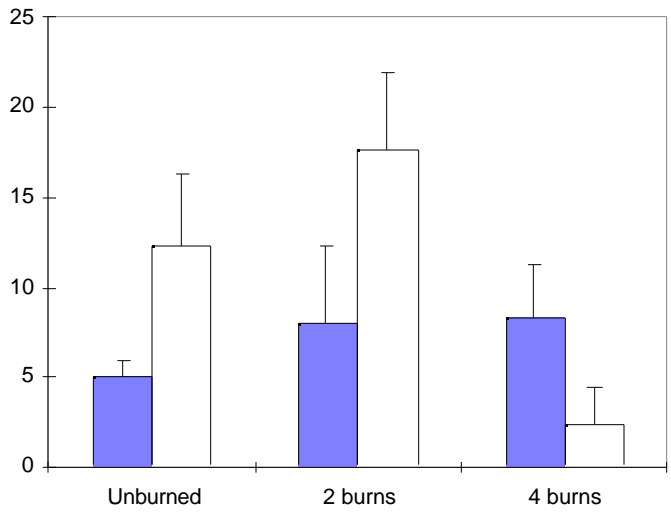
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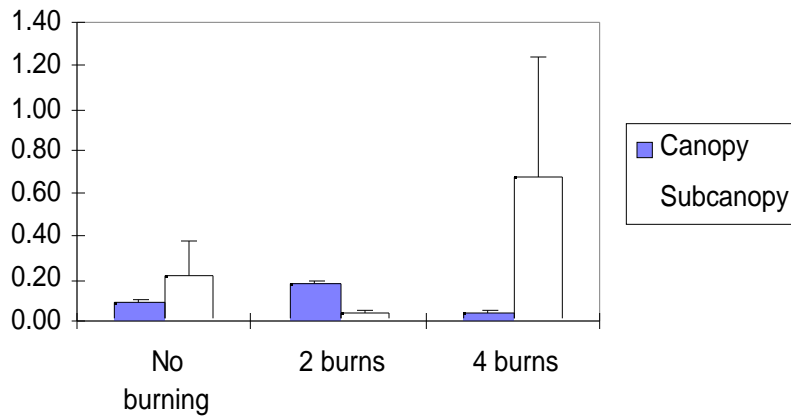
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**Figure 1. Average abundance of dead trees in canopy and juvenile classes in the plots from the three treatments. Gray bars represent canopy and white bar juvenile trees.**



**Figure 2. Average abundance of alive trees in canopy and juvenile classes in the plots from the three treatments. Gray bars represent canopy and white bar juvenile trees.**



**Figure 3. Relative abundance (proportion) of dead and alive trees in canopy and juvenile classes in the plots from the three treatments.**

**Table 1. Average abundance of dead and alive trees in the different treatments. All averages calculated from three replicates. *S.d.* is standard deviations for each treatment, *range* is the maximum and minimum densities found in each treatment, and *n* is the total number of tree per treatment/ dead or alive/ class categories.**

<i>Treatment</i>		<i>Class</i>	<i>mean</i>	<i>s.d.</i>	<i>range</i>	<i>n</i>
Unburned	dead	canopy	0.33	0.58	0-1	1
		juvenile	2.33	1.15	1 -3	7
	alive	canopy	5.00	1.00	4-6	15
		juvenile	12.33	4.04	8-16	37
2 burning	dead	canopy	1.33	0.58	1-2	4
		juvenile	0.67	1.15	0-2	2
	alive	canopy	8.00	4.36	5-13	24
		juvenile	17.67	2.31	15-19	53
4 burning	dead	canopy	0.33	0.58	0-1	1
		juvenile	2.33	2.08	0-4	7
	alive	canopy	8.33	3.05	5-11	25
		juvenile	2.33	2.08	0-4	7



**Table 2. Diameter distribution of logs and branches found on the forest ground.**

<i>Treatment</i>	<i>mean</i>	<i>s.d.</i>	<i>range</i>	<i>n</i>
Unburned	8.85	4.56	5 - 23	43
2 burning	8.92	3.87	5 - 25	51
4 burning	8.79	4.06	5 - 22	62

**Table 3. Abundance of fallen logs and branches found on the forest ground.**

<i>Treatment</i>	<i>mean</i>	<i>s.d.</i>	<i>range</i>	<i>n</i>
Unburned	13.67	3.79	11-18	43
2 burning	16.67	3.79	14-21	51
4 burning	20.67	6.03	15-27	62

**Table 4. Diameter of dead standing canopy trees.**

<i>Treatment</i>	<i>mean</i>	<i>s.d.</i>	<i>range</i>	<i>n</i>
Unburned	22	-	-	1
2 burning	33.13	6.65	27.5 -42.5	4
4 burning	17.5	-	-	1

**Table 5. Diameter of dead standing juvenile trees.**

<i>Treatment</i>	<i>mean</i>	<i>s.d.</i>	<i>range</i>	<i>n</i>
Unburned	6.93	1.74	5 - 10	7
2 burning	7.25	3.18	9.5 - 5	2
4 burning	7.86	4.42	5 - 15	7