Feb 15th, 8:10 AM

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Effects of Prescribed Fire on Mammoth Cave National Park's Oak-Hickory Vegetation: A Decade of Fire Monitoring

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Abstract

Mammoth Cave National Park contains a spectacular suite of plant communities; many of which are dependent on wildland fire as a disturbance process for their preservation. Over a third of the park is dominated by oak-hickory forests and woodlands. Fire is a fundamental process in the development and maintenance of this important community type. Since the park's first prescribed fire in 2002, 16,700 acres of forest, woodlands, and barrens have been treated with prescribed fire. Initial goals for the prescribed fires were to reduce the density of tree saplings in the understory and increase the cover of herbaceous herbs in the understory. After a single burn, wildland fuel loading was reduced by 18%, density of understory trees (dbh < 15cm) was reduced by more than 30%, and mean cover of graminoid species increased from < 0.01% to 5.2%.

Introduction

Containing approximately 53,000 acres, Mammoth Cave National Park (MACA) preserves a large area of diverse vegetation communities. Plateaus and hills broken by sinkholes, rocky glades, and the Green River characterize the relatively rugged topography of the park. Areas of both acidic and calcareous soils are common throughout this park. Due to the karst topography; water rapidly filters below the surface, resulting in not only the vast cave system below the surface, but also very little surface flow in streambeds (USDI NPS 2006). This lack of surface water would have limited the natural firebreaks on the MACA landscape, particularly south of the Green River. Prior to European settlement, and subsequent segmentation of the landscape, fire would have moved unbound until reaching rivers, excessively rocky bluffs and glades, or areas recently burned. While generally accepted that fire return intervals were maintained by Native Americans throughout the Holocene, Ray (1997) proposed that lightning-caused fires alone could have accounted for a pyrogenic landscape in this park.

These geologic and topographic factors greatly influence the vegetation found at any given area within the park (Olson & Noble 2005). The interaction of fire with the potential vegetation and topography would have greatly modified and maintained a variety of plant communities in this diverse ecosystem. Many of today's dominant species and ecosystems in the Central Hardwoods landscape likely owe their importance to the persistence of fire and its use by Native Americans since the Pleistocene (Anderson 1983, Nowacki & Abrams 2008). Historic and archeological evidence at MACA suggests that areas of prairie, savanna, and woodlands were commonplace, where they are rare today (Shull 1921, Ray 1997, Olson 1998, USDI NPS 2001, Cecil Frost - personal communication). The entire park contains some of the greatest biological diversity in the state of Kentucky; however, without natural and anthropogenic fire, unique communities and their associated species are at risk (Seymore 1997).

Although there are many vegetative alliances at this park, roughly one third of MACA is dominated by upland oak and oak-hickory vegetation (USDI NPS 1934, Olson & Ghitter 2000), a collective forest community that is currently showing significant declines due to a lack of disturbance processes necessary to maintain the dominance of fire-tolerant tree and herbaceous species associated with this community (Nowacki & Abrams 2008, Hutchinson 2006). The oak-hickory vegetation type and its associated dominant tree species are widely recognized as a disturbance dependent community, maintained by shade intolerant species that are capable of resprouting for decades and replacing overstory individual trees only if continually burned (Abrams 1992, Iverson et al. 2008, Buchanan & Hart 2012, Hutchinson et al. 2012).

Like many National Park Service (NPS) units in the Southeast, prescribed fire has been used at MACA since 1999 to maintain and restore fire-adapted ecosystems at MACA by reducing hazardous fuel levels, limiting encroachment of invasive woody species, and restoring the historical structure of plant communities on the landscape. As of May 2012, roughly 16,700 acres, roughly 30% of the park, have been treated with one to four prescribed fires. Including units that have been treated more than once, MACA has carried out some 22,752 acres of prescribed fire treatments. This park's Fire Management Plan and Fire Monitoring Plan identify management goals and objectives for the park, which indicate the need for continued fire management activities, including prescribed burning. The policy of the NPS requires that all prescribed fire activities have thorough plans that are accompanied by long-term monitoring (USDI NPS 2008). Fire effects monitoring at MACA began in 2000 and, since that time, has worked to ensure that the park's pyrogenic communities are being restored and biodiversity protected. While vegetation monitoring is not designed to answer all questions concerning fire ecology, short and long-term monitoring is part of the adaptive management cycle and provides a basis for altering management actions (USDI NPS 2003).

Methods

Monitoring Design

Fire effects monitoring at Mammoth Cave National Park follows the design outlined by the NPS Fire Monitoring Handbook (FMH) (USDI NPS 2003). Permanent vegetation/fuels monitoring plots were stratified randomly within target vegetation types, installed and read prior to fire treatments, read immediately after a fire, and are subsequently read on standard monitoring schedules of one, two, and five growing seasons after the fire. This vegetation and fuel monitoring methodology is outlined in the FMH and the plots are referred to as FMH plots. From 2000 to 2012, 38 permanently installed FMH plots were placed within MACA. Only twelve (N=12) of these plots were utilized for the analysis in this manuscript as they were dominated by oaks and hickories (*Quercus* spp. and *Carya* spp.; percent of total overstory basal area > 50%) and have been treated with prescribed fire (Figure 1). Ten of these plots have experienced at least one growing season since a prescribed fire (thus N = 10 for vegetation analysis), and only two have experienced a second fire. Selected plots were installed in various seasons of the year ranging from March through early November; however, each plot is subsequently read at the same season/month as its initial installation. One plot for this study was read in March (spring), three in June (early growing season), and eight from the last of September through early November (end of growing season). Plots are 20 x 50 m in size, but subsampling is used depending upon the variable being measured (USDI NPS 2013).

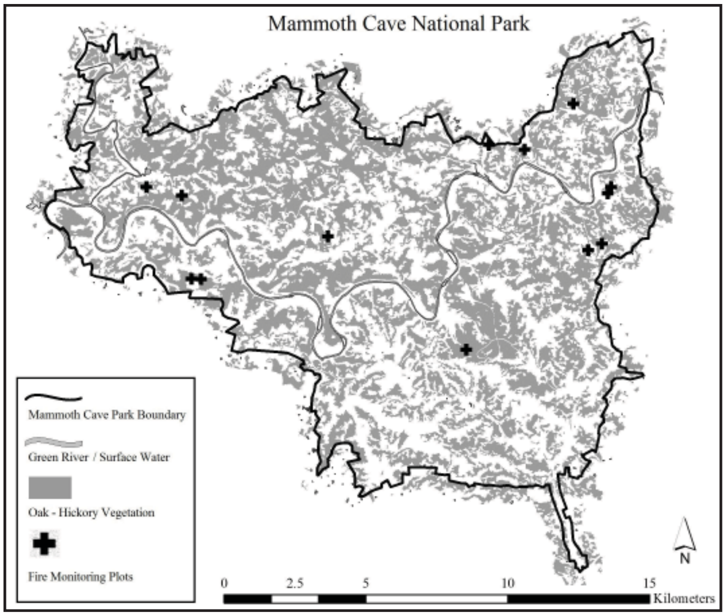

Figure 1: Mammoth Cave National Park boundary, predicted area currently dominated by mature oak-hickory vegetation, and FMH plots dominated by upland oak and hickory species.

Prescribed Fires

FMH plots utilized for this study were treated in nine separate prescribed fires within eight burn units. All plots were treated at least once with prescribed fire and only two plots were treated twice. The first fire monitored was April 2, 2002 and the most recent March 21, 2012. All prescribed fires took place late March and late April. Burn severities reported are indices from a coding matrix found in the FMH, with 1 representing severely burned to 5 representing unburned (USDI NPS, 2003, p. 110). Mean scorch and char values given represent percentages and heights of individual overstory trees that have measurable impacts. For example, scorch values are not recorded for hardwoods that are completely dormant, therefore, estimation of scorch and char are likely overestimates of actual impacts of any given fire.

Data Analyses

Graphical representations of selected results utilize mean values and error bars represent standard error of the mean. For the purposes of this paper, no values were transformed. Two-tailed paired t-tests were performed on the same plots to test differences before and after prescribed fires, as well as later read schedules for all variables discussed. The α level for all statistical tests was 0.05.

Results

Fire Severity

Average burn severity was 3.4 ± 0.3 (SE) for substrate (soil, duff, litter, and woody debris) and 3.6 ± 0.2 for vegetation immediately after the first burn (N = 12), representative of an intermediate stage between lightly burned and scorched. Average burn severity was 4.4 ± 0.5 and 3.7 ± 0.3 for substrate and vegetation, respectively, after the second burn (N = 2). Average scorch percent of live tree canopy was 4.3% ± 1.4 (N = 12) and average scorch height was 2.1 m ± 0.6. Mean of maximum char height of the overstory trees' trunks was 0.5 m ± 0.09.

Overstory Trees

Basal area (BA) ranged from 13.8 to 43.7 $m^2\ ha^{-1}$. Although eight of ten plots showed increases in total overstory BA, average total BA for these sites was approximately 31 $m^2\ ha^{-1}$ and was not significantly changed by a single prescribed fire (N = 10, P = 0.07). . Overstory tree density ranged from 220 to 550 trees ha^{-1} with a mean density of 340 trees ha^{-1} prior to burning. One growing season after the burn, average density was 334 trees ha^{-1}; however, this change was not significant (P = 0.22).

Understory Trees

Over 90% of the trees measured in the understory were not from the two genera dominant in the overstory, oaks and hickories (Figure 2). The average density of understory trees was 568 stems ha^{-1} prior to prescribed fires (N = 10), and was an average of 518 and 376 stems ha^{-1} one and five years post burn (N = 10 and N = 5). Albeit small, average plot reduction of the small trees was 10% one growing season after the first burn, a significant reduction (P = 0.01, Figure 3). Although highly variable, five growing seasons after initial fire, the average plot reduction was 32% (P = 0.11).

Seedling and Resprouting Trees

Mean density of total tree seedlings and resprouts is 33,820, 38,060, and 41,840 stems ha^{-1} for before, one year after, and five years after prescribed fire, respectively. No significant change was detected from pre-burn densities to one year or five years post-burn (N = 10, P = 0.60 and N = 5, P = 0.40 respectively). Before fire, approximately 66% of the tree species measured in the understory were species other than oaks and hickories. Five years post-burn this proportion has changed to roughly 50%; however, when oaks and hickory saplings are removed from the analysis, there was still no significant change in density.

Herbaceous Plant Cover

Average total plant cover measured by point intercept was 45% with no significant change after prescribed fire (N = 10, P = 0.74). Mean herbaceous plant cover (all plants excluding woody trees, shrubs, and

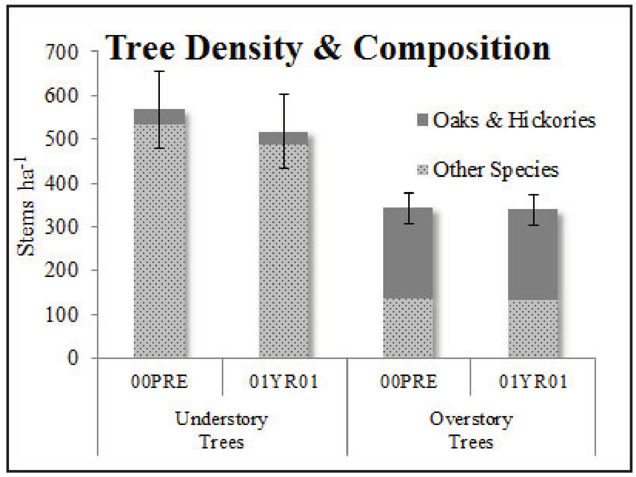

Figure 3: Density of understory and overstory trees for oak-hickory FMH plots. Mean density of understory trees was significantly reduced, while overstory density remained unchanged.

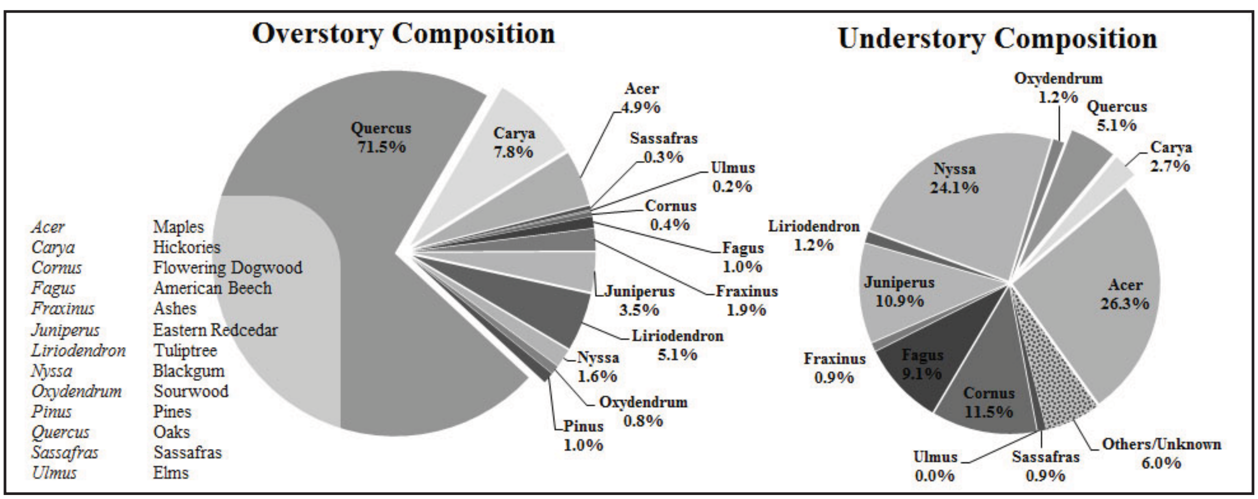

Figure 2: Tree composition of oak-hickory FMH plots. Overstory composition is based on mean BA for trees ≥ 15.0 cm at dbh. Understory composition utilizes stem density of trees ≥ 2.5 < 15.0 cm at dbh. Disproportionate compositions are remarkably apparent for three most dominant overstory species: oaks, hickories, and tuliptree (yellow poplar). Also surprising is the apparent lack of elms, a species that is generally quite common in long-unburned stands.

vines) was 7.7% before burning and 10.6% one to two growing seasons after; however, this was not found to be a significant change (N = 10, P = 0.31). None of the various plant types had a significant change after a prescribed fire with the exception of graminoids (N = 10, P = 0.03). Average pre-burn graminoid cover was only 0.008%; six plots did not contain any grass along the transect before prescribed fire. One to two growing seasons after a single prescribed fire, graminoid cover had increased to 5.2%.

Litter, Duff, and Woody Debris

The mean duff depth was 0.7 inches prior to burning, and 0.6 inches after one and two prescribed fires. While the mean duff load differed from 6.3 to 5.2 tons/acre, this difference was not found to be a significant change from pre-burn levels (N = 12, P = 0.15). The average litter depth was reduced from 1.2 inches to 0.5 and 0.3 inches after one and two fires, respectively (N = 12, P = 0.01; N = 2, P = 0.03). After a single prescribed fire the litter load was significantly reduced from approximately 2.7 to 1.5 tons acre^{-1} (N = 12, P = 0.01), an average reduction of 40%. A second burn again reduced to the litter load from 1.3 to 0.7 tons/acre, an average reduction of 77% when compared to levels measured immediately prior to the second treatment (N = 2, P = 0.03). Neither fine woody debris nor coarse woody debris was significantly changed from pre-burn levels (N = 12, P = 0.51; N = 12, P = 0.99; Figure 4). However, when all measured fuel loads are totaled, there is a significant change after the first burn (N = 12, P = 0.01). Mean total fuel loads were 15.5 tons/acre prior to burning and 12.6 tons/acre after a single treatment. The average fuel reduction for the FMH plots was 18% after the first prescribed fire.

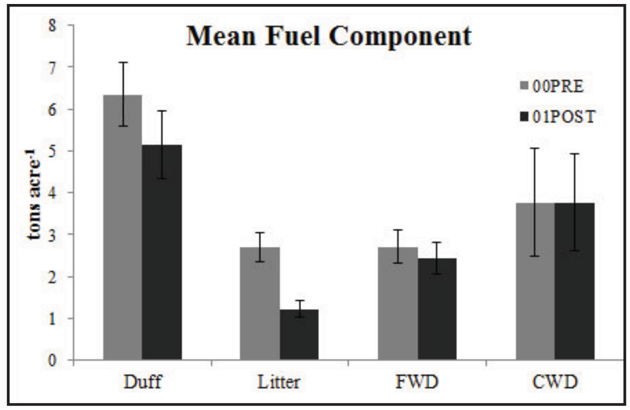

Figure 4: Changes in wildland fuels after a single prescribed fire. Total fuel load was reduced ~18%; however, as separate constituents (duff; leaf, needle, and herbaceous litter; fine woody debris (dead unattached woody stems < 3 in; FWD); and coarse woody debris (dead unattached woody stems ≥ 3 in, CWD), litter was the only significantly reduced component.

Discussion

Primary ecological goals, as stated by many of MACA's burn plans were to limit mortality of overstory trees, decrease the density of pole (understory) trees, increase native herbaceous cover, and reduce total fuel loads. Specific objectives derived from these goals are tailored for each of the various monitoring types; however, generally these goals encompass all upland oak-hickory vegetation at this park. Achieving these goals will help facilitate the restoration of woodlands at this park, while maintaining the dominance of oaks and hickories, two critically important species due to their production of hard mast for wildlife and other ecological functions.

A specific fire management objective is to limit the mortality of overstory trees to less than 20% (USDI NPS 2013). A single prescribed fire did not appear to have any impacts on the density of overstory trees. Indeed, basal area showed slight increases even as mean tree density declined, suggesting that these stands are aging and still moving through some form of successional trajectory. The vast majority of the understory is dominated by shade tolerant species (*Acer* spp., *Fagus grandifolia*, *Nyssa sylvatica*) while a very small proportion is made up of oaks, hickories, and other shade intolerant species, such as tuliptree (*Liriodendron tulipifera*). One year after a prescribed fire, there was a small reduction in understory density; however, these changes are small. This result is characteristic of other observations made in this ecosystem after only a single low-intensity fire (Brose et al. 2006). Repeated burns, within acceptable return intervals, would likely further reduce these densities allowing for shade intolerant species to be more competitive when canopy openings occur (Hutchinson et al. 2012). Tree seedling and resprout densities may not be reduced after one or two fires; however, other effects may be occurring (seedling height, etc.), allowing for noticeable changes in understory openness (Figure 5).

Figure 5: Photographic documentation of FMH plot QUMO 31. A) Photo taken fall 2000, prior to prescribed fire treatment. B) Photo taken fall 2011, two years after plot's second prescribed fire.

Remarkably, there was a large response from grasses and other graminoids from a single application of fire. Prior to burning, many of the transects did not intercept any of this group of species. Not surprising, is the delayed response of other herbaceous species. Other studies suggest that these species would increase their density and extent after further reductions in understory tree density and other abiotic factors through repeated fires (Hutchinson 2006, Royo et al. 2010). It has been well established that fires will favor grasses and other herbaceous species over woody plants (Noss 2012). The primary fine fuel in this vegetation, oak-hickory litter, can be a barrier to the germination of many plant species (Hutchinson 2006). While it was seen to be significantly reduced after a single fire, leaf litter can rapidly build back up to pre-burn levels within a few years (Stambaugh 2006). Exceptionally dense populations of white-tailed deer within the park could also confound herbaceous restoration efforts.

Long-term management of oak-hickory forests should strive to maintain fire frequencies on the landscape in order to attain more fire management goals in this broad level vegetation description. Biodiversity and conservation strategies should also strive to reestablish the complex mosaic that likely occurred in this topography (Noss 2012, Baskin et al. 1994). Managers should also investigate other seasons for burning, as burning exclusively in one season could have negative impacts on some species (i.e. spring ephemerals). Not only would endemic and unique plant species benefit from restoring fire adapted communities, but fauna, such as the diverse assemblage of bats, could benefit as well (Perry 2012). Fire management at Mammoth Cave National Park should continue to focus on restoring landscape diversity for the benefit and conservation of park's infrastructure and biota in the 21st century.

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