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How can prescribed burning and harvesting restore shortleaf pine-oak woodland at the landscape scale in central United States? Modeling joint effects of harvest and fire regimes

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ABSTRACT

Historical fire regimes in the central United States maintained open-canopy shortleaf pine-oak woodlands on xeric sites. Following large-scale harvest and fire suppression, those woodlands grew denser with more continuous canopy cover, and they gained mesic species at the expense of shortleaf pine. There is high interest in restoring shortleaf pine-oak woodlands; most have been converted to other forest types but those that remain are valued for high stand-scale and landscape-scale diversity. Prior stand-scale studies suggest that prescribed burning and harvesting could be effective for restoring pine-oak woodlands. However, previous short-term, stand-scale studies provided little insight into long-term, landscape-scale outcomes. To estimate outcomes of alternative restoration treatments on future species composition and forest structure, we employed an integrated field and modeling approach to simulate effects of prescribed burning and harvesting on the restoration of shortleaf pine-oak woodland composition and structure in the Mark Twain National Forest for a 100-year period. Six scenarios were modeled: no management, burn only, harvest only, and a combination of harvest with burns treatments followed by fire-free intervals of differing starting times or durations to facilitate regeneration recruitment. Both no management and prescribed burn only scenarios cannot restore current forest to historical woodland condition (i.e., 40–80% percent canopy cover or less than 55% stocking); however, scenarios including harvest can restore current forest to woodland condition in late 2020s. Under a no management scenario, total basal area would increase to a maximum around 31 $m^2 ha^{-1}$, and white oak group remained the most dominant species group throughout the simulation. Under the burn only treatment, total basal area was not reduced substantially as compared to that under no management scenario, however, there were small increases in the basal area and density of shortleaf pine. All of the treatments that included a combination of burning and harvesting reduced total basal area, which fluctuated around 13 $m^2 ha^{-1}$ throughout the simulation than those under no management and prescribed only scenarios. The simulations suggested that shortleaf pine would become the most dominant group, followed by white, red oak groups, and other species with combined prescribed burning and harvesting. When coupled with harvest, the prescribed burning regime affected species composition: increasing the number of burns increased the basal area and density of shortleaf pine and decreased the basal area and density of white oak group species.

1. Introduction

Historical fire regimes in xeric region of the central U.S. Central Hardwood Forest were characterized by low-severity yet frequent ground fires and periodic intense crown fires (Dey and Hartman, 2005; Stambaugh and Guyette, 2006). This disturbance regime led to subregions that were historically dominated by fire-resistant shortleaf pine (*Pinus echinata* Mill.), where they grew in pure stands and with other hardwood species such as oaks (*Quercus* spp.) (Nowacki and Abrams, 2008; Hanberry et al., 2012). By limiting successful establishment of fire-sensitive species as well as many pine and oak seedlings, the historical fire regime maintained the widespread pine-oak woodland dominated by large trees without a continuous canopy (Fralish and McArdle, 2009). Pine-oak woodlands serve as critical habitat for several

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threatened species, e.g., the federally listed endangered red-cockaded woodpecker (*Leuconotopicus borealis* Vieillot) (Hedrick et al., 2007).

Past harvest practices and large-scale fire suppression resulted in substantial changes in forest composition and structure in pine-oak woodlands in the central U.S. and most notably in the Ozark Highlands. From 1880s to 1920s, shortleaf pine was exploitatively harvested, which caused loss of mature trees and reduced seed sources (Olson and Olson, 2016). Effective, regional fire suppression starting in the 1940s, favored regeneration of tree species that are more shade-tolerant and fire-sensitive than shortleaf pine, (e.g., red maple, *Acer rubrum* L.), resulting in loss of pine and pine-oak woodlands (Hanberry et al., 2014). Some of the current forests in the central U.S. either have an understory dominated by fire-sensitive species, or have already transitioned to more mesic forests dominated by species which were not historically competitive (Fralish and McArdle, 2009). In the Missouri Ozark Highlands, the shortleaf pine forest has been reduced by 90% relative to its former extent, and frequently has been replaced by closed-canopy oak forests that are marginally suited to the xeric sites formerly occupied by pine. In addition to forest composition changes, there are also changes in forest structure. One of the most significant changes is forest densification, which refers to the phenomenon of increases in the density, basal area, stocking level, or canopy cover of trees (Hanberry et al., 2014). Thus, historical dominance of shortleaf pine in the central U.S. decreased, and pine-oak woodland has shrunk in acreages. Not only may such forest regime shift disrupt historical forest community relationship, but also alter long-established environment-species interactions (Amatangelo et al., 2011).

There is growing interest in restoration of pine-oak woodlands given their ecological significance and capacity to mitigate oak decline (Blizzard et al., 2007; Clabo et al., 2016). In 2009, the Collaborative Forest Landscape Restoration Program (CFLRP) was established to encourage collaborative, science-based ecosystem restoration on or around national forests lands in the United States (USDA, 2016). Within the CFLRP, the Missouri Pine-Oak Woodlands Restoration Project was established to restore pine-oak woodland on a portion of the Mark Twain National Forest in the Missouri Ozarks subregion of the Central Hardwood Forest. Goals of this project include reestablishment of landscape dominated by fire-adapted pine-oak woodlands with structure, composition and function similar to those of remnant pine-oak communities at landscape scale (USDA, 2016).

Past restoration studies employing prescribed burning and harvesting have yielded early success in restoring pine-oak woodlands (e.g., Olson and Olson, 2016; Rimer, 2004; Tuttle and Houf, 2007b). However, prescribed burning alone has had limited effect in changing forest composition or structure. For instance, during a 14-year field experiment, a few prescribed burns (without other treatments such as harvest) were not effective in increasing number of shortleaf pine seedlings or saplings, nor did they create an open-canopy woodland condition (Olson and Olson, 2016). Harvest has been suggested as necessary to substantially reduce basal area and canopy cover, create a characteristic woodland stand structure, and to establish and recruit shortleaf pine by reducing competition from hardwood species and increasing light intensity in the understory (Elliott and Vose, 2005; Olson and Olson, 2016). Prescribed burning and harvesting in combination are more effective in changing species composition (shortleaf pine was more favored) of pine-oak woodland than prescribed burn alone (e.g., Olson and Olson, 2016). However, few studies have examined the effects of different fire regimes, combined with harvest, on changes in species composition. Since shortleaf pine is more fire-resistant than oak species in the Ozarks, it is expected that frequent prescribed burning with harvesting would favor shortleaf pine over oaks. However, it is unknown how alternative fire and harvest regimes in combination might affect the future species composition and stand structure for stands and landscapes where restoration of oak-pine woodlands is desired.

Because most field-based restoration studies have been carried out at relatively small spatial (typically for stands) and temporal (typically a few years to less than 2 decades) scales, the results of which are only beginning to shed light on anticipated long-term changes in composition and structure at the landscape scale. Thus, in this study we employed an integrated field and modeling approach to answer the question: How can prescribed burn and harvest help restore shortleaf pine-oak woodlands on Missouri Ozark landscapes in the next 100 years? Specifically, we addressed the following questions: (1) Can frequent prescribed burn that mimics historic fire regime over long-term restore pine-oak woodland? (2) Is harvest necessary in restoration of pine-oak woodland? (3) Do different prescribe fire regimes in combination with harvesting result in landscapes with different compositions of shortleaf pine and oaks?

2. Materials and methods

2.1. Study area

The study area was jointly identified by several federal and state agencies, as well as conservation groups as a priority area for pine-oak woodland restoration. It contains the highest known concentration of restorable pine-oak woodlands, and known occurrences of species of conservation concern (Mark Twain National Forest, 2011). The study area covers 31,000 ha in Mark Twain National Forest in southern Missouri between 36.76° and 37.05 °N, and 90.51° and 91.39 °W. It has been allocated into 120 prescribed burn units with an average size of

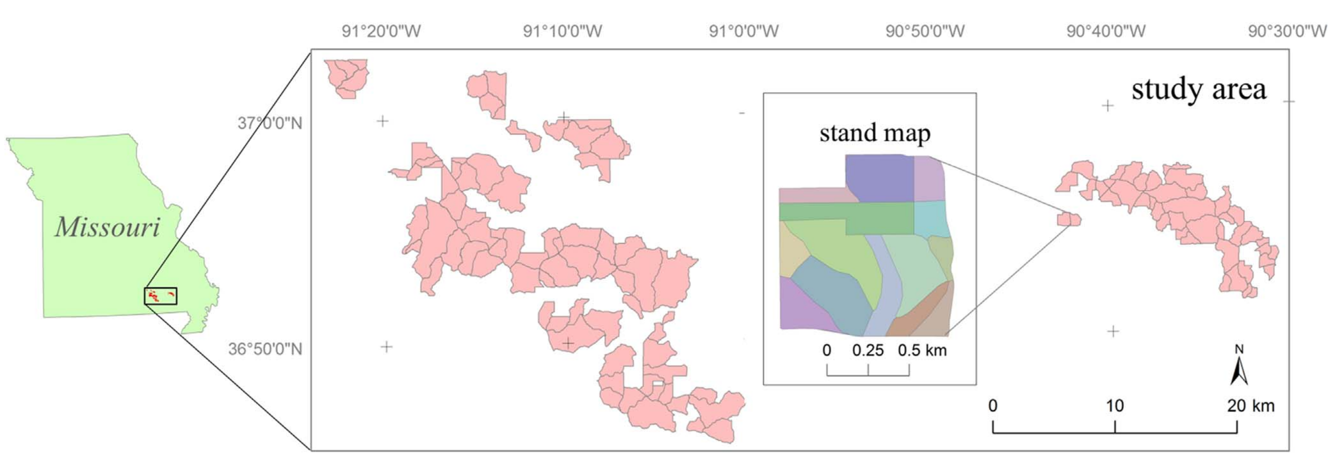

Fig. 1. Location of study area in southeastern Missouri, United States. The study area consists of 120 prescribed burn units (pink polygons), and each prescribed burn unit is divided into multiple forest stands (shown here with an example). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)