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Vegetation response to canopy disturbance and season of burn during oak woodland and savanna restoration in Tennessee

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ABSTRACT

The removal of fire's influence on plant community succession has resulted in the near disappearance of oak (*Quercus* spp.) woodlands and savannas from the Appalachian region. Negative trends in associated plant and wildlife species could be reversed if these communities are restored, but management has been limited by inadequate canopy disturbance, resprouting of woody plants, and a lack of empirical research. To address these issues, we evaluated herbaceous and woody vegetation response (2008–2012) on the Cumberland Plateau in Tennessee to 5 replicated treatments involving canopy reduction (14 m^2 ha^{-1} [woodland] or 7 m^2 ha^{-1} [savanna] residual basal area) and fire-season (mid-March [spring] or early October [fall]) combinations and unmanaged controls. All categories of woody vegetation except large-saplings ($\geqslant$1.4 m tall and $\geqslant$7.6 but <12.7 cm diameter at breast height [DBH]), increased in density as canopy disturbance increased. Fire temporarily reduced small-sapling ($\geqslant$1.4 m tall and <7.6 cm DBH) density, but resprouting resulted in densities equal to or exceeding pre-fire levels. Herbaceous richness increased from 22 to 167 species following canopy disturbance and fire (2008–2012). Native cool-season grasses dominated herbaceous response in treated sites. Herbaceous groundcover, richness, and diversity increased as canopy disturbance increased, and the rate of increase accelerated once basal area was reduced below 15 m^2 ha^{-1} or 30% canopy closure. Following fire, canopy disturbance remained influential as indicated by greater herbaceous response in savannas than woodlands. Graminoid and forb groundcover, herbaceous richness, and herbaceous diversity were 24X, 11X, 9X, and 8X greater, respectively, in treatments than controls by 2012. Invasive species were rare and increased minimally with increasing disturbance. Our results demonstrate the utility of canopy disturbance in conjunction with fire for restoring oak woodlands and savannas from closed-canopy forest conditions. Basal area reduction to 15 and 7 m^2 ha^{-1} respectively approximated woodland and savanna canopy conditions, and increased herbaceous-layer development. The less intense October fire had similar effects on vegetation as the more intense March fire, but greater differences could become apparent following repeated burning. Long-term research documenting the response of vegetation to repeated fire is needed to promote successful oak woodland and savanna restoration throughout the Appalachian region.

1. Introduction

Oak (*Quercus* spp.) woodlands and savannas are among the most threatened communities in North America (Noss et al., 1995). More than 99% of Midwestern oak savannas have vanished since European settlement (Nuzzo, 1986), and declines further east are similar (Delcourt et al., 1998; Brewer, 2001). Early explorers described scattered trees, ground-layers dominated by native warm-season grasses and forbs, and herds of large herbivores (Michaux, 1805; Ramsey, 1853; Van Lear and Waldrop, 1989) across much of the Central Hardwoods and Central and Southern Appalachian regions (hereafter Appalachian, Harper et al., 2016). A sparse oak overstory distinguished savannas (10–30% canopy cover) and woodlands (30–80% canopy cover) from prairies and forests (Faber-Langendoen, 2001; Nelson, 2010) and allowed light to reach a key characteristic of both; a robust ground-layer of

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herbaceous vegetation (Taft, 1997). Sparse overstories also created understory gradients in plant resources (Peterson et al., 2007) that promoted levels of herbaceous diversity that exceeded both prairies and forests (DeSelm, 1994; Leach and Givnish, 1999). These unique associations between sparse oak overstories and herbaceous dominated ground-layers (Faber-Langendoen et al., 2012) are rapidly disappearing as a result of succession in the absence of disturbance (Nowacki and Abrams, 2008).

Although the decline of oak woodlands and savannas involves many factors (Heikens and Robertson, 1994), the removal of fire from its historical role in shaping community development is most frequently implicated (Abrams, 1992; McPherson, 1997; Nowacki and Abrams, 2015). Fire suppression and exclusion decreases herbaceous groundcover and diversity (Breshears, 2006) by facilitating canopy closure, increasing woody encroachment (Briggs et al., 2005), and eliminating understory plant resource gradients (Brudvig and Asbjornsen, 2009). Invading woody growth often is dominated by fire-sensitive, mesophytic species (Abrams, 1992, 1998) that promote dark, moist, and cool micro-environments, decrease fuel-bed flammability (Nowacki and Abrams, 2008; Kreye et al., 2013), and reduce or preclude herbaceous vegetation (Hutchinson et al., 2005; Barrioz et al., 2013; McCord et al., 2014). Decreasing biodiversity increases oak ecosystem susceptibility to invasive species and disease (Knops et al., 1999) and may decrease sustainability and productivity (Tilman et al., 1996; Liang et al., 2016). The diverse array of niches present within oak woodlands and savannas result in an equally diverse wildlife community, increasing the conservation value of such communities in an era marked by widespread habitat loss and fragmentation (Cox et al., 2016; Vander Yacht et al., 2016).

Another critical form of disturbance, canopy reduction, produces desirable and immediate shifts in overstory species composition and structure (Nielsen et al., 2003) which promotes herbaceous response through increasing the amount of light reaching the forest floor (Leach and Givnish, 1999; Brudvig and Asbjornsen, 2009). Thus, canopy reduction accelerates restoration while possibly generating timber revenue to offset costs. On the other hand, the increased availability of understory light also results in the vigorous growth of woody seedlings and sprouts (McCord et al., 2014). The ability of repeated fire to transition understory dominance from woody to herbaceous species makes it an essential tool for community restoration and maintenance (McPherson, 1997; Peterson and Reich, 2001). However, using low- to moderately-intense fire is often insufficient because it is slow to alter overstory characteristics (Knapp et al., 2015). Fires of greater intensity can damage or kill overstory trees, but this is generally undesirable during woodland and savanna restoration where retained trees define the target community (Peterson and Reich, 2001). Restoration goals are best achieved when both canopy disturbance and fire are used in conjunction (Peterson et al., 2007; Lettow et al., 2014).

Most restoration has occurred along the western edge of the historical range of oak woodlands and savannas, where drier conditions and a more recent history of fire suppression and exclusion have allowed such structure to persist. The longer absence of fire and wetter climate within the Appalachian region necessitates restoration proceed from closed-canopy forests. Attempts to restore oak woodlands (Jackson et al., 2006; McCord et al., 2014; Brewer et al., 2015) and savannas (Barrioz et al., 2013) in this region are rare and characterized by the persistence of woody undergrowth. Such growth is usually controlled with dormant-season fire, but woody plants often resprout prolifically (Blankenship and Arthur, 2006; Knapp et al., 2009) and are only eliminated if such fire is applied repeatedly (Arthur et al., 2015). Research has demonstrated that a single late growing-season fire can result in comparatively greater woody plant mortality and herbaceous layer gains than a single dormant-season fire (Keyser et al., 1996; Brose and Van Lear, 1998; Gruchy et al., 2009). Thus, a transition to late growing-season burning could reduce the number of fires required to achieve similar restoration progress. However, the effects fire-season on Appalachian plant communities is poorly understood (Gilliam and Roberts, 2003; Hutchinson et al., 2005; Harper et al., 2016) because very few burning-season studies have occurred in the region (Knapp et al., 2009). In addition, effect interpretation is often complicated by seasonal differences in fire intensity (Brose et al., 2014).

We applied restoration treatments to closed-canopy oak forests in Tennessee to assess their relative effectiveness for restoring oak woodlands and savannas. Our objective was to assess the effects of canopy reduction (woodland vs. savanna) and season of burn (fall vs. spring) on key measures of oak woodland and savanna restoration success including (1) decreased ground-layer dominance of woody and semi-woody vegetation, especially pyrophobic species, (2) establishment of a dominant and diverse herbaceous ground-layer, and (3) control of nonnative and invasive species. We predicted herbaceous groundcover, richness, and diversity would increase with increasing canopy disturbance, but richness and diversity would peak at intermediate levels of overstory density. We similarly expected woody density in the understory to increase with increasing canopy disturbance. We expected fire applied prior to leaf abscission (fall) would result in greater control of woody density, and, therefore, greater increases in herbaceous metrics, than fires occurring just before bud-break (spring).

2. Methods

2.1. Study area

We conducted our research at Catoosa Wildlife Management Area (CWMA), a 32,374 ha property managed by the Tennessee Wildlife Resources Agency (TWRA) and located in the Cumberland Plateau and Mountains physiographic region (DeSelm, 1994). Site elevation ranged from 437 to 521 m and soils were mesic typic Hapladults (Soil Survey Staff Natural Resources Conservation Service, 2014) over weathered sandstone and conglomerate (Nicholson et al., 2005). Annual mean precipitation and temperature were 140 cm and 13 °C, respectively, for nearby Crossville, TN (National Climatic Data Center, 2014). Forests were established in the 1920s following logging and agricultural abandonment and are currently oak-dominated, mixed pine-hardwood stands. Shortleaf pine (*Pinus echinata* Mill.) was a major overstory component prior to a pine bark beetle (*Dendroctonus frontalis* Zimmerman) outbreak in 1999–2000. Salvage cutting began in 2002, and subsequently, TWRA implemented an oak savanna restoration project using prescribed fire. The rapid development of common prairie and savanna flora and historical accounts (i.e., pasturing cattle and frequent fire until ca. 1945) provided evidence of previous woodland and savanna conditions at our site (Coffey, 2012; Barrioz et al., 2013).

At our site (36° 07′ 51.71″ N, 84° 87′ 12.49″ W) prior to treatment (2008), white (*Quercus alba* L.), southern red (*Q. falcata* Michx.), black (*Q. velutina* Lam.), and scarlet (*Q. coccinea* Muench.) oaks, as well as red maple (*Acer rubrum* L.), sourwood (*Oxydendrum arboreum* L.), and hickories (*Carya* spp.) were all >1.0 m^2 ha^{-1} of total basal area (17.8 m^2 ha^{-1}) and canopy closure was >85%. Snags were common as a result of beetle-killed pines (3.9 m^2 ha^{-1}). Mid-story vegetation (>1.37 m tall, <12.7 cm diameter at breast height [DBH]) was dense (1936 stems ha^{-1}), and dominant species included blackgum (*Nyssa sylvatica* Marsh.), downy serviceberry (*Amelanchier arborea* (Michx. F.) Fern.), red maple, sourwood, and sassafras (*Sassafras albidum* (Nutt.) Nees.). Blueberry (*Vaccinium*