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Restoration of oak woodlands and savannas in Tennessee using canopy-disturbance, fire-season, and herbicides

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ABSTRACT

Establishing herbaceous groundcover is essential for oak woodland and savanna restoration. In the Appalachian region, woody vegetation in the understory can persist through many fires and interfere with achieving this goal. Herbicide applications could reduce such vegetation and interact with canopy-disturbance and fire to accelerate restoration. In stands thinned to woodland ($16\ m^2\ ha^{-1}$, 75% canopy closure) or savanna ($5\ m^2\ ha^{-1}$, 24% canopy closure) conditions and burned biennially in the fall (October) or spring (March), we economically applied triclopyr (Garlon® 3A) to understory woody plants using foliar and cut-surface techniques in the fall between fires. From 2011 to 2013, only minor differences in vegetation were observed between areas managed with canopy-disturbance and fire (CF) and areas where herbicides were also used (CFH). Small-sapling (≥1.4 m tall, < 7.6 cm DBH) density in CF was 2,566 stems ha^{-1} greater than CFH in 2012. This difference was (1) the only woody control CFH attained beyond CF, (2) only lasted a single growing-season because it was mostly fire-sensitive species top-killed by subsequent fire, and (3) only led to increased herbaceous groundcover in savannas burned in the fall. This included the greatest reported increase in herbaceous groundcover (graminoid +18.2%, forb +8.0%) to be associated with herbicide applications under partial oak canopies in the Appalachian region. Expanding herbicide target constraints, completely removing undesirable seed-sources, increasing triclopyr concentration, exploring tank-mixes, and alternative application timing (*e.g.*, prior to canopy disturbance) could improve effectiveness; however, fire suppression throughout the Appalachian region has increased the dominance of fire-sensitive woody species. Our results demonstrate how such composition can reduce the utility of herbicides relative to fire during oak woodland and savanna restoration.

1. Introduction

Oak (*Quercus* spp.) woodlands and savannas occupy a fraction of their pre-settlement extent (Nuzzo, 1986; Fralish et al., 2000; Hanberry et al., 2014) and are among the most threatened communities in North America (Noss et al., 1995). Only small, isolated remnants persist in the Appalachian region (as defined in Harper et al., 2016) where they were once prevalent (Noss, 2013). A robust and diverse herbaceous groundlayer (DeSelm, 1994) and relatively sparse overstory of oaks distinguishes woodlands (30–80% canopy cover) and savannas (10–30% canopy cover) along the continuum from forest to prairie (Nelson, 2010). In the absence of fire, succession has transformed these communities into closed-canopy forests (Nowacki and Abrams, 2008). This has drastically reduced herbaceous groundcover and diversity by facilitating canopy closure, eliminating understory resource gradients (Brudvig and Asbjornsen, 2009), and increasing competition from woody vegetation (Barrioz et al., 2013). Such structural homogenization of vegetation across landscapes threatens a diverse assemblage of wildlife (Cox et al., 2016; Vander Yacht et al., 2016; Harper et al., 2016), and reduced biodiversity could threaten overall ecosystem productivity, sustainability, and function (Tilman et al., 1996).

Fortunately, the disturbances responsible for creating and maintaining oak woodlands and savannas can also be used to address their decline (McPherson, 1997). Canopy disturbance can shift overstory composition toward desirable species and increase the light available for herbaceous germination and growth (Nielsen et al., 2003; Brewer, 2016). Restoration is then advanced and maintained using a long-term regimen of repeated fire (Dey et al., 2015). Biennial fire maximizes community heterogeneity and herbaceous species richness in the understory by suppressing woody vegetation (Peterson et al., 2007;

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Peterson and Reich, 2008). Increases in understory light can promote a dense layer of woody saplings and shrubs (McCord et al., 2014) which can limit herbaceous layer development (Lashley et al., 2011; Barrioz et al., 2013). Although expensive, the mechanical removal of this vegetation can restore gradients in light, moisture, and nutrients that encourage increases in herbaceous cover and diversity (Brudvig and Asbjornsen, 2009). Fire historically limited woody vegetation dominance in the understory of woodlands and savannas, and remains a cheap and effective tool for restoration efforts (Ryan et al., 2013). However, coupling midstory thinning with fire can result in a greater and more immediate herbaceous response than fire alone (Lettow et al., 2014).

In the Appalachian region, most prescribed fires are conducted in the dormant-season and are followed by prolific resprouting of woody vegetation (Knapp et al., 2009). Suppressing hardwoods with such fire, therefore, requires frequent burning (every 1–2 years) for many years (Hutchinson et al., 2012; Arthur et al., 2015; Knapp et al., 2015). Growing-season fire can result in less resprouting of woody plants and a greater herbaceous response than dormant-season fire (Waldrop et al., 1992; Gruchy et al., 2009; Robertson and Hmielowski, 2014). However, growing-season fire may have been uncommon in the Appalachian region, and its repeated use may be a departure from historical fire regimes (Guyette et al., 2012). Furthermore, studies examining herbaceous response to burn season are limited for hardwood ecosystems (Knapp et al., 2009). Regionally specific experiments that validate the effects of growing-season fire are needed (Gilliam and Roberts, 2003), but so are additional options of understory woody vegetation control.

Herbicide applications that target woody-vegetation in the understory could accelerate restoration without negatively affecting desirable herbaceous species (Ansley and Castellano, 2006; Engle et al., 2006). Such management may also be the most cost-efficient option among methods that reduce or eliminate resprouting potential (Bailey et al., 2011). Using herbicides to control woody vegetation can increase herbaceous groundcover and diversity (Gruchy et al., 2009) by increasing light infiltration (McCord et al., 2014), and the technique has been effective in managing pine savannas (Freeman and Jose, 2009). Most research related to oak woodland and savanna restoration has occurred in the Midwest. Comparatively, the Appalachian region is wetter and has a longer history of fire suppression. Such conditions increase the threat that understory woody growth can pose to restoration, and this could elevate the importance and utility of herbicides as a management tool. However, regionally-specific evaluations of herbicides have narrowly focused on wildlife response to woodland restoration (*e.g.* Lashley et al., 2011; McCord et al., 2014; Greenberg et al., 2016), regeneration of woody species (*e.g.* Schweitzer and Dey, 2011), or utilized soil-active herbicides in the absence of a residual overstory (Nanney, 2016). Also, the influence of canopy-disturbance and fire-season on herbicide treatment efficacy is uncertain. Combining growing-season fire with herbicides warrants further investigation for its potential to efficiently restore open-oak communities.

We conducted an experiment that documented the response of vegetation to understory herbicide treatments within the context of interactions with canopy disturbance and prescribed fire. Specifically, we assessed the ability of herbicide treatments to increase herbaceous groundcover and diversity through decreasing the density of woody and semi-woody vegetation in the understory. We also evaluated how herbicide treatment effects varied across canopy disturbance level (thinning to 16 $m^2\ ha^{-1}$ residual basal area and 75% canopy closure, or 5 $m^2\ ha^{-1}$ residual basal area and 24% canopy closure) and season of prescribed fire (October or March). We explored relationships between vegetation affected by herbicide treatments and site covariates (aspect, slope, slope position, and canopy closure) to inform herbicide use within the context of such variation. Our goal was to determine if herbicide applications could enhance oak woodland and savanna restoration in the Appalachian region.

2. Methods

2.1. Study area

Our research occurred at Catoosa Wildlife Management Area (36° 07′ 51.71″ N, 84° 87′ 12.49″ W), 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 over weathered sandstone conglomerate. Annual mean precipitation and temperature were 140 cm and 13 °C, respectively, for nearby Crossville, TN from 1981 to 2010 (Vander Yacht et al., 2017). Forests were established in the 1920s following logging and agricultural abandonment and are currently oak-dominated, mixed pine-hardwood stands. Shortleaf pine (*Pinus echinata*) was a major overstory component prior to a pine bark beetle (*Dendroctonus frontalis*) outbreak in 1999–2000. Salvage cutting began in 2002, and TWRA began an oak savanna restoration project using prescribed fire. Evidence of historical woodland and savanna conditions included the rapid development of prairie and savanna flora and historical accounts (*i.e.*, pasturing cattle and frequent fire until 1945, Barrioz et al., 2013).

Prior to canopy disturbance (2008), white (*Quercus alba*), southern red (*Q. falcata*), black (*Q. velutina*), and scarlet (*Q. coccinea*) oaks as well as red maple (*Acer rubrum*), sourwood (*Oxydendrum arboreum*), and hickories (*Carya spp.*) all comprised > 1.0 $m^2\ ha^{-1}$ of total basal area (17.8 $m^2\ ha^{-1}$ ± 1.6 SE) and canopy closure was ≥85%. Snags were common because of beetle-killed pines (3.9 $m^2\ ha^{-1}$). The density of understory woody stems (> 1.37 m tall, < 12.7 cm diameter at breast height [DBH]) was 1,936 stems ha^{-1}, and dominant species included blackgum (*Nyssa sylvatica*), downy serviceberry (*Amelanchier arborea*), red maple, sourwood, and sassafras (*Sassafras albidum*). Blueberry (*Vaccinium spp*.), seedlings, and litter dominated the ground-layer. Herbaceous plants were rare (4.4% cover, Vander Yacht et al., 2017).

2.2. Experimental design

We established 8, 20-ha stands that included 2 replicates of 4 randomly assigned treatments: spring fire and woodland residual basal area (SpW: 15.3 $m^2\ ha^{-1}$ ± 1.6 SE and 70.9% canopy closure ± 5.6 SE), fall fire and woodland residual basal area (FaW: 16.2 $m^2\ ha^{-1}$ ± 1.3 SE and 79.4% canopy closure ± 4.4 SE), spring fire and savanna residual basal area (SpS: 2.6 $m^2\ ha^{-1}$ ± 0.6 SE and 14.2% canopy closure ± 3.5 SE), and fall fire and savanna residual basal area (FaS: 7.3 $m^2\ ha^{-1}$ ± 0.8 SE and 32.7% canopy closure ± 4.2 SE). Overstory reductions were accomplished in winter 2008–2009 via commercial logging (Vander Yacht et al., 2017). Following canopy disturbance, 76% of total basal area was southern red, white, scarlet, post, and black oak. Remaining basal area was largely red maple, sourwood, and blackgum. We conducted fall fires (11 October 2010) prior to leaf abscission, and spring fires (22 March 2011) prior to leaf emergence. Fall burns were low to moderate in intensity, whereas spring burns were comparatively more intense. Canopy disturbance and 2010–2011 fire treatment details can be found in Vander Yacht et al. (2017).

Following fire (2011), paired plots (16 × 22 m) were installed at 5 random locations within the core (50-m buffer) of each stand (Fig. 1A). We randomly assigned herbicide application within paired plots (n = 40, Fig. 1B, C) that were separated by a 5-m buffer. This created plots managed with only canopy-disturbance and fire (CF) adjacent to plots managed with canopy-disturbance, fire, and herbicides (CFH). Herbicide was applied 2–14 September 2011 when no indications of drought were apparent. We selected triclopyr (Garlon® 3 A; triclopyr amine; [(3,5,6-Trichloro-2-pyridinyl)oxy]acetic acid; Dow Chemical Company, Midland, MI) based on its broad-spectrum control, lack of residual soil activity, and minimal effect on grasses (Dow AgroSciences LLC, 2005). Using backpack sprayers, we applied a 2% Garlon® 3 A and