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Effects of thinning and prescribed fire frequency on ground flora in mixed *Pinus*-hardwood stands

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ABSTRACT

Forest management is increasingly focused on enhancing native biodiversity. In temperate forests, a common goal is to increase native plant diversity of the ground flora and silvicultural treatments such as thinning and prescribed burning are often used alone or in combination to achieve this goal. These treatments often increase understory light availability, decrease litter depths, and increase nutrient availability. We examined the effects of thinning without fire and thinning with different fire frequencies (four burns on a three year return interval and two burns on a nine year return interval) to identify changes in community structure and species composition with a focus on taxonomic richness, diversity, and cover of ground flora in post-agricultural *Pinus*-hardwood stands on the Cumberland Plateau in Alabama, USA. This paper reports on one year of post-treatment data (two years post burn) within a longer-term study of thinning and repeated burns. Overstory basal area and density were lower with increased management intensity. Sapling density was substantially greater with increased management intensity; however, this did not affect ground flora richness, diversity, or cover. Ground flora richness, diversity, and cover were greatest in stands that were thinned and burned every three years, and these measures were negatively correlated with litter depth and positively correlated with exposed mineral soil in a non-metric multidimensional scaling (NMS) solution. Our results signify the need for a combination of thinning and burning in these systems. Forest managers that wish to promote native plant diversity in similar systems may consider thinning and frequent burning to increase light availability, decrease litter depth, and promote ground flora richness, diversity, and cover.

1. Introduction

Family and federal forest landowners are increasingly prioritizing amenity-oriented objectives, such as aesthetic beauty, wildlife habitat, and nature protection, over financial goals in management planning (Salwasser, 1991; Butler et al., 2016). Amenity-oriented objectives are often related to conservation of forest biodiversity (Bixler, 2014). Biodiversity is important for ecosystem function because the variety of functions that one species can perform in an ecosystem (e.g. microclimate modification, pollination, seed dispersal) is limited. Species diversity and richness are correlated with an increase in ecosystem function, or in many cases functional redundancy, which promotes the resilience of ecosystems to disturbances (Tilman et al., 1996; Peterson et al., 1998). Forest managers that wish to increase biodiversity and promote ecosystem function often focus on the ground flora (defined here as all vascular plants ≤ 1 m in height), which harbors the majority of plant diversity in temperate forest ecosystems (Gilliam, 2007).

Silvicultural treatments may be implemented to enhance ground flora richness, diversity, and cover (Puettman et al., 2009; Nagel et al., 2017). Silvicultural thinning may be used to achieve a range of objectives including to generate revenue through the harvest of economically mature trees, to increase vigor of desired trees, or to reduce the abundance of undesirable tree genera (Nyland, 2002; Cameron, 2002; Johnson et al., 2009; Schweitzer et al., 2016). Thinning operations often leave behind legacies (e.g. increased understory light and potentially increased nutrient availability) that may affect ground flora diversity (Phillips and Waldrop, 2008, Thomas et al., 1999; Duguid and Ashton, 2013). However, these effects are ephemeral and gradually decline as vegetation responds (Oliver and Larson, 1996; Nyland, 2002; Schweitzer and Dey, 2015).

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Prescribed fire is another silvicultural tool that may be used to promote ground flora richness, diversity, and cover. Prescribed fire often reduces litter accumulation and increases mineral soil exposure (Heirs et al., 2007; Schwilk et al., 2009; Arthur et al., 2017). Litter often inhibits light from reaching the seedbed and acts as a physical barrier to seed germination and early establishment (Hutchinson, 2006). Baskin and Baskin (1988) found that increased light availability resulted in increased germination for many winter and summer annual plants as well as monocarpic and polycarpic perennial plants in the temperate zone. When a seed germinates above or within the litter, the plant allocates more carbohydrates to root growth, and when a seed germinates underneath litter, the plant often exhibits less vigorous shoot growth (Facelli and Pickett, 1991; Ellsworth et al., 2004; Sydes and Grimes, 1981). Indeed, reduction of litter has been shown to significantly increase the germination and establishment of ground flora (Xiong and Nilsson, 1999). Consumption of live vegetation and litter from prescribed burning also releases nutrients into the mineral soil that may influence ground flora productivity (Hutchinson, 2006; Knoepp et al., 2009; Scharenbroch et al., 2012; Alcañiz et al., 2016, 2018). However, the effects of prescribed burning on nutrient composition and ground flora diversity are often not as pronounced when implemented without other silvicultural activities (Boerner, 2006, 2009; Phillips et al., 2007).

Thinning in combination with burning has consistently been shown to be better at increasing ground flora diversity and cover compared to either treatment implemented alone (Schwilk et al., 2009; Willms et al., 2017). However, if the site contains an abundance of hardwoods in the understory or midstory, thinning in combination with burning may increase competition from woody plants in the ground layer via prolific hardwood stump sprouts (McGuire et al., 2001; Phillips et al., 2007; Barbier et al., 2008; Schwilk et al., 2009). Frequent burning alleviated undesirable hardwood competition and maintained increased light levels in the ground layer to sustain high plant diversity in Waldrop et al. (1992), Brose and Van Lear (1998), and Hutchinson et al. (2005a).

A paucity of data is available on ground flora response to the combination of thinning and burning across different burn frequencies over extended periods and in mixed *Pinus*-hardwood systems (Hutchinson et al., 2005a). Furthermore, few studies have quantified the effects of ground flora more than a decade after overstory thinning (Thomas et al., 1999) and we know of no such studies on the response of ground flora to overstory thinning and burning in this region. Forest managers need long-term studies that analyze ground flora response years after thinning and across different burn frequencies to determine the most effective silvicultural system to promote ground flora diversity and cover (Matlack, 2013).

The overarching goal of our study was to quantify the ground flora during the growing season (one year post-treatment; two years post-burn) to three different fire frequencies in mixed *Pinus*-hardwood stands that were thinned to promote hardwood dominance and compare these results to an unthinned and unburned control. The stands we selected to sample were either untreated, thinned only, thinned and burned on a nine year return interval (two burns to date), or thinned and burned on a three year return interval (four burns to date).

The specific objectives of our study were to compare treatment-mediated differences in ground flora richness, diversity, and cover, and to analyze the environmental variables that may have influenced the ground flora response. Through the use of ordination, we examined and visually displayed ground flora composition and abundance as well as determined indicator species within each treatment. We hypothesized that the combination of thinning and burning treatments would result in greater richness, diversity, and cover of ground flora, with the greatest increases in the thinned and frequently burned treatment (burned on a three year return interval). We hypothesized that ordination would display the highest forb and grass richness, diversity, and cover in the thinned and frequently burned treatment. We also hypothesized environmental variables, specifically litter depth and understory light availability, would be key factors that influenced ground flora richness, diversity, and cover. The information synthesized in this study can be used in comparative studies to elucidate general patterns and long-term trends regarding ground flora response to different management prescriptions and aids in our ability to design silvicultural systems to promote plant richness, diversity, and cover.

2. Methods

2.1. Study site

This study took place on the William B. Bankhead National Forest (BNF), located in northern Alabama, USA. The study site is within the Central Hardwood Forest Region (Fralish, 2003). The BNF is located on the southern portion of the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman, 1938), and in the Southwestern Appalachians (level III) ecoregion (Griffith et al., 2001). The topography of the region is complex, no longer resembling a true plateau, characterized by steep slopes and narrow ridges (Smalley, 1979) that occasionally lead into steep gorges with rock bluffs (USDA Forest Service, 2004). The geology is primarily composed of the Pennsylvania Pottsville formation consisting of thick-bedded to pebbly quartzose sandstone and containing differing levels of interstratified shale, siltstone, and thin discontinuous coal (Szabo et al., 1988). The primary soil types are Enders loam, rolling phase (E_c) and Muskingum, stony fine sandy loam, steep phase (M_g) (USDA NRSC, 2017). The narrow ridges typically contain E_c and are flanked by the shallow, sandstone rich M_g (USDA SCS, 1949). The soils are strongly acidic, well drained, have moderate moisture holding capacity, and are relatively low in nutrients and organic matter (USDA SCS, 1949). The climate in the region is classified as humid mesothermal, characterized by long, hot summers and short, mild winters with no recognized dry season (Thornthwaite, 1948). Mean annual temperature is 16.0 °C with a mean monthly temperature of 4.5 °C in January and 25.6 °C in July (PRISM 2017). Mean annual precipitation from the past thirty years is 140 cm with the highest mean monthly precipitation of 14.2 cm in December and the lowest mean monthly precipitation of 9.4 cm in October (PRISM 2017). The frost-free period typically spans from March to November (Smalley, 1979).

Prior to federal acquisition in 1918, ca. 40% of the land base that now comprises the BNF was in cultivation and most ridgetops were cutover (USDA Forest Service, 2004). We explored the field notes for the three townships in which we installed plots and documented several tree species that were recorded during the land survey. The land survey was conducted in 1818 under the direction of the General Land Office and was held in the land records of the Alabama Secretary of State (2018). Field notes from several sections of each township were examined. Each treatment of this study contained similar tree species in 1818. Common trees listed by surveyors included: *Quercus* spp., *Carya* spp., *Pinus* spp., *Castanea dentata* (Marshall) Borkh., *Fraxinus americana* L., *Oxydendrum arboreum* (L.) DC., and *Sassafras albidum* (Nutt.) Nees. Stands were planted with *Pinus taeda* L. in the 1930s to re-establish forests on cutover and agricultural land and again planted with *P. taeda* in the 1960s–1980s to increase economic yield, totaling an estimated 31,970 ha of planted *P. taeda* on the national forest. Following a severe *Dendroctonus frontalis* Zimmermann (southern pine beetle) outbreak in the 1990s, which left *Pinus* spp. over approximately 7527 ha on the BNF weakened or dead, the Bankhead Forest Health and Restoration Initiative was launched (Addor and Birkhoff, 2004). Through these efforts, over 6400 ha were commercially thinned to reduce density in overstocked *Pinus* stands. Prescribed burning programs were initiated to reduce fuel loads, reduce the risk of wildfire (particularly from beetle-killed trees), and prepare the treated stands for regeneration of tree species native to the southern Cumberland Plateau region, primarily *Quercus* spp. (Addor and Birkhoff, 2004).