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Competition, size and age affect tree growth response to fuel reduction treatments in mixed-oak forests of Ohio

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ABSTRACT

Prescribed fire and thinning treatments are increasingly used to mitigate potential wildfire hazards, alter stand structure and restore forest functions. In this study, the effects of competition, tree size and age on tree growth following prescribed fire and thinning treatments were examined to better understand the consequences of these management tools on forest systems. Tree-ring data from 348 trees, comprising five species (white oak, black oak, chestnut oak, hickories, and yellow-poplar) were analyzed following standard dendrochronological protocols. Data were collected from 80 0.1-ha plots in two study sites, each with four treatment units (control, thin-only, burn-only, thin + burn) in mixed-oak forests of Ohio. A neighborhood analysis was used to assess the competitive status of each sampled tree. Basal area increment (BAI) and tree size were positively related, with the strongest correlation found in the burn-only treatment. Age was negatively related to BAI, though weakly. Competition was inversely correlated with BAI, with trees from the thin-only unit showing the strongest correlation. BAI was greater for larger trees when competition was low and declined at a steeper rate as competition increased. Smaller trees grew less in general but decreases in BAI were not as steep as competition increased. Overall, tree size, age, and competition explained ~40% of total variance in BAI across all species. Values for individual tree species ranged from 30% to 57%, indicating considerable variation in the responses of species to these factors. Yellow-poplar exhibited greater sensitivity to competition than the other species analyzed. Altogether, competition was more important than size and age for tree growth in these managed stands. Variation in competitive status of trees within treatments supports the view that prescribed fire and thinning influence forest growth by creating heterogeneity among stands, and thus demonstrates the need for individual tree-based analysis to fully understand prescribed fire and thinning impacts on forest ecosystems.

1. Introduction

Prescribed fire and thinning treatments are widely used to mitigate wildfire effects, alter stand structure and species composition, and restore forest functions (Hutchinson et al., 2005; Schwilk et al., 2009). Over the past two decades, many studies have examined the effects of these treatments on forest ecosystems; however, the response of large residual trees has received considerably less attention. The few studies focused on residual tree growth following these management disturbances have demonstrated interesting response patterns over space, time, and across species (Boerner et al., 2008; Chiang et al., 2008; Lutz et al., 2012; Anning and McCarthy, in press). While these patterns are becoming apparent, the underlying factors have not been investigated thoroughly at the scale of the individual tree. Understanding these factors is essential for predicting productivity and development of forest stands following prescribed burning and thinning (Johnson et al., 2002). More fundamentally, knowledge of the relative growth rates of different species in relation to competition, size and age is useful to forest managers interested in determining which species to favor in partial harvesting (Trimble, 1967).

Tree growth is regulated by many biotic and abiotic factors (Fritts, 1976; Kozlowski et al., 1991). Among these, competition between individual trees continues to receive greater research attention because of its strong controlling effects on stand structure and development (Kozlowski et al., 1991; McDonald et al., 2002; Weber et al., 2008; Thorpe et al., 2010). Competition affects the availability and acquisition of resources such as light, water, nutrients and physical space, and thus has profound implications for forest ecology and management. In the closed-canopy forest of eastern North America, for example, competition has been identified as a major determinant of plant growth and productivity (Phipps, 1982). Therefore, it is not surprising that release of certain desirable tree species from competition has become synonymous with many prescribed fire and thinning management efforts in these temperate hardwood forests.

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Prescribed fire and thinning treatments may create structurally complex forest stands, with trees varying in age, size, species and spatial arrangement, which require spatially-explicit, individual tree-based models to understand (Lorimer, 1983; Canham et al., 2004; Thorpe et al., 2010). Evidence from several studies suggests considerable differences in the nature and effects of these management operations, with prescribed fire being more variable but removing less basal area than mechanical treatments (e.g., Waldrop et al., 2008). Canham et al. (2004) noted that partial harvesting can lead to considerable changes in the physical and competitive environments of stands. Despite these differences or changes, and the fact that resources are generally spatially heterogeneous across landscapes (Coomes and Allen, 2007), most researchers continue to rely on coarser descriptors (e.g., stand basal area or density) when analyzing tree growth patterns within these complex systems. Consequently, how prescribed fire and thinning manipulations influence the competition status of individual trees, and how this, in turn, mediates residual tree growth remain unclear.

Traditionally, the effect of competition on tree growth has been assessed via neighborhood analysis (Lorimer, 1983; Canham et al., 2006). This approach typically requires the demarcation of the spatial extent of a tree's competitive environment (i.e., its neighborhood), within which tree growth is assumed to be a function of the number, size, species and spatial configuration of neighboring trees. Thus, integrating these neighborhood characteristics, ecologists have developed a variety of competition indices with which to measure the extent of resource limitation by a plant's growing environment (Shi and Zhang, 2003). The most popular of these are the distance-dependent and the distance-independent models (Wimberly and Bare, 1996; Canham et al., 2006). Weiner (1990) also distinguished between asymmetric competition models, which involve only individuals larger than the target tree and reflect competition for light or effect of shading, and symmetric competition models, which incorporate all neighbors irrespective of size and represent competition for nutrients. These indices are of great value in accounting for the spatial structure in community data (Shi and Zhang, 2003), although the choice of a particular competition index is rather subjective.

Tree growth is strongly related to size and age (Wyckoff and Clark, 2005; Macfarlane and Kobe, 2006; Coomes and Allen, 2007). Studies have shown that larger trees usually produce more wood than smaller trees (Kozlowski et al., 1991). For example, McDonald et al. (2002) state that the size of an individual tree has a direct effect on its future growth, while size in relation to competitors indirectly affects growth through competitive effects. The size of an individual tree relative to its neighbors also influences resource supply and tree growth. Smaller trees are often shaded and suppressed by their larger neighbors (Coomes and Allen, 2007); although, some trees naturally lack the capacity to grow into the canopy. Thus, failure to account for initial tree size in tree growth models may lead to residual size bias (Macfarlane and Kobe, 2006), which in turn may obscure the effects of environmental stresses on tree growth.

The present study examined the influences of competition, size and age on the growth response of residual trees to fuel reduction treatments. Three specific questions were addressed: (a) Does the size of an individual tree and its age affect its growth response to prescribed fire and thinning treatments? (b) Does competition among individual trees mediate tree growth response to these treatments? and (c) What are the relative contributions of competition, size and age to tree growth following prescribed fire and thinning treatments? These questions were evaluated using tree-ring data from five common tree species in the mixed-oak forests of southeastern Ohio. It was predicted that basal area growth would increase with size and decrease with age of trees following the treatment, with different treatments having varying effects on different-sized trees. If treatments conferred differential competitive advantages on trees or structural changes among stands due to differences in intensity (Waldrop et al., 2008), growth responses of the individual trees would be expected to differ among the treatments. Finally, it was expected that competition would influence tree growth responses to the treatment more than size and age.

2. Materials and methods

2.1. Description of sites and experimental treatments

Two replicate blocks within the Ohio Hills site of the national Fire and Fire Surrogate (FFS) study were used for this study. The Raccoon Ecological Management Area (REMA) block is located within the Vinton Furnace State Experimental Forest (39°12′41″N, 82°23′09″W), and the Zaleski block is within the Zaleski State Forest (39°21′17″N, 82°22′06″W); both are in Vinton County, Ohio. The Ohio Hills site lies within the unglaciated Allegheny Plateau physiographic region. The landscape is dissected into ridges, hills and valleys (Hutchinson et al., 2005), with elevation ranging from 200 to 300 m (Waldrop et al., 2008). Soils are mainly acidic and are derived primarily from sandstone, siltstone and shale (Boerner et al., 2003). Annual precipitation and temperature average 1024 mm and 11.3 °C, respectively (Sutherland et al., 2003). The vegetation is classified as upland mixed-oak (*Quercus* spp.) hardwood forests (Iverson et al., 2008). Prior to the start of the treatments in 2000, the even-aged stands within both blocks were fully stocked with tree basal area ranging from 25.5 to 29.4 $m^2\ ha^{-1}$ (Appendix A; Waldrop et al., 2008).

At each site, there are four experimental units, each ~50 ha in extent and containing ten 20 × 50 m (0.1 ha) permanent plots (i.e., 2 sites × 4 experimental units × 10 plots = 80 plots total). The four treatments consist of an un-manipulated control, a mechanical thinning (thin-only), a prescribed burning (burn-only), and a combination of the two (thin + burn). These plots are distributed across the landscape from ridgetops to lower slopes based on the integrated moisture index (IMI) developed by Iverson et al. (1997). The IMI combines four topographic and soil factors (hillshade, curvature, flow accumulation and water holding capacity of the soil) in GIS (geographic information systems) to derive relative moisture ratings for sites. The model has been used successfully to predict site productivity and species composition in the oak-dominated forests of eastern North America (Iverson et al., 1997).

Mechanical thinning was conducted in the fall and winter of 2000–2001. This operation was primarily thinning from below with a focus on removing midstory trees (15–30 cm diameter at breast height, DBH), and resulted in ~30% reduction in stand basal area, although variations in treatment intensity were discernible (Appendix A). For example, at REMA, the thin-only and the thin + burn treatments reduced stand basal areas by 31.4% and 18.9%, respectively, from their initial values of 27.4 and 27.9 m^2 ha^{-1}. Prescribed fires were conducted in the spring of 2001, and repeated in 2005 and 2010. The intensity of prescribed fire varied greatly over the years and across landscapes. In 2001, for example, fire intensity was generally low with flame lengths getting to about 1 m. However, higher intensity fires (i.e., flame lengths reaching 4–5 m) were deliberately created in 2005 and 2010, resulting in significant overstory mortality (Iverson et al., 2008; Waldrop et al., 2008).

2.2. Increment core sampling and measurements

In the fall and winter of 2011–2012, 696 increment cores were extracted from white oak (*Quercus alba*), chestnut oak (*Q. prinus*), black oak (*Q. velutina*), hickories (*Carya* spp. primarily *C. glabra*)