Forest Ecology and Management 354 (2015) 130–138

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Factors affecting broadleaf woody vegetation in upland pine forests managed for longleaf pine restoration

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ARTICLE INFO

Article history:
Received 27 December 2014
Received in revised form 11 June 2015
Accepted 22 June 2015
Available online 30 June 2015

Keywords:
Longleaf pine restoration
Canopy basal area
Soil texture
Fire frequency
Hardwood control
Sweetgum

ABSTRACT

Controlling broadleaf woody plant abundance is one of the greatest challenges in longleaf pine (*Pinus palustris* Mill.) ecosystem restoration. Numerous factors have been associated with broadleaf woody plant abundance in longleaf pine ecosystems, including site quality, stand structure, and fire frequency and intensity, yet the way in which these factors vary and interact across a landscape is poorly understood. The goal of this study was to quantify the importance of environmental and management factors and their interactions on the abundance of hardwood tree and shrub species in upland pine forests managed for longleaf pine restoration in Fort Benning, GA. We measured understory, midstory, and overstory vegetation in 189 fixed-area plots, and we assembled descriptive plot data about soil texture classes, slope and aspect, and fire management history. We used classification and regression trees to model broadleaf woody species abundance. Regression trees identified fire return interval, soil texture, and slope as the most important factors affecting understory woody plant cover, with high mean cover occurring in areas with longer fire return intervals (i.e. less frequent fire), on fine-textured soils (sandy clay loams and sandy loams), and on slopes less than 6%. An interaction between soil texture and fire return interval was present and suggested that frequent fire was especially important in controlling understory broadleaf woody plants on fine-textured soils. A significant interaction emerged between soil texture and pine basal area as well, suggesting that the potential to release woody competitors with canopy removal was higher on fine-textured soils than on coarse-textured soils. The presence of hardwood stems in the midstory was most dependent upon time since burn. Other factors, such as the number of burns conducted during the growing season and topographic aspect, did not contribute significantly to variation in woody plant cover or density. Of the woody species encountered, sweetgum (*Liquidambar styraciflua* L.) was the most abundant, especially on plots with fire return intervals $\geqslant$2.6 years, on fine-textured soils, and at low pine basal areas (<9.4 m^2/ha). Other species such as persimmon (*Diospyros virginiana* L.), winged sumac (*Rhus copallinum* L.), and southern red oak (*Quercus falcata* Michx.) were commonly encountered but at low densities. Our results demonstrate the general complexity of woody species control, but more importantly indicate site differences that could be used to prioritize prescribed fire application at the landscape scale.

1. Introduction

In recent decades increasing emphasis has been placed on restoring vegetation structure and composition of longleaf pine (*Pinus palustris* Mill.) ecosystems of the southeastern United States (Van Lear et al., 2005; Walker and Silletti, 2006). Historically, longleaf pine ecosystems experienced frequent fires that maintained open stand structures and diverse, herbaceous-dominated understory vegetation communities (Frost, 2006; Peet, 2006). Twentieth-century fire exclusion resulted in the expansion of non-pine, broadleaf woody vegetation (hereafter woody vegetation), such that current conditions in many remnant longleaf pine ecosystems are characterized by abundant hardwood trees and shrubs in the understory and midstory

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http://dx.doi.org/10.1016/j.foreco.2015.06.028
0378-1127/

vegetation strata (Van Lear et al., 2005). Once hardwoods are established, increasing fire frequency does not easily remove them because many species have the ability to resprout after aboveground stems are killed by a fire (Waldrop et al., 1992; Glitzenstein et al., 1995, 2003; Mitchell et al., 2006). Repeated cycles of topkilling and resprouting may confine woody species to the understory vegetation stratum, from which they may emerge during periods of fire suppression (Bond and Midgley, 2001; Grady and Hoffmann, 2012).

The probability of topkill from fire is generally inversely related to the size of the stem when burned (Grady and Hoffmann, 2012). On productive sites that favor rapid woody species growth, the temporal window for topkilling woody stems is shorter, requiring more frequent burning to prevent stems from developing into fire resistant sizes (Robertson and Hmielowski, 2014). While broadleaf woody vegetation is expected to be present on most sites in the longleaf pine range, species composition and woody vegetation abundance varies with edaphic conditions and site productivity, generally indexed by soil texture (Gilliam et al., 1993; Jacqmain et al., 1999; Rodgers and Provencher, 1999; Kirkman et al., 2004). More frequent fires may be needed to control woody vegetation abundance on finer textured soils compared to coarser textured soils in a given landscape. Understory vegetation responses to overstory silvicultural treatments may vary differentially with soil conditions as well (Knapp et al., 2014).

The likelihood of topkilling woody stems is contingent on characteristics of the fire regime, with high fire frequency and high fire intensity often offering the greatest woody plant control (Boyer, 1990; Robbins and Myers, 1992; Waldrop et al., 1992; Streng et al., 1993; Glitzenstein et al., 1995, 2012; Brockway and Lewis, 1997; Robertson and Hmielowski, 2014). Fire behavior and resultant effects on woody plant communities can be both complex and variable, however, based on weather conditions at the time of burning and factors such as soils and topography. Soil texture, for example, may influence fire behavior through effects on fuel types, loads, and availability. Topographic variables such as elevation, slope, and aspect also influence vegetation community composition and fuel characteristics (Gilliam et al., 1993; Peet, 2006), primarily through effects on soil moisture and light availability. For example, north-facing slopes tend to be wetter and more shaded than south-facing slopes and may enable greater fuel loads and fuel moisture. Topography also directly influences fire behavior by affecting rates of fire spread (Rothermel, 1983).

Pine canopy management activities may also interact with fire to affect the abundance of broadleaf woody vegetation. Pine overstory structure influences understory vegetation and fuels through belowground competitive effects and by mediating understory light environments (McGuire et al., 2001; Battaglia et al., 2002; Knapp et al., 2014). The removal of canopy pines via harvesting is a common restoration practice in longleaf pine ecosystems to encourage herbaceous plant community development and longleaf pine regeneration (Johnson and Gherstad, 2006; Mitchell et al., 2006). The characteristics of canopy structure (e.g., low basal area and canopy gaps) that are generally favorable for herbaceous plants and for longleaf pine seedling growth, however, are also favorable for woody plants in the sub-canopy vegetation layers (Jack et al., 2006; Pecot et al., 2007; Loudermilk et al., 2011; Knapp et al., 2014). Furthermore, the loss of pine needles as stands are thinned may reduce fuel continuity and fire intensities necessary for woody plant control (Harrington and Edwards, 1999; Jack et al., 2006; Mitchell et al., 2006; Knapp et al., 2014).

The cumulative evidence implicates multiple factors in the control of woody species abundance and structure, but how these factors interact and vary across a landscape is poorly understood. Our goal in this study was to examine the effects and interactions of multiple factors on the control of woody species abundance in a landscape managed for longleaf pine ecosystem restoration at Fort Benning, GA. Fort Benning is a 74,000 ha United States Army training installation located in west-central Georgia and eastern Alabama, where longleaf pine restoration activities have been on-going since the 1990s. The Fort Benning landscape is spatially extensive, with sites that encompass a wide range of environmental conditions, and thus provides an excellent opportunity for evaluating broad-scale patterns in woody plant dynamics. Using data from Fort Benning's long-term ecological monitoring program, we evaluated factors affecting woody plant cover in the understory vegetation stratum and woody plant density in the midstory vegetation stratum. We expected that understory woody plant cover and midstory density would be closely related to characteristics of the fire regime, such as fire return interval and time since last burn. However, we were specifically interested in better understanding how soil texture, overstory canopy conditions, and factors such as topography interact with the fire regime to affect restoration outcomes. We hypothesized that site productivity and canopy openness would each be positively related to broadleaf woody vegetation abundance, and therefore frequent fire would be especially important in controlling woody vegetation on productive, fine-textured soils as well as in stands with more open canopies. Additionally, we were interested in evaluating response patterns of individual woody species following longleaf pine restoration treatments. Such responses may be species specific based on plant tolerance to fire and life-history traits (Ratnam et al., 2011; Hoffmann et al., 2012; Veldman et al., 2013). We were particularly interested in evaluating sweetgum (*Liquidambar styraciflua* L.), as this species presents challenges to longleaf pine restoration due to its rapid growth and its potential for release following longleaf pine restoration treatments.

2. Materials and methods

2.1. Site description

Fort Benning is located in the Fall Line Sandhills region of the longleaf pine-bluestem (*Andropogon* spp; *Schizachyrium scoparium* Michx.) ecosystem described by Frost (2006). Two ecoregions are represented on Fort Benning (Keys et al., 1995). The East Gulf Coastal Plain covers approximately the northeastern two-thirds of the installation and includes the Sand Hills subsection, where soils are well-drained, loamy sands, and the major soil series are Troup and Ailey (Johnson, 1983; Green, 1997; USAIC, 2006). The Upper East Gulf Coastal Plain covers the southwestern one-third of the installation and includes the Upper Loam Hills subsection where soils are finer textured and are classified primarily as Nankin sandy loams and sandy clay loams. The topography of Fort Benning is characterized as rolling, with elevation ranging from 58 m to 226 m above sea level (USAIC, 2006). The climate is temperate, with a mean summer temperature of 26 °C and a mean winter temperature of 8 °C. Annual precipitation averages 1295 mm (USAIC, 2006). Upland sites at Fort Benning are dominated by pines and typically include a mix of longleaf, loblolly (*Pinus taeda* L.), and shortleaf (*Pinus echinata* Mill.) pines. Pine-hardwood stands are also prevalent, with common hardwood species including sweetgum, oaks (*Quercus* spp.) and hickories (*Carya* spp.). Longleaf pine is believed to have been the dominant upland species prior to Euro-American settlement of the area in the 1830s (USAIC, 2006).

In the mid-1990s, Fort Benning began an extensive longleaf pine restoration program on over 35,000 ha, with the primary objective of enhancing habitat for the federally endangered red-cockaded woodpecker (*Picoides borealis*; RCW). Fort Benning adopted at that time uneven-aged forest management practices