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Effects of overstory retention, herbicides, and fertilization on sub-canopy vegetation structure and functional group composition in loblolly pine forests restored to longleaf pine

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ABSTRACT

The desirable structure of longleaf pine forests, which generally includes a relatively open canopy of pines, very few woody stems in the mid-story, and a well-developed, herbaceous ground layer, provides critical habitat for flora and fauna and contributes to ecosystem function. Current efforts to restore longleaf pine to upland sites dominated by second-growth loblolly pine require information about how restoration treatments affect sub-canopy vegetation. We established a field experiment at Fort Benning in Georgia and Alabama, USA to determine the effects of four levels of approximately uniform canopy density (Control [$\sim$16 m^2/ha basal area], MedBA [$\sim$9 m^2/ha basal area], LowBA [$\sim$5 m^2/ha basal area], and Clearcut [0 m^2/ha basal area]) and three cultural treatments (NT [untreated], H [chemical control of woody and herbaceous vegetation] and H + F [chemical control plus fertilization]) on vegetation structure and functional group composition for three growing seasons following canopy removal. In general, cover (a measure of abundance) of ground layer vegetation increased with the amount of canopy removal. The ground layer was dominated by herbaceous vegetation in each year. Canopy trees generally suppressed the cover of graminoids in the first two years after treatment but only the Control plots had lower graminoid cover than Clearcut plots after the third growing season. Forb cover was significantly lower on Control plots than on Clearcut plots after only the first growing season, and woody stems/shrubs had lower cover on Control plots than on LowBA or Clearcut plots in each year. Vegetation cover increased following the first year after canopy removal, and the relative dominance of functional groups did not change through time. Canopy retention limited the development of mid-story woody stems, with the greatest stem densities in the Clearcut plots. The herbicide treatment (on both H and H + F) significantly reduced woody stem density in the mid-story in 2009, but the effect was no longer significant in 2010. Traditional methods for converting stands of other pine species to longleaf pine commonly include clearcutting followed by planting, but our results suggest that clearcutting may release woody vegetation to increase mid-story stem densities and will reduce the amount of pine needles in the fuel bed. Retaining low to moderate levels of canopy density (5–9 m^2/ha basal area) in loblolly pine stands may provide an effective balance for reaching multiple restoration objectives that include maintaining desirable vegetation structure and creating fuel conditions for a frequent fire regime.

1. Introduction

In the southeastern United States, the historical conversion of upland sites from longleaf pine (*Pinus palustris* Mill.) to loblolly pine (*Pinus taeda* L.) has been largely associated with land-use history (e.g., timber clearing, agriculture) and forest management decisions (e.g., use of plantation systems, fire exclusion) (Frost, 1993; Van Lear et al., 2005). Following widespread logging of historically dominant longleaf pine forests in the 1800s and early

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1900s, many upland sites were reforested with faster-growing species or allowed to follow natural succession processes, largely in the absence of fire (Frost, 2006; Schultz, 1999). Consequently, loblolly pine is currently found on many upland sites that are well-suited for longleaf pine. The differences between the two forest types are not limited to canopy composition. The stand structure of second-growth loblolly pine forests is often quite different from that of fire-maintained longleaf pine forests. For example, Hedman et al. (2000) reported that second-growth loblolly pine forests had lower ground layer herbaceous cover and higher mid-story stem densities than longleaf pine forests and largely associated such differences with land-use history and fire management. Currently, restoration of longleaf pine forests and woodlands is a widely shared goal among public and private landowners in the southeastern United States.

While many different restoration objectives could be identified, ranging from the presence of selected species or groups of species to recreating the historic disturbance regime, measures of characteristic stand structure are arguably among the most useful. The stand structure of longleaf pine forests with high conservation value is generally characterized by an open canopy that is dominated by longleaf pine, little to no mid-story, and a ground layer that is dominated by herbaceous vegetation (e.g., Gilliam et al., 2006; Peet, 2006). The ground layer typically includes large bunchgrasses that create a matrix of overlapping plant tissue and form an often continuous layer of well-aerated fuels. When combined with needlefall from canopy pines, this fuel layer burns readily as low-intensity surface fires (e.g., Clewell, 1989; Noss, 1989; O'Brien et al., 2008). Frequent surface fires reduce encroachment from hardwood species and maintain the dominance of herbaceous species (Brockway and Lewis, 1997; Glitzenstein et al., 1995). The importance of ground layer vegetation (particularly large bunchgrasses) as a fuel source, coupled with the need for burning to perpetuate the desired structure, represents a positive feedback cycle that becomes difficult to re-establish once disrupted (Martin and Kirkman, 2009). Thus, restoring the desired structure is necessary for restoring ecological dynamics.

Further, where restoring wildlife habitat or conditions suitable for characteristic plant species is an explicit objective, restoring structure is critical. For example, the gopher tortoise (*Gopherus polyphemus*) and many other reptile specialists in longleaf pine habitats require open stands for foraging herbaceous ground layer plants (Guyer and Bailey, 1993). Perhaps the most well-known faunal species associated with the longleaf pine ecosystem is the red-cockaded woodpecker (*Picoides borealis*), which uses live longleaf pine trees for nesting cavities and prefers open stands for foraging (U.S. Fish and Wildlife Service, 2003). Recent reports suggest that RCWs living in habitats dominated by herbaceous plants have higher reproductive potential than those in habitats dominated by shrubs (James et al., 1997), in part due to the diverse arthropod community supported by herbaceous ground layers plants (Folkerts et al., 1993; Hanula and Engstrom, 2000).

The management and land-use histories that contributed to the conversion of upland sites from longleaf pine to loblolly pine also altered the sub-canopy vegetation. For example, many such sites have experienced a recent history of fire exclusion that has resulted in the establishment and growth of hardwood species in the sub-canopy layers. As hardwoods gain dominance, herbaceous species such as grasses and forbs become less abundant due to competition for resources and the development of hardwood litter on the forest floor (Harrington and Edwards, 1999; Hiers et al., 2007). Such changes in the vegetation composition and structure lead to changes in the characteristics of the fuels in the forest, with shifts from the well-aerated, continuous fine fuels of the herbaceous layer to a less pyrogenic and patchier hardwood litter (Mitchell et al., 2009; Williamson and Black, 1981). Consequently, the ability to manage with frequent surface fires becomes more difficult, and the hardwood mid-story continues to develop (Mitchell et al., 2006).

Several studies have been designed to determine methods for restoring the desired vegetation structure and associated fuel matrix to longleaf pine sites. Herbicides that target woody vegetation can be used to eliminate woody competitors and increase dominance of herbaceous species in the ground layer (Brockway et al., 1998; Freeman and Jose, 2009; Jose et al., 2010). Other studies have used mechanical treatments, or mechanical treatments combined with herbicides, to control woody species for the restoration of desirable longleaf pine vegetation (Harrington and Edwards, 1999; Martin and Kirkman, 2009; Outcalt and Brockway, 2010; Provencher et al., 2001a). To sustain the longleaf pine ecosystem over the long-term, frequent prescribed fire must be incorporated into management, and prescribed burning is an important tool for restoring the vegetation structure of the longleaf pine ecosystem (Freeman and Jose, 2009; Outcalt and Brockway, 2010; Provencher et al., 2001a). Burning alone, over long timeframes, has been shown to reduce woody vegetation and increase the abundance of herbaceous vegetation (Brockway and Lewis, 1997; Haywood et al., 2001; Waldrop et al., 1992), and results from recent research suggest that fire alone may be effective at restoring vegetation composition in longleaf pine forests (Kirkman et al., 2013). However, responses of the vegetation community following restoration treatments are likely to vary in magnitude or effect according to local site factors or the initial condition of the vegetation community. Few studies have incorporated variability among sites into the evaluation of such treatments (see Gliztenstein et al., 2003; Haywood, 2005), but previous studies have demonstrated the importance of site characteristics, such as soil texture or moisture, in affecting the productivity or composition of vegetation in longleaf pine forests (Gilliam et al., 1993; Kirkman et al., 2001, 2004; Mitchell et al., 1999). As a result, more information is required to understand the effects of state variables on the responses of the vegetation community to restoration treatments.

Despite an understanding of the importance of ground layer vegetation in this ecosystem, longleaf pine restoration efforts on sites that have been converted to other canopy species often initially focus on the establishment of longleaf pine seedlings. Traditionally, artificial regeneration of longleaf pine has been accomplished following clearcutting of the existing canopy and the use of release treatments (e.g., Freeman and Jose, 2009; Johnson and Gjerstad, 2006; Knapp et al., 2006). Although this approach is expected to maximize longleaf pine seedling growth, complete canopy removal may also release sub-canopy hardwoods and make fire management more difficult by changing the fuels. Therefore, retaining canopy trees during the conversion of other pine forests to longleaf pine may provide additional benefits for meeting restoration objectives (Kirkman et al., 2007). Recent studies suggest that retaining low to moderate levels of canopy basal area may be a viable practice during the establishment of longleaf pine seedlings in loblolly pine stands (Hu et al., 2012; Knapp et al., 2011, 2013).

To make informed restoration decisions, land managers require information on how alternative silvicultural treatments affect vegetation structure during longleaf pine restoration. This study was designed to determine the effects of various levels of canopy retention and cultural treatments used during longleaf pine restoration on the structure and functional group composition of the sub-canopy vegetation in loblolly pine stands. Moreover, we established our study on two broad categories of soil texture, and we used this opportunity to determine the effects of soil texture on certain vegetation responses. Our specific objectives are to determine: (1) how canopy density and cultural treatments affect ground layer vegetation total cover and the cover of selected functional groups;