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Effects of overstory composition and prescribed fire on fuel loading across a heterogeneous managed landscape in the southeastern USA

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ABSTRACT

In the southeastern USA, land use history, forest management and natural geomorphic features have created heterogeneous fuel loads. This apparent temporal and spatial variation in fuel loads make it difficult to reliably assess potential fire behavior from remotely sensed canopy variables to determine risk and to prescribe treatments. We examined this variation by exploring the relationships between overstory forest vegetation attributes, recent fire history, and selected surface fuel components across an 80,000 ha contiguous landscape. Measurements of dead and live vegetation components of surface fuels were obtained from 624 permanent plots, or about 1 plot per 100 ha of forest cover. Within forest vegetation groups, we modeled the relationship between individual surface fuel components and overstory stand age, basal area, site quality and recent fire history, then stochastically predicted fuel loads across the landscape using the same linkage variables. The fraction of the plot variation, i.e., R^2, explained by predictive models for individual fuel components ranged from 0.05 to 0.66 for dead fuels and 0.03 to 0.97 for live fuels in pine dominated vegetation groups. Stand age and basal area were generally more important than recent fire history for predicting fuel loads. Mapped fuel loads using these regressor variables showed a very heterogeneous landscape even at the scale of a few square kilometers. The mapped patterns corresponded to stand based forest management disturbances that are reflected in age, basal area, and fire history. Recent fire history was significant in explaining variation in litter and duff biomass. Stand basal area was positively and consistently related to dead fuel biomass in most groups and was present in many predictive equations. Patterns in live fuel biomass were related to recent fire history, but the patterns were not consistent among forest vegetation groups. Age and basal area were related to live fuels in a complex manner that is likely confounded with periodic disturbances that disrupt stand dynamics. This study complements earlier hazardous fuels research in the southeastern USA, and indicates that succession, disturbance, site quality and decomposition interact with forest management practices to create variable spatial and temporal conditions. The inclusion of additional land use, disturbance history, and soil-topographic variables coupled to improved sampling methods may increase precision and subsequent fuel mapping.

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1. Introduction

In addition to weather, topography and wildfire suppression strategies, fuel load (FL) is a critical component affecting the extent of fires that exceed control by initial attack resources. In the southeastern USA the importance of FL accumulation on wildfires is long known from empirical observations (Davis and Cooper, 1963). In addition, fire emissions are becoming a critical component in attaining air pollution standards and the quantity of emissions is directly tied to FL (Goodrick et al., 2010). The reduction in FL by frequent prescribed fire is well established from both experimental and modeling studies (Brose and Wade, 2002; Glitzenstein et al., 2006; Hanula and Wade, 2003; Hough, 1978; Waldrop et al., 2009). Yet, increases in FL could be partially responsible for the rise in large fire size occurrences since the 1970s (Scott, 2006; Malamud et al., 2005). The area treated by prescribed fire annually remains relatively static in the southeastern USA. It is typically a small fraction (<10%) of the total pine forest area (Andreu and Hermansen-Baez, 2008; Haines et al., 2001). There are concerns that the latest United States Environmental Protection Agency (2011) "National Ambient Air Quality Standards", requiring reductions in particulate matter and ozone in the USA, may curtail prescribed fire in the future. Therefore, understanding the ecological and management processes that control the temporal and spatial variation in FL is important to reliably determine risk and to pre-

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scribe treatments (Keane et al., 2001; Hiers et al., 2003; Finney et al., 2007).

1.1. Previous studies

In the southeastern USA crown fires are relatively uncommon except where pine needle drape on shrubs creates a continuous fuel ladder to the canopy (Sackett, 1975). Fire behavior is generally dominated by FL associated with litter and available fine fuels in grass and shrub components (Andreu and Hermansen-Baez, 2008; Andreu et al., 2012). These live fuels are also the largest contributors to consumption following prescribed fires (Hough, 1978; Goodrick et al., 2010). Experiments on factors influencing FL within forest stands in the southeastern USA have demonstrated the influence of recent fire history, and to a lesser degree the influences of overstory density, disturbance, vegetation type, and succession. Several studies have shown that the prescribed fire return interval is critical in reducing available FL in southern Georgia and northern Florida in pine–gallberry–palmetto (*Pinus* spp.-*Ilex glabra* (L.) A. Gray-*Serenoa repens* (Bartram) Small) vegetation (Sackett, 1975; Hough, 1978, 1982; McNab et al., 1978; Hanula and Wade, 2003). Fire frequency intervals of 2–3 years are essential to maintain low levels of both live and dead fuels (Sackett, 1975; Glitzenstein et al., 2003). Annual and biennial cycles of growing season fire eliminate the accumulations of litter and shifted the live fuel composition from woody plants to one dominated by grasses and forbs (Waldrop et al., 1987). In contrast, limited effect on woody plant cover or biomass is observed from dormant season fires (Glitzenstein et al., 1995; Brockway and Lewis, 1997; Kush et al., 1999).

Ecological studies in frequently burned areas have revealed that understory biomass of the grass-forb community decreases dramatically as pine stocking increases (Carter and Hughes, 1974; McNab et al., 1978; Harrington, 2006). In contrast, as pine density decreases, litter biomass decreases due to lower crown biomass per unit area (Boyer and Fahnestock, 1966). Studies of biomass accretion as a function of succession have shown that the forest floor litter and humus layers increase annually, and can reach equilibrium in less than a decade (Brender et al., 1976; Switzer et al., 1979). For live FL the patterns are more complex (Cain and Shelton, 2001). Shrub biomass may increase, followed by a shift to more shade tolerant shrubs, then decrease. Grasses and forbs generally decline in the early stages of succession from canopy closure and root competition (Harrington, 2006). Small trees between 2 and 12 cm diameter breast height (DBH) can shift into larger DBH classes over several decades, but natural mortality appears the dominant process influencing stem density (Peet and Christensen, 1980). The consequence of catastrophic wind disturbances, thinning and understory mastication of woody trees and shrubs has been quantified in several studies (Wade et al., 1993; Kush et al., 1999; Provencher et al., 2001; Brose and Wade, 2002; Glitzenstein et al., 2006; Ottmar et al., 2007; Waldrop et al., 2009). Finally, the influence of vegetation type (i.e., species groupings) on FL in the southeastern USA is the basis for the standard fire behavior fuel model system (Scott and Burgan, 2005) and photo series (Ottmar and Vihnanek, 2000; Ottmar et al., 2003). These model systems provide coarse scale estimates of FL. More recently, FL data have been expanded in the southeastern USA by the Fuel Characteristic Classification System (FCCS) (Ottmar et al., 2007). However, these model systems offer no basis for predicting or mapping the local distribution of fuels, and understanding processes responsible for the patterns.

1.2. Objectives

Intensive and systematic field mapping of fuel loads is rare at scales of thousands of hectares (ha) (Fernandes et al., 2006). For economic reasons, most efforts to map surface fuels are based on remote sensing approaches with corresponding low density field measurements or simple categorical assignments of standard fuel models (Keane et al., 2001; Reich et al., 2004; Rollins et al., 2004; Buckley et al., 2006; Arroyo et al., 2008). In dynamic managed ecosystems, the reliability of these data and the implied assumptions provide limited utility for guiding fire management. The objectives of our research are: (1) to quantify the forest stand relationships that structure FL, (2) to gain insight into the dominant processes controlling fuel load levels, (3) to validate ecological and management factors predicted to influence FL, particularly recent fire, and (4) to produce spatial maps of FL by linking predictive equations to mapped polygons of forest vegetation group, site quality, forest

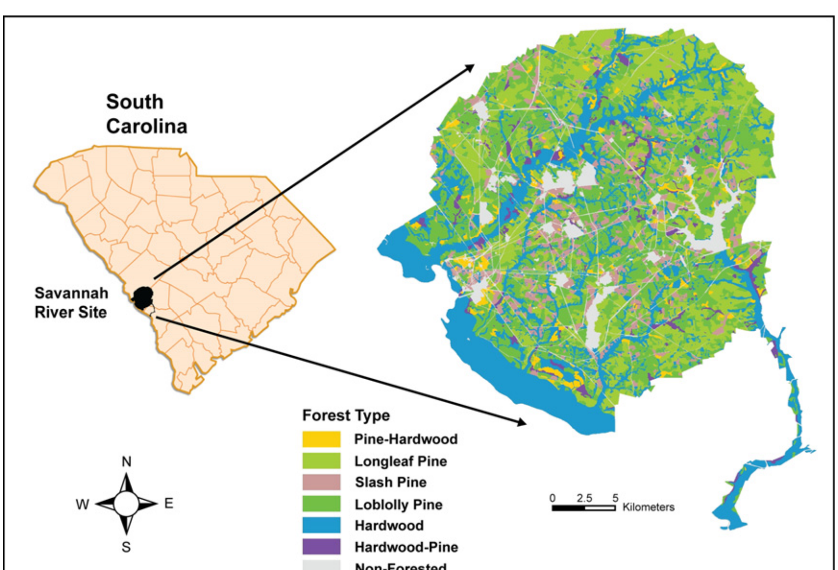

Fig. 1. The Savannah River Site in South Carolina, southeastern USA. Major forest vegetation groups are shown.