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Understory plant biomass dynamics of prescribed burned *Pinus palustris* stands

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ABSTRACT

Longleaf pine (*Pinus palustris* Mill.) forests are characterized by unusually high understory plant species diversity, but models describing understory ground cover biomass, and hence fuel load dynamics, are scarce for this fire-dependent ecosystem. Only coarse scale estimates, being restricted on accuracy and geographical extrapolation, are available. We analyzed the dynamics of ground cover biomass under different prescribed burning regimes in longleaf pine stands in the southeastern United States. We developed a set of functions to simulate ground cover biomass dynamics in stands of varying age, basal area and fire management history. The subsequent models allow for estimation of ground cover biomass for unburned stands and living woody and herbaceous ground cover biomass for burned stands. Woody ground cover was highly reduced as fire frequency increased, and also affected by stand basal area when time since last burning was longer than two years. Herbaceous ground cover was affected little by burning frequency but was reduced as basal area increased. This novel model system is a useful tool that can be incorporated into fire management and carbon balance models.

1. Introduction

Longleaf pine (*Pinus palustris* Mill.) forests harbor a diverse community of plant species in the ground cover layer, with as many as 40 species per square meter (Peet and Allard, 1993). High plant diversity of the ground cover layer is maintained by frequent fire and an open discontinuous tree canopy (Glitzenstein et al., 1995). Prescribed burning is an important management tool in longleaf forests, with recommended burning frequencies of at least once per 10 years but ideally, in many cases, every two to four years (Chapman, 1932; Glitzenstein et al., 2003; Loudermilk et al., 2011). The benefits of periodic prescribed fire in longleaf pine ecosystems include not only restoration of diverse native plant communities, but also seedbed preparation for longleaf seed germination and control of fuel quantity and quality, which affects fire intensity (Brockway et al., 2006; Harrington, 2011) and thus plant community structure (Hiers et al., 2007). Without frequent fire, longleaf ecosystems become susceptible to woody plant encroachment and may transition to hardwood dominated forests (Quarterman and Keever, 1962; Hartnett and Krofta, 1989).

Ground cover biomass has been shown to be linearly related to ground cover species richness and proportional to stand productivity in longleaf pine-wiregrass systems (Kirkman et al., 2001). Similarly, Brockway and Lewis (1997) demonstrated that recurrent fire over four decades increased ground cover diversity and the standing biomass of grasses and all forbs relative to less frequent burn intervals in a flatwoods longleaf pine-wiregrass ecosystem (Brockway and Lewis, 1997). In addition, the contribution of the ground cover layer to annual net primary productivity may be significant (Mitchell et al., 1999) and important in assessment of carbon stocks in low density stands (Samuelson et al., 2014). While fire volatilizes carbon, the immediate loss of plant carbon may not constitute a long-term loss in carbon stocks because of understory growth following fire.

Relationships between the forest understory and overstory offer a useful framework to understand the impact of forest management on species and community distribution and productivity. Management activities such as thinning and prescribed burning will alter those relationships. For example, thinning will reduce the number of trees and hence the basal area and leaf area index of the overstory, thereby altering the environment for ground cover species, and fire will directly affect the composition and biomass of the ground cover layer. Longleaf pine has wide ecological

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amplitude (Fig. 1) and ground cover biomass across the species range varies not only with fire interval and stand structure but also soils, climate, management history and native vegetation (Hiers et al., 2003; Scott and Burgan, 2005). However, models for prediction of ground cover biomass, and hence fuel load, are scarce and only provide coarse scale estimates (Scott and Burgan, 2005; Ottmar et al., 2009) or are restricted on accuracy and geographical extrapolation (Parresol et al., 2012).

In this study we analyzed the dynamics of ground cover understory biomass of longleaf pine stands with varying stand structure and fire management history in stands located in Georgia, Louisiana and North Carolina (Fig. 1). The objectives of the study were: (1) develop models to estimate ground cover biomass for unburned and burned longleaf pine stands, (2) develop models to estimate ground cover biomass partitioning into woody and herbaceous plants, and (3) assess the impact of stand density and prescribed fire frequency on ground cover biomass dynamics.

2. Materials and methods

2.1. Ground cover biomass for unburned stands

Ground cover biomass (GC_B) in all cases is defined as all live and dead plants <1 m in height. Because the majority of reports in the literature are for burned longleaf pine stands, we included data from two other southern pine species, loblolly pine (*Pinus taeda* L.), and slash pine (*Pinus elliottii* Engelm.), in modeling the dynamics of GC_B under unburned conditions (Bracho et al., 2012; Clark et al., 2004; Gholz and Fisher, 1982; Haywood and Grelen, 2000; Kush et al., 1999; Neary et al., 1990; Subedi et al., 2014; Vogel et al., 2011). In all reports in Table A1, GC_B was measured using clip plots (0.2–4.0 m^2) located randomly within a stand. The number of clip plots ranged between 4 and 20 for each site. Table A1 summarizes stand characteristics used for model fitting (all data from literature).

For the stands without periodic prescribed burning, GC_B was correlated to overstory basal area (BA, $m^2\,ha^{-1}$) and stand age (years). After testing several equations, the model selected was:

$$GC_B = a_1 \cdot \exp^{(-a_2 \cdot BA)} + \varepsilon_1 \quad (1)$$

where a_1 and a_2 are curve fit parameter estimates, exp is base of natural logarithm and ε_1 is the error term, with $\varepsilon_1 \sim N(0, \sigma_1^2)$. Stand age was not a significant factor in the model.

2.2. Ground cover biomass for burned stands

2.2.1. Recovery following fire

In order to estimate GC_B for longleaf pine stands subjected to periodic prescribed burning, a biomass consumption recovery function was fitted using data from the Fire and Environmental Research Applications Team (FERA, http://depts.washington.edu/nwfire/dps/). The dataset consisted of B_{GC} sampled in seven stands in the sandhills and eight stands in the flatwoods (Ottmar et al., 2000, 2003). In addition, two plots from one experimental site in Alabama (Kush et al., 1999) and two plots from one experimental site in Louisiana (Haywood, 2011) were included into the dataset. Stands ranged in time since last prescribed fire (TSF) from 1 to 23 years and in pine BA from 1.5 to 24.6 $m^2\,ha^{-1}$. For each report, all data were expressed as a fraction of the GC_B of the unburned condition. For stands reported by Ottmar et al. (2000, 2003), the average GC_B at TSF = 20 years was assumed to be the unburned condition that had a value = 1. Assuming an asymtotic response within the range of fire intervals under consideration, a sigmoidal model was fit to data of GC_B recovery after fire ($recGC_B$, the proportion of ground cover biomass on burned stands relative to initial unburned biomass), and TSF:

$$recGC_B = \frac{1}{1 + b_1 \cdot \exp^{(-b_2 \cdot TSF)}} + \varepsilon_2 \quad (2)$$

where b_1 and b_2 are curve fit parameter estimates, exp is base of natural logarithm and ε_2 is the error term, with $\varepsilon_2 \sim N(0, \sigma_2^2)$.

2.2.2. Biomass partitioning

For stands with periodic prescribed burning, the partitioning of GC_B into herbaceous and woody components was analyzed using data collected from longleaf pine stands located on Fort Benning Georgia (GA), Fort Polk Louisiana (LA) and Camp Lejeune North Carolina (NC) (Fig. 1). Data were collected from five stands in GA in 2012, 14 stands in LA in 2013, and 9 stands in NC in 2014.

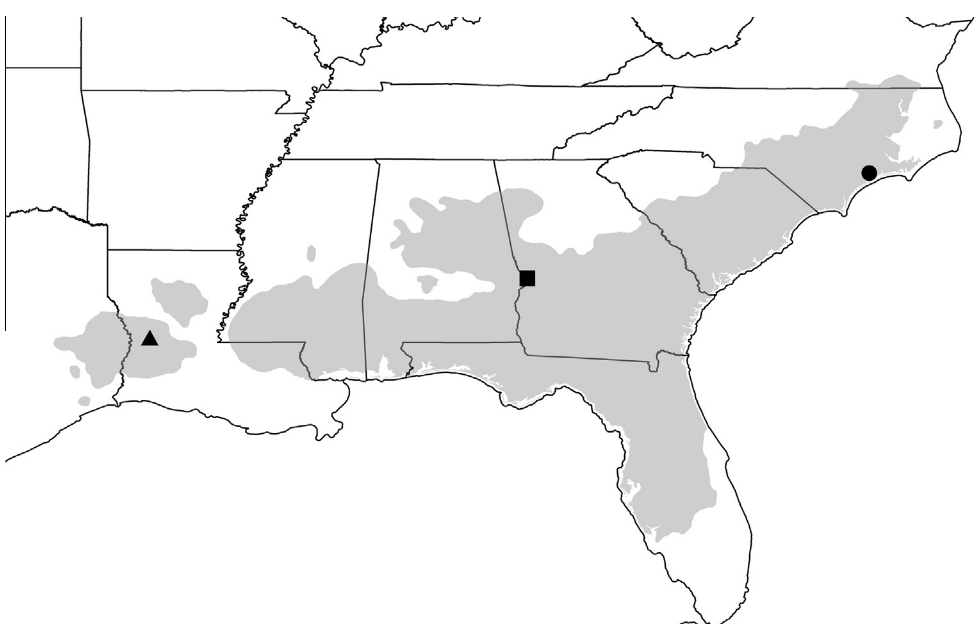

Fig. 1. Location of the sampling sites in Fort Polk Louisiana, LA (triangle), Fort Benning Georgia, GA (square), and Camp Lejeune North Carolina, NC (circle) within the species natural distribution range (shaded area).