Relationship of post-fire ground cover to surface fuel loads and consumption in longleaf pine ecosystems

Andrew T Hudak[A,C], *Roger D Ottmar*[B], *Robert E Vihnanek*[B], *Clint S Wright*[B]

[A]Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, 1221 South Main St., Moscow, ID 83843, USA
[B]Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, 400 N 34th Street, Suite 201, Seattle, WA 98103, USA
[C]Corresponding author E-mail: ahudak@fs.fed.us

Abstract: The RxCADRE research team collected multi-scale measurements of pre-, during, and post-fire variables on operational prescribed fires conducted in 2008, 2011, and 2012 in longleaf pine ecosystems in the southeastern USA. Pre- and post-fire surface fuel loads were characterized in alternating pre- and post-fire clip plots systematically established within burn units. Pre- and post-fire surface fuel loads summarized at the plot level were aggregated to estimate absolute consumption (tons/acre) and relative consumption (%) in 28 sample units. Percent cover of green vegetation, non-photosynthetic vegetation (NPV), black char, white ash, and mineral soil were ocularly estimated in plots co-located with the post-fire fuel plots and aggregated to the same 28 sample units. Spearman correlations were calculated between the usually non-normal distributions of ground cover fractions (%) and either surface fuel loads or consumption. There were highly significant correlations between many of these variables, with post-fire white ash cover and exposed mineral soil producing the highest correlations with pre- and post-fire surface fuel loads and consumption. This study provides empirical evidence for the assumption that post-fire white ash is the fire effect most indicative of surface fuel consumption.

Additional keywords: ash, char, fire effects, fuel consumption, prescribed fire

Introduction

Prescribed fires provide opportunities for physical measurements of pre-, active, and post-fire conditions on the ground, making them an important component for advancing fire science (Macholz *et al*. 2010). Because prescribed fire ignitions are planned in advance and often burn under less extreme conditions than wildfires, they simplify safety and logistical constraints. Furthermore, unlike many parts of the West and Alaska, the dense road network throughout the rural South typically allows one to position themselves on a Class 4 or 5 day, so one can select a fire that will provide an opportunity to collect pre-burn fuel and weather data as well as aerial and ground-based fire behavior and downwind smoke data. Some of these fires are likely to escape initial attack thereby providing extended opportunities to collect data.

Prescribed fires do not typically produce as wide a range of fire intensity and severity as wildfires (van Wagtendonk and Lutz 2007), but do exhibit spatial and temporal variability that can be measured to advance understanding of both fine-scale and landscape-level fire dynamics and effects. Lewis *et al*. (2011) accomplished this on the 2004 Taylor Complex wildfires in interior Alaska, and found significant correlations between fuel consumption and post-fire ground cover materials (green vegetation, non-photosynthetic vegetation (NPV), black char, white ash, and exposed mineral soil or rock) measured/estimated on the ground and/or by remote sensing. In that study, the post-fire cover measure most highly correlated to fuel consumption was green vegetation fraction (or the lack thereof), not black char or white ash, the respective products of incomplete and complete combustion (Smith and Hudak 2005). Other studies have shown that abundance and cover of black char and white ash are good indicators of fire severity (Smith *et al*. 2007; Lentile *et al*. 2009). Hudak *et a*l. (2013) found that white ash cover correlates significantly to surface fuel consumption across four very different fuel types, which they argued should be expected given that white ash is the direct result of complete fuel combustion. Our objective in this analysis was to assess if the ocularly estimated fractional cover of white ash and other post-fire surface materials correlates significantly to surface fuel consumption in frequently burned longleaf pine (*Pinus palustris*) stands in the southeastern USA, a much narrower range of surface fuel conditions than were measured by Hudak *et al*. (2013).

The RxCADRE research team (http://www.firelab.org/research-projects/physical-fire/205-rxcadre) destructively sampled fuels and deployed a dense network of instruments to directly or remotely measure fuels, meteorological conditions, fire behavior, combustion products, convection column characteristics, smoke transport and dispersion, and fire effects. While remote sensing of pre- and post-fire fuel and surface cover measures is a goal of the RxCADRE project, remotely sensed measurements will be described in future papers; thus, only the pre- and post-fire surface fuel load and post-fire ground cover measurements are presented in this paper.

Methods

The RxCADRE research team highly instrumented and measured pre-fire, active, and post-fire characteristics on 16 prescribed fires in the southeastern USA in 2008 (n=5), 2011 (n=2), and 2012 (n=9). All of the 2008 and 2011 burn units were forested with longleaf pine dominating the overstory and turkey oak (*Quercus cerris*) and saw palmetto (*Serenoa repens*) frequently occurring in an understory matrix of wiregrass (*Aristida beyrichiana*) and other grasses. One 2012 unit was dominated by longleaf pine while the other eight units were non-forested with a mix of grasses and shrubs.

In March 2008, two units were burned at Eglin Air Force Base (AFB) in northwestern Florida and three units were burned at the Jones Ecological Research Center in southwestern Georgia. Clip plots for destructive sampling of fuels were established in a grid pattern covering a 5 ha sample area randomly positioned within each unit; the 20 pre-fire and 20 post-fire plots (1-m x 1-m) were alternately situated at 20-m intervals along two parallel transects 40 m apart. In February 2011, two units at Eglin AFB were burned, with two widely separated sampling areas in one burn unit and three widely separated sampling areas in the other. One sampling area in the latter case had 20 pre-fire and 20 post-fire plots (1-m x 1-m) alternately situated at 5-m intervals along two parallel transects 30 m apart (similar to the 2008 sampling design). The other four sampling areas each consisted of 20 pre-fire and 20 post-fire clip plots (1-m x 1-m) distributed at 5-m intervals around the periphery of a 40-m x 40-m highly instrumented plot (HIP). In

November 2012, three large units (>200 ha each, comparable in size to the 2008 and 2011 burn units) and six small units (2 ha each) were burned at Eglin AFB. In each of the large units, 30 pre-fire and 30 post-fire clip plots were alternately situated at 50-m intervals along three roughly parallel transects ~100 m apart (similar to the 2008 sampling design). Within each large unit were an additional three sampling areas, each consisting of either 9 (two grass units) or 12 (one forested unit) pre-fire and post-fire clip plots alternately situated at 2.5-m intervals around the periphery of a 20-m x 20-m HIP (similar to the 2011 sampling design). The small units were each surrounded by 25 pre-fire and 25 post-fire clip plots alternately situated at 10-m intervals. Clip plots in the 2012 grass/shrub units were 1-m x 1-m (1 m^2) in size as in 2008 and 2011. Clip plots in the 2012 forested unit were 0.5-m x 0.5-m in size (0.25 m^2). Specific gravities and other sample processing details used to calculate fuel loads are described in Ottmar *et al*. (2003).

Ground cover fractions were estimated ocularly, under the constraint that the fractional cover of green vegetation, NPV, ash, and soil must sum to one. Char fraction was estimated as the combined percentage of residual NPV or exposed mineral soil that was charred.

All plot-level measurements were aggregated to the unit level in this analysis. Because pre- and post-fire clip plot locations must differ, absolute consumption (tons/acre) and relative consumption (%) were only calculable at the unit level. Spearman correlations were used to test the strength of relationships between surface fuel loads or consumption measurements and ground cover fractions (%) because many of the data distributions were non-normal. Data analysis was performed using R statistical software (R Core Team 2012).

Results

Pre-fire fuel loads averaged 5.4 tonnes/ha and post-fire fuel loads 2.0 tonnes/ha across the 28 sampling units (Fig. 1). This translated to a mean consumption of 3.4 tonnes/ha and a mean relative fuel consumption of 67%. (Note that because the sampling design of the pre- and post-fire clip plots limited fuel consumption calculations to the level of the sampling units, there are no measures of variability in Fig. 1c.) Higher pre-fire fuel loads in the forest units generally led to higher fuel consumption by weight and white ash production than in the grass units (Fig. 1). Post-fire ground cover was primarily composed of unburned NPV (mean 53%) and mineral soil (mean 39%) with minor contributions of green vegetation (mean 3%) and white ash (mean 4%). Slightly less than half (mean 48%) of residual NPV was charred.

All post-fire ground cover fractions were significantly correlated to pre- and post-fire fuel loads, except green vegetation and post-fire fuel load (Table 1). All ground cover fractions were significantly correlated with consumption, but only soil cover was significantly correlated with percent consumption. Percent exposed mineral soil was the ground cover material most highly correlated with the fuel variables overall, although white ash cover—the first order fire effect that directly results from complete fuel combustion—was indeed the post-fire ground cover material most highly correlated to consumption (Table 1). Sorting the 28 sampling units by consumption helps to visualize the highly significant relationship between consumption and pre-fire fuel load (Spearman's $\hat{\boldsymbol{\rho}}$ = 0.84, P < 0.001) and white ash cover ($\hat{\boldsymbol{\rho}}$ = 0.76, P < 0.001) but weakly significant relationship with post-fire fuel load ($\hat{\boldsymbol{\rho}}$ = 0.41, P = 0.032). However, post-fire fuel load was strongly correlated to relative fuel consumption ($\hat{\boldsymbol{\rho}}$ = 0.86, P < 0.001).

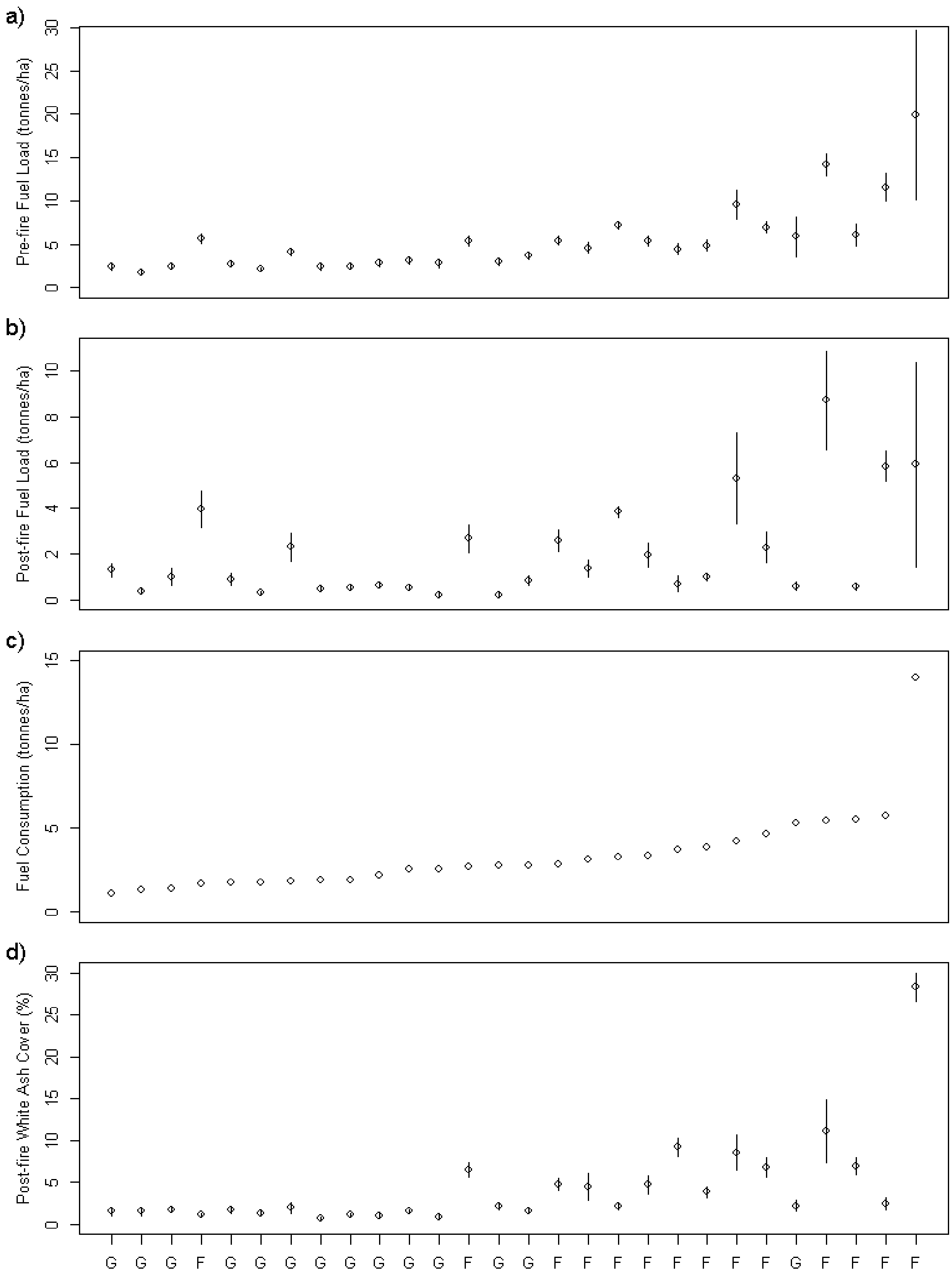

Fig. 1. Mean a) pre-fire fuel load, b) post-fire fuel load, c) fuel consumption, and d) post-fire white ash cover for 28 sampling units; F = forest (n = 14) and G = grass (n = 14). Standard error

bars are shown except in c), since fuel consumption is calculated at the sample unit level. The order of the sampling units is sorted from left to right by increased fuel consumption.

Table 1. Spearman ($\hat{\rho}$) correlations between surface fuel loadings or consumption versus post-fire ground cover fractions.

Significant correlations are indicated as follows: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$.

	Green (%)	NPV (%)	Char (%)	Ash (%)	Soil (%)
Pre-fire Fuel (tonnes/ha)	-0.39*	0.62***	0.67***	0.74***	-0.78***
Post-fire Fuel (tonnes/ha)	-0.10	0.55**	0.44*	0.58**	-0.77***
Consumption (tonnes/ha)	-0.44*	0.41*	0.57**	0.76***	-0.52**
Consumption (%)	-0.22	-0.38	-0.12	-0.21	0.53**

Discussion

These results show that white ash cover is the ground cover material most highly correlated to fuel consumption. This is an intuitive finding that corroborates the main conclusion of Hudak *et al*. (2013), but over a narrow range of fuel conditions in a single fuel type. Furthermore, Hudak *et al*. (2013) had only the five 2008 burn units in longleaf pine from which to calculate Spearman correlations between the same fuel and ground cover variables as presented here. The large number of sampling units (n = 28) included here show that white ash and other post-fire ground cover fractions may be stronger indicators of absolute consumption than relative consumption. This result is useful for making retrospective estimates of biomass consumption upon which emissions estimates are based (Jenkins *et al*. 1998), especially in wildfire situations where pre-fire fuel loads are more often unknown. This research on prescribed fires points to the value in making both pre-fire and post-fire measurements towards a more quantitative understanding of the relationship between fuel consumption and fire effects.

Conclusion

This paper provides a preliminary assessment of surface fuel consumption in longleaf pine ecosystems and its influence on ground cover fractions estimated immediately post-fire. The main conclusion is that white ash cover measured immediately post-fire is a strong indicator of surface fuel consumption, justifying the quantification of white ash cover in retrospective assessments of fuel consumption and fire severity. These and other data collected by the RxCADRE project team will be uploaded into an open repository that will become publicly available in 2014 for testing and evaluation of fuel, fire, and fire effects models.

Acknowledgements

This research was primarily funded by the Joint Fire Science Program, with additional support from the Pacific Northwest and Rocky Mountain Research Stations of the U.S. Forest Service. We thank Joe Restaino and Jon Dvorak for much of the fuels data collection and reduction, along with Eva Strand, Donovan Birch, and Ben Hornsby. We also thank Kevin Hiers and Brett Williams for outstanding logistical support at Eglin Air Force Base or the Jones Ecological Research Center. We appreciate Dale Wade's critical review for improving this paper.

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