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Photoload calibration of fine woody fuels in montane forests of Colorado: 2015-2018

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Introduction

Forest restoration treatments designed to improve forest health, reduce wildfire hazard, and move forests towards desired conditions are occurring at large scales throughout montane and dry conifer forests (Caggiano, 2017; Cannon et al., 2018; Dickinson & SHSFRR, 2014; Schoennagel et al., 2009; Schultz et al., 2012; USDA Forest Service, 2018). The Colorado Forest Restoration Institute (CFRI) monitors implementation and ecological effects of fuel reduction and ecological restoration treatments across forested lands in Colorado. Surface fuels are an important driver of fire behavior and accurate estimates of fine woody fuel loading are vital to predicting potential fire behavior and monitoring restoration effectiveness (Hiers et al., 2009; Keane & Dickinson, 2007; Tinkham et al., 2016). Fine woody fuels, defined as dead wood on the forest floor less than 3 inches (7.6 cm) in diameter, are divided into time lag size classes based on the fuel moisture response time to changes in ambient moisture, including 1-hour (< 0.25 in diameter; < 0.6 cm), 10-hour (0.25–1.0 in diameter; 0.6–2.5 cm), and 100-hour (1.0–3.0 in diameter; 2.5–7.6 cm) fuels. A technique called photoload sampling allows rapid estimation of surface fuels. With this technique, users compare surface fuels to reference photographs of known fuel loading to visually estimate surface fuel loads (Keane & Dickinson, 2007). However, visual fuel loading estimates from may overestimate low surface fuel loading and underestimate high surface fuel loading (Tinkham et al., 2016). Estimation biases can be reduced by a double sampling technique, where visually estimated fuel loadings are calibrated with direct measurements using a regression approach (Tinkham et al., 2016). To improve predictions of surface fuel loadings and improve monitoring efforts following restoration and fire mitigation treatments in montane forests of the Colorado Front Range, we developed calibration equations for 1-, 10-, and 100-hour fuels from more than 500 plots in fuel reduction and forest restoration projects.

Methods

We collected photoload calibration samples at hazardous fuel reduction projects across montane forests in Colorado, concentrated mostly in the Front Range. Fuel reduction activities included prescribed burning, mechanical thinning, hand thinning, clearcutting, and mastication. The residual slash created by thinning was managed by one or more of the following actions: removing it from the site, lop and scattering, pile burning, or mastication. We collected woody fuels in stands before fuel reduction treatments and approximately 1-3 years following treatments. Forest types included ponderosa pine, ponderosa pine with a gambel oak understory, mixed conifer, and lodgepole pine (Table 1).

Table 1: Summary of the number of photoload calibration plots with each forest type and treatment combination.

Forest Type	**Treatment**	**# Pre-treatment plots**	**# Post-treatment plots**
Dry Mixed Conifer	Thin, Lop & Scatter	20	24
Dry Mixed Conifer	Thin, Mastication	13	35
Dry Mixed Conifer	Thin, Pile Burn	0	11
Dry Mixed Conifer	Thin, Pile Burn, Lop & Scatter	16	24
Dry Mixed Conifer	Thin	0	9
Dry Mixed Conifer	Mastication	0	29
Lodgepole Pine	Clearcut, Lop & Scatter, Removal	9	6
Mixed Conifer	Thin, Mastication	15	0
Mixed Conifer	Thin, Pile Burn	8	34
Mixed Conifer	Thin	0	5
Moist Mixed Conifer	Clearcut	11	0
Moist Mixed Conifer	Thin, Mastication, Lop & Scatter	27	9
Ponderosa Pine	Burn	26	0
Ponderosa Pine	Mastication	0	2
Ponderosa Pine	Thin, Burn	13	16
Ponderosa Pine	Thin, Lop & Scatter	0	13
Ponderosa Pine	Thin, Mastication	17	22
Ponderosa Pine	Thin, Pile Burn	20	11
Ponderosa Pine	Thin, Removal	22	17
Ponderosa Pine	Thin	0	2
Ponderosa Pine / Gambel Oak	Burn	21	10
Ponderosa Pine / Gambel Oak	Thin, Mastication	0	2
	Total Plots	*238*	*281*

We conducted fuel treatment effectiveness monitoring between 2015 and 2018, collecting data on forest overstory composition and structure, surface fuel loading, and understory plant composition (CFRI 2017). We visually estimated fine woody fuel loading for each size class in 1 m^2 quadrats using the photoload sampling technique (Keane & Dickinson, 2007). We collected woody fuels from one quadrat per plot and separated fuels according to size class (1-, 10-, and 100- hour fuels). We oven dried all samples at 50°C for at least 3 days before recording dry weights of each sample to the nearest 0.01 g and converting weights to tons/acre to match units used in photoload estimates.

We generated separate linear regression models for each woody fuel size class using field photoload estimates to predict the corresponding measured dry sample weight. Outliers and influential values were examined and removed if appropriate.

Results and discussion

In general, we found that the accuracy of fine woody fuel measurements is improved using regression equations to correlate visual photoload estimates and observed woody fuel loading (Table 2, Figure 1). Specifically, we found that photoload accuracy was moderate for 1-hour fuels (r^2 = 0.43, RMSE = 0.22); was more accurate for 10-hour fuels (r^2 = 0.58, RMS = 0.60), and was most accurate for 100-hour fuels (r^2 = 0.62, RMSE= 0.99). Our results were in agreement with those from Tinkham et al. (2016), which concluded that field-based photoload estimates overestimate low fuel loadings and underestimate high fuel loadings. However, in our analyses, we treated 1-, 10-, and 100- hour fuels separately, and found that estimation bias of fuel loadings varies by fuel size class. We found that 1-hour fuels were overestimated by photoload sampling, while 10- and 100-hour fuels were underestimated by photoload sampling (Figure 1). A previous calibration effort using a small subset of these data revealed very similar calibration equations (Morici & Cannon, 2018). Our calibration equations can be used to refine field-based photoload estimates in montane forests of the Colorado Front Range and remove biases in photoload estimation for each woody fuel size class (Table 2; Figure 1).

Table 2: Fine woody fuel linear regression results by size class. P is the photoload estimate.

Size Class	Regression Equation (tons/acre)	sample size	R-squared	RMSE
1-hr	Biomass = 0.09 + 0.49*P	474	0.43	0.22
10-hr	Biomass = 0.24 + 1.16*P	430	0.58	0.60
100-hr	Biomass = 0.16 + 1.54*P	494	0.62	0.99

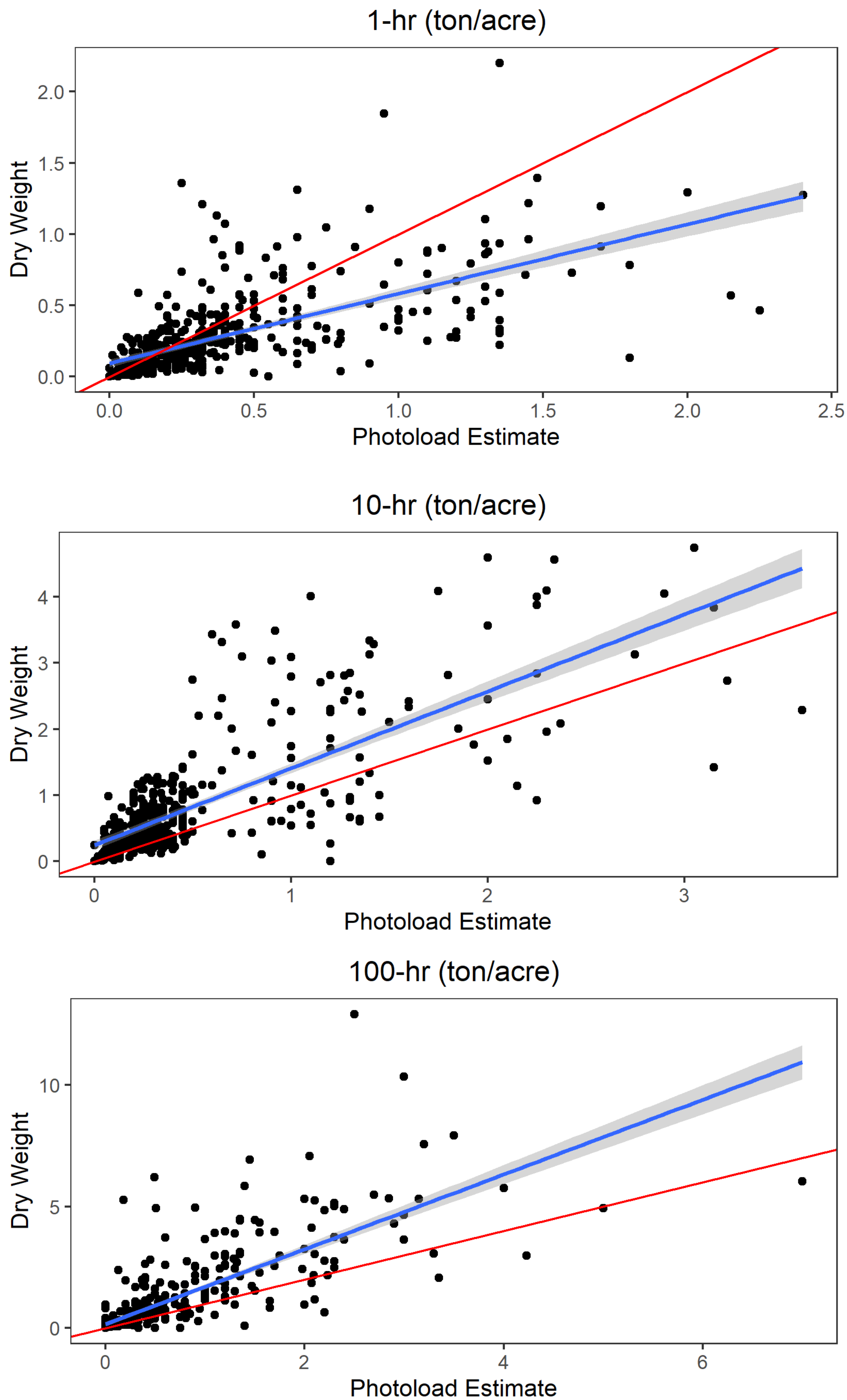

Figure 1: Regression models of photoload estimates and observed loading for each fuel size class, the shaded area represents the 95% confidence interval for the regression line. The red line is a 1:1 line shown for comparison, points above the line are underestimated observations and points below the line are overestimated observations. Regression equations are shown in Table 2.

Forest restoration and fire hazard mitigation treatments change surface fuel loading and distribution depending on how resulting slash is treated (Schwilk et al., 2009). Mastication treatments may bury woody fuels below the visible forest surface. The photoload sampling technique is intended to be used when fuels are on top of the litter layer and readily visible. Thus, photoload sampling alone may not be an appropriate method of estimating fuel loading in heavily masticated areas.

Photoload sampling is a rapid method used to estimate woody surface fuels (Keane & Dickinson, 2007; Tinkham et al., 2016). To reduce biases in visual estimation, we created regression equations using photoload estimates and oven dried biomass weight in destructively sampled 1 m^2 quadrats. Separate calibration equations were created for individual fuel size classes. These equations have remained stable over time and are critical for accurate estimation of surface fuels.

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