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Models for Predicting Fuel Consumption in Sagebrush-Dominated Ecosystems

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Abstract

Fuel consumption predictions are necessary to accurately estimate or model fire effects, including pollutant emissions during wildland fires. Fuel and environmental measurements on a series of operational prescribed fires were used to develop empirical models for predicting fuel consumption in big sagebrush (*Artemisia tridentata* Nutt.) ecosystems. Models are proposed for predicting fuel consumption during prescribed fires in the fall and the spring. Total prefire fuel loading ranged from 5.3–23.6 $Mg \cdot ha^{-1}$; between 32% and 92% of the total loading was composed of live and dead big sagebrush. Fuel consumption ranged from 0.8–22.3 $Mg \cdot ha^{-1}$, which equates to 11–99% of prefire loading (mean=59%). Model predictors include prefire shrub loading, proportion of area burned, and season of burn for shrub fuels (R^2=0.91). Models for predicting proportion of area burned for spring and fall fires were also developed (R^2=0.64 and 0.77 for spring and fall fire models, respectively). Proportion of area burned, an indicator of the patchiness of the fire, was best predicted from the coverage of the herbaceous vegetation layer, wind speed, and slope; for spring fires, day-of-burn 10-h woody fuel moisture content was also an important predictor variable. Models predicted independent shrub consumption measurements within 8.1% (fall) and 12.6% (spring) for sagebrush fires.

Key Words: *Artemisia tridentata*, big sagebrush, fire effects, modeling, shrubs

INTRODUCTION

Prescribed fires and wildfires are common and widespread in vegetation types where shrubs are the dominant fuel, including arid rangelands composed of various species of sagebrush (*Artemisia* spp.) and their associates. Recognition of fire as a keystone process in ecosystems generally, and in shrub-dominated types specifically, has led to an increase in the use of prescribed fire for a number of specific purposes, including to preserve or enhance ecosystem properties (Hiers et al. 2007; Keeley et al. 2009), promote specific compositional or structural changes (Beardall and Sylvester 1976; Outcalt and Foltz 2004; Moore et al. 2006; Bates et al. 2009), improve wildlife habitat (Wade and Lunsford 1989), and reduce fuels and potential wildfire behavior to desired levels (Biswell 1989; Brose and Wade 2002; Raymond and Peterson 2005).

Fire effects (e.g., smoke emissions, regional haze, nutrient cycling, plant succession, species composition changes, plant/tree mortality, wildlife habitat restoration and maintenance, erosion, soil heating, and carbon fluxes) are determined in large part by fuel characteristics, fuel conditions, and the energy and other by-products released upon combustion (DeBano et al. 1998; Reinhardt et al. 2001). Quantification of fuel consumption in shrub-dominated vegetation types during prescribed fires and wildfires is therefore critical for modeling fire effects and for meeting management objectives for terrestrial and atmospheric resources.

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Fuel consumption is the quantity of biomass fully combusted and converted to carbon gases, water vapor, other volatile gases, and airborne particulate matter (Hardy et al. 2001), and is typically determined by measuring the difference between the prefire and postfire fuel loading (Beaufait et al. 1977). Emissions of a particular pollutant from a fire are calculated as the product of the area burned, the loading of the fuel consumed per unit area burned, and the ratio of the emissions produced per unit mass of fuel consumed (i.e., the emission factor). Emission factors vary depending upon combustion phase (i.e., flaming vs. smoldering) and fuel type (e.g., woody material vs. leaf litter vs. sagebrush), but are typically treated as constants when calculating pollutant emissions as a function of area burned and fuel consumption (Seiler and Crutzen 1980; French et al. 2011). Fires that occur in locations with high shrub fuel loading or that cover large areas of shrub-dominated vegetation can produce substantial emissions and negatively affect local and regional air quality (Phuleria et al. 2005; Hu et al. 2008). The ability to accurately predict fuel consumption enables fire, air-quality, and natural-resource professionals to plan for and manage smoke from fires, and to mitigate negative impacts associated with air pollution.

Prescribed Fire and Big Sagebrush

Aboveground biomass in big sagebrush (*Artemisia tridentata* Nutt.) types in the western United States varies with site quality, species composition, disturbance history, and successional status, and can exceed 30 $Mg \cdot ha^{-1}$ (Ottmar et al. 2000, 2007). Prescribed fires and wildfires in sagebrush-dominated vegetation types commonly burn over large areas (thousands of ha in prescribed fires and tens of thousands of ha in wildfires; Kuchy 2008). The combination of relatively high biomass and large area burned make fires in sagebrush fuels major sources of greenhouse gases and other pollutant emissions. A variable

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