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Fuel Consumption and Flammability Thresholds in Shrub-dominated Ecosystems

A proposal for the Joint Fire Science Program Announcement for Proposals 2003-1, Task #3 – "Community health and ecosystem impacts from smoke"

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Abstract: Research to quantify fuel consumption and flammability in shrub-dominated ecosystems has received little attention despite the widespread occurrence of fire-influenced, shrub-dominated landscapes across the arid lands of the western United States. While some research has addressed issues relating to fire behavior in some shrub-dominated ecosystems, quantification of fuel consumption is critical for effective modeling of fire effects (e.g., smoke emissions, regional haze, erosion, plant succession, etc.) and landscape management. Preliminary research in this arena has generated hypotheses as to the controlling mechanisms for fuel consumption in shrub fuel types that require testing through field-based experimentation. The primary objective of this proposed research is to improve existing fuel consumption models for sagebrush fuel types and to develop new models for additional shrub-dominated fuel types for incorporation into a module for, or a new version of the software package CONSUME. This research will also address issues related to seasonal live fuel moisture and weather patterns and their relations to flammability in shrub-dominated fuel types. Making fuel and fire management decision support tools, such as CONSUME, more robust will aid managers, planners and researchers in developing environmentally, socially and legally responsible land management plans. This research will allow for more effective and informed use of fire behavior, fire effects, emission production and wildfire/prescribed fire trade-off models providing for better wildland fire emissions and fire effects accounting and planning at local, regional, national and global scales.

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Introduction

Background and Justification

Research to quantify and model fuel consumption during wildland fires has been conducted in "natural" and managed forest types (e.g., Ottmar 1983, Sandberg and Ottmar 1983, Little et al. 1986, Hall 1991, Brown et al. 1991, Albini and Reinhardt 1997, Reinhardt et al. 1997, Myanishi and Johnson 2002), but is generally lacking or of limited scope in shrub-dominated ecosystems (Sapsis and Kauffman 1991, Wright and Ottmar 2002). Most research in shrub types has focused on fire behavior prediction in a limited number of ecological types (e.g., Lindenmuth and Davis 1973, Green 1981, Brown 1982). Shrub-dominated ecosystems, including a wide variety of forms of chaparral, oak brush, pinyon-juniper and various species of sagebrush (*Artemisia* spp.) occur across several hundred million acres of private, state and federal lands in the western United States. These types may be remotely located or they may occur at the wildland/urban interface throughout their range. In addition, many shrub-dominated ecosystems are home to sensitive, rare, threatened and endangered species, including numerous species of birds, mammals, mollusks, insects, plants, fish, reptiles and amphibians. In terms of sheer land area, research in shrub-dominated types will address information needs related to a large land base for many arid-land managers, planners and researchers.

An increasing awareness of environmental issues by the public mandates that land managers fully evaluate regulatory requirements and potential impacts of land management decisions (i.e., no action, prescribed fire use, wildland fire use, grazing, mechanical treatment, chemical treatment, etc.) using the best available information. Where fire is concerned, quantification of fuel consumption is critical for effective modeling of 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, carbon cycling, etc.). Fuel consumption is the most critical variable to understand for effectively managing and evaluating the consequences of prescribed and wildland fire as related to land management objectives.

Regularly occurring fires are (or were in some areas) natural events in many shrub-dominated ecosystems in the arid portions of the western United States. Land managers have and will continue to use prescribed fire as a landscape-level treatment in a wide variety of shrub-dominated ecosystems for a number of specific purposes, including, for example, fuel and fire hazard reduction, wildlife habitat improvement, and ecosystem restoration. In contrast to forested systems where a large proportion of the fuelbed is composed of dead and down organic matter, in shrub-dominated ecosystems, the fuelbed is composed almost entirely of living (and standing dead) vegetation. As with forests, it is therefore desirable to predict fuel consumption, and therefore immediate treatment effects and the likelihood of treatment success (i.e., desired change in vegetation or fuel structure) prior to the application of fire. Change in the vegetation structure (i.e., fuel composition, amount and arrangement) is often the most critical measure of treatment success. If managers are to develop effective fire plans designed to meet desired objectives in terms of terrestrial and atmospheric resource management, research will be required to quantify both fuel characteristics and fuel consumption during prescribed and wildland fires in these vegetation types.

Objective

The primary objective of this research project is to improve a preliminary fuel consumption model and determine flammability thresholds for big sage ecosystems, and develop new fuel consumption models and flammability thresholds for additional shrub-dominated ecosystem types. These improved and new fuel consumption models and flammability thresholds will be incorporated into a module for, or a new version of the software package CONSUME. Achievement of this objective addresses AFP 2003-1 Task #3 (bullet #2), and will promote more effective and informed use of emission production, fire effects, fire behavior, and wildfire/prescribed fire tradeoff models allowing for better wildland fire emissions and fire effects accounting and planning at local, regional, national and global scales.

Methods

This study has two primary experimental portions; (1) fuel consumption and flammability thresholds will be evaluated on a series of already-planned prescribed fires under experimentally specified environmental conditions, and (2) seasonal live fuel moisture and flammability patterns will be measured in conjunction with weather monitoring equipment. Live fuel moisture and onsite weather sampling during the burning experiments will allow us to connect seasonal climate and live fuel moisture patterns to flammability thresholds and fuel consumption. We will evaluate the physical and environmental conditions that influence live fuel moisture, flammability and subsequent fuel consumption to build a predictive model useful to fire managers and planners.

Fuel Consumption and Flammability Thresholds

We propose to pursue a second phase of shrub consumption experiments to answer questions raised by research performed throughout the western United States in big sage ecosystems from 2000-2002 (research conducted as a portion of 1998 JFSP-funded proposal: "Modification and validation of fuel consumption models for shrub and forested lands in the Southwest, Pacific Northwest, Rockies, Midwest, Southeast, and Alaska"). These experiments will broaden the range of conditions under which fuel consumption has been evaluated and determine thresholds of flammability in shrub-dominated systems.

It appears from preliminary observations from 2001 prescribed burns that live fuel moisture, prevailing weather conditions (relative humidity, temperature, wind speed), fuel loading and arrangement, and lighting pattern are critical factors controlling fuel consumption (Figure 1). Live fuel moisture must be below a certain threshold value to enable combustion and fire spread and subsequent fuel consumption; live fuel moisture fluctuates seasonally (Agee et al. 2002, Weise et al. 1998). There may be multiple steps to the live fuel moisture threshold function whereby varying amounts of fuel become available to burn as live fuel moisture declines. Regardless of the nature of this threshold, once live fuel moisture has fallen below a critical threshold value, prevailing weather conditions and fuel loading appear to become the controlling elements.

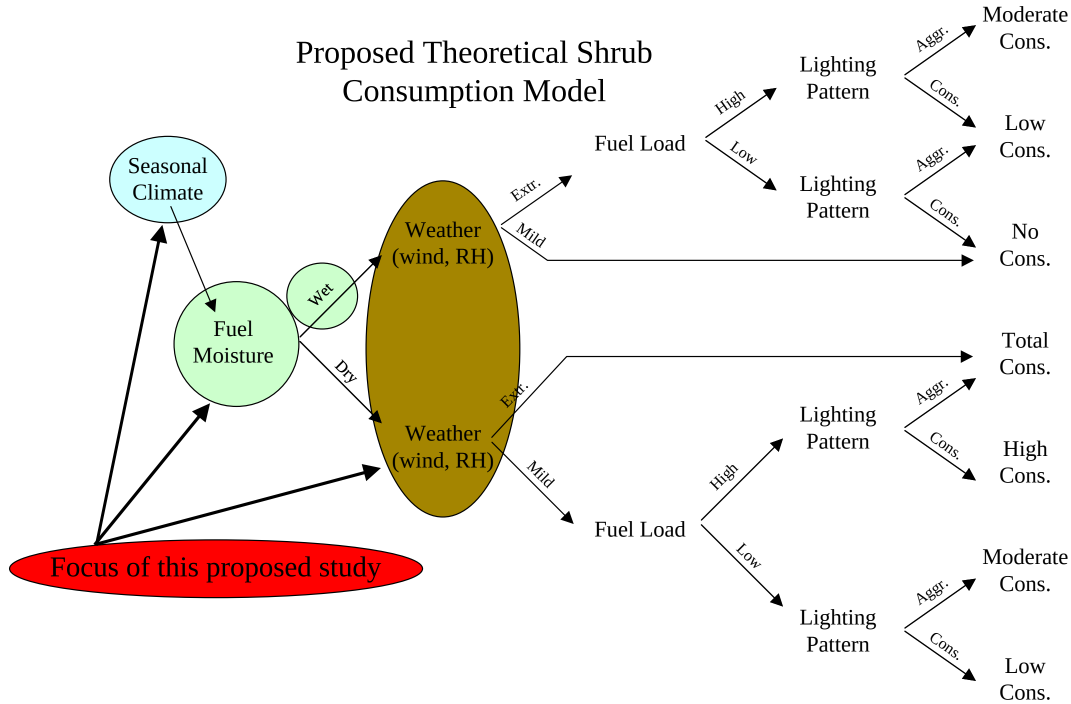

Figure 1. Proposed model of mechanisms controlling the consumption of shrub fuels.

Where sufficient amounts of fuel are available to burn, prevailing weather conditions are critical for determining fire behavior and fire effects. Like the live fuel moisture threshold, there appears to be a relative humidity threshold. The effects of relative humidity can be exacerbated or mitigated to some degree by temperature and wind speed.

Plant to plant spacing, interplant "understory" vegetation amount, overall biomass and live fuel:dead fuel ratios all may have an effect on how well fire spreads, how much heat and energy is generated, and therefore how much fuel consumes. We will quantify fuel characteristics (loading and arrangement) and examine the effects and thresholds of fuel characteristics through the large number of burns proposed for this study. Data gathered as part of this study will also allow us to design future experimental burns to more specifically quantify the effects of varying levels of fuel presence on fuel consumption.

Poor fuel consumption conditions (elevated live fuel moisture, elevated relative humidity, low wind speeds, lack of carrier fuels, etc.) may be mitigated to some degree by an aggressive burning operation. If enough fire can be introduced to the site at once, fuel consumption may be increased. Use of heli-torches, terra-torches and large numbers of hand lighters can be effective for mass ignition. We will document the effects of lighting patterns and ignition properties to better understand the effects these factors have on fuel consumption. As with our documentation of fuel characteristics, results of this study will enable us to design future burning experiments that will more specifically address the effects of lighting patterns and ignition properties on fuel consumption.

In this experiment, we propose to explore the relationships between live fuel moisture and relative humidity and fuel consumption in more or less uniform, shrub fuel types by burning small blocks within a single management unit under different relative humidities at different times of the year. With the aid of local fire managers we will identify putative thresholds of live fuel moisture (varying seasonally) and relative humidity (varying hourly on a diurnal schedule) that affect shrub fuel consumption. Season of burn and time of day will be targeted to achieve burns at, above, and below putative live fuel moisture and relative humidity thresholds. The experiment will be set up such that all burns in a given season can be accomplished in a single day by timing burning with diurnal fluctuations in relative humidity (i.e., morning/evening=high RH, mid-day/late afternoon=threshold RH, afternoon=low RH). Were all burning to occur according to plan, nine sets of plots (blocks) would be burned over three different days (Figure 2; three live fuel moisture levels x three relative humidity levels = nine treatment combinations per unit).

A 3-4 person field crew from the Seattle Forestry Sciences Laboratory will conduct pre- and post-burn inventory measurements at each location. Methods will involve vegetation clipping, drying and weighing (shrubs and herbaceous materials) in numerous (n=15-25) medium-sized plots (4-9 m^2) both before and after the application of fire. Clipped shrubs will be separated into live and dead fractions and size classes during sampling. Vegetation cover and height will also be measured pre-and post-burn. Surface fuels (litter, duff and small woody fuels), if present, will be quantified by collection in plots, or by measurement of depth and bulk density. Large woody fuels, if present, will be estimated using a planar intersect inventory (Brown 1974).

As various burn blocks come into experimental prescription, a field crew will be dispatched to the site to set-up portable weather monitoring equipment adjacent to the burn unit and to collect fuel moisture samples on the day of the burn. Field personnel will assist with the burning operation as required, and make observations of the fire behavior, lighting patterns, and in-unit weather as the plots are ignited and the fuels are consumed. Once the burning operations have been completed this crew will remain onsite to perform post-burn sampling.

Burn blocks can and should be small to facilitate burning under any and all environmental conditions. Management units of approximately 4-6 ha (10-15 ac) will be large enough to accommodate the nine treatment blocks and will provide adequate buffers to allow for blacklining and any other fire management operations (e.g., fire line construction, foam lines, hose lays, etc.). Treatments (live fuel moisture level, relative humidity level) can be assigned to different blocks by requirements of the burning operation, particularly if vegetation and terrain in selected units are relatively homogeneous.

To maximize the number of data points (i.e., the number of fires) we will group treatments (in this case relative humidity) so that it is necessary to perform only one pre-burn biomass inventory and one day-of-burn fuel moisture inventory that could serve as the baseline data for more than one post-burn set of plots. For example, we will select a 2-3 ha area within the larger management unit, place one set of pre-burn samples throughout the area, but set up three different post-burn sample blocks to be burned under different relative humidities (Figure 2). Ideally this design will be replicated in place and elsewhere for confirmation and validation of experimental results.

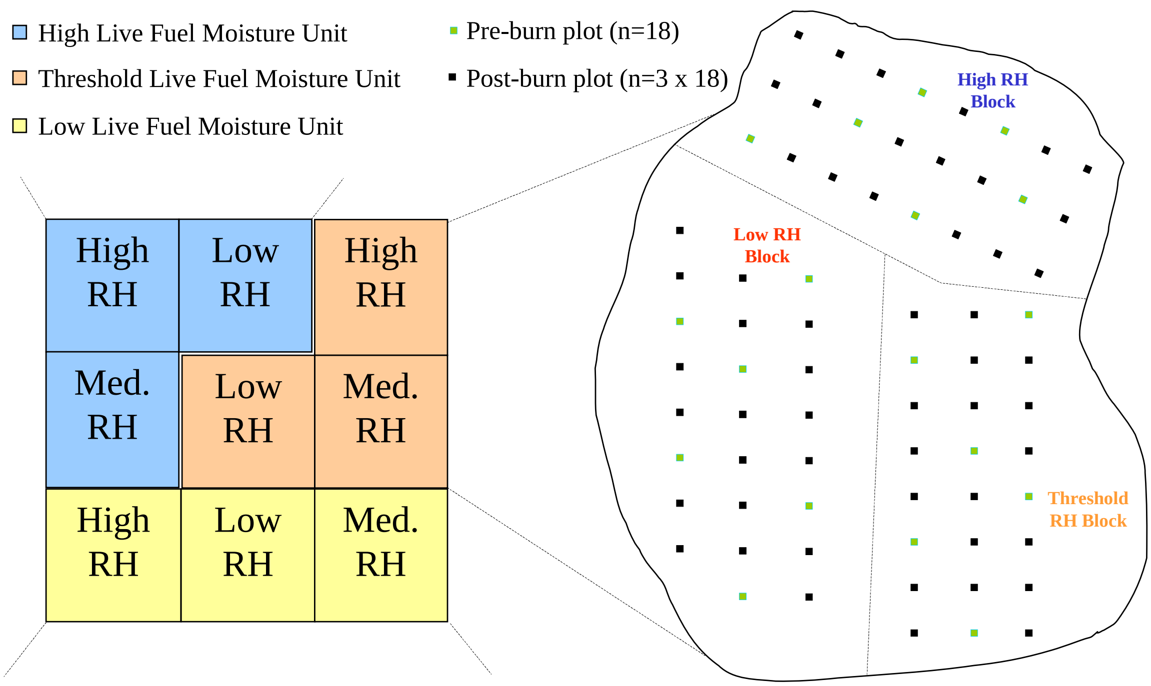

Figure 2. Idealized treatment layout for each site in the Fuel Consumption and Flammability Thresholds in Shrub-dominated Ecosystems study.

<u>Seasonal Live Fuel Moisture and Flammability Patterns</u>

Longer-term (monthly, seasonal, annual) weather and climate conditions are also important as factors influencing plant/soil/atmosphere water relations, and therefore live fuel moisture content and fuel flammability. Different plant species have adapted different strategies and phenological traits for coping with seasonal climate and water balance deficits. Climate is important in shrub-dominated ecosystems (which throughout the west are water-limited) because most of the fuel complex is living and subject to the physiological constraints of individual plants. The effects of climate on live fuel moisture, while widely measured, is not well documented (Agee et al. 2002), particularly for many ecosystems with little or no commercial value (i.e., not forest or grassland).

Periodic live fuel moisture samples will be collected for two dry seasons (spring, summer, fall) to define seasonal patterns in live fuel moisture content (and presumably flammability), and to determine when live fuel moisture and flammability thresholds are met (Figure 3). Local assistance will be beneficial for

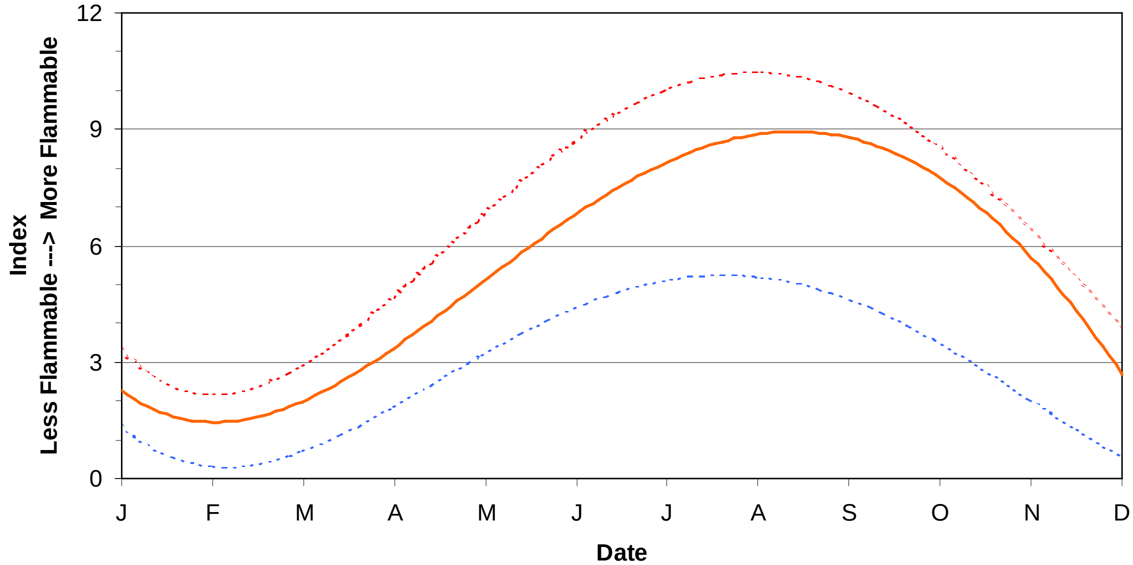

Figure 3. Hypothetical simplified patterns of flammability.

narrowly defining variability in live fuel moisture conditions. Several of our collaborators already collect some periodic live fuel moisture data. We will propose that they establish a more systematic collection regimen to meet the data needs of this experiment, and support them in this endeavor.

Live fuel moisture samples will be collected in the vicinity of existing weather stations (e.g., RAWS stations) located within the fuel types of interest. If feasible, additional instrumentation may be added to the standard array of weather recording instruments to capture soil moisture conditions. Live fuel moisture sample data collected on a series of prescribed burns in 2001will be used to determine the appropriate number of samples required to insure an acceptable level of measurement accuracy (see Agee et al. 2002, Weise et al. 1998).

Archival weather data will be used to explore correlations between ecosystem flammability and various weather phenomenon (e.g., El Nino-Southern Oscillation, Pacific Decadal Oscillation, etc.) and environmental indices (i.e., National Fire Danger Rating System, Palmer Drought Severity Index, Keetch-Byrum Drought Index, etc.).

Outcomes and Results

The primary goal of this project is to gather additional data for modeling fuel consumption in shrub ecosystems. This is meant to be a more directed, refined and improved version of previous approaches to sampling fuel consumption during prescribed fires in shrub ecosystems. To effectively model fuel consumption we need to understand the relationships and interactions among the factors that influence and control flammability and fuel consumption so that we can enumerate and incorporate these data into a module for or a new version of the software package CONSUME, a nationally-applied fuel consumption and biomass burning emissions prediction tool.

The enhanced version of CONSUME will be a stand-alone software product with an intuitive, user-friendly interface and reporting capability. The output from CONSUME will be formatted to feed various other models, model frameworks, and databases including the Emission Production Model (EPM; Sandberg and Peterson 1984, Ferguson et al. 1998), Fuels Management Trade-off Model (TOM/FETM; Ottmar et al. 1996), BlueSky (Ferguson et al. 2001), and FASTRACS, and to provide useful outputs for burn planning and smoke management. Training materials and a manual will accompany the software.

The proposed experiment, while fulfilling the primary need of quantifying fuel consumption in shrub-dominated ecosystems, will also, as a secondary outcome, quantify some of the seasonal patterns of live fuel moisture content and related flammability thresholds for shrub ecosystems. Recognizing, of course, that these patterns and thresholds will be only a subset of the areas and vegetation types encountered within the shrub ecosystem zone throughout the western United States. Exploratory analysis of potential correlations between historical weather conditions/phenomena and flammability will allow us to make inferences and extrapolations for areas where fuel moisture and fuel consumption data are lacking.

Elucidation of the correlations between predictable weather variables and live fuel moisture, flammability, and fuel consumption will provide the data necessary to build an inference tool of use for planning prescribed fires and planning for potential wildfires. The ability to predict fire effects (i.e., fuel consumption) under varying environmental conditions will facilitate prescription development, burn planning and scheduling to most effectively manage fuel consumption, fire effects and smoke production.

Replication of this study design in several locations will verify and validate the basis of our theoretical model for factors that govern shrub consumption. This study will also provide valuable data for future prescription development for the fire managers involved in the operational burning portions of the experiment. From early observations, it appears that a refinement of the relationship between flammability and fuel consumption will be critical for development of an effective decision-support tool.

In addition to fulfilling the objectives of this study, the extensive pre-burn inventory data will also allow us to develop a non-destructive site assessment tool for estimating aboveground biomass from easily measured variables (cover and height). Such a tool has utility for use in prescribed fire planning, as an input for FERA's Fuel Characteristic Class (FCC) system, and as a tool with application in the remote sensing field. As well, the actual site data will be useful for populating the FCC data library for the shrub-dominated ecosystems that are sampled.

This proposal links closely with several other proposals submitted to the Joint Fire Science Program for consideration in 2003, including: (1) Modeling fuel consumption rates during prescribed fires in the ponderosa pine/mixed conifer and longleaf pine forest types of the United States – Ottmar et al.; (2) Forest floor consumption and smoke characterization in boreal fuelbed types of Alaska – Ottmar et al.; and (3) Monitoring and modeling fuel consumption and smoke in fire camp and rural communities during major wildfire episodes in the United States – Ottmar et al.

The combination of a means to predict fire effects and site conditions, and an understanding of flammability thresholds and their relation to weather variables will allow land managers to better assess landscapes for opportunities and hazards, and to develop science-based treatment and mitigation strategies.

Deliverable Products

A software program (CONSUME) with an easy to use interface, user's manual and accompanying peer-reviewed documentation (research paper or journal article) will be delivered as a cohesive package upon completion of the study. As new data are gathered and analyzed, preliminary reports, manuscripts and models will be intermediate products.

The project will begin with a detailed problem analysis/literature review, and development of a study plan and field procedures while simultaneously initiating contacts with prescribed fire managers working in appropriate ecosystems to identify prospective burn sites and live fuel moisture sampling locations and personnel. Field data collection will begin in the fall of 2003 or early in 2004, and proceed and adapt as we learn from our initial experiments. Progress reports will be compiled annually, and data will be reduced and analyzed as they are collected. Model development will begin and continue as sampling and data analysis are completed for each fuel type. Once developed, the new version of CONSUME will be made available via the internet (www.fs.fed.us/pnw/fera) and in a CD-ROM format compatible with the then-current version of Microsoft Windows or its successor. Training sessions for the new software will be set-up for interested fire and land managers, or incorporated into the curriculum of the appropriate existing fire management training series course(s).

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