# Chapter 1:
# Fuels and Fire at the Landscape Scale

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## Project Goals 2007-8

We are investigating how landscape-level fuels and silvicultural treatments affect potential fire behavior and fire effects under different weather scenarios across the forested landscape of the Plumas National Forest project area. This analysis is critical for assessing the potential of severe or extensive fire occurring on the landscape. Initial results from this process are presented at length in the section of this paper entitled, “Results: Completed in 2007”.

In addition to our primary goal, both fuels treatments and fire alter forest structure, pattern and composition and thereby modify wildlife habitat that depends on the vegetation. Our assessments of potential change to landscape-scale vegetation will be instrumental when coupled with assessments of wildlife habitat conducted by the owl research module funding is available. We hope to completed this phase of the work in 2008.

## Research Objectives and Overview

Past management activities including fire suppression, timber harvesting, and livestock grazing have changed the structure and composition of many coniferous forests in the western United States, particularly those that once experienced frequent, low-moderate intensity fires (Biswell 1961; Hartesveldt and Harvey 1967; Parsons and Debenedetti 1979; Beesley 1995; Erman 1996; Menning 2003). These changes in vegetation have altered habitat for a variety of species. Correspondingly, changes in vegetation and fuel loading have changed the probability of fire spreading across the landscape.

The USDA Forest Service aims to actively manage vegetation with the goal of reducing the probability of large, intense, or severe fires while minimizing negative effects on wildlife habitat and ecosystem stability. Proposed treatments include group selections and defensible fuel profile zones (DFPZs). Group selection treatments involve the harvest of all trees smaller than 30" diameter at breast height (DBH) over a one to two acre area (Stine et al. 2002). DFPZs are areas with extensive forest thinning intended to reduce surface and canopy fuel loads. They are also known as shaded fuel breaks and are designed to allow access for active fire suppression. DFPZs are spatially-extensive, covering hundreds to thousands of hectares (Stine et al. 2002).

Currently, there is limited information on the effects of landscape fuels treatments on reducing severe fire behavior and effects, especially at the landscape scale (Erman 1996; Agee et al. 2000; Fites-Kaufman et al. 2001). Elsewhere in the Sierra Nevada, group selections have been shown to have little effect on the landscape-level behavior of fire (Stephens and Finney 2002); the proposed group selections in the Plumas, however, retain more large trees per acre than typical group selections. To date, the modeled effects of group selections with large tree retention have not been published for this forest type.

Assessing the effects of these vegetation management strategies—group selections and DFPZs—across the forested ecosystems of the Plumas and Lassen National Forests is the goal of the Plumas-Lassen Administrative Study (Stine et al. 2002). The study is composed of five research teams with distinct focuses: California spotted owls, small mammals, songbirds, fuels and fire, and vegetation. Due to practical considerations of a study as spatially extensive as this, we have to mix research with monitoring. The overall study does not comprise a formal scientific experiment in that the scientists involved have little control over actual treatments. The study amounts to far more than monitoring, however, in that we are independently assessing a large landscape and modeling changes to that landscape given a set of prescriptive treatments.

For the Fuels and Fire Module, which is the focus of this study plan, we aim to address the landscape-scale effects of the proposed forest treatments by answering a suite of questions: First, what are current conditions, in terms of fuel loads and vegetation, measured directly in the field? Second, what is the current potential fire behavior and effects given these measured fuel and vegetation conditions? Third, how would landscape fuels treatments affect vegetation condition and fire behavior and effects?

Fourth, in addition to these efforts to characterize fuels and fire relationships, it is essential to link results of our research with findings from the other research modules (figure 1). It is clear that any landscape-level fuels or forest management strategy will affect many interrelated components of forest ecosystems (Erman 1996; Bahro 2004). Therefore, it is important to understand the synergistic effects between potential treatments and various areas of concern—forest conditions, risks of severe or extensive fire, and habitat alteration. Our goal in answering this fourth question is to produce an analytical model in which we integrate maps of current conditions with models that project responses of fire behavior and effects given prescriptions of treatment and weather scenarios. The vegetation component of the current conditions maps would act simultaneously as input to the Spotted Owl Module's habit suitability models. By coupling these data layers and models between research modules we will model the likely effect of a landscape fuels strategy on both *fire* and *owl habitat* given various prescriptions and weather scenarios.

Taken together, these four research goals form the top level of a hierarchical set of research goals that may be best expressed in a table. Hence, we have shown these research objectives and their supporting details and questions in Table 1. Details supporting the modeling efforts follow the table.

**Fig 1: Ecosystem Relationships Examined in PLAS**
(Topics addressed in this module emphasized in bold)

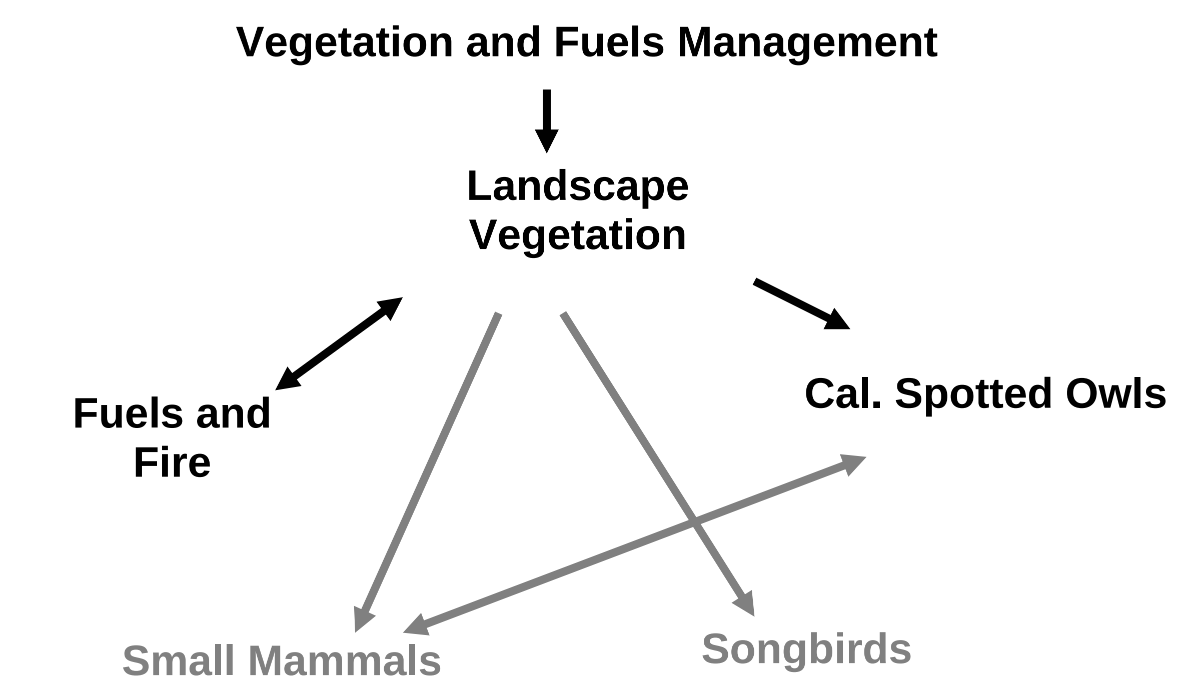


***Table 1: Fuels and Fire Module: Summary of hierarchical arrangement of study topics***

1.0 Current conditions: measurement of vegetation and fuels at the landscape scale
- 1.1 Current vegetation: What are current vegetation conditions prior to treatment?
  - 1.1.1 Forest sampling in the field (forest plots)
  - 1.1.2 Remote sensing of forest conditions
    - 1.1.2.1 Forest and vegetation classification (IKONOS imagery)
    - 1.1.2.2 Forest structural diversity analysis (IKONOS imagery)
- 1.2 Current fuels: What are current fuel loads prior to treatment?
  - 1.2.1 Fuels sampling in the field (forest plots)
  - 1.2.2 Ladder fuels: probability of fire ascending forest canopy (LaFHA)
  - 1.2.3 Integration of data sources into a fuel model/map for the study area

2.0 Fire modeling: how might current conditions (above) affect fire *behavior* and *effects*?
- 2.1 Fire *behavior*: What is the range of potential fire behavior given current conditions & a range of weather scenarios? (FARSITE & FlamMap models)
- 2.2 What are likely *effects* of fire behavior on these landscapes as determined by simulation models? (Stephens approach using FARSITE & FlamMap outputs)
- 2.3 Temporal dynamics of forest stands, including tree growth (FVS)

3.0 Effects of treatments: how might landscape-scale treatments change fire behavior and effects (using FlamMap)?
- 3.1 Group Selections (GS) and Defensible Fuel Profile Zones (DFPZs)
  - 3.1.1 Measure: how does the installation of GSs & DFPZs affect fuel loads?
  - 3.1.2 Model: how does the placement of GSs & DFPZs affect potential fire behavior? Do they reduce the probability of catastrophic fire under extreme weather conditions?
  - 3.1.3 Modeling: how does the installation of GSs & DFPZs affect fire effects such as mortality to different species and size classes of trees? Would the reduction in fire extent and intensity reduce the severity of canopy fires?
- 3.2 Spatial allocation and efficiency: DFPZs and Strategically Placed Landscape Area Treatments (SPLATs)
  - 3.2.1 How does the installation of alternative treatments affect fuel loading?
  - 3.2.2 How does the placement of alternative treatments affect potential fire behavior?
  - 3.2.3 How do different levels of management intensity (extent of treatment) affect the treatment's ability to reduce the size or intensity of fires?
  - 3.2.4 What effect would alternative treatments have on resulting fire *effects*?

4.0 Fire and habitat model integration
- 4.1 Correlate spectral entropy canopy diversity with habitat variables
- 4.2 Model interaction between vegetation management and both fuels and fire, and owl habitat given current conditions, prescriptions and weather scenarios

## Study Area

Our study area is a subset of the Plumas National Forest in Northern California, USA. The Plumas and Lassen National Forests cover hundreds of thousands of acres, and sampling an area this size with a limited field crew and small remote sensing budget is beyond our capacity. As a result, we have chosen to focus on the study area's treatment units (TU) 2, 3 and 4 (Stine et al. 2002), which present widely varying topographical conditions and contain a variety of owl habitat quality. The total area of these three TUs is about 60,000 ha (150,000 ac) (Keane 2004). Vegetation varies widely through this region, presenting a good opportunity to examine fire behavior and end effects across a spectrum of conditions. The town of Quincy lies directly eastward of TU 4 and would be immediately affected by fire in this area and the resulting smoke. In addition, TU 2 has been evaluated to have high quality spotted owl habitat while areas 3 and 4 have lower qualities (Keane 2004). As a result, these three treatment units present a good range of conditions in which to conduct this research and test our model integration.

Vegetative cover in this area is primarily mixed conifer forest. The mixed conifer forest community comprises a mix of three to six conifers and several hardwoods (Barbour and Major 1995; Holland and Keil 1995; Sawyer and Keeler-Wolf 1995). Common conifers include ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*P. jeffreyi*), sugar pine (*P. lambertiana*), incense-cedar (*Calocedrus decurrens*), Douglas fir (*Pseudotsuga menziesii)* and white fir (*Abies concolor*). Red fir (*Abies magnifica*) is common at higher elevations where it mixes with white fir (Holland and Keil 1995; Sawyer and Keeler-Wolf 1995). At mid to lower elevations, common hardwoods include California black oak (*Quercus kelloggii*) and canyon live oak (*Q. chrysolepis*) (Rundel et al. 1995).

In addition, a number of species are found occasionally in or on the edge of the mixed conifer forest: western white pine (*P. monticola*) at higher elevations, lodgepole pine (*P. contorta*) in cold air pockets and riparian zones, western juniper (*Juniperus occidentalis*) on dry sites, California hazelnut (*Corylus cornuta*), dogwood (*Cornus spp.*) and willow (*Salix spp.*) in moister sites, California bay (*Umbellularia californica*) and California nutmeg (*Torreya californica*) in lower, drier areas (Griffen and Critchfield 1976; Holland and Keil 1995; Rundel et al. 1995).

A variety of vegetation types currently comprise the matrix of covers in which the mixed conifer forest is arrayed. Vegetation in the matrix ranges from chaparral on exposed, poorly watered south and west facing slopes to oak woodlands and riparian meadows. At higher elevations, particularly toward the Bucks Lake Wilderness, some red fir may be found in pure stands (personal experience).

## Methods

This study is conducted under a passive adaptive management framework administered by the USDA Forest Service; we have no control over the implementation of the landscape fuels treatments. The HFQLG Act outlines the landscape fuels treatment strategies, and defines the types of timber harvest to be implemented.  Decisions on the timing and placement of fuels treatments will be determined at a local level by the Plumas National Forest.

We do have control over the data collection and modeling aspects of the project. Our research topics (table 1) can be divided into several methodological groupings. Here, we present summaries of methodologies for field data collection, remote sensing, and model integration. Data are collected from a series of field plots (discontinuous data) as well as from satellites (continuous forest canopy data). Additional data products are derived through modeling.

### *Methods: Field data collection*

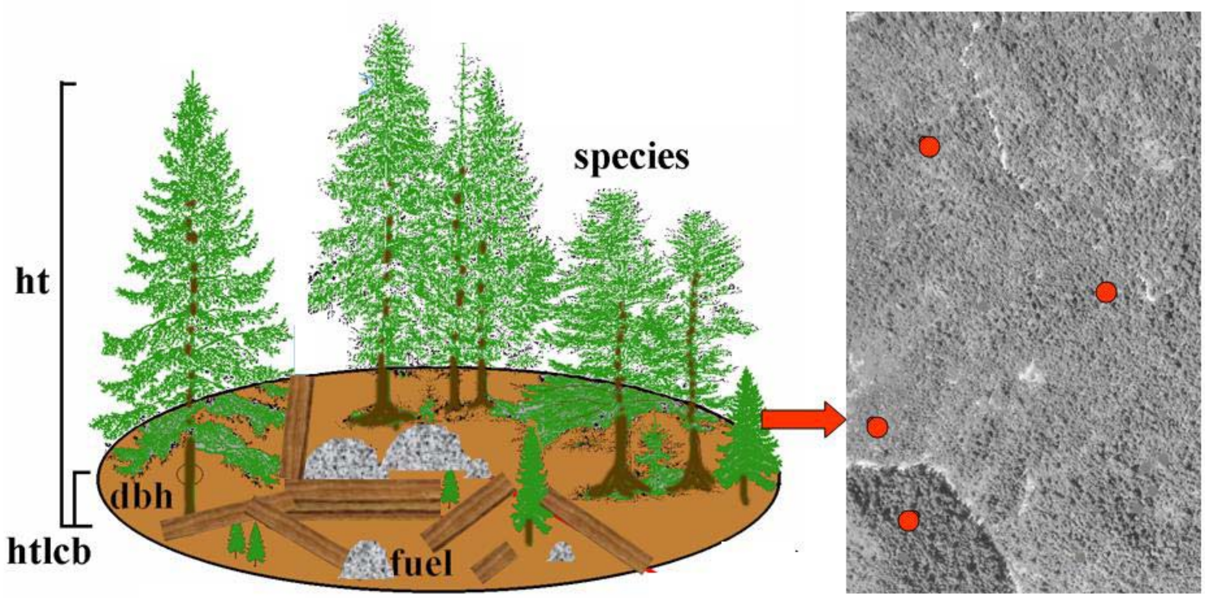
### *Plot Layout and Design*

Data on forest cover and fuels is being collected in 0.05ha (0.125 ac) plots 12.6m (41.3 ft) in radius (figure 2). Plot locations are established using a stratified-random approach. Strata of elevation, aspect and vegetation type were defined using the layers previously supplied by the contractor VESTRA (Stine et al. 2002). This process resulted in data being collected from over 600 plot locations in treatment units 2, 3 and 4. In addition to the randomly-stratified plot locations described above, similar data have been collected at locations identified by the other modules: plots are located at each owl nesting site and mammal study grid in the three treatment units.

### **Forest Structure and Composition; Site Data**

We collect data on tree species, diameter at breast height (DBH), categorical estimate of

Figure 2: Data sources: field plots and satellite imagery
(plots shown scattered on landscape on satellite image to right)



height, and height to lower crown (see Appendix A for sample data sheet). Site data collected include location (using high-precision GPS), slope, and aspect. Canopy cover is assessed at 24 points (every 1 meter) along two linear fuels transects (described below).

***Ground based sampling of ladder, surface, and ground fuels***

Surface and ground fuels are sampled in each plot using the line intercept method (Brown 1974; Brown et al. 1982). Ground and surface fuels are sampled along two transects radiating from plot center. The first transect is located along a random azimuth and the second falls 90 degrees clockwise from it. We sample 1 and 10 hour fuels from 10-12 meters along each transect, 100 hour fuels from 9-12 meters, and 1000 hour fuels data from 1-12 meters. Duff and litter depth (cm) are measured at 5 and 8 meters along each transect. Maximum litter height is additionally sampled at three locations from 7 to 8m (Brown 1974; Brown et al. 1982). Total fuel loads for the sites are occularly estimated using fuel photo series developed for the Northern Sierra Nevada and Southern Cascades (Blonski and Schramel 1993).

***Ladder Fuel Hazard Assessment (LaFHA)***

We have devised and implemented a mixed quantitative-expert system for assessing ladder fuels (submitted paper). The Ladder Fuel Hazard Assessment (LaFHA) requires a trained field crew member to rapidly assess the presence and continuity of fuel ladders in each of four quadrants in a plot using a flowchart. The first step is to determine the presence of low aerial fuels: the fuels that would create sufficient flame lengths to reach several meters from the forest floor. Sparse vegetation, or vegetation widely distributed, probably has too little fuel per volume of air to create and sustain large flames. Therefore, we define a clump of low aerial fuels to be brush or small trees covering an area of at least 4 square meters (2m x 2m) with gaps of less than 50cm. If it is particularly dense, or tall and brushy, a clump may cover a small area. A particularly dense clump may cover as little as $2m^2$ on the forest floor, for example. Branchy dead fuel or stems may be included in the assessment. The size and density of these clumps of fuel and vegetation are based upon personal experience (S. Stephens, K. Menning). If there is no clumping of low aerial fuels, the site would fall in the two lowest ladder fuel hazard categories (C, D); conversely, if there is a clumping of low aerial fuels, the site would fall in one of the two higher-risk categories (A, B). It is important to note that isolated clumps of low aerial fuels, well removed from any ladders, are discounted. Letters (A, B, C, and D) are assigned to hazard ratings instead of numbers to prevent confusion: categories are not of interval or ratio quality (e.g., "Is category 4 twice as risky as category 2?" No, we would not know the quantitative relationship without a direct test).

The second step is to make a determination about the vertical continuity of the fuel ladder from the ground to the canopy. Gaps of more than 2m might be enough to prevent the spread of flames vertically (S. Stephens). Vegetation with gaps of less than 2m from the ground to the upper canopy may present a good ladder to conduct flames. Sparse vegetation lowers the probability and reduces the quality of the ladder. The technician is expected to look at the vegetation and determine whether there are gaps of 2m or more. If the maximum gap is less than 2m, then the site would be categorized as the higher hazard of the two options.

After placing the site in one of the four categories (A, B, C, or D), the technician records the minimum height to live crown (HTLCB) and the size of the maximum gap in the best ladder. These two values may later be used to help verify the classification is correct. The process is repeated for each of the four quadrants of the plot.

The effect of slope is not considered during the hazard evaluation in the field, slope data are used later, to modify the hazard rating. Because the effect of slope on flame length is non-linear (Rothermel 1972), the slope must have a non-linear multiplicative effect on the hazard rating. Final analysis of the plot is performed in the laboratory by combining the ratings of the four quadrants and applying a non-linear slope factor. A plot with one quadrant of high ladder fuel hazard and three low hazard ratings is certainly not as great a risk as a plot with continuous, high-risk ladders in each quadrant. While this semi-quantitative, semi-qualitative process is experimental, and the exact numerical relationships between slope and hazard are yet to be determined, we feel the method has merit; importantly, the field crews report consistent ratings after training and repetition (K. Menning).

### ***Methods: Remote sensing***

Initial results of IKONOS imagery indicate that we will be able to use this imagery for classification of landscape vegetation. As a result, we have dropped the LANDSAT imagery analysis. Instead, all our effort in remote sensing goes into analyzing the IKONOS imagery. This high spatial resolution imagery is being used to provide information on continuous forest pattern, structure, cover and variability using methods developed by Menning (2003) including spectral entropy canopy diversity analysis (SpECDA—see appendix E of Fuel and Fire Study Plan). These data and analyses have the benefit of being linked to analyses of vegetation and wildlife habitat conducted by other researchers in the project (see model integration, below). In 2003, high-resolution (1-4m) IKONOS imagery of several treatments was collected covering treatment units 3 and 4. In 2004, IKONOS imagery covering TU 2 and 3—overlapping the data collected in 2003—was collected to provide additional coverage of the area with high owl population. Remote sensing data were processed, orthorectified and mosaicked in 2006 and 2007.

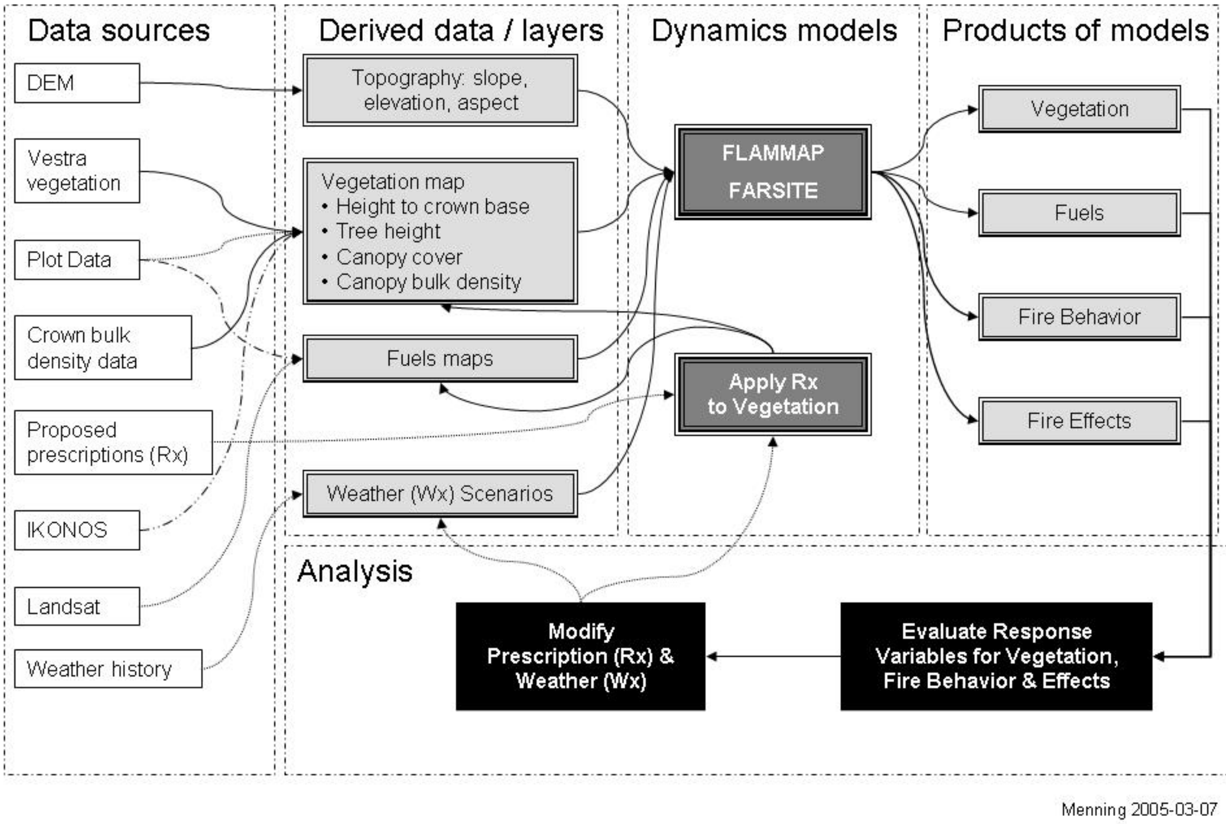
## *Methods: Data Processing, Analysis and Model Integration*

Fire behavior models require maps of vegetation, topography, and fuels, as well as weather scenarios, in order to model the spatial behavior of fire (figure 3). These data are integrated from a variety of different sources. Development of the vegetation map has been described above, in the remote sensing methodology. Topographic variables—slope, elevation and aspect—are mapped across the study area using pre-existing Digital Elevation Models (DEM) on a 30x30m grid. Assembling fuels maps requires that fuels be measured at select sites (a discontinuous set) and then extrapolated across the landscape where fire may burn (continuous coverage). Fire modeling will be conducted in two major phases: first, we will evaluate fire behavior and potential at one time, either the current condition or post-treatment, using Farsite and Flammap; second, we will use Forest Vegetation Simulator (FVS) to create a dynamic simulation of change through time at the stand level.

### *Calculation of Fuel Loads and Development of Fuel Models*

Many fuel inventories done in the Sierra Nevada have assumed that the fuel particles being inventoried had similar properties to those found in the northern Rocky Mountains (Brown 1974) but Van Wagtendonk's work in quantifying Sierra Nevada surface and ground fuel properties allows custom fuel load equations to be developed for a site-specific project such as this. This methodology previously has been used to produce accurate estimates of fuel loads (Stephens 2001). Additional validation of these fuel load coefficients are provided by Menning's research in Sequoia National Park (Menning 2003). As tree species in the northern Sierra Nevada are the same as those sampled by Menning and van Wagtendonk, the data should be relevant to this study site.

**Figure 3: PLAS Landscape Vegetation, Fuels and Fire**




Field measurements provide data on species mixes and fuel particle size distribution. Using these data, ground and surface fuel loads are calculated by using equations developed for Sierra Nevada forests (van Wagtendonk et al. 1996; van Wagtendonk and Sydoriak 1998; Menning 2003) as well as the production of fine fuels as determined by field measurements. Coefficients required to calculate all surface and ground fuel loads are arithmetically weighted by the basal area fraction (percent of total basal area by species) that are collected in the plots.

Plot based fuel measurements are being used to create a set of customized and spatially-extensive fuel models for the study area (Burgan and Rothermel 1984) for this area. Fuel model development includes a stochastic element to more closely model actual field conditions that have a large amount of spatial heterogeneity. Stochastic fuel models are being produced for each stratum identified using van Wagtendonk and Root's methods (forest type, aspect, seral stage, etc.). Plot data provide crown cover, height to live crown base, and average tree height at each site. Canopy bulk density estimates are based on previous work by Stephens (Stephens 1998). All of these spatially-discontinuous data derived from plot-specific measurements are extrapolated across the landscape using the remote sensing imagery maps of vegetation.

***Simulations: Potential fire behavior***

Potential fire behavior is being estimated using a similar technique developed by Stephens (1998) but at much broader spatial scales. The effectiveness of the different restoration treatments will be assessed with computer models such as FARSITE (Finney 1996; Finney 1998; Finney 2000) and FlamMap (Finney 2003). FARSITE is a deterministic, spatial, and temporal fire behavior model that requires as inputs fuel measurements and models; topographic data, including slope, aspect, and elevation; forest structural data including canopy cover, tree height, height-to-live crown base, and canopy bulk density; and weather. A historic fire occurrence map is being produced to estimate the probability of ignitions in the study area. Data come from the Plumas National Forest archives and current GIS layers. This derived map will be used to generate an actual ignition point in each FARSITE simulation. FlamMap is similar to FARSITE but does not use a user-determined ignition but burns the entire landscape using one set of weather data. These models will be used to quantify the potential fire behavior of the different treatment approaches.

The duration of each simulation would be seven days, a period that approximates the duration of many landscape-scale wildfires in the Sierra Nevada before they are contained (Stephens, personal experience). Weather scenarios using data from the 70$^{th}$ (moderate), 90th (severe) and 97$^{th}$ (extreme) percentile conditions is being used and this data is being collected from local weather stations. Fire simulations would be constrained by suppression activities. Constrained simulations will use realistic suppression elements (15 person hand crews, aircraft, bulldozers, etc.; Stephens, personal experience).

Outputs from the fire simulation include GIS files of fire line intensity (kW/m), heat per unit area (kW/square meter), rate of spread (m/s)**,** area burned (ha), emissions (tons) and if spotting and crowning occurred. Scorch height (m) would be calculated from fireline intensity, air temperature, and wind speed. This information will be used to compare the effects of the different landscape level restoration treatments on altering fire behavior.

***Simulation: Fire effects***

After the fire has passed, the effects of the fire linger: trees die, exposed soils erode, and insects invade. Some fire effects such as tree mortality are being modeled using the GIS outputs from the FARSITE and FlamMap simulations coupled to previously-tested quantitative models that estimate tree mortality (Stephens and Finney 2001). In addition to the tree-mortality measure of fire severity, the amount of bare mineral soil exposed by the simulated fires is being estimated for each 30m by 30m pixel.

***Simulation: landscape dynamics over time***

The second major phase of fire modeling takes advantage of the temporal dynamics of the Forest Vegetation Simulator (FVS) model. We will place the DFPZs on our virtual landscape at the probable time of their occurrence and use the model to grow trees in all other areas at the same time. The resulting landscape can then be evaluated for fuel loading and fire potential.

# Results: Completed in 2007

We completed two papers in the last year. Our analysis of Ladder Fuel Hazards was published in the Western Journal of Applied Forestry: Menning, K. M. and S. L. Stephens (2007). "Ladder Fuel Hazard Assessment: A Semi-Qualitative, Semi-Quantitative Approach." Western Journal of Applied Forestry 22(Number 2 April): 88-93.

In addition, we have completed a draft of a paper integrating our work on remote sensing, image processing, GIS, and fire modeling. It is being submitted to the journal Landscape Ecology. Key findings from that paper are presented in the following section.

These results were achieved despite a severe loss of funding that resulted in the termination of our full time assistant and postdoctoral researcher. Any future efforts depend upon renewed funding.

## 2008 Report: Potential forest fire behavior as a function of three weather scenarios and two landscape fuels treatments based on a fuels and vegetation landscape derived from fine-grain IKONOS satellite imagery, Sierra Nevada (USA)

***Submitted to*** Landscape Ecology; ***Authors:*** Kurt M. Menning and Scott L. Stephens

# Abstract

Landscape-scale forest fuels treatments are intended to prevent fires from sweeping across broad swaths of the landscape in moderate and severe weather conditions. Treatments such as defensible fuel profile zones (DFPZs) both resist the spread of fire and provide safe access for fire fighters. While DFPZs are intended for moderate and severe conditions, the effects they would have during extreme fire weather remains largely unknown. At the same time, many uncharacteristically extensive fires occur during extreme fire weather conditions. In order to determine what benefits DFPZs would offer in extreme conditions we conducted sets of fire simulations to compare fire behavior in three weather scenarios—moderate, severe and extreme—and two fuels treatment conditions: the current, untreated condition, and post-DFPZ fuels treatment. Using IKONOS imagery, we created a fine-grain vegetation and fuels layer and created another post-treatment layer with DFPZs on the landscape. We chose ten stochastically-determined ignitions and simulated fire in FARSITE for 3 days without suppression. Some ignitions led to fires that were affected by DFPZs while others were not. Fires not encountering DFPZs were statistically similar to those on the untreated landscape. Fires encountering DFPZs, however, experienced reductions in all measures of fire behavior—extent, perimeter, number of individual fires, and spot fires—of at least 50% under moderate and severe conditions. Contrary to expectations, the greatest benefit occurred with fires burning under extreme conditions. Simulations under extreme weather showed reductions in all fire measures exceeding 70%.

While it is thought that DFPZs would likely fail in extreme conditions, we found that they offered the greatest benefit in these conditions.

## Introduction

A century or more of extensive logging and fire suppression had enormous impacts on the forests of the Sierra Nevada (Kilgore and Taylor 1979; Parsons and Debenedetti 1979; McKelvey et al. 1996; Beaty and Taylor 2001; Keeley and Fotheringham 2001; DellaSala et al. 2004). In recent decades, increasing fuel loads and risks of uncharacteristically severe and extensive fire, coupled with concern about forest management impacts on wildlife and timber yield, have led to concerns about the most effective means to manage forests given changing conditions and goals (Stephens and Ruth 2005; Menning 2007). In 1993, a citizens group was founded in 1993 in the town of Quincy, California, by an unusual coalition of individuals concerned with timber yield and economics, fire risk and wildlife habitat (Ingalsbee 2005). Dissatisfied with Forest Service land management, the Quincy Library Group eventually proposed a series of landscape fuels breaks, or defensible fuel profile zones (DFPZs). Congress and the Forest Service decided to implement a set of these DFPZs on the landscape (Stine et al. 2002; Ingalsbee 2005).

Defensible Fuel Profile Zones are designed to provide three primary functions: provide safe access for fire fighters, limit fire behavior to prescribed levels (e.g., limit flame lengths at the 90$^{th}$ percentile weather condition to 48”), and create conditions in which canopy fires are less likely to spread: minimal ladder fuels (Menning and Stephens 2007) and a well-spaced canopy. These DFPZs are designed to withstand fire in severe conditions—the 90$^{th}$ weather percentile. The utility of DFPZs in more extreme conditions is not known, however, it is often thought that they will fail and yield little benefit to stopping uncharacteristic landscape-scale fires (Hardy 2005).

As part of the research team tasked with evaluating the system (Stine et al. 2002), we evaluated whether DFPZs would significantly modify fire behavior at the landscape scale. In discussions with some forest service employees and QLG members we were encouraged to study fire weather scenarios well-beyond severe fire weather. Many large, severe wildfires occur at the $97^{th}$ to $98^{th}$ weather percentile, for example. At the same time, a number of people discouraged us from simulating more extreme weather scenarios on the grounds that as the DFPZs were likely to fail in more extreme conditions we should not evaluate their effectiveness under conditions in which they were certain to fail. As analysts, we determined that we must test the landscape fuels treatments in the extreme conditions under which uncharacteristically-severe fires would occur; these are the fires that most people worry about.

To test the effectiveness of DFPZs at moderating large fires, we conducted sets of simulations of landscape-scale fire behavior under three weather scenarios—moderate, severe, and extreme—and two treatment conditions: pre-treatment, or current-conditions, and post-DFPZ treatment (Table 1). The matrix of results allowed us to directly compare the effectiveness of treatments by examining fires from the same ignitions burning under the same weather conditions. At the same time, we were able to compare how the same ignitions would lead to different fire behavior given different weather scenarios.

| Table 1: matrix of simulations: three weather scenarios and two treatment options. | | Weather Scenario | | |
|---|---|---|---|---|
| | | Moderate | Severe | Extreme |
| Treatment | Pre-treatment (current condition) | ? | ? | ? |
| | Post-DFPZ treatment | ? | ? | ? |

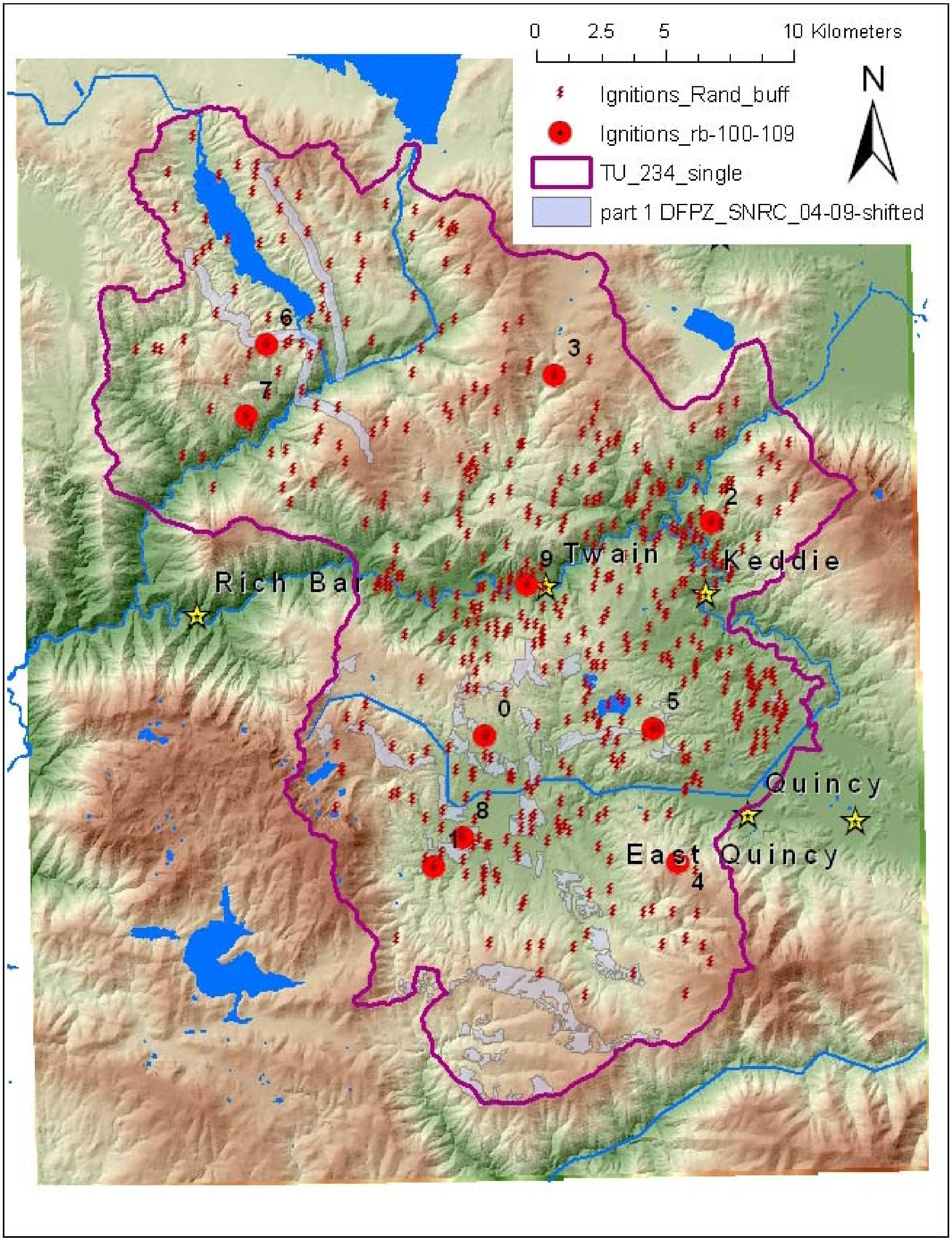
In order to make fire simulations as realistic as possible, we acquired high-resolution remote imagery (IKONOS) of the region to generate a fine-grain (4 m by 4 m pixel) map of fuels and vegetation. The fine-grain imagery creates a more realistic fine-scale intermixing of fuels types and characteristics than can be gained from simply mapping stand boundaries and assigning characteristics. Forests in this area, for example, are often mixed with chaparral and grass across the span of tens of meters. Further, we anticipated that fine-scale mapping of vegetation and fuels would lead to more accurate depictions of fire spread and reduce the need to superimpose impenetrable fire breaks—such fire breaks often fail to contain in extreme conditions.

# Methods

## Field site and conditions

The Plumas National Forest is located in the northern Sierra Nevada, California (USA). The climate is Mediterranean with a predominance of winter precipitation totaling about 1600 mm per year. The forest in the study area ranges from approximately 1000-1500 m elevation and spans over 60,000 ha (150,000 acres) (Figure 1).

Figure 1: overall map showing location (latitude, longitude), candidate and modeled ignitions, towns, and DFPZs.



Vegetation on this landscape is primarily Sierra Nevadan mixed conifer forest (Schoenherr 1992; Barbour and Major 1995), a mix of conifers and several hardwoods: white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*Pinus lambertiana*), ponderosa pine (*P. ponderosa*), Jeffrey pine (*P. jeffreyi*), incense-cedar (*Calocedrus decurrens*), and California black oak (*Quercus kelloggii*). Montane chaparral and some grasslands are interspersed with the forest (Schoenherr 1992; Barbour and Major 1995). Tree density varies by fire and timber management activity, elevation, slope, aspect, and edaphic conditions. The typical fire regime is frequent, low-severity fire with patches of high-severity canopy fire with fire return intervals of 10-30 years (Caprio and Swetnam 1995; McKelvey et al. 1996; Sierra Nevada Ecosystem Project 1996; Skinner and Chang 1996; Stephens and Collins 2004).

## Creation of model layers

### *Ignitions*

A database of historic fire ignitions for the last thirty years was acquired from the Forest Service (Charbonnier 2006). Each historic ignition that occurred within a one square mile section was marked as being located at the center of that section. Based on this mapping method, if four fires occurred in a section, then all four would be mapped with the same ignition point at the center of the section.

To create an ignition probability map for fire modeling, we created a one-to-one probability coverage by generating one random potential ignition within 0.5 mile (0 .8 km) of each historic ignition using ESRI's ArcMap 9.2. As a result, spatial density of potential ignitions matches the spatial density of historic ignitions. To limit the possibility that simulated fires would start near the boundary of the area and burn outside where we had no data on forest and fuel conditions, and where we could not measure spatial extent, we internally buffered the study area in ArcMap to ensure each candidate ignition was located at least 1 km from the edge of the study area. We randomly chose ten potential ignitions from thousands of candidates on the stochastic ignition map (Figure 1).

### *DFPZ Fuels Treatments*

Acquiring a consistent map of proposed DFPZ projects posed a challenge. We acquired separate "current" DFPZ coverages from the Forest Service's Sierra Nevada Research Center (SNRC) and Plumas National Forest. Comparing the two sets, we found that many DFPZ projects that had been spatially planned were modified. Others that had been detailed had their spatial designation removed and were assigned generally, leaving large tracts of land as potential locations for DFPZs. In one case, a potential DFPZ was changed from a specific location to cover an entire district of the Plumas National Forest. Further, some districts had completed detailed DFPZ planning while others lagged in the process. As a result, we created a DFPZ map as systematically as possible. First, we removed any DFPZ designations where the area was treated prior to our acquisition of remote imagery of the area. Thus, any pre-existing DFPZ that modified vegetation and would appear on the imagery was eliminated; we didn't want to reapply a potential treatment to the landscape where it already had altered vegetation mapped using the imagery. Second, when specific areas that had been allocated on the ground were changed into general designations covering entire landscapes, we retained the earlier, more specific version for our modeling. Third, when DFPZ projects had been revised and made more detailed, we chose the latest mapped version. Fourth, according to some records some "thinning" projects were considered parts of DFPZs while others were not (HFQLG 2004 Program of Work Accomplishments; Plumas National Forest; HFQLG Proposed Program of Work FY 2005, Plumas National Forest; HFQLG Program of Work, FY05 to FY09, Plumas National Forest). In order to resolve ambiguity in definitions, we corresponded with agents of the Forest Service (Felker and Dillingham 2007) to resolve conflicts and create a realistic DFPZ map.

***Remote sensing and image processing***

High resolution IKONOS imagery covering part of the study area was acquired from Space Imaging in 2003 and another, overlapping section, in 2004. In both cases the prescribed acquisition was intended to be near the summer solstice at noon to ensure minimal topographic and tree shadowing. Imagery in 2003 was collected on June 30 at 12:08 pm local time in two scenes with a sun angle azimuth of 138.5 and elevation of 69.1 degrees. Due to poor weather as well as budget transfer constraints in 2004, image acquisition was delayed until September 3 at 12:08 pm. The three scenes in 2004 were acquired with a sun angle azimuth of 155.1 and elevation of 54.9 degrees. Overlap between the two years was approximately 50%.

Both acquisitions had identical prescriptions: 1 m panchromatic and 4 m multispectral imagery collected with an upgraded and narrowed field of view (72-90 degrees from azimuth). Delivered products were not radiometrically or geometrically corrected but were sent in a GeoOrtho kit. We completed radiometric corrections in our lab to minimize backscatter and distortion due to atmospheric moisture and haze. We used PCI Geomatica 9.1’s EASI modeler module to apply sun angle corrections. Dark target haze removal corrections were completed using lakes in the scenes as targets. These radiometrically-corrected images were spatially corrected—orthorectified—using Geomatica 9.1’s Orthoengine module. To support this effort, ground control points (GCPs) had been collected in the field using a Trimble GeoXT Global Positioning System (GPS) with hurricane antenna with sub meter accuracy using wide-angle area support (WAAS). After the orthorectification was completed we evaluated the results using twelve independent ground reference points. The analysis indicated the five scenes of the imagery were accurate within 2.0, 2.6, 2.8, 3.4 and 3.6 m with an overall average of 2.9 m. Each of these measures is within a single 4 m pixel of the multispectral imagery and so the resulting orthorectification was deemed precise and consistent enough to use. A mosaic of all five scenes was created using Erdas Imagine 9.0's mosaic function.

***Creation of fuels layers***

Fuel characteristics were mapped from the IKONOS mosaic using supervised classification. Five layers were created as inputs to the FARSITE fire area simulator (version 4.1.054): vegetation and fuel type, canopy cover, crown base height, crown height, and crown bulk density (Finney 1998). We mapped vegetation and fuel types applying fuel types described in Scott and Burgan (Scott and Burgan 2005). The national Landfire (Keane 2007) project uses these fuel types and we were able to apply a reduced set drawing on extensive personal field time in the area. We chose fuel type TL1 to represent defensible fuel profile zones (DFPZs)—shaded duel breaks—because the fuel and vegetation characteristics most closely match actual DFPZs. Forest Service technicians confirmed our set of fuel types was appropriate for the area.

Table 2: Fuel model table values were modified from those used in LANDFIRE

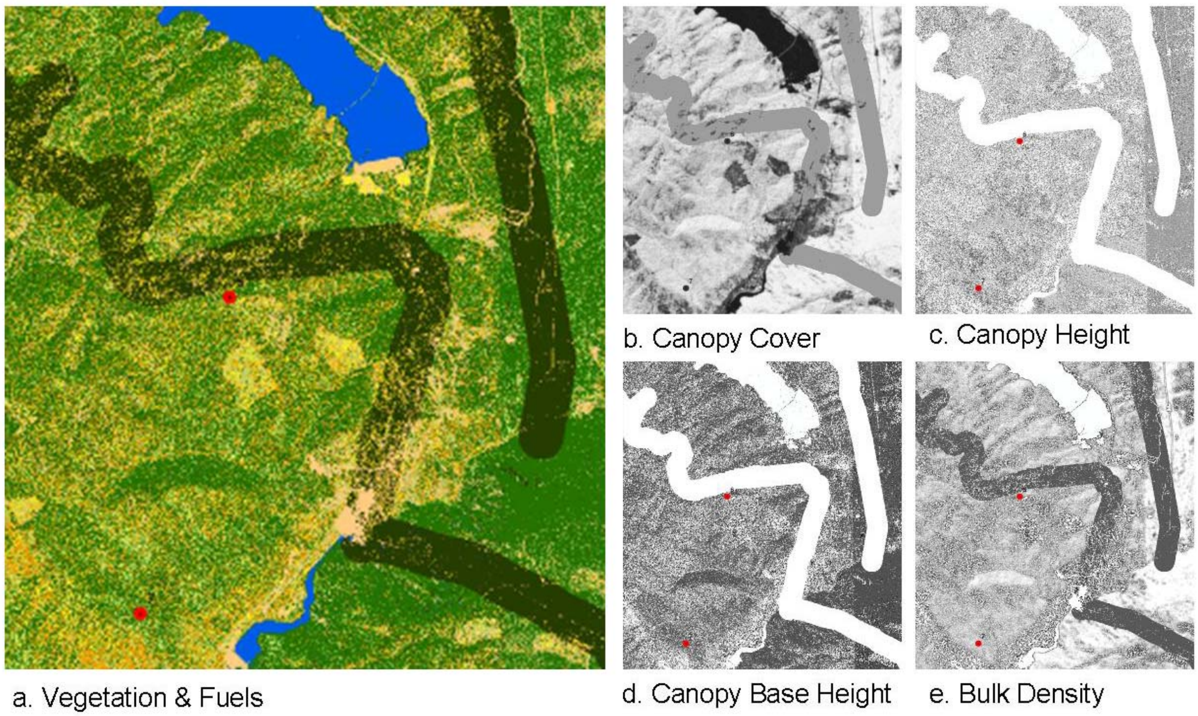
| *#* | *Scott & Burgan Fuel Model* | *Description* | *Occurrence in study area* | *Initial Canopy Cover (%)* | *Canopy Bulk Density (kg/m$^3$)* | *Canopy Height (m)* | *Canopy Base Height (m)* |
|---|---|---|---|---|---|---|---|
| 98 | NB8 | Water | • Major water bodies | 0 | 0 | 0 | 0 |
| 99 | NB9 | Bare ground | • Bare ground, talus, roads, urban areas | 0 | 0 | 0 | 0 |
| 102 | GR2 | Grass – Low load dry grass | • Extensive grasslands in American & Indian Valleys | 0 | 0 | 0 | 0 |
| 122 | GS2 | Grass-shrub moderate loading, dry | • South facing slopes<br>• Recovering timber harvest | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | areas | | | | |
| 147 | SH7 | Shrub – chaparral | • Chaparral type, dense, south and west aspects | 0 | 0 | 0 | 0 |
| 165 | TU5 | Timber-shrub | • South aspects only<br>• Dominant classification by Landfire (>50% of landscape) | 0.25 | tracks canopy coverage from 0-0.25 | 20 | 1 |
| 181 | TL1 | Timber with compact, low volume fuel bed. Used for DFPZ designation. | • Red fir, and higher white fir areas<br>• *Fresh timber operations, DFPZs, just after cuts* | 0.9 | tracks canopy cover 0-0.25 | 35 | 7 |
| 186 | TL6 | Hardwood with fuel understory | • Aspen stands<br>• Oak stands in riparian areas | 0.75 | tracks canopy cover 0-0.25 | 15 | 5 |
| 184 | TL4 | Conifer with moderate litter/fuel load | • Extensive | 0.9 | tracks canopy cover 0-0.25 | 25 | 3 |
| 185 | TL5 | Conifer with higher litter load | • Northern aspects only | 0.9 | tracks canopy cover 0-0.25 | 30 | 3 |

Supervised classification of vegetation and fuel models was completed in Erdas Imagine 9.0. Training sites for were chosen using the high resolution panchromatic imagery as well as the multispectral IKONOS mosaic. Between five and ten training sites were chosen for each class (Table 2) with emphasis on minimal intermixing of other vegetation types in the training sample.

Four additional data layers were created for input into FARSITE. Canopy cover was linked to the vegetation and fuel type. Vegetation classes were initially assigned a canopy cover value (Table 2). Under an individual tree, canopy cover, by definition, is very high. Canopy cover drops as multiple trees in an area are considered and the gaps between them expose the ground. Hence, we applied a high canopy cover value—90%—to forest vegetation types. To accept these values in a fine-grain mosaic would be problematic, however. To create a more realistic set of continuous values for the canopy cover, we smoothed the canopy cover values (7x7 pixel FAV filter, PCI Geomatica). The resulting canopy cover across the landscape ranges from zero, where no trees are classified, to 90% for pure, almost completely overlapping stands that occasionally occurred on northern aspects. As a result of the smoothing, however, patches of forest usually average a more realistic and variable 30-80% canopy cover, depending on tree density. Predictably, the densest stands grow on northern aspects and this is where the canopy cover is highest. Canopy height and crown base height were assigned as set values for each vegetation and fuel class (Table 2). Values were compared with those used for these classes by the Landfire team and were comparable.

Figure 2: Five input layers for FARSITE simulations: vegetation and fuels, canopy cover, canopy base height, canopy height, and bulk density. These layers are shown are post-DFPZ installation for illustration purposes. Canopy cover and bulk density were modeled conditionally so as not to raise values above existing values.




As we were unable to differentiate different species of conifers, we assigned a standard bulk density for each class and made it respond to the canopy cover. Thus, where canopy cover is high, bulk density is assumed to be high (up to 0.1 kg/$m^3$) and where canopy cover is low, so is bulk density. All values were multiplied by a correcting factor of 2.5 (Stpephens, unpublished data).

To create the post-treatment landscape files we altered a copy of the original vegetation by changing the vegetation and fuel in areas where DFPZs would be created: we compared the two coverages—vegetation and fuels along with DFPZs—in PCI's EASI modeling module. In every raster cell in which a DFPZ treatment was planned, we conditionally changed the vegetation and fuel values. If the vegetation and fuel type was any kind of forest cover with surface fuels, we changed it to TL1, the designation of a sparse forest with little surface fuel. If the vegetation and fuel value was grassland or woodland, we left the value the same. Thus, we did not “create” a forest where none was previously; these areas retained their non-forest characteristics. Areas that did have forest were redefined to have DFPZ characteristics. We believe this conditional technique creates a realistic mosaic of forest and non-forest types as a planned DFPZ extends across the landscape.

The additional four layers for FARSITE simulations were created using this post-treatment vegetation and fuels layer using the same steps as before. Only values in areas with DFPZ treatments were modified. For canopy cover we applied conditional modeling to avoid artificially inflating canopy cover in low-density areas. According to the Forest Service (Collin Dillingham, unpublished data), the average canopy cover after DFPZ installation in the Plumas National Forest was 29%. Hence, in our model, if the canopy cover was greater than 29% we reduced it to 29%. If it was lower than 29% we retained the lower value.

***Fire Weather***

Weather data were drawn from the remote access weather station (RAWS) in Quincy, CA from a recent ten year period and processed in Fire Family Plus (version 3.05). We chose this ten year period rather than a longer duration as we wanted to simulate conditions given the likely continuing warming and drying this region has experienced in the last decade. Data were collected for three weather scenarios—moderate, severe, and extreme (Table 3).

Table 3: Fire weather data from Quincy for the period from June 20 to September 20, covering the years from 1997 to 2006, inclusive. Fuel moistures were calculated using South and Southwest winds which are typical during fires. Enhanced winds in the last column were applied for only the peak burning time each day: 1300 to 1600 hours. At other times, winds were at the levels set in for Extreme conditions.

| | Scenario and Percentile of Weather Conditions | | | |
|---|---|---|---|---|
| Scenario | Moderate | Severe | Extreme | Extreme with Enhanced Winds |
| Weather Percentile | 70 | 90 | 97.5 | 97.5 |
| Fire Weather | | | | |
| Relative Humidity | 13 | 10 | 7 | 7 |
| Temperature (Fº) | 94 | 100 | 104 | 104 |
| Wind (mph) | 6 | 7 | 9 | 26.4 |
| Fuel Moistures (FM) | | | | |
| 1 hour | 2.4 | 2 | 1.6 | 1.6 |
| 10 hour | 3.7 | 3.1 | 2.8 | 2.8 |
| 100 hour | 8.5 | 7.3 | 7.7 | 7.7 |
| 1000 hour | 9.5 | 8.6 | 9.2 | 9.2 |
| Herbaceous FM | 37 | 34.9 | 36 | 36 |
| Woody FM | 72 | 71 | 70.6 | 70.6 |

Wind data for the extreme scenario were enhanced because the RAWS data tend to underestimate actual wind speeds during fire events (Crosby and Chandler 2004). A number of individuals in the Forest Service and our lab had expressed concern about how realistic the winds were in the extreme scenario (9 mph). To create a more likely extreme weather scenario in which a fire might create its own fire weather and sustain strong winds for long periods, we used Fire Family Plus to calculate the maximum hourly winds for each month during the same period. The overall average of these sustained winds during the fire season of the ten year period was 26.4 mph.

### *Fire modeling*

All fire model simulations were completed on a single dual processor computer operating Windows XP and running Farsite (version 4.1.054). Simulations were conducted using 30m perimeter and distance resolution over three twenty-four hour periods (24, 48 and 72 hours).

Model parameters included setting timestep to 30 minutes. Fire behavior options included enabling crownfire (standard setting, not Scott and Reinhardt), embers from torching trees, spot fire growth (5%), and fire-level distance checking. Fire acceleration, post-frontal calculations and dead fuel moistures were set to default. Duration was limited to 72 hours beginning in the midst of the fire season, beginning August 12 at 4pm and extending to august 15 at 4pm. Fuels conditioning was initiated seven days in advance (8/5). Simulation options were set to preserve intact enclaves and operate with four simulation threads.

Spatial and temporal settings were chosen for practical reasons. A practical constraint, given the number of simulation runs to be conducted was the number of days a simulation took to complete, as well as computational calculation limitations on high-resolution vegetation and fuel maps. Medium-sized fires modeled at a 4 m spatial setting would take at least five days to run. Large fires much longer.

In addition, we wanted to focus on the physical potential of fire independent of human intervention; to add in human suppression efforts at this stage would result in our analysis being clouded by subjective suppression efforts when the goal was actually to evaluate fuel treatment effects given identical weather conditions. We limited the length of the simulation, however, as people certainly would begin to suppress a fire within the first 72 hours; simulating un-suppressed fires beyond that period was considered unnecessary. After the physical effects—independent of human suppression—are understood through this work, we will be able to add in an analysis of human suppression efforts and effectiveness.

## Results

Six fires were simulated for each stochastic ignition: three given the current, pre-treatment landscape, and three after. For each of the two treatment conditions—pre and post treatment—there were three weather scenarios. Maps of fire extent from a select set of these simulations are presented in Figure 3. Data from the set of all simulations are shown in Figure 4 and Table 4. Installation of DFPZs reduced spot fires by about a third in moderate and severe conditions and 51% in the extreme with enhanced winds scenario. Similarly, the largest percent reduction of burned area (-33%), perimeter (-42%) and number of fires (-44%) occured in the extreme winds scenario.

Figure 3: Six simulations of fires starting from ignition 0. Images are paired left and right by weather scenario—moderate, severe, and extreme—and arranged vertically by fuel treatment. All fire events in the left column occurred on the landscape depicting current conditions—before fuels treatment; fires depicted in the right-hand column were simulated after the installation of DFPZ fuels treatments. With the exception of the vegetation and fuel characteristics in the DFPZ zones (shown in very dark green), the landscapes are identical.

Figure 4: Data from all simulations, regardless of effect of fuels treatments. I = initial conditions (pre-treatment); P = post-DFPZ treatment. Lines are paired: solid represents Initial conditions, dashed = post. Time data are shown on the horizontal axis with measurements made after 1 day (24 hours), 2 days and 3 days.

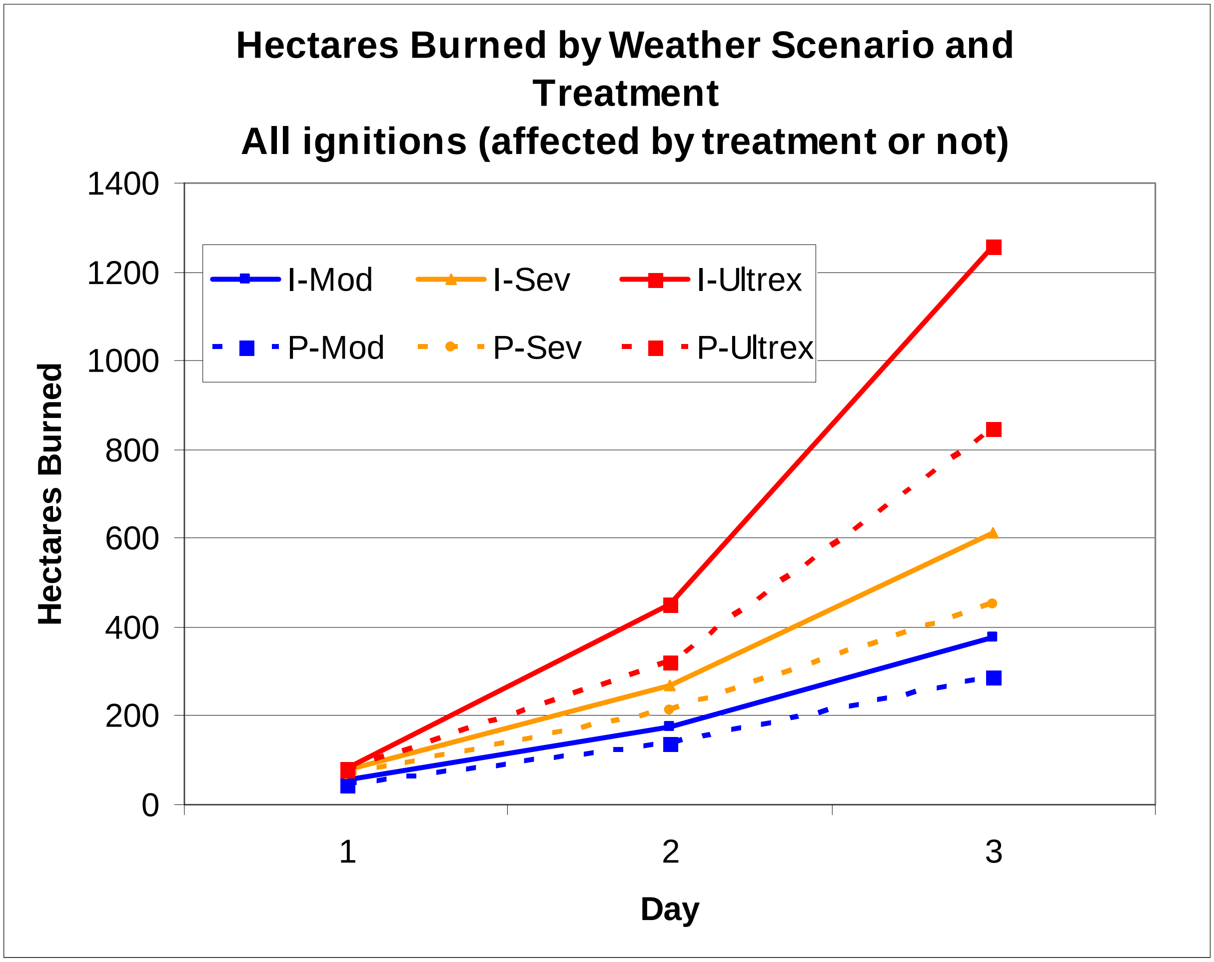


Table 4: Data collected from the set of all simulated fires, regardless of the influence of DFPZs. Ten ignitions were modeled, each with three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

| Fire Status | | Initial pre-treatment scenarios | | | | Post-treatment scenarios | | | | Percent Change | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weather | Day | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots |
| Moderate | 1 | 55 | 10 | 118 | 23 | 45 | 8 | 92 | 22 | -18 | -20 | -22 | -4 |
| | 2 | 177 | 27 | 276 | 26 | 137 | 19 | 173 | 15 | -23 | -30 | -37 | -42 |
| | 3 | 378 | 44 | 425 | 30 | 288 | 33 | 295 | 20 | -24 | -25 | -31 | -33 |
| Severe | 1 | 79 | 16 | 184 | 29 | 67 | 14 | 158 | 23 | -15 | -13 | -14 | -21 |
| | 2 | 270 | 39 | 387 | 38 | 211 | 30 | 304 | 31 | -22 | -23 | -21 | -18 |
| | 3 | 612 | 71 | 776 | 65 | 451 | 52 | 528 | 45 | -26 | -27 | -32 | -31 |
| Extreme + winds | 1 | 83 | 18 | 205 | 29 | 80 | 18 | 212 | 34 | -4 | 0 | 3 | 17 |
| | 2 | 450 | 88 | 1143 | 134 | 323 | 65 | 831 | 102 | -28 | -26 | -27 | -24 |
| | 3 | 1256 | 200 | 2606 | 277 | 847 | 117 | 1453 | 136 | -33 | -42 | -44 | -51 |

Due to the stochastic nature of the spatial location of ignitions, however, DFPZs affected some fires and not others. As they burned across the virtual landscape, some fires encountered DFPZs on the first day, some later, and some not at all. In order to minimize subjectivity in determining the timing, strength or intensity of a DFPZ’s influence on fire behavior, we simply analyzed the fires after they burned the full period—72 hours—and categorized them as influenced by a DFPZ or not. Predictably, data from fires unaffected by the placement of DFPZs indicated marginal change. In Figure 5, paired lines of pre- and post- treatment should be essentially co-linear. Differences are due to stochastic variables of spotting as FARSITE is otherwise a deterministic program. Fires burning under moderate and severe weather conditions were similar before and after fire with no percent change for any statistical category higher than 8% by the third day (Table 5). In the extreme with enhanced winds scenarios, total area burned on the “treated” landscape vacillated between being higher and lower than the untreated landscape and ended up, due to random effect of spot fires, slightly higher; spot fires were 50% higher in the post-treatment scenario after 3 days.

Figure 5: Simulated fires *not* affected by treatments. Given the lack of a treatment effect, there should be little difference between paired lines.

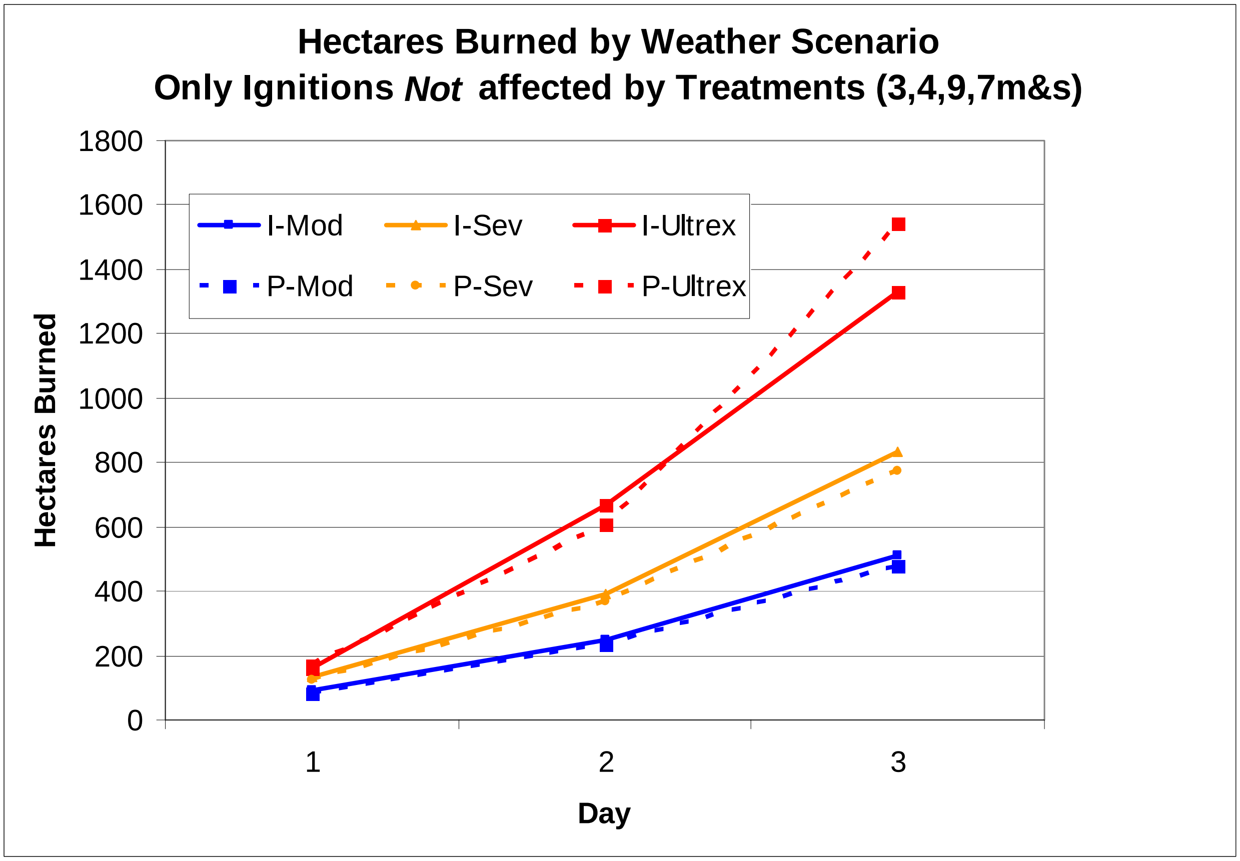


Table 5: Data collected from the set of simulated fires that did not encounter DFPZs while burning. Simulations cover three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

| Fire Status | | Initial pre-treatment scenarios | | | | Post-treatment scenarios | | | | % change | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weather | Day | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots |
| Moderate | 1 | 92 | 16 | 198 | 38 | 83 | 14 | 173 | 44 | -10 | -13 | -13 | 16 |
| | 2 | 250 | 34 | 360 | 30 | 235 | 32 | 319 | 30 | -6 | -6 | -11 | 0 |
| | 3 | 511 | 56 | 546 | 37 | 477 | 52 | 503 | 37 | -7 | -7 | -8 | 0 |
| Severe | 1 | 133 | 25 | 288 | 35 | 126 | 24 | 300 | 44 | -5 | -4 | 4 | 26 |
| | 2 | 391 | 51 | 537 | 54 | 369 | 50 | 549 | 61 | -6 | -2 | 2 | 13 |
| | 3 | 833 | 86 | 984 | 87 | 773 | 83 | 946 | 94 | -7 | -3 | -4 | 8 |
| Extreme + winds | 1 | 159 | 32 | 410 | 43 | 172 | 40 | 531 | 84 | 8 | 25 | 30 | 95 |
| | 2 | 670 | 108 | 1468 | 168 | 607 | 122 | 1753 | 231 | -9 | 13 | 19 | 38 |
| | 3 | 1331 | 171 | 2107 | 175 | 1542 | 207 | 2791 | 263 | 16 | 21 | 32 | 50 |

In scenarios in which fires were affected by DFPZs, the fuel breaks had a dramatic impact on all measures of fire behavior. Hectares burned by fire after treatment in the extreme with enhanced winds scenario was less than burned by fire under severe conditions on an untreated landscape at all three time-steps (Figure 6). Similarly, by the close of the third day of simulation, all measures—burned area, perimeter, number of fires and spots—in all three weather scenarios dropped by fifty percent or more (Table 6). In the extreme with enhanced winds scenarios, all measures declined by 71 to 79 percent.

Figure 6: Data from the fire simulations that encountered or were limited by landscape fuels treatments while burning. In contrast with sites not affected by DFPZs, these ignitions should be strongly affected and there should be a big difference between treatments for each weather scenario.

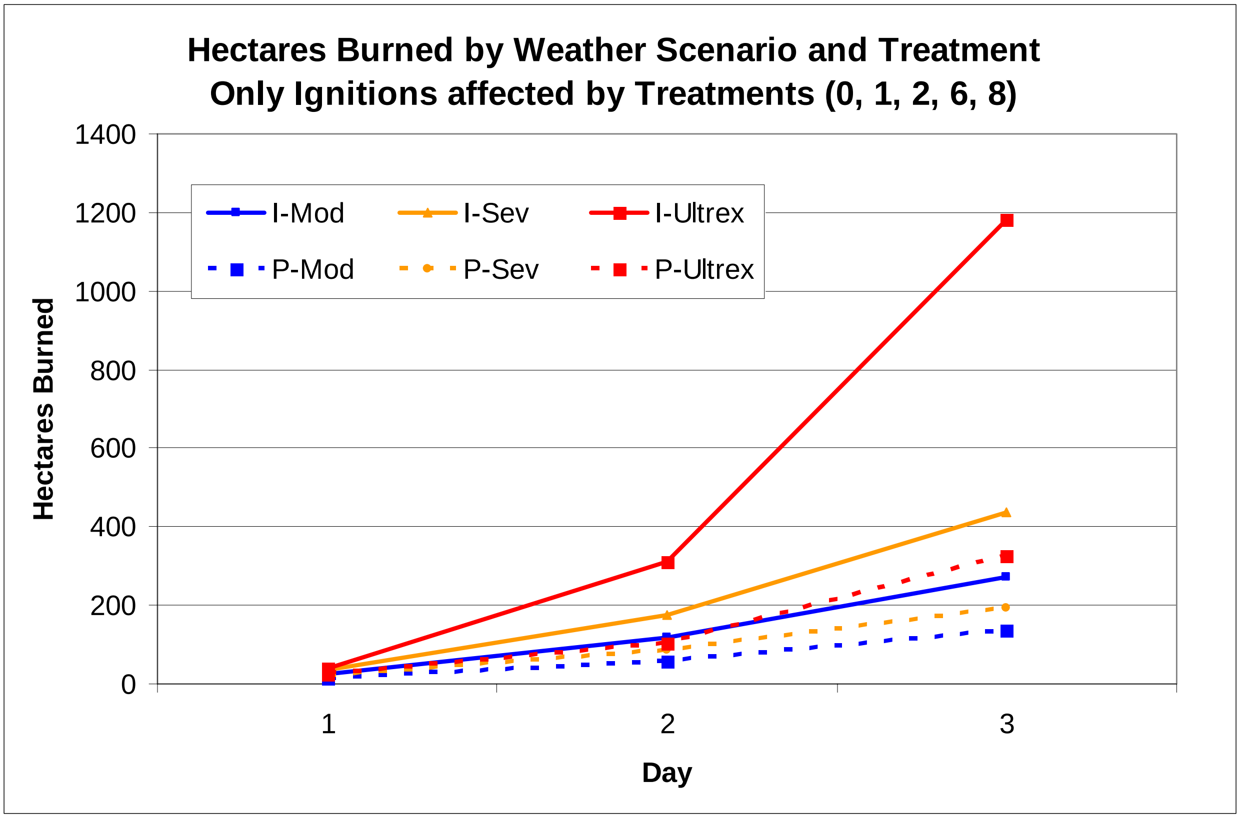
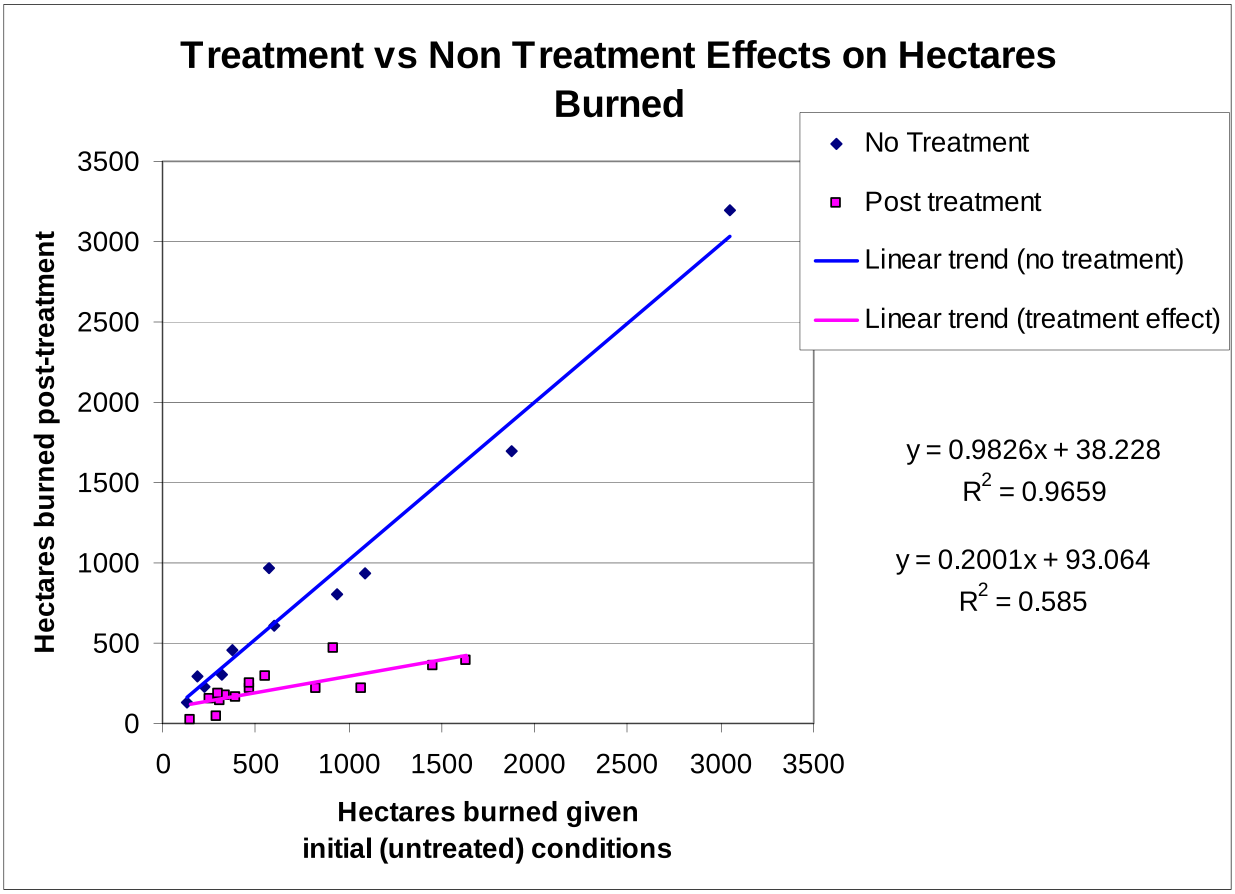


Table 6: Data collected from the set of simulated fires that were affected or contained by DFPZs while burning. Simulations cover three weather scenarios—moderate, severe, and extreme with enhanced winds—and two treatment conditions—pre-treatment and post. Fire area and perimeter are measured in surface rather than planimetric (horizontal) measurements. Fire counts (“Fires”) and spot fires (“Spots”) are simple tallies of the total number of fires occurring as well as the number of spot fires initiating outside the active perimeter.

| Fire Status | | Initial pre-treatment scenarios | | | | Post-treatment scenarios | | | | % change | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weather | Day | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots | Area | Perim | Fires | Spots |
| Moderate | 1 | 25 | 6 | 53 | 11 | 15 | 4 | 26 | 6 | -40 | -33 | -51 | -45 |
| | 2 | 118 | 21 | 208 | 22 | 58 | 9 | 56 | 3 | -51 | -57 | -73 | -86 |
| | 3 | 272 | 34 | 329 | 25 | 136 | 17 | 129 | 7 | -50 | -50 | -61 | -72 |
| Severe | 1 | 37 | 10 | 101 | 24 | 20 | 5 | 44 | 6 | -46 | -50 | -56 | -75 |
| | 2 | 174 | 30 | 267 | 25 | 85 | 14 | 108 | 7 | -51 | -53 | -60 | -72 |
| | 3 | 435 | 59 | 609 | 48 | 194 | 27 | 194 | 6 | -55 | -54 | -68 | -88 |
| Extreme + winds | 1 | 38 | 11 | 117 | 27 | 24 | 6 | 56 | 10 | -37 | -45 | -52 | -63 |
| | 2 | 311 | 80 | 1018 | 123 | 104 | 24 | 205 | 14 | -67 | -70 | -80 | -89 |
| | 3 | 1182 | 231 | 3168 | 378 | 327 | 66 | 734 | 79 | -72 | -71 | -77 | -79 |

If there is no treatment effect, an XY graph of pre- and post-treatment hectares burned should be a straight line with a slope of 1. In Figure 7, we contrast the two groups of fire simulations—those affected by DFPZs and those not. As predicted, the no-effect group has a slope near 1 (0.98). In sharp contrast, in scenario pairs affected by the fuels treatments, the line is nearly flat (slope 0.20): ignitions that led to large fires before treatment grew only into much smaller fires after treatment. Total suppression would yield a post-treatment slope of 0. The larger the difference between pre- and post-treatment trend lines, the stronger the effect of the treatment.

Figure 7: Comparison of hectares burned before treatment (horizontal axis) and after (vertical). A positive treatment effect is shown by a flattening out of the line to the horizontal. A line with slope of 1 indicates there is no change in fire behavior as a result of treatment. The blue / no-treatment line approaches a slope of 1, as predicted. The pink line mapping fires limited by DFPZs indicates there is a large reduction in fire size for all fires that encounter a treated area.




# Discussion

## Analysis

As expected, installation of landscape-scale fuel breaks (DFPZs) significantly reduced the extent of the overall fire as well as the numbers of individual fires and spots. Contrary to expectation, however, DFPZs had the largest effect on fires burning in extreme conditions with enhanced winds. Because the DFPZs had been designed to reduce the spread of fire, particularly crown fire, at the 90$^{th}$ percentile, it had been expected that they would “fail” in extreme conditions. In contrast, these landscape fuels treatments provided the largest benefit under the most extreme conditions and with the largest fires (Figures CC and EE, Table 6). Fires burning under extreme with enhanced winds conditions experienced proportionately greater benefit from DFPZ treatments even if the treatment was designed for the 90$^{th}$ percentile. All measures of fire extent were reduced by at least 70% after three days of burning (Table 5).

As a check, we confirmed that simulations with landscapes where DFPZs did not affect fires during the burning period showed little to no change between the pre- and post-treatment scenarios. Only the random nature of spot fires led to some higher fire metrics after 3 days (Figure 5, Table 5).

From these results we draw the conclusion that impeding the spread of fires with a landscape fuel treatment is more important than changing the on-site conditions of how fire would behave if it got to a site. In short, these data suggest that it is better to prevent fires in extreme weather from getting to a site than engaging in fuels reduction at that site itself. To do this, landscape fuel breaks need to be created and distributed prior to fire.

***Comments on the remote sensing, fuels mapping and fire modeling***

The fine-grain modeling effort itself is promising. Instead of characterizing a landscape as being divided up into homogenous polygons with clean breaks between then, this approach leads to a more realistic intermix of grass, chaparral and forest, or other vegetation and fuel types. In reality, fuels certainly vary significantly at a fine scale like this (Menning 2003). Further, the approach allows us to dispense with the unrealistic approach of creating impermeable fire breaks where roads and streams are located. Forest Service roads may block ground fire spread, but forest canopy may actually reach across the roads providing connectivity in extreme fires. In reality, these breaks resist the spread of fire rather than entirely stop it—

particularly under extreme conditions. Our method results in various degrees of permeability across streams and roads due to the fine grain nature of the imagery.

***Future directions***

We would like to extend this top-down supervised classification fuel mapping approach to a bottom-up, field data-driven approach. A fuels map built from extensive field data would be even more powerful. Such an approach would have more detailed data on crown base and total heights, and canopy cover.

The results here suggest that comparing different landscape fuels treatment approaches—DFPZs as well as strategically placed landscape area treatments, or SPLATs (Finney 2001; Stephens and Ruth 2005))—would be a good way to compare their efficiency in modifying fire behavior. Our remote sensing and modeling approach allows us to create any post-treatment landscape for comparison with current conditions.

Further simulation approaches could include expert-opinion driven suppression efforts. Indeed, DFPZs are intended not only to reduce fire intensity, severity, rate of spread, and occurrence of crown fire, but to allow safe access for fire crews to engage in suppression. Now that we are beginning to understand the physical behavior of fire under these different weather and treatment scenarios we can begin considering the role of human intervention. Having results indicating that landscape fuels treatments can positively modify fire behavior— even in extreme weather conditions—is critical for any such modeling or planning effort.

# Acknowledgements

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# Publications and Presentations 2005-8

- Menning, K.M., and S.L. Stephens (2008: draft complete, being submitted to Landscape Ecology). "Potential forest fire behavior as a function of three weather scenarios and two landscape fuels treatments based on a fuels and vegetation landscape derived from fine-grain IKONOS satellite imagery, Sierra Nevada (USA)." Draft being submitted to Landscape Ecology.

- Menning, K.M., and S.L. Stephens (2007) Fire Climbing in the Forest: a semi-qualitative, semi-quantitative approach to assessing ladder fuel hazards, Western Journal of Applied Forestry.

- Menning, K. M. and S. L. Stephens (2006). Modeling Landscape Fire Behavior and Effects in the Northern Sierra Nevada. 3rd International Fire Ecology and Management Congress, San Diego, CA.

- Menning, K. M. and S. L. Stephens (2006). Landscape-scale Fire Risk Wildlife Habitat Considered Jointly. 21st Annual Symposium of the United States Regional Chapter of the International Association for Ecology (US IALE), San Diego, CA.

- Menning, K. M. and S. L. Stephens (2006). Assessing Ladder Fuels in Forests. 3rd International Fire Ecology and Management Congress, San Diego, CA.

- Menning, K.M., and S. L. Stephens (2005) “Fire rising in the forest: Ladder fuel hazard assessment using a mixed qualitative and quantitative approach,” Ecological Society of America, August 7-12, 2005, Montreal Canada. (Abstract attached to end of report).

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Linking fire and wildlife habitat in California: Spectral entropy canopy diversity analysis*. UK Centre for Ecology and Hydrology, Monks Wood, Cambridgeshire, England, UK. November 21, 2005.

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Spatial Ecological Links Between Fire, Forests and Habitat in the Plumas-Lassen Administrative Project*. Geographic Information Centre Seminar: City University, London, London, England UK. November 22, 2005.

- Menning, K. M. and S. L. Stephens (2005). (Invited speaker:) *Forest Structural Diversity: Spectral Entropy Canopy Diversity Analysis*. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland. December 5, 2005.

## Goals for 2008

Having collected the field data, processed the remote imagery and having completed fire modeling, we are ready to conduct additional modeling exercises with SPLATs and other treatments, as well as suppression. Also, we would like to initiate the integrative modeling of fire and habitat scenarios with John Keane and the owl.

## Expected Products (Deliverables)

In addition to the above goals, results will be published regularly in the Plumas-Lassen Administrative Study Annual Reports. We will present results directly, as they are derived, to interested parties. More formal scientific publications are targeted covering a variety of areas including a validation of the LaFHA approach being piloted in this study that was published in 2007, performing SpECDA analyses of forest structure and its variability, fire behavior and effects, integrated model results with the Owl Module, and assessments of the efficiency of DFPZs and other treatments in moderating the landscape-level effects of fire.

## Additional Publications Planned for 2008

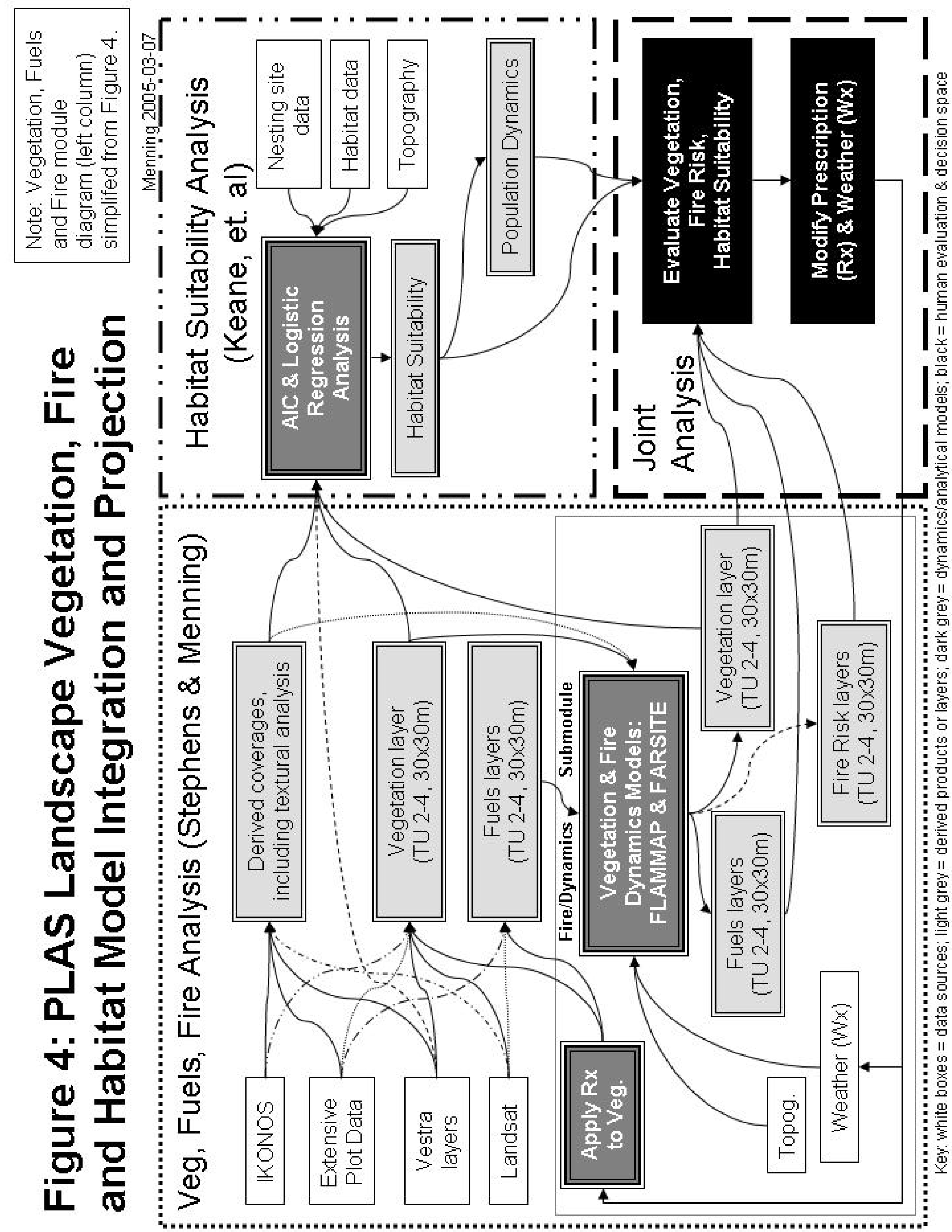
- Menning, K. M. and S. L. Stephens. "Spectral Entropy Canopy Diversity Analysis (SpECDA) used to Assess Variability in Forest Structure and Composition" to be submitted to Photogrammetric Engineering and Remote Sensing.
- Menning, K. M., S. L. Stephens, J. Keane, D. Kelt, and others. "Integrated modeling of fire and California Spotted Owl habitat conditions given different weather and landscape treatment scenarios" <u>To be submitted to a journal mutually agreed upon</u>.
- Menning, K. M. and S. L. Stephens. "Fire Behavior and Effects as a Result of Defensible Fuel Profile Zones" <u>To be submitted to International Journal of Wildland Fire</u>.
- Menning, K. M. and S. L. Stephens. "Landscape Forest Variability across the Northern Sierra Nevada" <u>To be submitted to Landscape Ecology</u>.

Additional publications based on analysis of the field data, remote sensing products, and results of integrative modeling with Keane.

## Data Management and Archiving

All data will be archived with the USDA Forest Service's Sierra Nevada Research Center (SNRC) in Davis, California, as well as the Fire Science Lab (Stephens Lab) at the University of California, Berkeley. Some derived products will be put on-line by the SNRC or Stephens Lab.

## Appendix A: Model integration with California Spotted Owl team (Keane)



## Appendix C: Budget projections: Proposed budget 2008

# Landscape Fuel & Fire in the PLAS

10/13/06

**PI: Dr. Scott Stephens**

**Postdoctoral coordinator: Kurt Menning**

| Item | | FY2006-7 Budg. request |
|---|---|---|
| **Salaries and Benefits** | | |
| | Principal investigator (Stephens 0.5 months) | 4,191 |
| | Benefits, 25% | 1,048 |
| | | |
| | Postdoc (Menning: 1.0 FTE) | 43,000 |
| | Benefits, 23% | 9,890 |
| | | |
| | Undergrads (0): full time summer | 0 |
| | Benefits, 5% | 0 |
| | Assistant for academic year (1.0) | 29,000 |
| | Benefits, 23% | 6670 |
| | **Total Salaries & Benefits** | **93,799** |
| | | |
| **Rent, Communications, Utilities** | | **0** |
| | Forestry camp operations | |
| | | |
| **Travel** | Per diem | 500 |
| | Rental vehicles, gas | 500 |
| | Fire modeling & training expenses | 0 |
| | Conference travel | 3,000 |
| | **Total travel** | **4,000** |
| | | |
| **Contractual Services** | | |
| | Imagery | 0 |
| | Software processing and licensing | 500 |
| | **Total contractual services** | **500** |
| | | |
| **Materials and Supplies** | | |
| | Lab supplies | 500 |
| | Field supplies | 0 |
| | Computer equipment | 500 |
| | **Total materials & supplies** | **1,000** |
| | | |
| **Overhead: indirect costs to UCB (0%), USDA Coop** | | 0 |
| | | |
| **Annual Funding requested for year** | | **99,299** |

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