Predicting Post-Fire Severity Effects in Coast Redwood Forests Using FARSITE

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***Abstract**—Assessing post-fire impacts in coast redwood (Sequoia sempervirens) forests can be difficult due to rough terrain, limited roads, and dense canopies. Remote sensing techniques can identify overstory damage, locating high intensity damage areas, although this can underestimate the effects on the understory vegetation and soils. To accurately assess understory impacts requires field assessment techniques, which can be expensive for larger burn areas. Where geospatial data for fuels and topography can be combined with weather data using FARSITE, a fire behavior simulation model, landscape fire behavior predictions can be made. Fire behavior outputs can be generated to produce a post-fire predicted landscape map of fire severity. The 2003 Canoe fire burned 4,000 hectares, primarily in old-growth redwood forests in Humboldt County, California. Post-fire sampling of burn impact was assessed using the Composite Burn Index methodology and found to be unrelated to FARSITE produced fire behavior variables using regression analysis. This finding is understandable because basic FARSITE landscape data available for this fire lacked fuel load information for post-combustion analysis. The Canoe Fire had a slow rate of spread, and with the deep fuel beds present; long duration burning was observed. Fire severity, as described by the Composite Burn Index, was greatest in the forest understory. FARSITE was a useful projection tool for perimeter advance and flame lengths associated with the fire front.*

Introduction

The short-term effects of wildfire on vegetation, soils, wildlife, and watersheds are poorly understood in the coastal redwood [*Sequoia sempervirens* (D. Don) Endl.] forests of northern California. The September 2003 4,575 hectare, (11,214 acre) Canoe Fire, ignited by lightning in Humboldt Redwoods State Park, provided a rare opportunity to better understand the mixed effects of fire following logging and over a half century of fire exclusion in old-growth and second-growth forests.

Assessing post-fire impacts in coast redwood forests can be difficult due to rough terrain, limited access, and dense canopies. Remote sensing techniques can identify overstory damage, locating high intensity damage areas, although this can underestimate the effects on the understory vegetation and soils. To accurately assess understory impacts requires field assessment techniques, which can be expensive for larger burn areas.

Where geospatial data for fuels and topography can be combined with weather data using a fire behavior simulation model, landscape fire behavior predictions can be made. Fire behavior outputs can be generated to produce a post-fire predicted landscape map of fire severity.

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Methods

The 2003 Canoe fire started in Humboldt Redwoods State Park in Humboldt County, California, burning primarily old-growth and young-growth redwood forests. Stand species included coast redwood, Douglas-fir (*Psudeotsuga menziesii)*, and tanoak (*Lithocarpus densiflorus*) in the overstory. Understory species included suppressed redwood, tanoak, huckleberry (*Vaccinium* sp.) and *Oxalis oregana*. The burn included unlogged old-growth areas, partially logged areas with a residual old-growth component, and previously logged areas that have stands of 60 to 100 year young-growth. A field based fire severity assessment was completed 9 months after the burn using the Composite Burn Index Methodology (FIREMON 2003) and was used to calibrate a map of the fire effects based on remotely sensed data. We tested the prediction ability of the FARSITE (Finney 2004) fire simulator to produce a similar map.

CBI Analysis

An initial fire severity map was created using a remote sensing approach. Pre- and post-fire IKONOS imagery (2002 pre-burn versus 2004 post-burn) was visually compared to delineate fire severity boundaries. Oblique imagery taken after the fire from a helicopter in December 2003 was used to validate three established severity classes. Severity classes were defined as: low with no visible change to the canopy; medium with <50% canopy loss; and high with a >50% loss. The minimum mapping unit was approximately 5 acres and boundaries were drawn with heads-up digitizing.

The forests of the burned area were classified into one of three community types (alluvial redwood, slope redwood and Douglas-fir forests), two management histories (old-growth or second growth stands), and two fire severity types based on observations of canopy conditions, with low representing green canopy conditions, and high with canopy mortality. This design created a factorial of 12 stand types and five replicate plots that were assigned at random using a GIS application. One type, old-growth alluvial high severity did not exist and therefore was excluded. As a result, 55 plots were installed and utilized for comparisons.

The Composite Burn Index (CBI) is a field technique developed by the interagency FIREMON program to identify and quantify fire effects over large areas. FIREMON is designed for repetitive measures. We applied the CBImethodology during the summer of 2004, nine months post-burn in 0.04 hectare (0.1 acre) circular plots. Characteristics were related to individual strata and scores averaged for the whole plot. The strata consisted of a) substrates or soils, b) herbs, low shrubs and small trees < 1 meter tall, c) tall shrubs and saplings 1< 5 m, d) intermediate and subdominants trees, and e) the dominant trees. The color and condition of the soils, the amount and quality of the fuels and vegetation consumed, the regeneration post-fire, the establishment of new seral species, and blacking, scorching and torching of the trees was evaluated.

We used the field data to calibrate or validate the remote sensing results. Our results are presented as an average of the scores for 1) total plot (i.e. all strata) 2) overstory (i.e. only the dominant tree stratum) and 3) understory (i.e. soil to vegetation <5 m tall). The CBI produces a score on a 0-3 basis with 3 as extremely high severity.

NCSS was used to analyze the data using ANOVA and means separation was performed with Fisher's Protected LSD.

FARSITE Analysis

FARSITE is a spatial fire behavior simulation system. The base landscape data was created at the Northern California Geographic Area Command Center, Redding, California in September 2003, and was used during the fire to predict short and medium range fire growth. Slope, aspect, and elevation data are derived from 30-meter resolution USGS Digital Elevation Models. The fuel model layer was derived from the California Department of Forestry and Fire Protection's Forest and Rangeland Assessment Program remote sensing data. Crown canopy values were estimated by H. Scanlon during the fire. No fuel loading data for post-frontal combustion analysis was available.

Weather data for analysis are derived from the nearby Eel River Remote Automated Weather Station (RAWS) and a portable RAWS.

The Eel River RAWS was used hourly for all wind data. The portable RAWS was deployed in the fire area from September 23 to October 1. These stations were used to develop the diurnal cycle of maximum temperature—minimum relative humidity, minimum temperature—maximum relative humidity for the fire.

In the early stages of the fire, perimeter data was estimated visually by aircraft and are therefore sparse and imprecise,. No CBI data sample plots were within these initial fire areas. As the fire increased in size, fire perimeters were determined primarily using helicopter mounted thermal imaging technology. Usually only one perimeter was generated at the end of each flight day. The daily fire perimeter was used as an ignition starting point for FARSITE, and the burn was projected for at least 48 hours. Initially, a 6 hour daily burning period was used since the fire advance was initially slow. This was extended to a 10 hour active burning period by the second week of the fire. Additional ignition was added where perimeter conrol firing operations are known to have been used and actual fire advance was not reasonably predicted by model.

Where the fire was projected to advance, FARSITE predicted the following values for each 30 m x 30 m raster cell: time of fire arrival from run initiation; rate of spread; flame length; fireline intensity: heat per unit area. Raster output from FARSITE was imported to ESRI ArcMap for compilation and analysis. For each overlapping CBI sample site and FARSITE raster cell, the resulting fire behavior values were evaluated against the corresponding fire intensity for the understory, overstory, and combined CBI values using linear regression (Microsoft Excel 2003).

Results and Discussion

The Canoe fire produced a complex mosaic of fire effects, with the majority of the burned area classified as low or low-moderate severity, based on remote and field calibrated data. Results of the remote evaluation (Ikonos imagery and aerial photos) were well correlated with the field established CBI ratings for the overstory, but significantly under-estimated the fire severity observed in the understory. The Canoe Fire had a slow rate of spread, and with the deep fuel beds present, long duration smoldering burning was observed. Some patches of high severity effects were observed along the ridges where fire intensity was the greatest.

Since fire severity was under-estimated in all but the high severity areas using remote sensing, modeling the fire using FARSITE had some potential to provide better prediction for these sites. As applied, FARSITE only modeled the advancing fire front, not the long duration burning following the front's passage.

The Composite Burn Index (CBI) results were found to be unrelated to FARSITE produced fire behavior variables using linear regression analysis. The FARSITE outputs of fireline intensity, flame length, heat per unit area, rate of spread, and reaction intensity were poor predictors ($r^2 < 0.10$) and not significant for field derived understory, overstory, and combined CBI values.

Knowing that the longer these models project into the future, the more inaccurate they become, we reassessed our data to use only those CBI plots where the fire arrived within 48 hours, then 24 hours of the run initiation. The linear regression fit did not improve substantially. Review of scatter plot diagrams did not suggest improvement by using transformation functions (Figure 1).

Finding the fire behavior outputs as unrelated to the CBI results is understandable because the basic FARSITE landscape data lacked fuel load information for post-combustion analysis. The fire burned for a long time after the passing of the fire front, which we were unable to model. FARSITE was a useful projection tool for perimeter advance and flame lengths associated with the fire front.

Several additional factors contributed to the poor correlation of fire intensity predictions to field observations. Fire perimeters were usually determined between 1900 and 2100 hours for any given day, generally near the end of the active burning period. The next day's projected progression did not begin until 1100, about 14 hours after the last known fire location. In this area, two

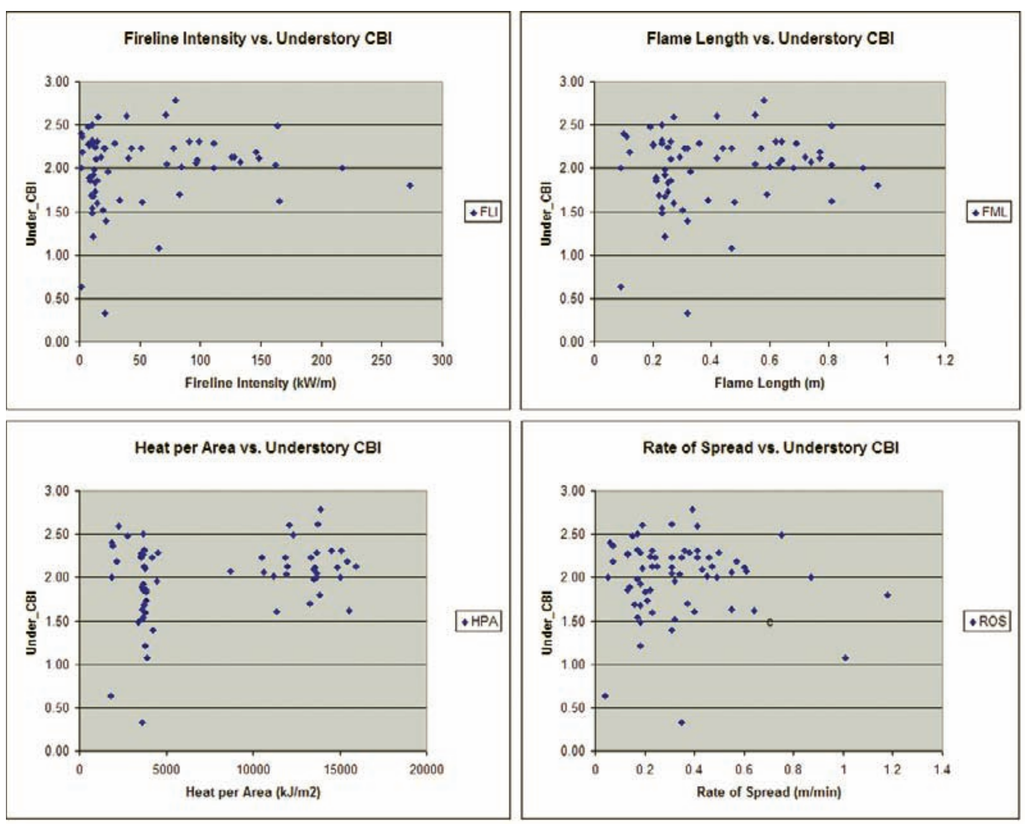

Figure 1—Scatter plot diagrams of fire behavior output versus understory CBI values.

separate burning periods were observed – one during peak fire conditions, and a second beginning at 0100 hours for the upper slopes. The FARSITE simulator is not designed to handle a two-burning period situation, since it relatively uncommon.

Fire control actions also influenced the burn response. In most areas, control lines were established, followed by a firing operation to blacken in the perimeter prior to the arrival of the main fire. We attempted to include these operations in the modeling. However, the records were sparse for when and where these actions were taken and may not have been applied at the correct time or date. Aerial ignition spheres were also used in the fire control operation to accelerate interior burn out in some areas. Higher severity was observed in some of these areas (southeastern portion of the fire) than were predicted by the model.

Differences in winds were not likely a major factor. The dense canopy cover tends to reduce the wind effect in most burn areas. Winds only had substantial effects on exposed ridgelines. Those areas were not used in the CBI assessment. Other error may have been introduced in determining and mapping CBI plot locations (plots landing in the wrong raster cell), and inaccurate assessment of fuel models. However, fuels, topography, and weather did not vary substantially within the immediate area of a plot in either the field, or as modeled. Post-fire vegetation was assessed in the FIREMON process, challenging the accuracy of the remotely sensed fuel model data.

Conclusions

With improved pre-fire data we believe that FARSITE could assist in predicting the landscape effects of fire. Additional research and fuel load data is needed to produce better modeling. Users are cautioned to have a good understanding of model limitations before applying the results. Predicting understory impacts of fire across large areas will remain a challenge without improved remote sensing techniques.

Acknowledgments

We are grateful for the funding provided by Save-the-Redwoods League and for the project assistance provided by Humboldt Redwoods State Park.

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Microsoft Excel 2003 Statistical functions.