A fire severity mapping system for real-time fire management applications and long-term planning (The FIRESEV project)

Subtask 4 – Develop Fire Severity Keys
(Classification of fire severity from first-order fire effects using computer-simulated burns)

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Introduction

As prescribed fires become important fuel-reducing agents and wildfires consume an average of six million acres each year, it is increasingly important to develop models that can predict fire severity and the fire effects that may result from burning available fuels. Even though decades of fire suppression have caused fuels to buildup and fire regimes to change, on-site fuels and moisture condition are still the most practical tools that scientists and managers have to estimate how much damage a prescribed fire or wildfire might do to a landscape or ecosystem. Currently, there is no widely-accepted, standardized, objective measure of fire severity based on available fuels. Fire severity is used as a general term for the degree of environmental change caused by fires or as a specific loss of organic matter or biomass above and below ground that is caused by the burning process (Keeley, 2009; NWCG, 2006). Fuel consumption, soil temperature, fire temperature, and fire duration are all fire effects that affect organic matter and biomass. Each of these factors affects biotic and abiotic elements in a landscape or an ecosystem. What is needed is a classification system that predicts fuel consumption, fire intensity, burn time, and/or soil heating using the available fuels and moisture conditions. Classifying fire effects using these basic components will enable scientists and managers to estimate the severity of prescribed burns or create a concrete plan to reduce fuels before wildfire episodes. It is also crucial to proactive planning, setting realistic restoration goals in burned areas, and preserving or maintaining landscapes and ecosystems that are extremely sensitive to fire. The first step toward developing a predictive model from available fuels is to develop a classification of burn severity that captures the range of fire effects that can result from burning thousands of fuel beds under a range of moisture conditions.

In this study, a burn severity classification is created that links fuels with consumption, moisture conditions, physical energy produced by the fire (fire intensity), and the temperature effects on the soil. Thousands of fuel beds are burned under ten moisture scenarios using computer simulation, which insures that the classes created for this classification system encompass a wide range of fuel bed compositions and burning conditions.

Background

Several classification systems have been proposed to describe burn severity after a fire (Bradley et al., 1992; Brown & DeByle, 1987; Ryan & Noste, 1985; Schimmel & Granstrom, 1996; Tarrant, 1956; Wells et al., 1979). Each is limited in application because it does not objectively relate a physical measure of intensity during a fire to quantified effects produced during the burning of known fuel loads. All of the classifications are relative determinations based on human judgments of severity that are made after a fire is over and depend on the experience and impressions of the individuals assessing the respective burn effects. In British Columbia, two severity classifications have been developed that use quantitative measures. One uses a measured depth of burn to assign burn severity (Feller, 1998). The other uses depth of burn and duff/slash consumption to rate severity (Trowbridge et al., 1989). Like the subjective classifications, the British Columbia severity classifications are assigned after a burn. They use only one or two fuel types to create the classification or represent only prescribed-burn conditions, and they suffer from the same drawbacks as more subjective classifications. None of the classifications are based on the range of fuels that would commonly be found in forest or grassland ecosystems. None relate fire intensity achieved during a burn directly to its fire effects. None can be used as predictors of how severe a fire might be and none has become widely used by fire managers.

PROJECT OBJECTIVES

This project has three general objectives:

- To develop a burn severity classification based on on-site fuels and the fire intensity values that result from burning those fuels
- To describe the relationships between available fuels, fuel-moisture content, and soil heating
- To validate the classification categories using classification and regression procedures

MATERIALS AND METHODS

Two data sets will be used to create a classification of burn severity. The first data set is compiled from actual field samplings of fuels. The second data set is computer-generated with each fuel bed consisting of randomly generated values for each of seven fuel components. The computer model used to simulate burning is the First Order Fire Effects Model (FOFEM) (Reinhardt & Keane, 1998).

Data sets

The actual data set consists of fuel-load data collected from a combination of (a) literature searches and (b) actual fuel sampling from over 4,000 locations across the United States. The data set was originally compiled by Lutes and others (in press) to construct a classification of fuel loading models for fuel beds in the United States. Because this data set is derived from actual fuel sampling, it provides realistic inputs for FOFEM's soil-heating module in computer simulations of burning. The fuel beds from the actual data set are composed of the following fuel components that vary in proportion within each fuel bed:

- 1 hour – <1 cm (0.25 inch) diameter
- 10 hour – 1-2.5 cm (0.25-1.0 inch) diameter
- 100 hour -- 2.5-7 cm (1-3 inch) diameter
- 1,000 hour solid – 7-50 cm (>3 inch) diameter
- 1,000 hour rotten – 7-50 cm (>3 inch) diameter
- Litter
- Duff
- Herbs
- Shrubs

All values for the woody debris fuels, litter, and duff vary in the data set as per actual sampling. However, constant values were assigned to the herb, shrub, crown foliage, and crown branch components for the fuel loading model classification. These values are 0.23, 0.35, 2.8, and 0.28 T $acre^{-1}$, respectively.

The second data set consists of computer-generated fuel beds. Values for the woody debris, litter, duff, and vegetation cover are randomly assigned and then assembled into a synthetic fuel bed. The overall limits for the randomly-generated values are at least twice the maximum values that each component has in the actual data set, which allows for fuel beds that might exist in the field but may not have been captured by the actual sampling. The lower limit for litter and the upper limit of duff are set by FOFEM itself. The values for each fuel component are randomly generated between predetermined limits so that the fuel values for each component cover the full range between zero and twice its maximum value in the actual data set. The pre-determined intervals are comparable to the values of each component in the fuel loading models of Lutes and others (in press). However, extra intervals are added on the upper end of the fuel loading model limits to least double the range of each component in the synthetic data set compared to the actual data set. The seven random values for each component are combined into a fuel bed, which is submitted to FOFEM for burning. Tertiary diagrams are used to compare the proportions of compositions in the total data set of actual beds with the proportions in the total data set of synthetically-created fuel beds to ensure that the synthetic fuel beds cover many more fuel bed possibilities than the actual fuel bed samplings do. Although the possibilities to generate synthetic fuel beds are endless, a balance needs to be struck between creating thousands of fuel-beds, creating many of the same types of fuel beds that burn similarly, and creating too many fuel beds to analyze within the confines of current statistical programs. This balance will take some experimentation to achieve a robust, but manageable, synthetic data set.

Simulation burns

At this time, FOFEM v.5 is the only computer program that computes soil heating and duration within burn simulations. The program does not, however, make the heating or duration values readily accessible to the user so some program adjustments have been made for this study. Adjustments to programming code include output intensity and soil heating values in a columnar format that can be imported into a statistical program for analyses. The modified version also outputs several new burn intensity and soil heating values that are not currently computed in FOFEM 5.0 including a maximum fire intensity value for each stand, a sum of fire intensities through all steps of the BURNUP portion of FOFEM, the maximum soil temperature values for 0-10 cm depths, the start and end times for each soil layer (0-10 cm) when temperatures are above 60^{o}C, the amounts of each fuel type consumed by the burn, and a flag that indicates a short fire duration with minimal soil heating.

Both the actual and synthetic fuel beds will be “burned” in FOFEM using 10 moisture scenarios. These moisture scenarios have been compiled from suggestions and information on fire moisture conditions during prescribed burns and wildfire fire supplied by fire managers in the Midwest, Northeast, Florida, and the Rocky Mountain West. The 10 moisture scenarios are summarized in Table 1.

Table 1: Moisture Scenarios for Burn Severity Classification Project.
(10H = 10 hour fuels; 1000H = 1000 hour fuels)

Moisture Scenario Name	10H Moisture	1000H Moisture	Duff Moisture	Soil Moisture
A	4	10	20	5
B	4	20	125	5
C	6	15	50	10
D	8	20	100	15
E	8	75	75	20
F	8	25	175	25
G	10	15	40	10
H	10	20	100	15
I	10	20	175	25
J	12	40	35	20

Data storage and analysis

Data from the original data sets and the outputs from each simulated burn in FOFEM will be stored in a single database. From the database, appropriate variables will be exported to statistical and graphing programs to explore the data, make graphical comparisons, and run statistics for cluster analysis. At a minimum, graphical plots will be made of data ranges for each original fuel component; the relationships between (1) original fuel totals vs. sum of fire intensity, (2) fuel consumption vs. depth of burn, (3) fuel consumption vs. sum of fire intensity, (4) fuel consumption vs. median intensity and (5) fuel consumption/original fuel vs. intensity vs. depth of burn; and the groupings from cluster analysis.

Data from both the actual and synthetic data sets will be subjected to non-hierarchial (k-means) clustering and partitioning around medoid (PAM) cluster analysis using depth of burn, fuel consumption, and one or more intensity as the analyses variables. With k-means clustering, the number of groups can be specified and the analysis will seek the optimum structure for that number of groups in each data set. However, user designation of the number of classes may not be totally objective, so an analysis with PAM may better indicate the optimal number of classes. With PAM, the clustering technique is more robust than k-means and the fit of the data using specified numbers of classes can be evaluated using silhouette diagrams created during the clustering process. The burn-severity classification will be made using the cluster groupings from the method that seems most appropriate. The cluster analyses will be done using the statistical packages with the R program.

Validation procedures

Validation of the classification groups will be conducted on the final classification using classification and regression trees (CART) to develop keys that uniquely identify each developed class. After the cluster analysis identifies groups, CART uses predictor variables test how well the variables identify groups, and a tree is created to optimize the classification. CART will also be run using the R statistical package.

PROJECT SCHEDULE

This study will be completed by June, 2011, including simulated runs, analyses, classification validation, and preparation of two manuscripts.

BUDGET

This project is a sub-task under the FIRESEV project funded by Joint Fire Science Program of the Bureau of Land Management. Salary for P. Sikkink will come from this project.

DELIVERABLES

This project will result in several products that will be useful to managers that are responsible for fire management in many government agencies. Excepting the normal publication delays, all deliverables will be available at the conclusion of the study.

- A classification scheme for burn severity
- A comparison of the simulation classifications with burn severity classes currently in use (International Journal of Wildland Fire/ Canadian Journal of Forest Research).

TECHNOLOGY TRANSFER

Technology transfer will include:

- Publication of classification structure in IJWF or CJFR
- Publication of a comparison of this classification method with other burn severity classifications in IJWF or GTR

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