Mapping the Potential for Severe Fire in the Western United States

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INTRODUCTION

With extensive areas burned in recent decades and the potential for large, severe fires increasing (NWCG 2009), fire managers and others need accurate, efficient, and economical methods to assess the severity of a fire at landscape scales (Brennan and Hardwick 1999, Lentile et al. 2006). Knowing where and under what conditions fires are likely to burn severely could help fire managers and natural resource managers make effective decisions before, during and after fires. Such decisions include assessing the effects of fire and mitigating damage through rehabilitation activities such as reforestation, erosion control, invasive weed treatment, and habitat restoration (NWCG 2003), as well as where to focus fuels management, fire suppression, and fire use and how to manage costs and benefits as part of strategic fire management (NWCG 2009). Fire severity mapping tools and technologies are critical for 1) identifying where and when fires may burn severely, 2) facilitating enlightened wildfire management, and 3) strategically implementing costly rehabilitation and restoration efforts (Lachowski *et al*. 1997; Eidenshink *et al.* 2007).

Burn severity refers to the ecological effects of fires (Lentile et al. 2006) and more specifically to the loss or decomposition of organic matter both aboveground and belowground (Keeley 2009; Keeley et al. 2008). Indicators of burn severity should be ecologically meaningful, measureable in the field and remotely from air or satellite, and readily interpretable (Lentile et al. 2006; Hudak et al. 2007). Ideally, they will be useful in describing ecosystem recovery, including vegetation, carbon, water and nutrients (Lentile et al. 2009). Often we seek to map burn severity from satellite imagery, such as Landsat, in order to get rapid, consistent evaluation across large areas. Burn severity is often inferred from satellite imagery such as Landsat TM data using Normalized Burn Ratio (NBR) (Key and Benson 2006, Roy *et al.* 2006). The NBR is usually differenced across pre- and post-fire TM scenes to create a dNBR, and this can be calculated relative to pre-burn NBR to obtain RdNBR (Miller and Thode 2007). Burn severity maps often include unburned, low, moderate and high severity classes (Lentile et al. 2006). The thresholds between classes are often adjusted using field data such as Composite Burn Index (Key and Benson 2006). dNBR and RdNBR do effectively measure the relative degree of vegetation and soil char between pre- and post-fire conditions (Smith et al. 2005; Lentile et al. 2007, Hudak et al. 2007), and they have been related to one-year post-fire vegetation cover in many studies (but relatively few long-term studies).

Powerful new statistical models combined with extensive historical burn severity data provided by the Monitoring Trends in Burn Severity (MTBS, http://mtbs.gov) program provide an opportunity to infer potential severity for future fires from an understanding of recent fires. Holden et al. (2009) used a 20-year database of burn severity data for the Gila National Forest coupled with topographic and biophysical predictor variables derived from Digital Elevation Models. They found that using the Random Forest machine learning algorithm (Brieman 2001) classified burn severity data with an accuracy of greater than 80%. This statistical model was then used to develop a predictive burn severity map for unburned areas of the Gila National Forest. A preliminary analysis of topographic and biophysical drivers of burn severity using MTBS data from across the Pacific Northwest found that by carefully sampling burn severity data and topographic variables, it is possible to map the occurrence of high severity fire with greater than 70% accuracy (Holden et al. *In Preparation*). These results demonstrate that the predictive models developed for the Gila NF can also be developed for other regions of the western US.

This research is a part of a larger project funded by the USDI/USDA Joint Fire Science Program (JFSP project number 09-1-07-4). The Fire Severity Mapping System project is geared toward providing fire managers across the western United States with critical information for dealing with and planning for the ecological effects of wildfire at multiple levels of thematic, spatial, and temporal detail. It will provide fire management a comprehensive set of methods to develop a wide variety of fire severity maps. These will become part of a fire severity mapping system that will integrate with currently available burn severity mapping products (e.g., BARC, MTBS) to provide fire management with a suite of spatial fire severity data products when they are needed. In this larger project, the Fire Severity Mapping System for the western United States will be designed so that it could easily be expanded across all 50 states sometime in the future when input data are available. Immediate users of these data and procedures are RAVAR (www.fs.fed.us/rm/wfdss_ravar) and WFDSS (wfdss.usgs.gov/wfdss).

Our specific objectives are to develop the methods for and then a "wall-to-wall" map of potential fire severity (defined as probability of high severity fire) for all lands in 11 western states in the USA, excluding areas of agricultural and urban land use. The map will be at 30-m resolution.

METHODS

Study area

Our analysis area encompasses all lands in 11 western states (AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY), excluding areas of agricultural and urban land use.

Potential Fire Severity

We will use data from the Monitoring Trends in Burn Severity (MTBS) project (http://www.mtbs.gov) for large fires that burned in the western U.S. between 1984 and 2006 (currently 5,436 fires). Products from MTBS include the Landsat-derived differenced Normalized Burn Ratio (dNBR; Key and Benson 2006) and Relative differenced Normalized Burn Ratio (RdNBR; Miller and Thode 2006) indices. We will use these data to build statistical relationships between satellite-derived burn severity data and topographic and climatic predictor variables, and then use these in predictive models that relate observations of high fire severity, as indicated by the RdNBR mapped by the MTBS project, to biophysical gradients. The result will be predictions of the probability for severe fire for combinations of topographic and climatic conditions, which we will then apply spatially to produce a map.

Unlike fire severity maps produced by the MTBS project, the potential fire severity map we will produce will not depict ordinal categories of burn severity (e.g., low, medium, high). Rather, similar to the map produced by Holden et al. (2009) for the Gila National Forest, our map will depict the probability (0-1) for severe fire within each pixel. Further, as our map will be based on landscape-scale biophysical factors, and not on actual vegetation cover or fuels information, our product will be referred to as the Landscape Potential for Severe Fire Map ("Landscape PSF Map"). Future variations of our methods that incorporate fuels data could result in a "Fuels PSF Map" and possibly an "Integrated PSF Map" that combines predictions based on biophysical factors and fuels information.

The process of creating the Landscape PSF Map will consist of two primary phases: 1) methods development and 2) production. Each phase will include four primary tasks that are outlined below: 1) compile data layers, 2) develop predictive models, 3) create potential fire severity map, and 4) assess accuracy. During the methods development phase, we will prototype the entire process from start to finish. We will work through detailed methodological considerations and develop an operational process that will include as much automation as possible. As part of this, we will delineate a number of analysis areas that will serve to spatially subdivide the work of creating a west-wide map. The number, size and extent of these analysis areas will be determined based upon dominant climate regimes, generalized potential vegetation types, and number of MTBS fires within each area (to ensure large enough sample sizes for model development). Our analysis areas will be based primarily on CEC ecoregions (CEC 1997) and LANDFIRE Environmental Site Potential (ESP; www.landfire.gov), although we may consider other sources such as USDA Forest Service ECOMAP provinces and sections (McNab and Avers 1994), LANDFIRE map zones, and USGS hydrologic units (www.water.usgs.gov/GIS/huc.html). Upon completion of the methods development phase, we will then iterate through the four tasks for each analysis area, eventually merging outputs from each into a seamless, wall-to-wall geospatial product.

Compile data layers

The first task is *to compile the dependent and independent variable data layers* that will be used to model the potential for severe fire. The dependent, or response, variable in our modeling will be derived from the RdNBR spatial data layers produced by the MTBS project. We will acquire all available RdNBR data from the MTBS web site (www.mtbs.gov) for fires that burned in 11 western states (AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY) between 1984 and 2006 (currently 5,436 fires). For each fire, we will convert the RdNBR from a continuous scale of vegetation change to a four-category classification of burn severity using a fuzzy C-means clustering approach (Holden and Evans accepted). This will provide a more consistent definition of high severity across all fires as compared to the thematic burn severity layer directly available from MTBS, which is created using subjective thresholds of the dNBR. For the independent, or predictor, variables we will acquire or produce a suite of spatial data layers representing topographic and climatic conditions. For topography, we will first acquire digital elevation data from the National Elevation Dataset (NED; http://ned.usgs.gov), then produce a number of derived indices of topographic shape and complexity that have proven to be useful predictors of fire severity in recent studies (Holden et al. in prep, Morgan et al. in prep, Table 1). For climate, we will investigate the usefulness of two different sources of spatial climate data for the western US: 1) the environmental gradient layers produced by the LANDFIRE project, and 2) climate surfaces produced using thin plate splines and the ANUSPLIN model (Hutchinson 2000, Table 2). For the latter, we may be able to acquire 30-m spline surfaces of temperature and precipitation produced by the USDA Forest Service, Forest Health Technology Enterprise Team (FHTET) (Ellenwood pers. comm.), or we may need to produce them ourselves. Other spatial predictor variables that we may consider, especially if we attempt to produce a Fuels PSF Map or Integrated PSF Map, include: soil drainage index and insect and disease risk from FHTET; existing vegetation type, canopy cover, and fire behavior fuel model from LANDFIRE; and spectral variables from LANDSAT imagery.

One important aspect of this first task will involve adjusting the fuzzy C-means clustering of RdNBR data in each of our analysis areas, with the goal of applying a consistent definition of high burn severity across all fires. Holden and Evans (accepted) developed the fuzzy C-means clustering methodology by comparing various methods of classifying dNBR data with field-collected data (Composite Burn Index, Key and Benson 2006). While Holden and Evans (accepted) found good correlation between mapped levels of high, moderate, and low severity with field-measured values, they used the dNBR (as opposed to the RdNBR) and their field sites were all in Rocky Mountain montane and subalpine conifer forests. We expect the RdNBR index will provide somewhat different results and the clustering algorithm may perform differently in other ecosystems, especially non-forested ones. Miller and Thode (2007) developed the RdNBR to provide meaningful and consistent estimates of burn severity across a variety of ecosystems, including those where the total prefire aboveground biomass was low, such as semi-arid shrublands and woodlands. We plan to scrutinize, and modify as needed, the classification of RdNBR data in each analysis area to maintain consistency with field-based concepts of fire severity and with definitions of burn severity being used by others in this project. Where possible, we will use field data and local experts to help us in this assessment.

Develop predictive models

As the first step in developing predictive models, we will sample a large number of pixels from the classified burn severity layer (response variable) and subsequently extract values for each predictor variable layer at the same points to create the input datasets for modeling. The number of pixels in a sample will be as large as possible but constrained by computing resources and statistical considerations such as spatial autocorrelation (Theobald et al. 2007). We plan to then use the Random Forests (Breiman 2001) machine learning algorithm to develop predictive models. Random Forests is a variant of Classification and Regression Trees (CART). It provides a means by which to identify associations between response and predictor variables and thereby predict the value of the response variable at new locations. It has become widely used in ecological studies (Evans and Cushman 2009), in part because it implements a bootstrapping procedure to generate thousands of classification trees and permutes multiple predictor variables through each tree node as a means of preventing over-fit and assessing the mean square error (MSE) variable importance, all while making few assumptions that are robust. Random Forests is computationally intensive, but has yielded robust predictions across a variety of applications including tree species distributions, genetic analysis and medical research (Evans and Cushman 2009; Prasad et al. 2006; Rehfeldt et al. 2006).

We will build unique Random Forest models for each of our analysis areas across the western US. Within each analysis area, we will use a two-phase stratified sampling approach, whereby pixels are randomly selected from combinations of burn severity classes and LANDFIRE ESP to ensure that each model is well distributed across the range of available biophysical settings and severity classes. We will also select a subset of burn severity pixels (10% of total pixels) to build validation data sets. Before final prediction maps are produced, we will evaluate the performance of the predictive models, using these validation data sets.

Table 1. Potential topographic predictor variables to be used in statistical models.

Data layer	Description	Reference
DEM	Elevation (meters)	NED; Gesch (2007)
CAT	Slope cosine aspect	Stage (1976)
SAT	Slope sine aspect	Stage (1976
CTI	Compound Topographic Index	Moore et al. (1993)
HLI	Heat Load Index	McCune and Keon (2002)
DISS (3, 15, 27)	Martonne's modified dissection coefficient [1]	Evans (1972)
ERR (3, 15, 27)	Elevation Relief Ratio [1]	Pike and Wilson (1971)
HSP	Hierarchical Slope Position	
LFI	Landform Index	McNab (1993)
TRASP	Solar-radiation aspect index	Roberts and Cooper (1989)
TPI (150, 300, 2000)	Topographic position index [2]	Weiss (2001)
INSO	Solar insolation	Fu and Rich (1999)
PRR	Potential relative radiation	Pierce et al. (2005)

[1] Variable is created using a square moving window, with size N x N pixels. Numbers in parentheses after the data layer name (3, 15, 27) indicate the N values we will use to produce multiple scales of the variable.
[2] Variable is created using an annular (doughnut-shaped) moving window, with an outer radius of N meters. Numbers in parentheses after the data layer name (150, 300, 2000) indicate the N values we will use to produce multiple scales of the variable.

Table 2. Potential climate predictor variables to be used in statistical models, by source. All are available or could be produced at 30-m resolution.

Source	**Data layer**	**Description**
LANDFIRE[1]	PPT	Average annual precipitation
	Swavgfd	Average shortwave radiation flux density
	Tmax	Average daily max temperature
	Tmin	Average daily min temperature
	VPD	Average daylight vapor pressure deficit
	Dday	Average annual degree days
	Dsr	Average days since rain
	Tave	Average daily mean temperature
	Tday	Average daily daytime temperature
	Tnight	Average daily nighttime temperature
	Tsoil	Average daily soil temperature
	Wxsrad	Average incoming shortwave radiation
ANUSPLIN[2]	MAT	Mean annual temperature
	MAP	Mean annual precipitation
	MonthT[3]	Average monthly mean temperature
	MonthM[3]	Average monthly min temperature
	MonthX[3]	Average monthly max temperature
	MonthP[3]	Average monthly total precipitation
	GroupT[4]	Multi-month groupings of MonthT
	GroupM[4]	Multi-month groupings of MonthM
	GroupX[4]	Multi-month groupings of MonthX
	GroupP[4]	Multi-month groupings of MonthP
	MTCM	Mean temperature in coldest month
	MMIN	Min temperature in coldest month
	MTWM	Mean temperature in warmest month
	MMAX	Min temperature in warmest month
	TDIFF	Summer-winter temperature differential
	DD5	Number degree-days >5^{o} C
	DD0	Number degree-days <0^{o} C
	FFP	Length of frost-free period
	AMI	Annual moisture index [DD5/MAP]
	PRATIO	Ratio of summer to total precipitation [GSP/MAP]

[1] Climate model = WxBGC (Holsinger et al. 2006); Climate data source = DAYMET (1987-1997, www.daymet.org)
[2] Climate model = ANUSPLIN (Hutchinson 2000); Climate data source = A) climate normals 1961-1990 (Rehfeldt 2006), or B) climate normals 1971-2000 (NOAA-NCDC 2008, Ellenwood (unpublished data))
[3] Variable is created for each month (e.g., janT, febT, etc.)
[4] A variety of multi-month groupings are possible, such as growing season, winter, spring, summer, fall, or specialized groupings that may correspond with synoptic patterns (e.g., FMA, McAfee and Russell 2008).

Create Potential Fire Severity Map

To create the *Potential Fire Severity Map (Landscape PSF Map),* we will use the aspatial statistical models created using Random Forest. There are a few different tools available for applying these spatially, pixel-by-pixel, to create a geospatial prediction surface, including the prediction function available in the Random Forest package for R (Liaw and Weiner 2007) and two tools developed as part of the LANDFIRE project (B. Ward and C. Toney, unpublished public-domain software). We will evaluate these tools and choose the one most appropriate and efficient for our needs. The final product will be a wall-to-wall, 30-m resolution raster geospatial layer with each cell assigned a probability (0-1) of burning as high severity. This layer will be served alongside LANDFIRE data layers at the USGS National Map website (http://landfire.cr.usgs.gov/viewer/), where it will be available for download.

Field Sampling and Accuracy Assessment

We will determine error rates and misclassifications for the Landscape PSF Map resulting from the previous tasks. In addition to evaluating errors during the model development process (including errors reported by Random Forest as well as error rates calculated from withheld burn severity pixels), we will also perform an accuracy assessment on our final product using independent field data. We will collect field measures of burn severity on selected fires that occur in 2008, 2009, and 2010 to use specifically as a validation dataset (Appendix). We will compare predicted areas of high severity (Landscape PSF Map) with observed burn severity (both field observations, and new burn severity calculated from imagery), and evaluate results using standard chi-square and contingency table analysis.

PROJECT SCHEDULE, DELIVERABLES, AND TECHNOLOGY TRANSFER

Project Schedule

We will complete the methods development phase of the project by December 2010. We will then move into the production phase in 2011, producing the Landscape PSF Map for each analysis area across the western US, and completing the west-wide Landscape PSF Map by December 2011. The final six months through June 2012 will be spent doing further analysis, report writing, manuscript preparation, and review.

Deliverables

1. By December 2009, we will have sampled in fires burned in 2008, and we will assemble those data into a database for use in this project.
2. By May 2010, our data layers will be compiled into a spatial database, complete with metadata. This will be available on a local server.
3. By December 2010, we will write and submit a manuscript for publication as a General Technical Report or a journal article, "Mapping Potential for High Burn Severity for Western US". This will focus on the methods that we use to create the statistical models, and will include a summary of the spatial database. The spatial database will be made available to scientists and the public via the Internet at this time.
4. By December 2011, the map of potential fire severity will be released via LANDFIRE and WFDSS, complete with assessment of accuracy.
5. By June 2012, we will submit an article for publication in a refereed journal such as the Canadian Journal of Forest Research, International Journal of Wildland Fire or others.

Technology Transfer

1. In fall of 2009, we will present our proposed project and initial findings at the International Fire Ecology Congress, Nov. 30-Dec. 4 in Savannah, Georgia.
2. In fall of 2010 and 2011, we will include results of this study in two University of Idaho courses offered on-campus and online to current and future fire professionals.
3. We will produce 1-2 page summaries of our project and email them to multiple scientists and fire professionals. These will be produced midway and then at the end of our project. They will include objectives, methods, results, and a link to web sites for additional information
4. We will have a summary of this project on research web pages at the Fire Sciences Laboratory and the University of Idaho.

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APPENDIX: FIRESEV Field Sampling Methods

Purpose for sampling

Our primary purpose for this sampling effort is to collect field data we can use to assess the accuracy of the maps we'll be producing of the probability of severe fires for the western US. In addition, we are collecting data to analyze the degree to which various measures of burn severity interpreted from satellite imagery (NBR, dNBR, RdNBR) are correlated with field indicators of burn severity collected one year post-fire. We seek to assess measures in the field and remotely that can relate to three different axes of burn severity used in this project. These include a) soil heating, b) surface fuel consumption, and c) change in vegetation cover and mortality.

For the sampling methods and field form, we have drawn upon the GeoCBI (De Santis and Chuvieco 2009), CBI (Key and Benson 2005), ongoing analysis by S. Bunting and E. Strand of burn severity in woodlands and shrublands in southern Idaho (personal communications, University of Idaho) and our experience with sampling burn severity in multiple vegetation types (Hudak et al. 2007; Lentile et al.2007; Lentile et al. *In press*). Further, we have tried to produce a streamlined version of field sampling, with continuous measures (e.g. %) where possible. We have deviated from the CBI and GeoCBI forms because we have experienced the challenge that people enter a plot with an assumption of severity and then that influences the assessment of fire effects upon substrate and vegetation layers. Nonetheless, the data collected can easily be used to calculate CBI (Key and Benson 2005), GeoCBI (De Santis and Chuvieco 2009), fraction green and fraction charred (Hudak et al. 2007; Lentile et al. *In press*), size of smallest twig (Keeley et al. 2008), and other indicators of burn severity.

Field Methods

Landscape-Level Sampling: We will sample areas within selected areas burned by wildfires in 2008 and 2009 with the goal of sampling one year post-burn. Because we are focused upon high burn severity and the threshold for identifying high burn severity with the satellite imagery and field data, we propose to sample about ½ of all plots in high burn severity, with about ¼ in moderate and ¼ in low severity. Further, because we have assembled more data from others that were collected in forests than in woodlands, shrublands or grasslands, we wish to ensure that we have a balance of data across these four physiognomic types, or that we have more in the latter three than in forests.

We will opportunistically locate plots to represent areas of different burn severity levels (from BARC maps when possible), cover types, and successional stages. Our primary objectives in locating plots will be to: a) capture the diversity of sites that exist within a burned area, and b) get a wide geographic distribution of samples. We will reject locations for sampling if they are not large enough to allow for 90 m x 90 m area to be sampled, with that area relatively uniform with respect to overstory density and fire severity. Within locations subjectively chosen to be representative of a set of conditions, we will randomly locate plot center by taking a random number of paces (between 2 and 10) in a randomly chosen azimuth. This plot center must be at least 90 m from a road or stand boundary.

All plots will be 1/10 acre (400 m^2) fixed-area circular macroplots with a radius of 37.2 ft (11.3 m). We will use the FIREMON sampling protocols as the template for sampling in this study.

Many of the fields on the sampling form (attached) are from the Plot Description and CBI forms used in FIREMON.

Fields 17-65 on the FIRESEV PD form are from the FIREMON Plot Description form and instructions are available online for those (Keane 2006).

CBI - Modified

Just as in CBI (Key and Benson 2006), field personnel need to judge whether a stratum or characteristic of a stratum to be rated has some minimal level of significance as a reference to burn severity on a plot. Did it have enough presence on the plot before fire so as to show representative effects after the fire, or did it influence and reflect fire behavior? If, for example, there is only one large fuel item, and it covered an insignificant portion of a plot, then it may not be worth rating. That one piece of wood is not likely to provide much information about severity realized across the plot. If a factor is not assessed, do not enter zero (0) on the form, as that is a valid value. Instead, either draw a line through the entry box or enter NA.

Remember that the goal of this sampling is to evaluate the change in conditions as a result of the fire one year post-fire. You may need to compare burned and unburned locations on similar sites to get a sense of pre-burn conditions. Make sure to take in the whole plot in the average score, including unburned areas.

Strata to be assessed will vary with vegetation physiognomy. Further, we expect ratings of B (but not B1 and B2) in forests, and all three B, B1 and B2 (B represents the combination of B1 and B2) in woodlands, shrublands and grasslands. In woodlands, shrublands and grasslands, do not rate the strata C, D, E, or F unless they are present with at least 10% canopy cover.

Generally seek to avoid sampling in sites with extensive post-fire rehabilitation, salvage logging, or other post-fire disturbance that will likely greatly change the interpretation of change in vegetation attributed to fire (i.e. the burn severity). However, if such treatments cannot be completely avoided, please make note of them in the comments. Also, as with CBI, you should not include litter, duff, or woody fuels that accumulated after fire in your assessment of stratum A, substrates, because we are seeking measures of direct fire effects (fuel consumption) with these fields.

Below, we provide explanations of individual fields on the Modified CBI portion of the FIRESEV Burn Severity form. In general, when recording percent values, use the FIREMON classes (Table A-1).

- **% Plot Area Burned:** Before examining the individual severity factors within strata, record the percent surface area showing *any* impact from fire for the entire 1/10 acre plot. This always reflects the area of burned substrates and low-growing plants. If there is a rare case with area of burned overstory but unburned understory, count that overstory burn as well, as if viewed from the air. Do not subtract, however, unburned overstory from the burned area of the understory.
- **FCOV:** For each stratum (A through F), estimate the fractional cover both pre-fire and at the time of measurement. Record pre-fire values before the slash (/) and post-fire values

after the slash, using the FIREMON percent cover classes (Table A-1). The total in each case (pre vs. post) must add to 100% (+/- 10%). In woodlands, shrublands, and grasslands, the FCOV for the B stratum should be the sum of values for strata B1 and B2. As FCOV is intended to be fractional cover that would be seen from a direct overhead view, we suggest starting with the tallest stratum and working downward.

- **Stratum A (Substrates):**
  - Record the **percent change of each of the following: litter, fine fuel (<3 inches (7.6 cm) diameter), duff, woody fuel (≥3 inches diameter).** Base consumption on the percent of volume or weight lost in relation to plot-wide pre-fire fuel load for each class. Consumption includes conversion of woody material to inorganic carbon (charcoal), as well as the complete loss woody fuel. Don't rate any of these that cover less than about 5 percent of the plot. Ignore stumps that existed before fire.
  - **Soil & rock cover/color:** Assess the change in percent cover of newly exposed mineral soil and rock, over and above estimated pre-fire levels plotwide. Exposed soil is considered soil or rock surface that is visible from eye level and not covered by litter, duff, or low herbaceous cover less than about 12 inches (30 cm) high. Such surfaces that are likewise visible, but under taller shrubs and trees, count as exposed soil. Ash and charcoal from consumed woody fuel, as well as newly exposed fine root mass within consumed duff layers, are overlooked when estimating exposed soil (that is, all the new soil below those components is considered). Change in soil color may also provide clues to severity. Base ratings on the proportion of exposed soil changing from native color to a general lightening with loss of organics at moderate to moderate-high severity, and up to 10 percent soil cover changing to a reddish color from oxidation at high severity. The amount of reddish soil varies by soil type, thus adaptation to particular ecosystems is warranted. See CBI methods (Key and Benson 2006) if you have further questions.
  - **Soil color, fractional cover (must sum to 100%):** Record the fractional cover of soil color in percent, using FIREMON classes (Table A-1). This must add to 100% (+/- 10%), and includes %green/brown (this is unburned vegetation, litter), %black/grey (this is charred organic material and partially charred organic matter that is mixed with ash), and %red (oxidized soil). We suggest that you estimate those colors with smallest amounts first, then the largest category.
- **Strata B (B1, B2) and C:**
  - **% Foliage Altered (blk-brown):** Percent of pre-fire foliage that was turned black or brown by the fire. If a plant is resprouting, ignore the green vegetation (it gets assessed in the following rows). If as in many fires, including many of low intensity or severity, plants are all top-killed, then this is 100%.
  - **Frequency % living:** Percent of individual prefire plants still alive 1 year after fire. This is a measure of survivorship based on numbers of individuals and not necessarily on change in cover. Consider resprouting perennial herbs, low shrubs, and small trees plotwide. Resprouting plants are ones that burned but survive

from living roots and stems. Include all green vegetation as well as burned plants that have not had enough time to resprout but remain viable. Burned plants may need to be examined for viable cambium or succulent buds near growth points. Dead stems will be brittle when bent; living ones will be supple. Do not include new colonizers or other plants newly germinating from seed. Make sure to take in the whole plot in the average score, including unburned areas.

- **% change in cover:** Estimate the % increase (+) or decrease (-) in canopy cover, relative to pre-fire cover. For example, if there was 20% pre-fire cover in stratum C and half of it burned, then you would record -50%.
- **Species composition – Relative abundance:** Rate this as **U**nchanged, **L**ittle change, **M**oderate change or **H**igh change. Change in species composition, and/or relative abundance of species anticipated within 2-3 years post-fire. This is a community-based assessment that gauges the ecological resemblance of the post-fire community compared to the community that existed before fire. It represents alterations in dominance among species (biomass or cover) as well as potential change in the species present, such as absence of prefire species and/or presence of new post-fire species. Consider the distribution of abundance or dominance among the species present after fire, compared to before fire. Such factors qualitatively determine the similarity or dissimilarity of the site from before to after fire. Increases or decreases in certain species abundance and dominance, or changes in the species present after fire, raise the score for this rating factor. If all plants in a particular stratum were killed by fire, then this would be recorded as high change.
- **Diameter of smallest branch/base:** Assess the skeletons of the shrubs and record the diameter of the smallest branches that remain.
- **Species for smallest branch:** If possible, record the four-letter code for the species on which the smallest diameter branch was assessed.

- **Strata D, E and F:**
  - **%Green (unaltered):** Percent of pre-fire crown foliage volume (living or dead) unaltered by fire, relative to estimated pre-fire crown volume of the plot.
  - **%Black/Brown:** Record the percent black of pre-fire crown foliage (living or dead) that is now black or brown as a result of the fire. This includes foliage consumed (black) or damaged by heating or desiccation or because stem was girdled (brown, scorched). This includes delayed mortality from fire or insects and disease that has occurred post-fire.
  - **Frequency % living:** Percent of individual pre-fire plants still alive one year after fire. This is a measure of survivorship based on numbers of individuals and not necessarily on change in cover. For trees, only consider resprouting plants if the new sprouts can be anticipated to reach the height of the pre-fire individual within 2-3 years post-fire. For example, if a 30-foot-tall tree was top-killed and is resprouting from its base, only consider it as surviving if the new shoot will reach a height of 15-60 feet within 2-3 years. Otherwise,

consider the tree to be dead and the new shoot as a new individual. Burned plants may need to be examined for viable cambium or succulent buds near growth points. Dead stems will be brittle when bent; living ones will be supple. Do not include new colonizers or other plants newly germinating from seed. Make sure to take in the whole plot in the average score, including unburned areas.

Table A-1. FIREMON classes for recording percentages (adapted from Keane 2006).

Code	Percent Range
0	0 %
0.5	>0 – 1 %
3	>1 – 5%
10	>5 – 15%
20	>15 – 25%
30	>25 – 35%
40	>35 – 45%
50	>45 – 55%
60	>55 – 65%
70	>65 – 75%
80	>75 – 85%
90	>85 – 95%
98	>95 – 100%

Additional Burn Severity Measures

In addition to the Modified CBI, we have included a few other measures of burn severity. These measures are tied to other on-going projects at the Missoula Fire Sciences Lab related to burn severity (e.g., FLEAT). We include them here because they are quick to obtain once the Modified CBI form has been completed, and will make the plot data useful for other purposes beyond the FIRESEV project.

- **LS (LANDSUM) Burn Severity:** Assign an overall severity level (**NLS** = non-lethal surface, **MS** = mixed severity, **SR** = stand replacement), based on **overstory** mortality. Use the guidelines on the form for breaks between classes. Overstory is defined as the tallest lifeform (trees, shrubs, herbs) with at least 10% canopy cover pre-fire.
- **FH (FIREHARM) Burn Severity:** For each of the three elements of burn severity (overstory change/mortality, fuel consumption, soil heating) rate the overall degree of burn severity (**0** = unburned, **1** = low, **2** = moderate, **3** = high). Use the guidelines on the form for breaks between classes. After rating each of the three elements, record an overall rating in the top box (next to “FH Burn Severity”).
- **Pre-fire and Post-fire vegetation type and structural stage:** Record your best estimates of the pre-fire and post-fire existing vegetation type (EVT), structural stage

(SS), and PVT/ESP (potential vegetation type / environmental site potential). For EVT and PVG/ESP, use codes for LANDFIRE EVT and ESP units specific to the area being sampled. Post-fire ESP can be left blank, as this should always be the same as pre-fire ESP.

Literature Cited:

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FIRESEV PD Form

Reg ID	MFSL	Examiners		Field Date	
Project ID	FIRESEV	Fire Name		Fire Date	
Plot ID		Plot Radius	37.2 ft		

Plot Description

	Field	Description	
Geo. Position	17	UTM E plot center	
	16	UTM N plot center	
	18	UTM Zone	
	19	GPS Datum	
	20	GPS Error (m)	
Biophysical Setting	22	Elevation	
	23	Aspect	
	24	Slope	
	25	Landform	
	26	Vert. Slope Shape	
	27	Horiz. Slope shape	
Tree Cover	33	Total Tree Cover	
	34	Seedling Tree Cover	
	35	Sapling Tree Cover	
	36	Pole Tree Cover	
	37	Medium Tree Cover	
	38	Large Tree Cover	
	39	Very Lg. Tree Cover	
Shrub Cover	40	Total Shrub Cover	
	41	Low Shrub Cover	
	42	Medium Shrub Cover	
	43	Tall Shrub Cover	
Herb Cover	44	Graminoid Cover	
	45	Forb Cover	
	46	Fern Cover	
	47	Moss & Lichen Cover	

	Field	Description	
Composition	48	Upper Dom Spp 1	
	49	Upper Dom Spp 2	
	50	Mid Dom Spp 1	
	51	Mid Dom Spp 2	
	52	Lower Dom Spp 1	
	53	Lower Dom Spp 2	
	54	Potential Veg ID	
	55	Potential Lifeform	
Ground Cover	56	Bare Soil Cover	
	57	Gravel Ground Cover	
	58	Rock Ground Cover	
	59	Litter & Duff Cover	
	60	Wood Ground Cover	
	61	Moss & Lichen Cover	
	62	Charred Ground Cover	
	63	Ash Ground Cover	
	64	Basal Veg. Cover	
	65	Water Ground Cover	

Photos		
	North ground photo ID	
	North stand photo ID	
	Other phots (ID and description):	

Site Comments:

FIRESEV Burn Severity Form

Reg ID	MFSL	Examiners		Field Date	
Project ID	FIRESEV	Fire Name		Fire Date	
Plot ID		Plot Radius	37.2	% Plot Area Burned	

CBI - Modified

A. SUBSTRATES	**FCOV= /**	
Duff		% consumed
Litter		% consumed
Fine fuel, <3" diameter		% consumed
Woody fuel ≥3" diameter		% consumed
Soil & rock cover/color		Δ % cover
Soil color, fractional cover (must sum to 100%)		
%green/brown		
% gray/black		
% red		

B. HERBS, LOW SHRUBS AND TREES < 3 FT (1 M)	**FCOV= /**	
% Foliage altered (blk-brn)		% altered
Frequency % living		% living
Spp comp - Rel abundance		*
Diam of smallest branch left		#
Species for smallest branch		

B1. HERBS	**FCOV= /**	
% Foliage altered (blk-brn)		% altered
Frequency % living		% living
Spp comp - Rel abundance		*

B2. LOW SHRUBS	**FCOV= /**	
% Foliage altered (blk-brn)		% altered
Frequency % living		% living
Spp comp - Rel abundance		*
Diam of smallest branch left		#
Species for smallest branch		

C. TALL SHRUBS AND TREES 3 TO 7 FT (1-2 M)	**FCOV= /**	
% Foliage altered (blk-brn)		% altered
Frequency % living		% living
% change in cover (+/-)		% pre-fire cov
Spp comp - Rel abundance		*
Diam of smallest branch left		#
Species for smallest branch		

D. SMALL TREES 7 TO 15 FT (2-5 M)	**FCOV= /**	
% Green (unaltered)		% rel. cover
% Black/Brown		% rel. cover
Frequency % living		% living
Diam of smallest branch left		#
Species for smallest branch		

E. INTERMEDIATE TREES 15-60 FT (5-20 M)	**FCOV= /**	
% Green (unaltered)		% rel cover
% Black/Brown		% rel.cover
Frequency % living		% living

F. TALL TREES > 60 FT (> 20 M)	**FCOV= /**	
% Green (unaltered)		% rel. cover
% Black/Brown		% rel. cover
Frequency % living		% living

COMMENTS:

* level of change: **U**= unchanged **L**= low **M**= moderate **H**= high
\# categories: **0**: < 0.25 in **1**: 0.25 - 0.5 in **2**: 0.5 - 1 in **3**: none

LS Burn Severity		NLS = Non-lethal Surface (0-10% mortality)	MS = Mixed Severity (10-90% mortality)	SR = Stand Replacement (90% + mortality)

FH Burn Severity		0	1	2	3
Overstory change/mortality		unburned	<40%	40-70%	>70%
Fuel Consumption		unburned	<20%	20-50%	>50%
Soil Heating		unburned	low	moderate	high

	Pre-fire	**Post-fire**	**Code**
EVT			See EVT Key
SS			herb (HE), shrub (SH), seedling (SE), sapling (SA), pole (PO), mature (MA), very mature (VM), old growth (OG)
PVG / ESP			See PVG/ESP key