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A Fire Severity Mapping System for Real-Time Fire Management Applications and Long-Term Planning: The FIRESEV project

Robert E. Keane
US Forest Service

Penny M. Morgan
University of Idaho

Gregory K. Dillon
US Forest Service

Pamela G. Sikkink
US Forest Service

Eva C. Karau
US Forest Service

See next page for additional authors

Authors
Robert E. Keane, Penny M. Morgan, Gregory K. Dillon, Pamela G. Sikkink, Eva C. Karau, Zack A. Holden, and Stacy A. Drury

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Keane, Robert E.	Principal Investigator	US Forest Service, Rocky Mountain Research Station (RMRS), Fire, Fuel, Smoke Program, Missoula Fire Sciences Laboratory, Missoula Montana
Morgan, Penny M.	Co-PI	University of Idaho, Forest, Rangeland, and Fire Sciences, Moscow, Idaho
Dillon, Gregory K.	Co-PI	US Forest Service, RMRS, Fire Modeling Institute, Missoula Fire Sciences Laboratory, Missoula Montana
Sikkink, Pamela G.	Co-PI	US Forest Service, RMRS, Fire, Fuel, Smoke Program, Missoula Fire Sciences Laboratory, Missoula Montana
Karau, Eva C.	Co-PI	US Forest Service, RMRS, Fire Modeling Institute, Missoula Fire Sciences Laboratory, Missoula Montana
Drury, Stacy A.	Co-PI	Sonoma Technology Inc., Fire & Forest Ecology, Sonoma, California
Holden, Zack A.	Collaborator	US Forest Service, Region One, Missoula, Montana

Abstract

Accurate, consistent, and timely fire severity maps are needed in all phases of fire management including planning, managing, and rehabilitating wildfires. The problem is that fire severity maps are commonly developed from satellite imagery that is difficult to use for planning wildfire responses before a fire has actually happened and can't be used for real-time wildfire management because of the timing of the imagery delivery. Moreover, imagery is difficult to use for controlled fires such as prescribed burning. This study, called FIRESEV (FIRE SEVerity Mapping Tools) created a comprehensive set of tools and protocols to deliver, create, and evaluate fire severity maps for all phases of fire management. The first tool is a Severe Fire Potential Map (SFPM) that quantifies the potential for fires to burn with high severity, should they occur, for any 30m x 30m piece of ground across the western United States. This map was developed using empirical models that related topographic, vegetation, and fire weather variables to burn severity as mapped using the Monitoring Trends in Burn Severity (MTBS) digital products. This SFPM map is currently available on the Fire Research and Management Exchange System (FRAMES, http://www.frames.gov/firesev) web site and can be used to plan for future wildfires or for managing wildfires in real time, e.g. by including it as a layer in Wildland Fire Decision Support System or other GIS analysis. The next tool was the inclusion of a fire severity mapping algorithm in the Wildland Fire Assessment Tool (WFAT) developed by the National Interagency Fuels Technology Transfer (NIFTT) team. WFAT is used for fuel treatment planning to predict potential fire effects under prescribed fire weather conditions (http://www.frames.gov/partner-sites/niftt/tools/niftt-current-resources/). Now, fire severity can be mapped explicitly from fire effects simulation models (FOFEM, Consume) for real-time and planning wildfire applications. Next, the FIRESEV project showed how results from the WFAT simulated fire severity can be integrated with satellite imagery to improve fire severity mapping. And last, the FIRESEV project produced a suite of research studies, synthesis papers, and popular articles designed to improve the description, interpretation, and mapping of fire severity for wildland fire management: (1) a research study created a completely objective method of quantifying fire severity from fire effects to obtain nine unique classes of fire severity, (2) a research study comprehensively contrasted all current classifications of fire severity using Composite Burn Index (CBI) as measured on over 300 plots across the western United States to determine commonalities and differences, and (3) a synthesis paper was written discussing the problems involved in measuring, describing, and quantifying fire severity. This FIRESEV project yielded over 15 deliverables that we feel provides a comprehensive suite of products to create useful fire severity maps, along with current satellite imagery products, and also FIRESEV provides a thorough background on how to measure, interpret, and apply fire severity in fire management.

Project Justification

Each year, thousands of acres of wildland are severely burned in wildfires, in some cases due to high canopy and surface fuel loadings that have accumulated over seven decades of fire exclusion (Ferry *et al.* 1995) and in other cases as part of fire regimes characteristic of some forests and rangeland ecosystems. Most land management agencies in the United States work in accordance with the National Fire Plan and agency guidelines to assess and mitigate the effects of fire during and post-fire such as reforestation, erosion control, invasive weed treatment, and habitat restoration (NWCG 2003). Doing so before, during and after fires requires accurate, efficient, and economical methods to assess the severity of a fire at landscape scales (Brennan and Hardwick 1999). Wildfire managers are also asking for tools that easily and quickly forecast potential fire severity to determine if a wildfire is restoring fire-adapted ecosystems or degrading the landscape. Planned and unplanned wildfires can used to treat hazardous fuels and restore fire-dominated ecosystems (Keane and Karau 2010). Fire severity mapping tools and technologies are critical for 1) identifying severely burned areas, 2) facilitating enlightened wildfire management, and 3) implementing cost-effective rehabilitation and restoration efforts (Lachowski *et al*. 1997; Eidenshink *et al.* 2007).

Most fire severity mapping efforts use satellite imagery (Landsat TM data) to create maps of "burn severity" using an ordinal classification with three to five categories. This involves evaluating spectral reflectance characteristics of landscape features and relating that information to the severity of a fire. For Landsat TM imagery, Bands 4 and 7 are considered the wavelength ranges that, when combined in an index called the Normalized Burn Ratio (NBR), best correspond to burn severity mapped on the ground (Key and Benson 2005, Roy *et al.* 2006). The NBR is usually differenced across pre- and post-fire TM scenes to create a dNBR value, and it is sometimes calculated relative to preburn conditions as RdNBR; the values are then is related to burn severity using various techniques. Unfortunately, imagery-derived burn severity maps are rarely used for planning, real-time, or short-term wildfire operations because smoke and cloud obfuscation, lack of sufficient image processing expertise, and image availability issues (new TM data are only available every 14 days) make it nearly impossible to quickly obtain useable imagery. Fire managers need is a suite of tools to generate fire severity maps for any geographical area at any time to aid in the most appropriate fire management action.

A newer method of mapping fire severity involves using computer models to mechanistically simulate fire effects that can then be used to predict fire severity (Keane et al. 2010). Fire effects models, such as FOFEM and CONSUME, have been available to fire management for over a decade (Ottmar *et al.* 1993; Keane and Reinhardt 1994). These models simulate the direct effects of a fire on the vegetation, fuels, and soils for a point in space and output these effects using biophysically based variables such as fuel consumption and tree mortality. Keane *et al*. (2010) have implemented FOFEM into a spatial computer model called FIREHARM to develop spatially explicit maps of fire hazard and risk. FIREHARM predicts fire severity using simulations of tree mortality, fuel consumption and soil heating computed using wildfire fuel and weather conditions. By modeling direct fire effects, burn severity assessments can be tailored for specific applications and maps could be produced anytime during a wildfire to provide instant assessments for real-time fire management. Most FIREHARM input data can now be obtained for the continental United States from the National LANDFIRE Mapping Project (www.landfire.gov), a multi-agency effort to provide land managers with comprehensive spatial data and planning-focused analysis tools). The effort required for managers to independently create FIREHARM input data layers may be cost, time, and resource prohibitive (Reinhardt *et al.* 2001), but the availability of LANDFIRE data layers has enabled managers to run FIREHARM to generate fire hazard and burn severity maps with relative ease.

Powerful new statistical modeling methodologies combined with extensive historical burn severity data provided by the Monitoring Trends in Burn Severity (MTBS, http://mtbs.gov) program provide a third approach to mapping fire severity. 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 (Breiman 2001), classified burn severity data could be predicted 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 (see figure). 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. These results demonstrate that the predictive models developed for the Gila NF can also be developed for other regions of the western US.

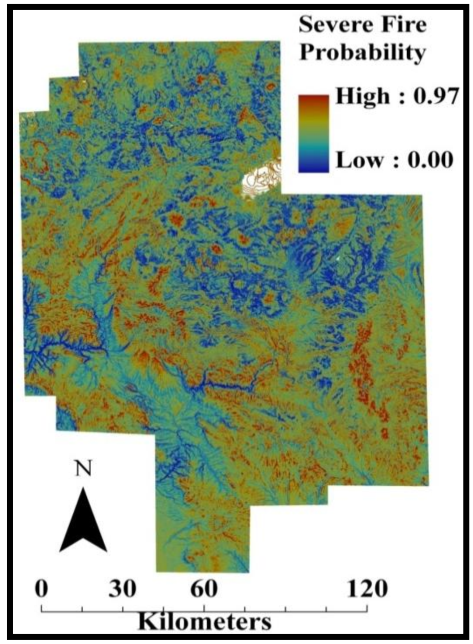

Figure 1-The fire severity map from Holden (2009)

This project, called FIRESEV, created a system for evaluating fire severity for the western United States that will deliver the most appropriate fire severity map product for the right fire management application at the right time frame. This system is composed of a suite of digital maps, simulation models, analysis tools, study results, and synthesis papers that are integrated into a comprehensive system for the creation of fire severity maps for wide-ranging fire management applications: (1) real-time forecasts and assessments in wildfire situations, (2) wildfire rehabilitation efforts, and (3) long-term planning. This system is not intended to replace the suite of burn severity products currently used by fire management (e.g., BARC and BAER severity maps), but rather, it would complement them to provide a more comprehensive suite of fire severity mapping products. A blending of many fire severity mapping approaches will help meet demands for accurate and rapid assessment of spatial fire severity given time, funding, and resource constraints.

Project Objectives

The primary objective of this project was *to create a suite of tools and information to generate and interpret fire severity maps for real time, short- and long-term fire management applications*. This fire severity mapping system integrates 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. We developed this system for the western United States, but it is designed so that it could easily be expanded across all 50 states sometime in the future when input data are available. These data can now be readily incorporated into RAVAR (www.fs.fed.us/rm/wfdss_ravar) and WFDSS (wfdss.usgs.gov/wfdss) for immediate use in fire management. Already, managers are eager to do so.

The System

The FIRESEV system's design can be viewed as three nested tools designed to deliver the most appropriate fire severity map. To satisfy the immediate needs of fire management, we developed a wall-to-wall severe fire potential map (SFPM) that can be instantly accessed over the Internet to evaluate potential fire severity for a burned area. A more comprehensive fire severity map can be delivered overnight from fire effects simulation modeling using the WFAT program developed by NIFTT and revised using information developed from this FIRESEV project. Satellite imagery can be used to develop other maps of fire severity (MTBS, BARC) in 2-4 weeks, but these maps can be improved by merging simulation modeling and satellite imagery to estimate fire severity as detailed in this FIRESEV project (Table 1).

Table 1. The three products that comprise the FIRESEV project

Characteristic	Severe Fire Potential Map	WFAT-Simulated Fire Severity Mapping Program	Integrated Fire Severity Mapping Procedure
Delivery	Immediate	Overnight	2-4 weeks
Accuracy	Lowest	Moderate	Highest
Expertise required	Lowest	Moderate	Highest
Primary use	WFDSS, wildfire planning, long range fire planning, resource allocation	WFDSS, RAVAR, wildfire planning, rehabilitation, restoration	Rehabilitation, restoration, BAER activities
Robustness, flexibility	Lowest	Moderate	Highest
Time required to create	None	1 day	2-4 weeks
Spatial extent	Entire western US	Region, Zone	Fire event

This study has also yielded new and synthesized study results that will improve the understanding, interpretation, and application of fire severity products in fire management. First, we conducted extensive fire severity sampling across the western United States to create a comprehensive field database that was used in all FIRESEV projects. We then created a digital tree list that links to LANDFIRE map products that can be used to estimate tree mortality and to describe fire severity. We also created an objective fire severity classification from the combustion of surface fuels to describe potential and observed fire severity classes. We then compared the diverse suite of fire severity classifications using the sampled field data to understand, describe, and illustrate the differences between classifications. We also wrote a synthesis journal article that discusses the problems with fire severity and its use in fire management so that managers and researchers can understand and interpret fire severity maps in the appropriate context. This article also discusses the future of fire severity concepts and emphasizes that any use of fire severity in fire management must be ecologically based with a standardized terminology.

Since the discussion of study location and key findings are specific to each of our deliverables, we have decided to format this final report by each class of deliverables produced by the FIRESEV project. Next are the presentation of the deliverables and a brief discussion of each.

Deliverables

The deliverables specified in the 2009 FIRESEV proposal and study plan (Table 2) represent but a small fraction of what is being delivered in this final report.

Table 2. *Original list of deliverables detailed in the proposal and study plan along with the proposed delivery dates*

Deliverable	Description	Delivery Dates
Empirical fire severity map	Map of potential fire severity for the entire western US at 30 m resolution delivered via LANDFIRE map site	March 2011
FOFEM mapping tool vers 2.0	A software tool for managers to use to estimate fire severity for real-time wildfire operations or long-term planning	March 2011
Lesson plans courses for future fire professionals	Incorporate examples, including demonstration and interpretation of use of tools into courses at Univ. of Idaho, some of which are taught online to fire professionals (http://401series.net)	Spring 2010
Journal Article	Article comparing and contrasting various methods of describing fire severity and suggested merging of technologies	March 2011
RMRS GTR	A report describing how to create accurate fire severity maps by merging the simulation and imagery approaches	March 2011
Fact Sheet	Brief summary of project objectives and findings, sent via email to federal land managers and scientists with an interest in this project and its application	March 2010,2011, 2012

The deliverables generated from this FIRESEV project are listed in Table 3 and are stratified by the four classes of project products: (1) the Severe Fire Potential Map, (2) the WFAT program modification, (3) the integration of simulation modeling with remote sensing protocol, and (4) the suite of research studies designed to understand, interpret, and use fire severity in fire applications. Details of the products are discussed by FIRESEV deliverable classes.

Table 3. *Updated list of deliverables that will now be delivered on the specified delivery dates. Deliverables in* ***bold*** *indicate ORIGINAL deliverables (Table 2)*

Deliverable	Description	Status	Notes	Citation
			Severe Fire Potential Map	
Data Layer	**Severe Fire Potential Map**	Published	Map of potential for high severity fire for the entire western US at 30 m resolution, delivered on-line.	http://www.frames.gov/firesev FIRESEV
Journal Article	Description of prototype methods for empirical fire severity model	Published	Article describing prototype methods and results for the Severe Fire Potential Map This paper was written as part of the FIRESEV project and details some of the prototype methods and their successes	Dillon et al. (2011a)
Journal Article	Synthesis paper on empirical mapping of fire severity	In preparation	Article highlighting insights gained from the Severe Fire Potential Map, and its application to fire ecology and fire management	Dillon et al. (2013a)
Journal Article	Severity Fire Potential Map	Published	This paper was written to advertise the forthcoming release of the Severe Fire Potential Map	Dillon et al. (2011b)
RMRS General Technical Report	Technical document on the building of the SFPM	In preparation	Report detailing the methods used to create the Severe Fire Potential Map	Dillon et al. (2013b)
Lesson plans	**SFPM educational tools**	Completed, but will be further revised for spring	We incorporated examples, including demonstration and interpretation of use of tools into courses to be taken by future fire professionals at the Univ. of Idaho, some of which are taught online to fire professionals (this was one of	http://401series.net

		and fall 2013.	the original deliverables)	
Fact Sheet	**One page handouts describing projects**	in preparation	Brief summary of project objectives and findings, sent via email to federal land managers and scientists with an interest in this project and its application. We are thinking that this will be a Fire Management Today article	Keane et al. (2014[in prep])
Database	Fire severity field database for western US	In preparation	This is an archived database for all the field data collected for use in all phases of the FIRESEV project	Keane et al. (2013[in prep])
Presentation	SFPM-methods, findings, and discussions	Done	Presentations on the development of the SFPM	Dillon et al. (2012); Dillon (2012a, 2012b)
WFAT Modification – Mapping fire severity from fire effects computer simulation				
Tree List Data Layer	Technical report detailing the development of the National Tree List Layer including the actual layer	Report, Data Layer	This publication was identified in the FIRESEV proposal but somehow did not get on our deliverables list. It is now published and the product is being used by NIFTT for computing fire effects and by carbon scientists for assessing carbon stores	Drury and Herynk (2011)
WFAT modification	**A software tool for managers to use to estimate fire severity for real-time wildfire operations or long-term planning**	March 2011	NIFTT has developed this tool with algorithms researched for this JFSP FIRESEV project and there is an on-line course available to learn how to operate WFAT.	WFAT Modification (2011)

Integrating imagery with simulation: Improving fire severity mapping by merging fire effects simulation with remote sensing				
Journal Article		In review	A report describing how to create accurate fire severity maps by merging the simulation and imagery approaches	Karau et al. (2013[in review])
Presentation	Methods, findings, and discussions	Done	Presentations on the development and application of the integration of simulation with remote sensing	Karau et al. (2012)
New Fire Severity Research – Studies designed to improve the understanding, interpretation, and application of fire severity				
Journal Article	The challenges with fire severity and its use in fire management	In review	Article describing the problems and limitations of describing and mapping fire severity; lessons learned during the FIRESEV project This manuscript includes other fire severity researchers as authors	Keane et al. (2013[in review])
RMRS Research Paper	**Predicting fire severity using surface fuels and moisture**	Publish ed	Research paper describing a methodology on creating an objective fire severity classification from simulation results.	Sikkink and Keane (2012)
Presentation	Methods, findings, and discussions	Done	Presentations on the development of an objective fire severity classification	Sikkink and Keane (2009)
Journal Article	**Comparing eight fire severity classifications**	In review	Article comparing and contrasting various methods of describing fire severity using field data, and suggested merging of technologies	Sikkink (2013[in review])

Severe Fire Potential Map (SFPM)

A major component of the FIRESEV project is a comprehensive map of the western U.S. depicting the potential for fires to burn with high severity if they should occur. We call this map the FIRESEV Severe Fire Potential Map (SFPM). Developed as 30m-resolution raster dataset, the map is intended to be an online resource that managers can download and use to evaluate the potential ecological effects associated with new and potential fire events.

The first step toward creating the SFPM was to expand the modeling methods developed by

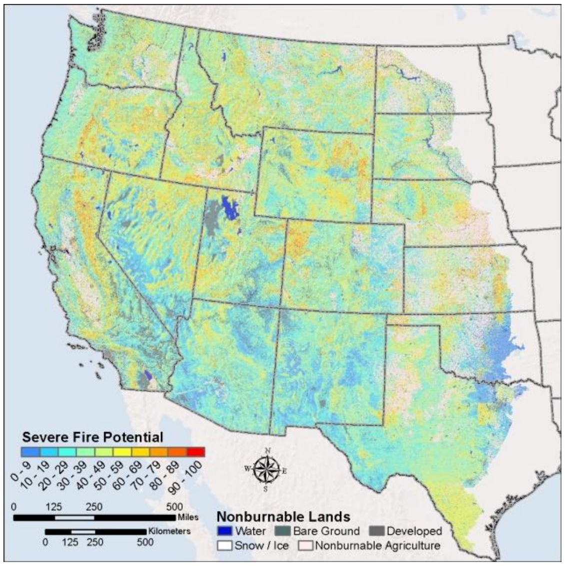

Figure 2-The Severe Fire Potential Map for the western US

Holden et al. (2009), and test them in different regions of the western U.S. We acquired satellite-derived burn severity data from MTBS for more than 1,500 fires in six ecoregions in the Southwest and Northwest U.S. and extensively tested different ways to use the Random Forest machine learning algorithm to analyze and predict the spatial occurrence of high severity fire. In the process we evaluated a large number of potential topographic, climatic, and fire weather variables as predictors of burn severity. We found that we could predict severe fire occurrence with classification accuracies ranging from 68% to 84%, and the topographic variables always appeared to be relatively more important predictors than either weather or climate variables. This analysis was published as a journal article (Dillon et al. 2011a).

Next, taking lessons learned from the Dillon et al. (2011a) analysis, we began the process of creating the SFPM for all lands in the western U.S. We first acquired and processed burn severity data from MTBS for over 7,000 fires that burned between 1984 to 2007 across the western U.S. Using the more than 500 burn severity field plots that we collected for this project, combined with over 2,500 more that we were able to acquire from other investigators, we developed robust thresholds for classifying the Relative differenced Normalized Burn Ratio (RdNBR) data from MTBS into standard severity classes (Dillon 2012a). This enabled us to confidently identify areas in the satellite-derived burn severity data that burned with high severity. We then developed Random Forest models separately for forested vs. non-forested settings in each of 17 mapping regions. Using a Random Forest model selection routine created as part of the Dillon et al. (2011a) analysis, we were able to select the set of predictor variables (i.e., landscape characteristics) for each model that provided the best possible predictions of severe fire occurrence. We retained some of the topographic predictor variables that performed well in our initial analysis, and added some new variables. Specifically, we incorporated a satellite-based measure of pre-fire vegetation condition (NDVI), a climate variable that provides a good measure of seasonal drought and susceptibility to burning at any point throughout a fire season (1000-hour fuel moisture), and modeled solar radiation variables that reflect the specific influence of topography on vegetation. Cross-validated classification accuracies for individual models ranged from 65% to 83% for forest models, and 69% to 82% for non-forest models. We found that elevation, 1000-hour fuel moisture, and NDVI were always among the five best predictor variables, often with some combination of slope, broad-scale (2km) topographic position, and solar radiation.

Finally, we used the Random Forest models to predict, for every 30m pixel in the western U.S., the potential for severe fire, conditional on that pixel experiencing fire at a particular percentile level of 1000-hour fuel moisture. It is important to note that we inverted our 1000-hour fuel moisture percentiles so that higher percentiles reflect dryer conditions, consistent with how fire managers are accustomed to referring to other fire weather indices such ERC. For our spatial predictions, we simply set 1000-hour fuel moisture constant across the entire landscape. We chose to produce the SFPM initially for 90th percentile (i.e., very dry) fuel moisture conditions, but it could easily be generated for other fuel moisture conditions as well. Our SFPM also used NDVI calculated from 2011 MODIS satellite imagery to reflect current vegetation condition. Again, updated versions of the SFPM could be easily generated in the future by using newer MODIS NDVI mosaics. Mosaics of the 90th percentile SFPM by our 17 mapping regions and by forest and woodland vs. non-forest settings are available online at the FRAMES website (http://www.frames.gov/firesev).

In addition to the Dillon et al. (2011a) paper, one other paper was published introducing the intent and general methodology of the Severe Fire Potential map to the fire management community (Dillon et al. 2011b), and two other manuscripts are in preparation. The first of these is an RMRS General Technical Report (Dillon et al. 2013a) that will detail all methods used to create the SFPM and present an evaluation of its performance. The last paper (#13 Table 2) will be a journal article presenting the SFPM in a refereed journal and discussing its application in fire management along with insights gained about burn severity and fire ecology from the modeling and mapping process. These last two manuscripts are less than 50% completed; both will be submitted by June 2013.

Extensive field data and severity observations were critical for all FIRESEV projects, but especially for the creation of the SFPM. For three years, we mobilized field crews to collect post-fire tree, fuels, vegetation, and effects data after wildfires across the western US. These data were used extensively in all phases of the FIRESEV project. There are data for approximately 500+ plots in this data set. The data set consist of two types of data: (1) fire severity inventory where only post-burn data were collected and (2) pre- and post-fire data collections were taken but the pre-fire conditions were estimated from unburned areas adjacent to the post-burn sampling site. These data were summarized, synthesized, and quality checked, and then entered into a database that is now stored on the RMRS data archive (Keane et al. 2013).

We have incorporated findings from this project into Fire Ecology (FOR 526, a graduate course) and Fire Ecology and Management (FOR 426, taught online to seniors and graduate students and taken by many future fire professionals), as well as REM 407 (GIS Applications in Fire Ecology and Management, taught online to seniors and graduate students and taken by many future fire professionals). The concept of fire severity will also be introduced into REM 244 Wildland Fire Management, taken by undergraduates on the University of Idaho campus who are majoring in fire and some related natural resource programs. In all cases, students learn about concepts, and to think critically about the concept of fire severity. For more advanced classes, students read in primary literature and relate the findings and maps to what they can measure about vegetation response on the ground in field trips to recent wildfires that burned with a range of severity.

WFAT Modification

The prediction of fire severity from simulation modeling has never been packaged into a fire management tool for many reasons. First, there are few fire severity classifications that describe severity in terms of quantitative fire effects, such as tree mortality, soil heating, and fuel consumption. That has since changed as a result of the Keane et al. (2010) FIREHARM program. Next, the inputs to the simulation models were sorely lacking. However, the development of the comprehensive fuels spatial data layers in the LANDFIRE project provided the first wall-to-wall assessment of surface and canopy fuels at resolutions fine enough for most local management applications. However, LANDFIRE did not provide any spatial data layers that quantitatively describe tree populations. Most fire effects models that predict tree mortality need a list of trees by diameter, height, height to base of crown, and species, often called a “tree list”. Therefore, this FIRESEV project created the first National Tree List Layer (Drury and Herynk 2011). A prediction of tree mortality is critical in the evaluation of fire severity and the only way to predict tree mortality is to have a list of trees that are on a fixed area. The National Tree-List Layer (NTLL) project used FIA plot data to create tree lists for combinations of the LANDFIRE vegetation composition and structure map products to produce the first national tree-list map layer that represents tree populations at pixel and stand levels. The NTLL was produced in a short time frame to address the needs of Fire and Aviation Management for a map layer that could be used as input for simulating fire-caused tree mortality across landscapes. FIA plots were selected based on the living trees to survive fire. Simulated tree mortality estimates using the NTLL as model input provided acceptable results when compared with tree mortality simulations using field-sampled tree attribute data. Results indicate that fire managers can expect simulated tree-mortalities using the NTLL to predict fire-caused tree mortality as well as field-measured plot data, especially during extreme wildfire events. Decision makers can use tree mortality maps that are produced using the NTLL to develop and support decisions such as where to place fuels treatments or where to most effectively position fire suppression resources. The NTLL was also used in other phases of the FIRESEV project. There are currently three integrated efforts to create an improved tree list data layer using FIA data. Note that although the tree list data is for forests and woodlands, the FIRESEV tools also apply to nonforest systems.

The advent of these technologies (FIREHARM, LANDFIRE fuels layers, and the NTLL) has facilitated the operational simulation of fire severity. In our original proposal, we specified that the FOFEM mapping tool is the vehicle to use to predict fire severity from simulation modeling. However, the FOFEM mapping tool has since been implemented into a spatial computer program under ArcGIS called WFAT (Wildland Fire Assessment Tool) and is currently available for use by many across the Forest Service and DOI agencies (WFAT Modification 2011). The NIFFT group has created an on-line course for people from state and federal agencies and other organizations to learn WFAT and apply it to fuel treatment planning. WFAT now contains the FIREHARM fire severity key that was created during the FIRESEV project for mapping fire severity from current weather conditions. WFAT 2.2.0 is now available - on the FRAMES website (http://www.frames.gov/partner-sites/niftt/tools/niftt-current-resources) and the NIFTT program has developed an extensive tutorial and users' guide available at the same website as above. In addition, there is an on-line course designed to teach WFAT to interested individuals (http://www.frames.gov/partner-sites/niftt/training/courses-registration/). WFAT is also taught in workshops at major fire conferences such as the International Fire Ecology Congress sponsored by the Association for Fire Ecology that took place in Portland, Oregon in December of 2012.

Integrating Simulation with Satellite imagery

Both satellite imagery and spatial fire effects models are valuable tools for generating burn severity maps that are useful to fire scientists and resource managers. The purpose of this FIRESEV project was to test a new mapping approach that integrates imagery and modeling to create more accurate burn severity maps. Karau et al. (2013[in review]) developed and assessed a statistical model that combines the Relative differenced Normalized Burn Ratio (RdNBR), a satellite image-based change detection procedure commonly used to map burn severity, with output from the Fire Hazard and Risk Model (FIREHARM), a simulation model that estimates fire effects at a landscape scale. Using 289 Composite Burn Index (CBI) plots in Washington and Montana as ground reference, they found that the integrated model explained more variability in CBI (R^2 = 0.50) and had lower mean squared error (MSE = 0.28) than image or simulation-based models alone, and all model relationships were strongest when the data were stratified geographically. Overall map accuracy was also highest for maps created with the integrated model (61%), though user's accuracy for the high severity class was highest for the RdNBR model (75%). They suspected that simulation model performance would greatly improve with higher quality and more accurate spatial input data. Results of this study indicate the potential benefit of combining satellite image-based methods with a fire effects simulation model to create improved burn severity maps.

This study shows that integrating remote sensing products with simulation products will greatly improve fire severity mapping but there are many hurdles for this to become operational. First, high quality fuels and tree spatial data are desperately needed for inputs to the simulation models. Current LANDFIRE and tree list maps are useful and state-of-the-art, but they have high error and uncertainty. But more importantly, there needs to be a more consistent measure of fire severity that integrates ecological principles and fire effects into the classification so that physical measures of fire effects can be directly included in fire severity applications.

New Fire Severity Research

It was obvious from conducting the FIRESEV project that there are many limitations associated with the concept and application of "fire severity", and these limitations caused problems across all the tasks in the FIRESEV project. So, instead of describing these problems in each FIRESEV publication, we decided to write our own review and synthesis paper on fire severity and its application (Keane et al. 2013[in review]). However, the limitations of the fire severity concept went well beyond the FIRESEV project so we asked several other eminent fire severity scientists to also contribute to the paper. This paper was written during the winter of 2012 but once we involved other fire severity researchers the paper was rewritten in the summer of 2012 and it will be submitted to a journal sometime in the winter of 2013. While there has been extensive material written on fire and burn severity, most has been in the context of remote sensing and image processing. Instead, we took a purely ecological approach to the limitations of fire severity and then integrated the ecological understanding of severity across all disciplines of wildland fire science including fire behavior, remote sensing, simulation modeling, and field sampling. We hope this paper will set the stage for a new era in fire severity research.

All contemporary fire severity classifications are mostly subjective in nature where the categories were created without a dispassionate analysis of field data using objective classification methods. Categories are often created towards a specific application, such as rehabilitation or salvage, and these categories are rarely tested for fidelity, consistency, and precision. A major problem in the FIRESEV project was to determine which fire severity classification to use and to find common ground between classifications. To address this, Sikkink (2013[in review]) used our extensive FIRESEV field database to compare field-measured estimates of fire severity, namely Composite Burn Index (CBI), to keyed categories in eight existing fire severity classifications. She classified 289 field plots using eight different fire severity classification methods to explore these questions and found that the eight methods classified to the same severity class only 30% of the time. Most methods did not adequately represent the severity recorded in field plots that were sampled for fire effects using the CBI standard fire severity measure. When compared to each other, the four remote-sensing methods scored only slightly better than 30% agreement among their classes. Problems encountered when classes were assigned in each method and make recommendations for improving the fire severity classification process. Granted, CBI is also highly subjective in its design, but that only highlights the pressing need to develop a concept of fire severity that allows for flexibility, standardization, and objectivity, while also providing quantitative estimates useful for fire management applications.

We also attempted to create another fire severity classification using objective classification procedures. This study was to illustrate the need for an objective classification and also to provide a more comprehensive classification for the severity caused by surface fuel combustion (Sikkink and Keane 2012). The objectives were to (1) quantify the relationships between fuel loading and moisture characteristics of surface fuels and the temperature and energy produced during combustion, and (2) to produce a classification that summarized these relationships into unique, realistic classes of fire severity. Using computer simulation, they created 115,280 synthetic fuel beds with diverse compositions and moisture conditions and burned them using computer simulation with the First Order Fire Effects Model (FOFEM). Using average fire intensity, fire residence time, total fuel consumed, depth of soil heating, and temperature in the top 1 cm of soil, we created a nine-group classification that separated fire severity classes based first on soil heating, second on intensity and duration of burning, and third on fuel consumed. Fuel beds were correctly placed into the nine fire severity classes 98% of the time using subsets of the synthetic fuel beds. This is another task that was presented in the FIRESEV proposal but not specified as a deliverable. This study shows that a useful fire severity classification system can be created by integrating simulation results will classification procedures, and this classification can be used in both pre- and post-fire application.

Project Summary

We feel that the extensive deliverables developed as part of the FIRESEV project form a comprehensive set of tools, protocols, and knowledge needed to map fire severity today and into the future. The Severe Fire Potential Map provides immediate spatial quantification of the conditional potential for severe fire for prescribed fire, wildfire, and managed wildfire applications. Three category fire severity maps can be created using the WFAT program overnight for the same applications – in many cases this will be more accurate and useful for local applications because additional local data can be incorporated into WFAT that is not included in the Severe Fire Potential Map. Further, both of these products can be integrated with remote sensing to create even more accurate fire severity maps, albeit over longer creation times. However, we feel that the future of fire severity mapping involves the mapping of actual fire effects instead of an over-generalized three category classification system, and the products generated from the FIRESEV project form a starting point for this direction. We feel that we have produced science and tools managers can use that will help them integrate ecological considerations into fire management decisions more readily. These tools are part of a system of tools for immediate "off-the-shelf" use, in addition to those that can provide more accurate, locally useful tools incorporating local data that some managers will find useful. All of the tools have been developed based upon discussions with managers about the tools they can use. Further, we have advanced the science of fire severity and look forward to doing more. We appreciate funding from Joint Fire Sciences Program that has made this possible.

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