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Seeing Red: New Tools for Mapping and Understanding Fire Severity

Forecasting where severe fire may happen on a landscape is an important fire management tool, and giving managers the tools to assess severe fire potential is the focus of the RMRS Fire Severity Mapping Tools (FIRESEV) project. Photo by Bob Keane.

The 2012 fire season was, by most accounts, disastrous for many towns and communities in the western United States. Many fires driven by drought conditions, triple-digit temperatures, wind, near-zero relative humidities, and heavy accumulations of forest fuels became huge wildfires. In late June, there were at least eight fires burning simultaneously throughout Colorado, and by the end of the 2012 fire season, the Waldo Canyon and High Park Fires were on the books as the state's first- and second-most destructive fires on record, in terms of property loss. In the northwest, Oregon's Long Draw Fire burned through more than half a million acres of high-desert rangeland in July to become the largest fire in the state in more than a century. When the smoke finally cleared, over 9 million acres had burned across the US in over 67,000 separate fires—an area roughly equal to the area of Massachusetts and Connecticut combined. According to the National Interagency Fire Center, 2012 ranks third for "number of acres burned" nationwide since 1975, costing the taxpayers over $1.6 billion.

"Acres burned" is a fire statistic that gets a lot of attention from the public. Like the number of trees in a forest, say, or the number of calories in a meal, the extent of area burned is

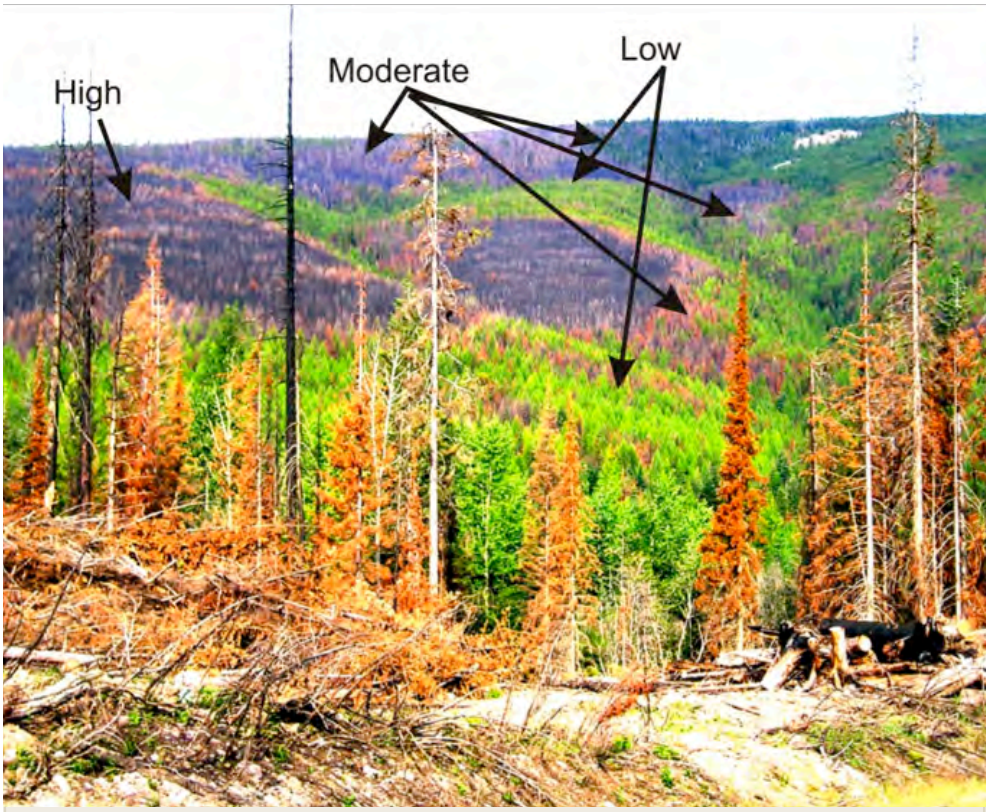
SUMMARY

Large, severe fires are ecologically and socially important because they have lasting effects on vegetation and soils, can potentially threaten people and property, and can be costly to manage. The goals of the Fire Severity Mapping Project (FIRESEV), which covers lands in the continental western United States, are to understand where and why fires burn severely, and to give fire managers, fire ecologists, and natural resource managers tools to assess severity before, during, and after a wildfire. FIRESEV has produced a suite of tools for a wide range of fire management applications, including real-time forecasts and assessments in wildfire situations, post-wildfire rehabilitation efforts, and long-term planning. The suite of five products described in this article includes three mapping tools: 1) the new Severe Fire Potential Map, 2) the Wildland Fire Assessment Tool (WFAT) modification, 3) the Integrated Fire Severity Mapping Procedure, and two conceptual tools: 4) a fire severity classification for surface fuels based on simulation modeling, and 5) a review paper that examines problems with the concept of fire severity and suggests ways to assess severity using an ecologically based approach. The development of these tools was supported by National Fire Plan and Joint Fire Science Program funding.

"Statistics like 'area burned' are not always useful to managers—they need the number of acres broken down by severity type," says fire scientist Bob Keane.

relatively easy to measure, but it is ultimately only one piece of a much more complicated scenario. Fires can burn much more severely in some areas than others, depending on factors such as climate, fuels, and landform. As a result, when a wildfire sweeps through an area it usually creates a mosaic across the landscape of low-, medium- and high-severity burn patches. This has implications for post-fire recovery and operations such as erosion control, land rehabilitation, hazard mitigation, and timber salvage. According to Bob Keane, a fire scientist from the Rocky Mountain Research Station Missoula Fire Sciences Lab, "Statistics like 'area burned' are not always useful to managers—they need the number of acres broken down by severity type. A map that shows the severity of a wildfire that just burned provides the details that managers can use for planning the next steps."

With stretched budgets and the looming threat of future large fires, managers must be able to quickly and efficiently assess fire severity after a wildfire to meet objectives such as protection of water quality and restoration of wildlife habitat. At the same time, predicting severe fire potential can help managers understand which parcels are likely to burn with high severity (if no mitigation is completed) if or when they catch fire in the future, thereby helping managers with planning and mitigation efforts.



When a wildfire sweeps through an area, it usually creates a mosaic of low-, medium-, and high-severity burn, with implications for post-fire operations such as erosion control, land rehabilitation, hazard mitigation, and lumber salvage operations. Photo by Terrie Jain.

And for these goals, they need the right tools in their toolboxes.

Creating the right pre- and post-fire severity assessment tools for managers has been the most recent focus of Keane and his Fire Sciences Lab colleagues Greg Dillon, Pam Sikkink, and Eva Karau, along with collaborator Penny Morgan from the Forest, Rangeland, and Fire Sciences Department at the University of Idaho. According to Eva Karau, "There isn't just one single tool that is going to be useful for assessing burn severity. Managers have different needs and objectives related to burn severity when it comes to planning, restoration, and real-time fire situations, and the goal is to have multiple tools for managers to be able to use, depending on these needs."

To this end, the researchers behind the Fire Severity Mapping Project (FIRESEV), developed based upon a National Fire Plan-funded project and additionally supported by the Joint Fire Sciences Program, are working towards developing a comprehensive set of tools and procedures to create, evaluate, and deliver fire severity maps for all phases of fire management, including : 1) real-time forecasts and assessments in wildfire situations, 2) wildfire rehabilitation efforts, and 3) long-term planning. In a nutshell, their goal is to create a mapping and classification system that will deliver the most useful fire severity map product for the right fire management application in the right time frame.

Defining "Severe" in Ecological Terms

Fire severity is often evaluated by how much of the forest or rangeland overstory is killed, either through consumption by crown fires or by

Whether severe fire is viewed as a positive or negative force depends on the ecological context—namely, the type of forest ecosystem that burned and the extent to which the ecosystem is adapted to high-severity fire. Photo by Bob Keane.

heating of the bark and foliage. A high-severity forest fire leaves a lot of charred, dead trees in its wake—seven out of every ten, by definition—and consumes most of the litter and surface fuels. (In contrast, many trees can survive within areas burned in low- to moderate- severity fire, or unburned "islands" may remain within a fire mosaic.) Although the term "severe" has negative connotations, a severe fire is not necessarily bad for landscapes in the grand scheme of things—stand-replacing fires can be critical for maintaining certain ecosystems over the long term. Whether severe fire is viewed as a positive or negative force depends on the ecological context—namely, the type of ecosystem that burned.

Greg Dillon explains: "In forests where tree species like lodgepole pine, spruce, and fir are dominant, high-severity fire is an essential ecological process. It helps to promote the germination of new seedlings, clean out pathogens like dwarf mistletoe, and initiate large, even-aged forest stands." In other words, in ecosystems adapted to high-severity fire, the return of the fire at regular intervals is essential, and in this case the negative connotations of the word "severe" can be misleading. "Lodgepole pine is adapted to propagate after a fire," said Bob Keane. "If you have a high-severity fire in lodgepole, it's able to regenerate because fire has opened up its cones and put the seed on the ground. So as far as the ecosystem is concerned, you haven't actually had a devastating fire. Many shrubs, wildflowers and grasses rapidly regrow as fires rejuvenate vegetation and alter wildlife habitat."

Obviously, high severity fire can be problematic as well, so it is critical to be able to plan for and manage it in the landscape. According to Penny Morgan, "There are many cases where having extensive crown fires is not desirable because they threaten people and property in the wildland-urban interface, or when plants and animals are not well adapted because ecosystems historically didn't burn that way." Ponderosa pine forests, for example, evolved in most places with a regime of frequent, low- and mixed-severity fires. When higher-severity fire sweeps through these forests and kills trees in large patches, the potential for re-establishment of the trees may be lowered due to lack of seed sources, and the forest may convert into grass or shrubland for extended periods of time. Historical fire suppression may have played an important role in introducing high-severity fire to these landscapes.

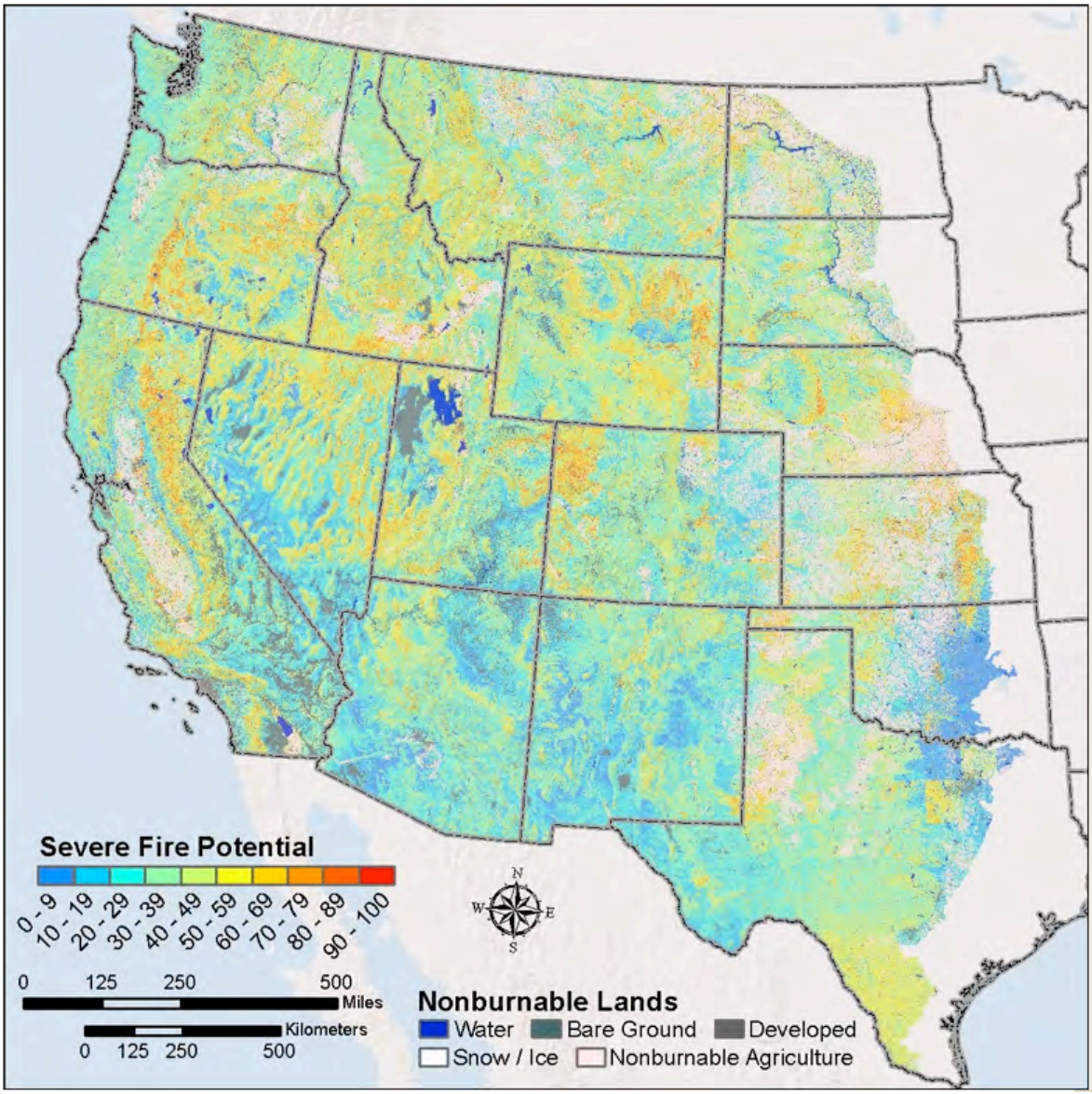
Again, Greg Dillon explains, "While some patches of high-severity fire have surely always occurred in all fire-adapted ecosystems, land management over the past century has created a more continuous spatial arrangement of greater fuels in many places, which can lead to larger patches of high-severity fire." Since high-severity fire can have negative consequences for soil erosion, water quality, and wildlife habitat, it is important that managers and fire ecologists have a variety of tools available to assess severity and design appropriate management actions.

"Land management over the past century has created a more continuous spatial arrangement of greater fuels in many places, which can lead to larger patches of high-severity fire," says spatial fire analyst Greg Dillon.

Management Applications of the FIRESEV Project

Large "X's" indicate the tool's primary use; smaller "x's" indicate additional applications of the tool.

FIRESEV Tools	Management Application		
	Real-time forecasts & assessments in wildfire situations	Post-wildfire rehabilitation efforts	Long-term planning & vmitigation
Mapping Products			
1. **Severe Fire Potential Map (SFPM):** To meet immediate needs of fire management, this map quantifies the likelihood that a fire would burn with high severity at any 30-m cell across the contiguous western United States. This wall-to-wall map can be accessed over the Internet to rapidly evaluate potential for high severity fire for any location. The SFPM can help managers mitigate risk of high-severity fire where needed through strategic planning of fuel treatments, and in evaluating potential risks and effects associated with new fire events.	X	x	x
2. **Wildland Fire Assessment Tool (WFAT) Simulated Fire Severity Mapping Program:** A fire severity mapping algorithm in the Wildland Fire Assessment Tool (WFAT) was developed by the National Interagency Fuels Technology Transfer (NIFTT) team. Training for the Wildland Fire Assessment Tool is available on-line and also at workshops that are part of major fire conferences. In general, the simulation tools provided in WFAT, along with weather forecasts, allow managers to produce more accurate fire severity predictions for short-term analysis, such as during an active fire (http://www.frames.gov/partner-sites/niftt/tools/niftt-current-resources/).	x	X	x
3. **Integrated Fire Severity Mapping Procedure**: RMRS researchers are developing a statistical model that can integrate results from simulated fire severity with satellite imagery to potentially enhance fire severity mapping for localized applications. Simulation modeling of fire effects done during or after a wildfire event can be merged with satellite indices to improve estimates of severity. These maps will be most useful for post-fire hazard mitigation, rehabilitation and restoration planning. *This tool is still under development.*		X	
Conceptual Products			
4. **Fire Severity Classification System**: In order to predict fire severity in a management area, managers must know how fire effects are related to on-site surface fuels and moisture levels. RMRS researchers have produced a classification system that objectively quantifies several of these effects into nine classes of fire severity. This system can be used by managers to more precisely predict and/or describe fire severity based upon fuels, moisture conditions, and fire characteristics.	X	X	X
5. **The Fire Severity Concept**: The traditional use of fire severity has many weaknesses that limit its use to managers into the future. RMRS researchers have summarized how fire severity has been used in the past and suggested future directions (such as considering fire severity based on specific measureable endpoints) for classifying and mapping severity that accommodate new science and technological advances and can be used to improve severity estimates.	X	X	X

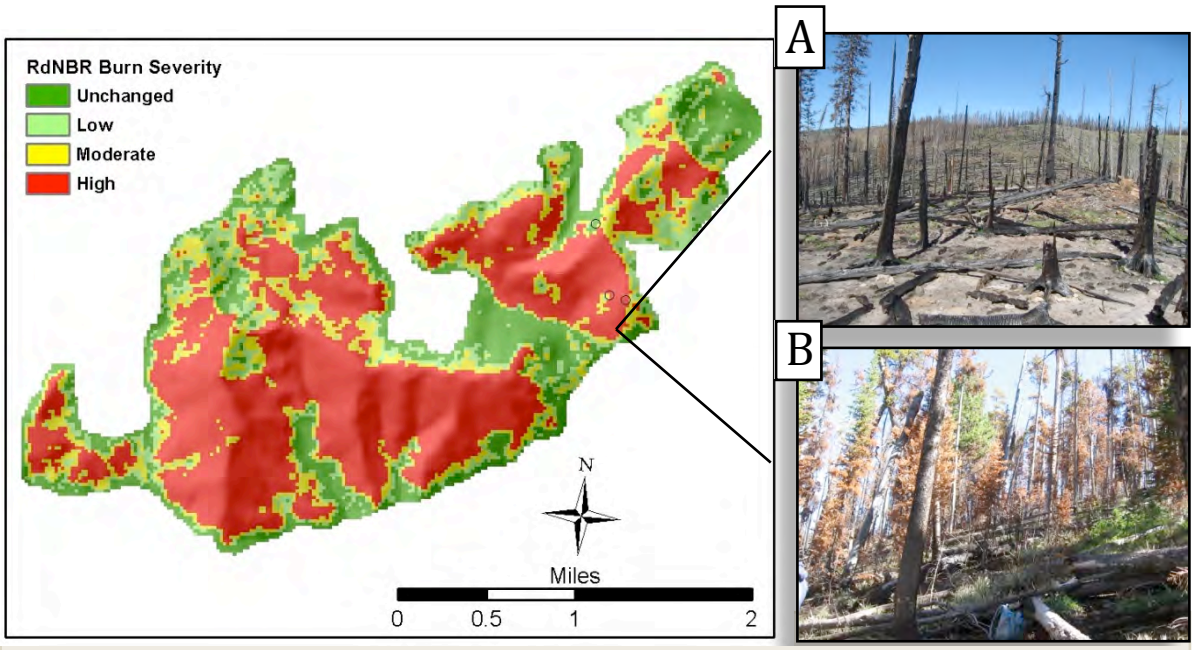


The Severe Fire Potential Map combines data from more than 7,000 past fires with spatial data on topography, climate, and vegetation to give managers an indication of how likely any location may be to experience severe fire if it were to burn at 90th percentile weather conditions. Map by Greg Dillon.

Where Will It Burn the Hottest? The New Severe Fire Potential Map (FIRESEV Tool 1)

Forecasting where fires will burn with high severity when they occur is an important fire management tool. A major part of the FIRESEV project is the new Severe Fire Potential Map (SFPM), a downloadable map covering the continental western U.S. Fire severity can be thought of, in its simplest terms, as the amount of biomass burned. However, predicting the likelihood that fires will burn with high severity is a complicated exercise involving interactions among topography, fuels, climate, and vegetation over space and time. For this reason, satellite imagery is a useful tool, in that pre- and post-fire images can be linked with field-measured fire severity data to assess the degree of change. The SFPM combines a database of satellite-derived burn severity estimates from 7,000 past fires with spatially explicit topography, climate, and vegetation data to assess the potential for fires to burn with high severity if they should occur. This map will allow managers to forecast the potential severity of new fires in real time because it delineates which parts of the landscape are most likely to burn severely.

"The Severe Fire Potential maps are potentially useful for anyone who cares about a particular piece of land, how it might burn, and what the ecological effects may be when it does burn," says Professor Penny Morgan.



This is a map of burn severity for a single fire as derived from satellite imagery, and an example of the type of data that was used for creating the Severe Fire Potential Map. Photo A is located on a ridge and illustrates high-severity fire effects, with complete mortality of overstory trees, consumption of most surface fuels, and moderate to high soil heating. Photo B is from mid-slope on a west aspect, and illustrates low- to moderate-severity fire effects, with needle scorch on some trees and only partial consumption of surface fuels. Photos and maps by Greg Dillon.

Penny Morgan hopes that the end users of this map will include fire managers, fire ecologists, and natural resource managers. As she puts it, "On the map, there is a probability of high-severity fire for every pixel in the West (with the exception of Alaska, cities, and agricultural land). So the maps are potentially useful for anyone who cares about a particular piece of land, how it might burn, and what the ecological effects may be when it does burn."

The Severe Fire Potential Map uses 90th percentile fire weather conditions. These fire weather conditions represent a climatological breakpoint based on local conditions that is roughly equivalent to "very dry" fuels. For any particular time of year and location, if managers know the approximate Energy Release Component—a metric that tracks seasonal changes in fuel moisture for their area—they can use their judgment in interpreting whether specific severe fire potential might be higher or lower than what the Severe Fire Potential Map indicates. According to Greg Dillon, the usefulness of the map lies in its ready availability and ease of employment. "The SFPM provides a planning and decision support tool that does not require managers to do simulation modeling. As a resource that can be downloaded from the web, the maps will be available when new fires start and managers can use them to evaluate potential risks and effects associated with new fire events."

Bob Keane explained that the Severe Fire Potential Map can also be useful for planning fuels treatments: "If managers wanted to do fuel treatments in an area to minimize fire severity, they could bring up the map, and look at the places that are projected to burn with high severity. If it is an ecosystem that doesn't usually have high-severity fire, they could choose to treat to reduce fuel loads. If it is in lodgepole pine, where high severity fire is the norm, from an ecological perspective they can leave it alone. This map allows you to make decisions like that."

More Mapping Tools for Improved Severity Assessments (FIRESEV Tools 2-3)

When a fire is actively burning, a manager may require a more detailed and localized fire severity assessment than is available from the Severe Fire Potential Map (for example to support firefighting operations and/or assess ecological effects). The FIRESEV researchers have introduced a modification to an already existing tool that provides a way to map fire severity effects in detail using simulation modeling keyed to local fuels and weather conditions. This popular tool, called the Wildland Fire Assessment Tool (WFAT), uses spatial data layers such as fuels (from LANDFIRE) and tree populations (from the National Tree List Layer, also developed as part of FIRESEV) to simulate fire severity. The FIRESEV team

	1. Severe Fire Potential Map	2. WFAT-Simulated Fire Severity Mapping Program	3. Integrated Fire Severity Mapping Procedure
Delivery	Immediate	Overnight	2-4 weeks
Potential for Accuracy	Lowest	Moderate	Highest
Expertise required	Lowest	Moderate	Highest
Primary use	Wildland Fire Decision Support System (WFDSS), wildfire planning, long range fire planning, resource allocation	WFDSS, Rapid Assessment of Values at Risk (RAVAR), wildfire planning, rehabilitation, restoration	Rehabilitation, restoration, Burned Area Emergency Response (BAER) activities
Robustness, flexibility	Lowest	Moderate	Highest
Spatial extent	Entire western US	Region, Zone	Fire event

A comparison of the three FIRESEV mapping products (FIRESEV Tools 1-3).

modified WFAT to add fire severity keys that enable prediction of fire severity before, during and after fires using local data. A potential use for this tool is summarized by Bob Keane: "Let's say a fire is burning and the LANDSAT satellite hasn't gone over yet, but you need an assessment of fire severity—here is where we use modeling. WFAT will calculate fire severity using modeling, and then provide you with a map of not only which areas burned today and with what severity, but also what the outlook will be for the next day."

In general, the simulation tools provided in WFAT, along with weather forecasts, allow managers to produce more accurate fire severity predictions for short-term analysis. However, the drawback may be the time and expertise needed to run WFAT. While the Severe Fire Potential Map is available immediately for download by anyone, maps created using the WFAT generally take a day to prepare and require the expertise of someone who is trained in using the computer model (training is available on-line at http://ww.frames.gov/partner-sites/niftt/training/courses-registration and also at workshops that are part of major fire conferences).

An additional resource being created as part of the FIRESEV project merges modeling and satellite imagery together to further improve burn severity mapping, primarily for post-fire management and rehabilitation. As Eva Karau states: "We are working on new methods that should have the capability to provide a more ecologically-based spatial assessment of fire effects." This method, the Integrated Fire Severity Mapping Procedure, is a set of statistical analyses that combines satellite image-based change detection with output from simulation models (e.g., WFAT) to estimate fire effects at a landscape scale. According to Eva, one of the advantages of this approach is its ability to provide actual estimates of fire effects—for example, estimates of fuel consumption are expressed in units of fuel consumption—as opposed to something more general such as low-medium-high fire severity classes. Currently, this mapping product is in the development phase, but the research team hopes that it will become operationally feasible for burn severity mapping once accurate fuels and weather information is available. Of the three mapping products, this one has the potential to provide the highest level of understanding, detail, and accuracy (depending on the quality and accuracy of the spatial input data), but it would also take the longest time to produce. Maps could take on the order of two to six weeks and would have to be done for each fire. As such, these maps would probably be most useful for post-fire hazard mitigation, rehabilitation, and restoration planning.

Towards a Greater Conceptual Understanding of Fire Severity (FIRESEV Tools 4-5)

Along with the modeling and mapping projects, FIRESEV researchers have tackled some of the more difficult problems that come with applying the concept of fire severity to fire ecology and research. First, they saw a need for a more repeatable, accurate, and robust fire-severity classification system, (rather than low, medium, high) for use in both modeling and predicting fire severity in the field after a fire. Fire severity classifications are used by managers and researchers to help with tasks such as describing post-fire burn patterns and evaluating prescribed fire success. The problem with most fire severity classifications, according to Bob Keane, is that they were developed with a large degree of subjectivity because they were designed for a specific post-fire task

KEY FINDINGS

- The tools and procedures that are being developed as part of the Fire Severity Mapping Project (FIRESEV) can help managers in all phases of fire management including real-time forecasts and assessments in wildfire situations, wildfire rehabilitation efforts, and long-term planning.
- FIRESEV mapping products such as the Severe Fire Potential Map (SFPM), the Wildland Fire Assessment Tool (WFAT), and the Integrated Fire Severity Mapping Procedure (under development) can help managers both mitigate risk of high-severity fires and quickly and efficiently assess fire severity after a wildfire to meet objectives such as protection of water quality and restoration of wildlife habitat.
- FIRESEV conceptual products such as the Fire Severity Classification System and the Fire Severity Concept are intended to set the stage for a new era in fire severity research and to further foster the development of helpful management tools.

or they were built using arbitrary classes without local field data. The researchers created a fire severity classification for surface fuels using computer simulations, where they designed over 100,000 fuel beds with diverse compositions of burnable material and variable moisture levels; these fuel beds were then burned using a simulation model. The end result was a robust, repeatable, nine-group classification that separated the fuel beds based on soil heating, intensity and duration of burning, and fuel consumed. The researchers hope this will be the model for fire severity classifications created in the future, in that it places numeric values on the fuels, moistures, and fire characteristics needed to produce specific fire effects. Pam Sikkink explains: "Our classification system is a first effort at linking fuels, moisture conditions, and fire characteristics. Managers can use it to predict how severe a fire might be from existing fuels in their management area. We tried to make the classification useful for field managers by providing a link between existing fuels and the type of effects that might be expected."

Secondly, as the research team was developing the tools in the FIRESEV project, they realized that defining fire severity itself was not at all straightforward. Because fire severity lacks measurement units, the diverse, complex, and interacting effects of fire are often collapsed into a simple fire severity index in which important information is lost. To address this issue, the FIRESEV researchers invited other prominent fire ecologists to collaborate with them on the goal of considering fire severity from a purely ecological standpoint and then integrating this new understanding across all disciplines of fire science. The end result was the recommendation for an ecologically based approach to assessing severity. "We advocate for defining the elements of severity in terms of specific fire effects. So, if tree mortality is an important driver of severity for a particular project, then map tree mortality; if exposed mineral soil is important, then map that," Keane explained.

By considering fire severity based on specific ecological endpoints, the direct effects of fire can be measured and then integrated into fire severity index keys. The new ideas in this publication, which is currently in review, have the potential to set the stage for a new era in fire severity research and to further foster the development of management tools to help communities recover from and plan for severe fires.

FURTHER READING

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PENNY MORGAN is a professor in the College of Natural Resources at the University of Idaho. She directs the University's Wildland Fire Program. She earned her Bachelor of Science and Master of Science degrees from Utah State University and holds a doctorate from the University of Idaho. Penny is committed to helping people understand and use science in natural resources management in Idaho, the western U.S., and beyond.

PAMELA SIKKINK is a Post-Doctoral Research Ecologist with the Fire, Fuel, and Smoke Program at the Rocky Mountain Research Station Fire Sciences Lab, Missoula, MT. She has an M.S. in geology and an M.S. and Ph.D. in forestry from the University of Montana, Missoula. She brings experience in vegetation and fuels sampling protocols, trend analyses, and GIS and statistical skills to her projects. In addition to the FIRESEV project, she has conducted vegetation studies in Yellowstone National Park, worked on the seasonal development grass as fuels in western Montana, and developed guides for managers for visually estimating and comparing fuel loads.

EVA KARAU is a Biological Scientist with the Fire Modeling Institute in the Fire, Fuel, and Smoke Program at the Rocky Mountain Research Station Missoula Fire Sciences Lab. She has an M.S. in Forestry from the University of Montana. Previously in a research support position, Eva's projects focused on landscape simulation modeling, fire effects, and burn severity mapping. She currently uses spatial analysis skills to support national fuels prioritization strategies.

GREG DILLON is a Spatial Fire Analyst with the Fire Modeling Institute (FMI), which is part of the Fire, Fuel, and Smoke Science Program at the Rocky Mountain Research Station's Missoula Fire Sciences Lab. He has a M.A. in Geography from the University of Wyoming. Greg's work at the Fire Lab has included mapping potential vegetation for the United States as part of the LANDFIRE project, analyzing trends and spatial influences on wildfire severity in the western U.S. for FIRESEV, and a variety of spatial and statistical analyses for FMI, including support for national wildland fire risk assessment.

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