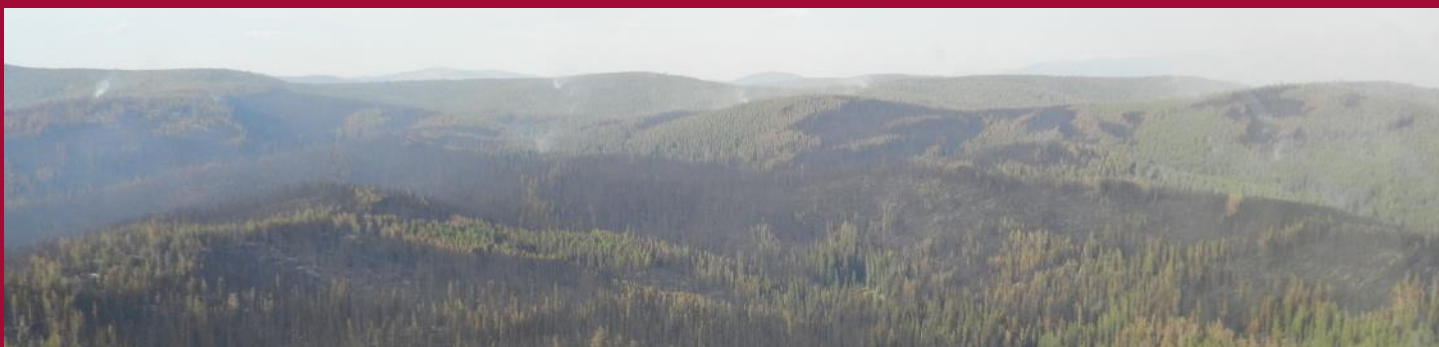




United States Department of Agriculture



FIRE, FUEL, AND SMOKE SCIENCE PROGRAM 2015 RESEARCH ACCOMPLISHMENTS

Missoula Fire Sciences Laboratory
Rocky Mountain Research Station

Faith Ann Heinsch,
Charles W. McHugh,
and Colin C. Hardy,
Editors



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Cover photos, clockwise from top: Bear Lake Fire, Pioneer Mountains, Montana, September 1, 2015. Photo by LaWen Hollingsworth / FFS; Reynolds Fire, Glacier National Park, Montana, July 29, 2015. Photo by Charles McHugh / FFS; Whitebark pine growing after daylight treatment and prescribed burn. Photo courtesy of Bob Keane / FFS. Peak and trough structure of flame front of experimental fires. Photo courtesy of Mark Finney / FFS. Photo on opposite page: Whitefish Lake 1 Fire, Alaska, July 3, 2015, 3:49 p.m. Photo by Charles McHugh / FFS.

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ROCKY MOUNTAIN RESEARCH STATION
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Photo: Angel Rocks, Chena River State Park, Alaska. Photo by LaWen Hollingsworth / FFS

THE FIRE, FUEL, AND SMOKE SCIENCE PROGRAM

The Fire, Fuel, and Smoke Science Program (FFS) of the U.S. Forest Service, Rocky Mountain Research Station focuses on fundamental and applied research in wildland fire, from fire physics and fire ecology to fuels management and smoke emissions. Located at the Missoula Fire Sciences Laboratory in Montana, the scientists, engineers, technicians, and support staff in FFS conduct national and international, cutting-edge work in wildland fire research and develop research and management tools and applications. Their work is designed to improve understanding of wildland fire as well as safe and effective fire, fuel, and smoke management. The research is divided between six general focus areas of study, described on the next page.



Photo: Research burn unit on the Eureka Ranger District of the Kootenai National Forest near Eureka, Montana. Note the heat sensors located at various points uphill of the flaming front (page 18). Photo by Dan Jimenez / FFS.

2015 YEAR IN REVIEW

Each year I spend as the Program Manager for the Fire, Fuel, and Smoke Science (FFS) Program seems to be more satisfying than the last. Even as resources seem to be decreasing, and distractions seem greater, we can honestly and proudly celebrate 2015 as another year of remarkable success. In this 2015 annual report we describe progress and achievements in each of our six Research Focus Areas: Physical Fire Processes, Fuel Dynamics, Smoke Emissions and Dispersion, Fire Ecology, Fire and Fuel Management Strategies, and Science Syntheses and Delivery (see descriptions of these in the next section of this report). We accomplish this work through the leadership of our 12 full-time scientists who organize teams comprised of our post-doctoral scientists; professionals, term-appointed personnel; temporary employees; numerous resident contractors and cooperators; and scores of external partners and institutions. These teams use innovative approaches to discover new information and refine our understanding of the role, behavior, and effects of wildland fire.

In addition to the core FFS Program organization, we have two “sub-units” chartered to focus on specific areas of research as well as development and science delivery. Our Fire Modeling Institute (FMI) is chartered to provide a workforce and resources to support, maintain, and develop collaborations between fire research and fire managers in the field across the U.S. We provide details on FMI in the section beginning on page 8 of this report. We have just re-chartered the National Fire Decision Support Center (NFDSC), designed to build upon previous science achievements that (1) promote and facilitate the development of new fire behavior science and practical prediction tools; (2) strengthen the science of fire management activities and performance; and (3) advance the science, development, and dissemination of quantitative wildland fire risk analysis

methods. In addition, a third unit within Rocky Mountain Research Station aligned with the FFS Program is the Wildland Fire Management Research, Development, and Applications (RD&A) Program based in Boise, Idaho. Overlap and interaction of these three entities—FMI, NFDSC, and the Wildland Fire Management RD&A—is critical to the practical implementation of research produced in FFS.

This Annual Report offers many details and examples of the work we did in 2015. I wish to offer highlights of several particularly compelling topics.

Fire Effects Information System Turns 30

This year we celebrate the 30th anniversary of the Fire Effects Information System (FEIS), an online collection of synthesis reviews of the scientific literature about fire effects on plants and animals, fire studies, and fire regimes of plant communities in the United States (pages 11, 45, and 46). We are proud of our new FEIS user interface (www.feis-crs.org/feis/), which enables readers to search for species information using many criteria, including maps, as well as to connect information from all three FEIS products: Species Reviews, Fire Studies, and Fire Regimes. This interconnected system allows land managers, researchers, and the public — at their desks or in the field — to find the best available science about fire and its ecological effects. It is a truly interactive, world-wide web of knowledge, receiving more than half a million Internet visits per year and accessed from more



Image: The Fire Effects Information System website provides access to synthesis reviews about fire effects on plants and animals; fire studies; and fire regimes.

than 100 countries. Our longstanding leader for FEIS, Jane Kapler Smith, retired this year, and we are indebted to her for the legacy of her persistent and passionate leadership. Now, we are excited to declare that FEIS — the system, the operation, and the staff — is in the highly capable and experienced hands of our new FEIS manager, Ilana Abrahamson.

International Contributions and Recognition

While the community of science and scientists dedicated to the study of wildland fire is small, the scope is clearly global. FFS scientists must interact with the international community as they are both producers and consumers of science. Whether delivering new science or learning from international colleagues about how to better direct our own efforts, scientific exchanges inform the production as well as use of fire science and research. These exchanges are also indicators of a scientist's impact and stature, and as such, are explicitly addressed in the Office of Personnel Management's Research Grade Evaluation Guide:

“Although not a specific requirement, international recognition of a scientist is increasingly used to reflect scope as well as “quality, significance, and impact” in considering ... the global scale of some scientific problems...”

The quality, significance, and impact of our Program Scientists is evident by their contributions in 2015 to the international community. Fire Chemistry Team Leader Wei Min Hao continues his work with the French Nuclear Energy Commission assessing black carbon emissions for Northern Eurasia. This year, Wei Min presented one of only two invited papers in a special session at the United Nations Conference on Climate Change in Paris, France, and presented similar work at the 36th International Symposium of Remote Sensing on Environment in Berlin, Germany. Research Forester Mark Finney



delivered an invited keynote lecture to the Australasian Fire and Emergency Service Authorities Council (AFAC) meeting in Adelaide, Australia, regarding fundamental fire research conducted by the Missoula Fire Sciences Laboratory. Mark also serves as an international advisor to the AEGIS Greek wildfire risk and disaster assessment project funded by the European Union, and participated in two related exchanges in Greece. Related work took Finney to Rome, Italy as well as Corsica, France. Research Ecologist Bob Keane also participated with Finney in the AEGIS Greek wildfire risk and disaster assessment project in Greece, and has lectured at the University of British Columbia, Canada. Research Ecologists Matt Jolly and Russ Parsons presented papers and participated with international colleagues at the 6th International Wildland Fire Conference in Pyeongchang, South Korea. Research Mechanical Engineer Sara McAllister presented papers at conferences in Greece and Cyprus that are attended by most of the combustion and fire protection engineers in Europe. Finally, Research Engineer Bret Butler and Electrical Engineer Cyle Wold traveled to Northwest Territories, Canada, to assist the Canadian Forest Service in conducting a series of field experiments designed to test material

response, energy release, and fire behavior in full-scale crown fires.

Award Winning Research and Publications

This year, four of our Program scientists—Mark Finney, Research Physical Scientist Jack Cohen, Mechanical Engineer Jason Forthofer, and Sara McAllister — reported their breakthrough work, titled "Role of buoyant flame dynamics in wildfire spread," in the prestigious U.S. journal *Proceedings of the National Academy of Science* (PNAS) (page 17). PNAS has a rigorous screening by associate editors with an acceptance rate of 18% of direct submissions and an impact factor of 9.6. Their research paper describes the discovery of a previously unknown physical explanation for flame spread, solving one of the longest held mysteries in wildfire behavior science. Many models have attempted, but failed, in the past 70 years to discover how the coupling of energy release, heat transfer, and ignition produces a self-sustaining process of flame spread. This paper is a scientific breakthrough in many areas since it is the first to identify buoyant flame instabilities as the source of convective heating and ignition—essentially the missing, organizing principle of flame spread. It

overturns long-held beliefs that thermal radiation alone can account for particle heating and ignition, showing instead that particle ignition is driven by direct, non-steady flame contact. This paper required four years of research and the coordination of teams working at the Missoula Fire Sciences Laboratory, the University of Maryland, and the University of Kentucky. The research brought together data from both laboratory and field-scale fires, finding buoyancy-based scaling of flame behaviors that should extend from very small to the very largest of fires. Their work suggests a means of advancing practical fire prediction methods that could not have existed before. The paper was awarded the Rocky Mountain Research Station's 2015 Scientific Publication of the Year.

The highly esteemed journal *Nature Communications* published FFS Research Ecologist Matt Jolly's study, "Climate-induced variations in global wildfire danger from 1979-2013." This significant work described fire weather seasons across the globe getting longer, generating an intense international media interest. The study was a collaborative, multi-year, international effort, including contributions from six coauthors representing five partner organizations: South

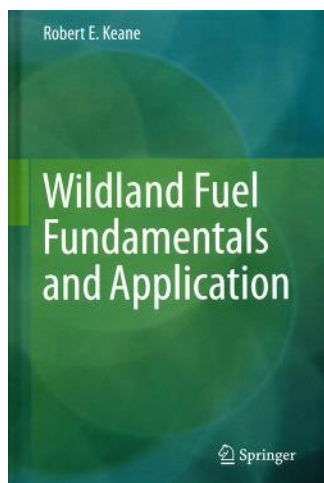
Dakota State University (M. Cochrane, P. Freeborn), USFS Northern Region (Z. Holden), Desert Research Institute (T. Brown), and University of Tasmania (G. Williamson, D. Bowman). The authors determined that fire weather seasons have lengthened across 25.3% of the Earth's vegetated land surface, resulting in an 18.7% increase in global mean fire weather season length. In addition, the second half of the study period (1996-2013)



Photo: Researchers are preparing for the next phase in examining physical fire processes by adding the effect of slope and fire-on-fire interaction. The apparatus in the photo above can be set on an angle as shown as well as in a V-shape to begin to simulate fires in complex terrain. Photo courtesy of Mark Finney / FFS.

shows increased frequency of long fire weather seasons across 53.4% of the globe's vegetated areas. The immediate impact of the study's publication was intense media interest. Matt participated in and was cited in 51 media interviews over a two-week period that ranged from local to international news sources from Missoula, MT to New York, NY, Washington DC, Australia, France and the United Kingdom. He was also interviewed for *Discover Magazine's* 2016 January/February special issue on "The year in science," in which his work was featured as one of the 100 most important scientific advancements of 2015. As a result of the media attention and selection for *Discover Magazine*, Dr. Jolly was presented the 2015 Rocky Mountain Research Station's Science in the Media Award.

Fuel Science Is for Ecology, Too



The case for considering wildland fuels in an ecological context cannot be overstated. In the 2014 Annual Report we featured Research Ecologist Bob Keane's new textbook *Wildland Fuel Fundamentals and Application* (published by Springer), which has been in full production and available for a full year now. This book provides fire scientists and

managers a comprehensive understanding of the science of fuel ecology to realistically evaluate fire effects and behavior across the diverse ecosystems and landscapes of the world. With this book, we remind our fire science colleagues that they are often the first-order customers of fuel science.

Applied Science and Boots on the Ground

Whether for science-first or in service to fire management, many of our scientists and staff are qualified in the Incident Qualifications Certification System (IQCS) for fire assignments in a variety of positions, including Division Supervisor, Task Force Leader, Long-term Analyst, Geospatial Analyst, GIS Specialist, and Fire-EMT. Having these folks in these positions offers us insight into our customer's needs and frequently provides us the access needed to study, observe, and measure fire phenomena in situ 'full-scale' and in 'real time.' The section in this report labelled "Boots on the Ground" (page 40) offers in-depth examples of why and how we engage in operational incident management.

These are just a few of the accomplishments from 2015. I invite you to read the rest of the report to discover the wide-reaching research being done by the scientists and staff of FFS. And, of course, you can find most or all of this information on our Program website at <http://www.firelab.org>. Please also visit our Rocky Mountain Research Station's website, found at <http://www.fs.fed.us/rmrs/>, to learn more about our other seven science programs and our station.

Colin Hardy, Program Manager,
Fire, Fuel, and Smoke Science Program

The Fire, Fuel, and Smoke Science Program Focus Areas

Physical Fire Processes



Laboratory studies and theoretical physical modeling, informed and validated by field observations, are used to examine

physical fire processes and improve our capability to manage fire safely. This research is designed to improve understanding of the fundamental, multi-scale, physical processes that govern fire behavior, including combustion processes, heat and energy transfer, atmospheric dynamics, and transitions from one type of fire behavior to another. Scientists analyze the combustion process and the factors that determine fire behavior with the goal of developing a comprehensive physics-based fire modeling system that includes the full range of combustion environments and fire events observed in wildland fuels. New physics-based understanding will be incorporated into models suitable for use by fire and fuels managers both for characterizing fire danger and predicting fire behavior. Scientists need to model fire behavior for a wide range of purposes including improving firefighter safety, simulating site-specific vegetation, predicting loss of life or property, and global carbon accounting.

Fuel Dynamics



Research on fuel dynamics helps land managers describe the vegetation that burns during wildland and prescribed fires. FFS scientists investigate and design consistent, accurate, and comprehensive methods for quantifying wildland fuels, which vary spatially, differ in size, and change with time. Through

laboratory and field studies, FFS scientists are developing tools to predict seasonal and multi-year changes in fuels that allow managers to more accurately predict fire behavior and fire effects. Improved data for fire behavior modeling and fuel hazard assessment and improved fuel dynamics algorithms for temporal models of fire behavior, fire danger, and fire effects are critical additions for the next generation of fire models.

Smoke Emissions and Dispersion



Officials charged with supporting public health and safety need better tools to estimate effects of wildfire on smoke emission levels, visibility standards, and carbon budget applications as

well as to anticipate the movement of smoke across the country and around the globe. FFS researchers are developing and testing methods for implementing a real-time emissions inventory and dispersion models for smoke emissions from wildland fires. Researchers are integrating field observations, satellite data, and smoke chemistry with models of emissions, smoke composition, and movement either within a fire plume or through layers of the atmosphere to improve understanding and prediction of smoke emissions and dispersion. This work applies to issues relating to National Ambient Air Quality Standards under the Clean Air Act, regional haze issues, and continental and global climate change questions.

Fire Ecology



To predict post-fire succession, managers require better understanding of interactions between fire-adaptive traits of plant species and fire severity. They also need improved understanding of treatments, such as prescribed fire with and without harvest, mechanical treatment, and/or herbicide application, and resulting effects on fundamental ecosystem characteristics, such as nutrient cycling, carbon storage, long-term fuel dynamics, and weed invasion. Understanding how treatments interact is important as well. Field and laboratory studies address how fires and, more specifically, the associated heat transfer, fuel consumption, and fire duration, affect plants and plant communities, how fires alter the flow of carbon and nutrients in ecosystems, and how fire influences native and nonnative species. Research results contribute to improved conservation, appropriate ecological use of fire, improved management strategies for ecosystem restoration and maintenance, and better, more defensible fuel management treatments.

Fire and Fuel Management Strategies



To improve predictive ability for future fire regimes, FFS scientists and their research partners simulate landscape-level interactions among changing climate, fire regimes, and vegetation under different management scenarios. To better understand the drivers of historical fire regimes, they conduct fire history research. To improve the predictability of fire's impacts on the biota, the atmosphere, and

human health and safety, they use case studies, ecological research, and models based on physical fire processes and fuel dynamics research. FFS research improves fire and fuel management policies and practices, resulting in increased forest resilience, maintenance of forest cover, increased carbon capture and storage, and better understanding of the complex interactions between climate change and fire regimes. Moreover, improved fire danger rating and fire behavior prediction systems support sound fire and fuel management decision making.

Science Synthesis and Delivery



Scientific publications form the foundation of science delivery. Synthesis of past research builds on this foundation. FFS is committed to delivering new science knowledge in forms

usable by scientists and resource managers alike. While FFS synthesis and delivery efforts are anchored in refereed scientific publications, science delivery includes the entire range of communications media to help land managers apply new and existing research, including computer programs, photo guides, and mentoring. Additional products include presentations, classes, field tours, and training materials. To develop and test products, FFS personnel collaborate with users and other stakeholders to design new ways to exchange information and bring science into application. FFS personnel provide educational programs for children and young adults. They also maintain the website <http://www.firelab.org>, where information about FFS publications and products is available. The Program's Fire Modeling Institute (FMI, page 8) is an essential component of this focus area.

FIRE MODELING INSTITUTE

The Fire Modeling Institute's (FMI) mission is to connect fire managers, technical experts, and scientists with the best fire analysis technology and with the most current information from the scientific literature available to respond to their fire-related resource management needs.

FMI is a national and international resource for fire managers. It is a joint effort between the Fire, Fuel, and Smoke Science Program (FFS) of the Rocky Mountain Research Station and Washington Office Fire and Aviation Management. FMI was chartered to create an organization and work force to support, maintain, and develop collaborations between U.S. Forest Service Research and Development and fire managers in the field. The three branches of FMI — Application Team, Information Team, and Modeling Team — fill different roles, yet all provide assistance to managers in the application of fire science. The Application Team provides analysis, development, training, and support in fire behavior, fire ecology, modeling, and fuel treatment effectiveness. The Information Team develops literature reviews and other synthesis documents on how fire interacts with plants and animals of the United States. These products are delivered through the Fire Effects Information System (FEIS). The Modeling Team maintains and develops a suite of fire behavior modeling systems that includes BehavePlus, FireFamilyPlus, FlamMap, and FARSITE. They also manage the operation, support, and expansion of the Wildland Fire Assessment System (WFAS) and the Weather Information Management System (WIMS).

Application

In 2015, FMI staff developed data products to facilitate fire-planning activities and helped land managers throughout the nation develop risk assessments, forest plans, and fuels treatment plans. They also

contributed to the advancement of burn severity research; helped develop datasets and methodology for conducting quantitative assessments of wildfire risk across large landscapes; and performed analyses to support national-scale strategic fuels management on U.S. Forest Service lands.

Modeling

FMI staff maintain and enhance FFS applications and products, including BehavePlus, FEAT-FIREMON Integrated (FFI), the Fire Effects Information System (FEIS), the Weather



Photo: Wildflowers, including camas and prairie smoke, are adapted to fire, including these located on the Tenderfoot Experimental Forest. Information on such plants can be found in the Fire Effects Information System.

Information Management System (WIMS), the Wildland Fire Assessment System (WFAS), and many others. FMI is always striving to improve these applications and products.. For example, FlamMap5 was formally released, including major program improvements. In 2016 updated and new versions of BehavePlus6, FOFEM 6.3, FireFamilyPlus 4.2, and the next version of FuelCalc are expected along with an updated and improved version of the U.S. National Fire Danger Rating System (NFDRS) in 2016.

Information

In 2015 The Fire Effects Information System (FEIS, <http://www.feis-crs.org/beta/>), celebrated 30-years of providing quality information synthesis reviews of the scientific literature about fire effects on plants and animals, fire studies, and fire regimes of plant communities in the United States (page 11). In 2015, FEIS released a new and updated user interface. This year, FEIS added fire regime information for all the plant communities in the United States. These Fire Regime Reports and Fire Regime Syntheses connect LANDFIRE data to all 1,078 Species Reviews in FEIS. Seven new Fire Regime Syntheses covering plant communities in Alaska and California were added to FEIS and six species reviews were updated in 2015 updating those that were a decade old. Notable among these are reviews covering white spruce, Pacific willow, western sword fern, and sticky whiteleaf manzanita.

Members of FEIS are also working to expand the FireWorks educational curriculum to cover a wider range of ecosystems. Examples include working on curricula development specific to the Sierra Nevada and updating the curriculum for the Northern Rocky Mountains. The FireWorks program continues to be a shining example of teaching and information sharing for students in grades 1-12.

Support

Each year, FMI staff provide support services for users of FFS applications and products, and in 2015, they reported more than 250 technology support contacts regarding their operation. FMI staff also provide field support during wildfire incidents and were out on fire assignments in excess of 140-person-days in 2015.

Training and educational course development in support of interagency fire managers is an important task of FMI. FMI staff provide instruction on the use of FFS applications and products and instruct many regional and national-level National Wildfire Coordinating Group courses.

The staff at FMI work with a range of national and international partners, including other federal agencies, state and local governments, academia, and nonprofit groups to accomplish its tasks. For example, they contributed to wildfire risk assessments for the Lolo and Bitterroot National Forests, provided feedback and review for the Helena-Lewis and Clark Forest Plan Revision, and led the writing and publishing of a report assessing the current state of fire management for the Eastern Province of Zambia, Africa.

For more information, contact: Charles McHugh at cmchugh@fs.fed.us



Photo: LaWen Hollingsworth discusses cloud types relevant to wildland fire with elementary school students. Tours are an important part of FMI's outreach efforts.

PARTNERSHIPS



Developing partnerships and creating cross-disciplinary research teams are critical in addressing the growing number of increasingly complex questions related to wildland fire. Fire, Fuel, and Smoke Science Program researchers at the Missoula Fire Sciences Laboratory work collaboratively with national and international partners to improve wildland fire research that maintains healthy, productive ecosystems and reduces risk to people and property. The summaries in this report include collaborations with other federal agencies, tribes, state and local governments, universities, and non-governmental organizations. In 2015, FFS investigators collaborated with diverse teams of researchers at over a dozen universities around the country as well as with other federal agencies including the Bureau of Land Management, Bureau of Indian Affairs, Department of Defense, Environmental Protection Agency, National Aeronautics and Space Administration, and U.S. Agency for International Development. Nationally, FFS researchers collaborated with scientists from Arizona to Florida

and from the Appalachians to the Cascades to better understand a range of topics, including physical fire processes, fuel dynamics, smoke emissions, fire and fuel management treatment strategies, and fire ecology. Partnerships combine each member's strengths to produce more effective and far-reaching research and to develop and deliver new tools and scientific understanding. We are formally engaged with the work of the Northern Rockies Fire Science Network (a member of the Joint Fire Science Program fire science exchange network), and we have benefitted from long-term agreements with both University of Montana and University of Idaho

fire science and technical transfer partners. Our program works closely with faculty and staff at Salish Kootenai College — one of the four largest Tribal Colleges and Universities (TCUs) in the nation — as well as with tribal forestry at Confederated Salish and Kootenai Tribes to enhance connections between traditional knowledge and western science.

Internationally, FFS researchers have developed partnerships with colleagues from nearly every continent, including North America, Northern Eurasia, and Australia. International partnerships take advantage of FFS researchers' scientific expertise, technological capability, and on-the-ground experience in fire ecology, fire climatology, and fire management. The FFS Program has had "boots on the ground" in over 20 countries, as illustrated by our map of International partners presented on our webpage at <http://www.firelab.org>.

Photo: FFS researchers partnered with fire personnel from the U.S. Fish and Wildlife Service to examine prescribed fire behavior on the Loxahatchee National Wildlife Refuge, part of the Florida Everglades. Photo courtesy of Bret Butler / FFS.

FROM THE ARCHIVES: 30 YEARS OF THE FIRE EFFECTS INFORMATION SYSTEM (FEIS)

Thirty years ago, Fire Lab researcher William (Bill) Fischer proposed to establish a highly innovative computer system to provide managers with information about the effects of prescribed fire. In his 1985 analysis of the need for such a service, Fischer noted that a recent survey had found that fire and land managers in western Montana and northern Idaho needed more and better information on fire effects and prescribed fire. These results confirmed an earlier survey from the 1970s that documented a long list of outstanding questions about fire effects and prescribed burns even though, as Fischer wrote, “a considerable body of literature already exists.”

In response to this need expressed by field managers, Fischer and a team of colleagues at the Intermountain Fire Sciences Laboratory, as the Fire Lab was then known, initiated a program to summarize the information about fire effects on individual species in the intermountain region. By 1989, they were committed to publishing 1,000 such “Species Reviews,” covering plants and animals throughout the United States, and to developing two new applications for computer technology: a system using the agency’s first networked computer system to provide Species Reviews electronically to Forest Service users, and a database to manage the thousands of citations used in the reviews. With development of the computer systems underway, Fischer and other ecologists tackled the monumental task of summarizing all state-of-the-art research on the biology and fire ecology of 1,000 species native to the United States. A decade after Fischer’s initial work began, this encyclopedic collection, the Fire Effects Information System (FEIS), was nearly complete, but it served managers only in the Forest Service.

The system became readily available to managers in other agencies and the general public when it was moved to the Internet in 1994.

Research on the effects of fire on plants, animals, and ecosystems has grown since 1985, and FEIS has grown and developed as well. Throughout the 1990s, ecologists at the Fire Lab added reviews covering more native species and developed more



Photo: Large scar made by surface fires on old ponderosa pine (Pinus ponderosa) in Umatilla National Forest, Oregon. FEIS ecologists are currently writing Fire Regime Syntheses for forests dominated by ponderosa pine. Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org.



rigorous methods for searching the literature and synthesizing knowledge. Between 2000 and 2011, they added Species Reviews covering more than 150 nonnative invasive plant species, including

spotted knapweed (*Centaurea stoebe* subsp. *micranthos*) in the western states and the invasive yams (*Dioscorea* spp.) in the Southeast. They also added summaries of recent fire studies to

supplement the Species Reviews. Beginning in 2013, FEIS ecologists initiated a collection of information on fire regimes throughout the United States. Each of these Fire Regime Syntheses describes the historical fire regime of a plant community, plus current changes in fuels and potential changes in fire regimes. Fire Regime Syntheses for Alaska are nearing completion, and FEIS ecologists are now working on syntheses for forests dominated by ponderosa pine (*Pinus ponderosa*). As climate change and invasive species continue to affect fuels and weather, Fire Regime Syntheses will become even more



Top photo: Infestation of Chinese yam (*Dioscorea polystachya*) spreads through the trees. Chinese yam is invasive in the eastern and central United States. Photo by Jack Ranney, University of Tennessee, Bugwood.org. Bottom photo: Extensive infestation of flowering spotted knapweed (*Centaurea stoebe* ssp. *micranthos*) spreads across the landscape. It is invasive mainly in the northwestern United States. Photo by L. L. Berry, Bugwood.org.

useful for planning, rehabilitation after wildfire, and environmental analysis.

Technology has changed radically since Fischer originally envisioned a computer program to provide fire effects information electronically. The FEIS user interface (www.feis-crs.org/feis/) now enables readers to search using many criteria, including maps, as well as to connect information from all three FEIS products - Species Reviews, Fire Studies, and Fire Regimes. This interconnected system allows land managers, researchers, and the public — at their desks or in the field — to find the best knowledge available about fire and its ecological effects. It is a truly interactive, world-wide web of knowledge, receiving more than half a million Internet visits per year and accessed from more than 100 countries. FEIS is a system that that fully realizes Bill Fischer’s original, innovative vision.

For more information, see:

Fischer, William C. et al. 1996. Fire Effects Information System: Users Guide. INT-GTR-327. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 132 p.

Smith, Jane Kapler. 2015. Strengthening Syntheses on Fire: Increasing Their Usefulness for Managers. RMRS-GTR-337. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

For more information, contact: Diane Smith at dianemsmith@fs.fed.us or Ilana Abrahamson at ilanalabrahamson@fs.fed.us.



Image: A timeline of key events in the history of FEIS is presented.

PHYSICAL FIRE PROCESSES

In the laboratory, in the field, and through computer simulations, experiments in physical fire processes are designed to improve our understanding of fire at its most basic level. Research during 2015 explored the influence of radiant and convective heating of fuels. In the laboratory, FFS researchers investigated convective and radiant heat transfer from fire using equipment designed and built at the Missoula Fire Sciences Laboratory. They burned wood particles, wood cribs, and high-cellulose cardboard fuel beds to isolate and measure these mechanisms of heat transfer. Experiments showed the influence of radiant and convective heat for igniting fine fuels and the buoyant nature of flames. Prescribed fires in Montana and Canada provided opportunities to explore the relative contribution of radiant and convective heating to fire outside the laboratory.



Photo: The flame zone of experimental fire spreads away from camera showing flame parcel formation of peaks and troughs behind the flaming front. Photo courtesy of Mark Finney / FFS. For more information, see "Buoyant Flame Dynamics and Wildfire Spread " on page 17.

Understanding Burning Rate and Residence Time of Porous Fuel Beds Using Wood Cribs

Flame residence time is critical to the spread of wildland fires; if it is less than the ignition time, the fire won't spread. Although even surface fires demonstrate spread thresholds, this is of particular concern when discussing the thresholds for crown fire spread, currently a poorly understood aspect of wildland fire. Curiously, no single theory exists for the prediction of flame residence time. Expressions in the literature vary from linear to quadratic dependence of flame residence time on fuel thickness. Better understanding of flame residence time and burning rate of fuel structures will allow for better fire spread and fire effects predictions.

Research Mechanical Engineer Sara McAllister is studying the burning rate of fuel structures to better understand residence time using three-dimensional grids of sticks called cribs, commonly used in the fire protection engineering (structural fire) literature. Cribs were built with different stick thicknesses and densities to vary the burning rate of the source fire. Even though wildland fuels do not have the same predictable arrangement as cribs, wildland fuels are similar to cribs in that they are essentially individual fuel particles arranged with some spacing distance between them. Thus, the fundamental understanding of what governs the burning rate of a crib should apply to wildland fires.

Using a wide variety of layouts and geometries, wood cribs were burned to determine whether results from structural fire hold in the wildland. Comparisons included the effect of stick dimension (length and width) ratios and the effect of the vertical gap between the crib and the ground. McAllister found a correlation that predicts the burning rate for even the most

unconventional crib designs as well as shapes more likely to resemble wildland fuel beds. A correction factor was also developed that adjusts this predicted burning rate for the changes that occur as the vertical gap between the ground and the fuel bed varies. Since this vertical gap changes the burning rate by as much as 90 percent, the correction factor will be critical when comparing surface fuels to crown fuels.

As wildland fires rarely occur on calm days, the effect of wind is also being considered. Cribs of a wide variety of designs are being burned in the Fire Lab's wind tunnel. Preliminary results indicate that the effect of wind depends on the fuel element thickness. Cribs built with thicker fuels show an increase in burning rate with wind, while cribs built with thinner fuels show a decrease. Work is ongoing to confirm and explain these trends.

For more information, contact: Sara McAllister at smcallister@fs.fed.us.



Photo: A wood crib burns under the influence of wind. Photo by Sara McAllister / FFS.

Ignition by Convective Heating

Recent research conducted at the Missoula Fire Lab has found that the amount of radiant heat in wildland fires is not sufficient to ignite fine fuel particles such as needles and grasses. These fine fuels are highly efficient at convective heat transfer, so any amount of airflow can easily offset the radiant heat generated by the fire. As a consequence, fine wildland fuels do not ignite until bathed by the flame. As radiant heating has been assumed to drive ignition in wildland fires as it does

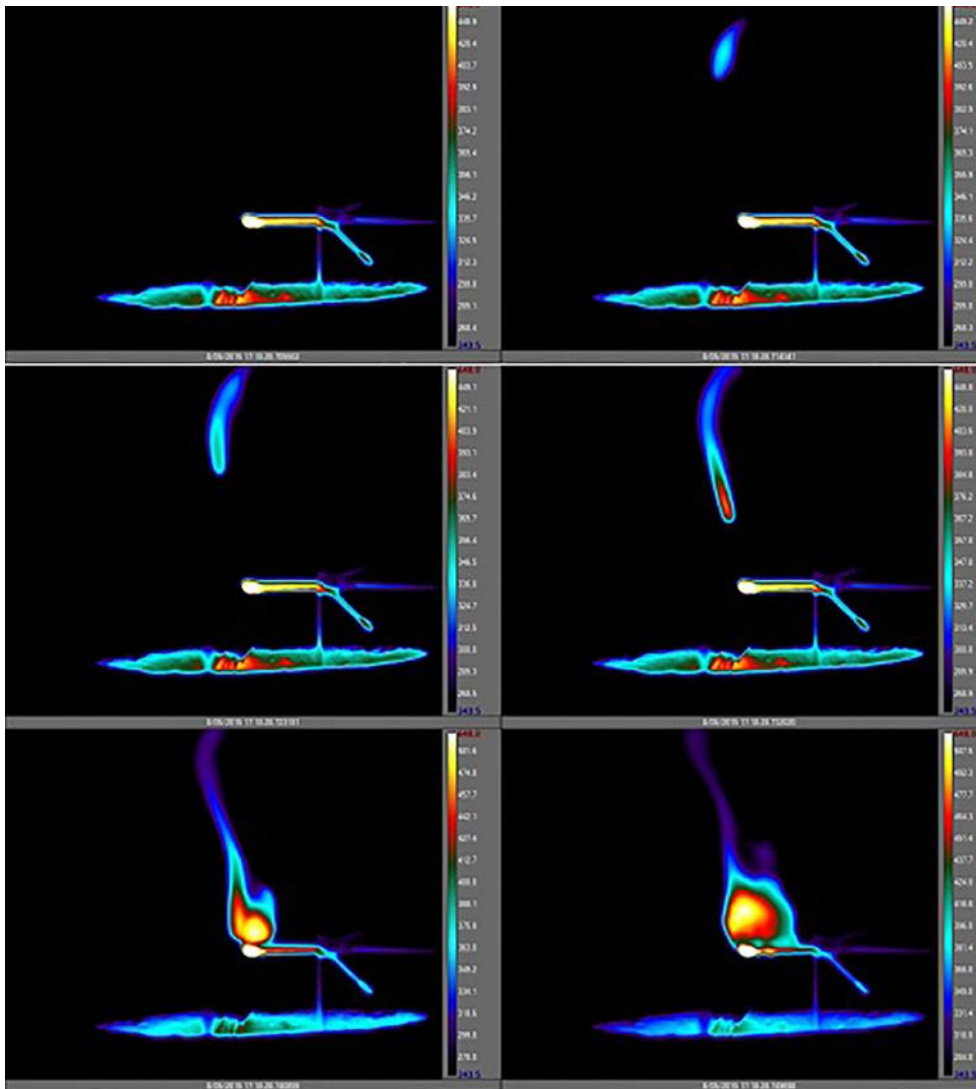
in structural fires, ignition by convective heating is not well understood.

Experiments are underway to determine if and how ignition due to convective heating is different than that from radiative heating. We built an apparatus using two electrical heaters to heat air up to 1,200°C (2,200°F). So far, wood cylinders of different diameters have been tested. A simple model has been shown to predict the ignition times of these simple fuels with reasonable accuracy. Several differences between convective and

radiative heating have been noted. For example, the convective heating and ignition process is far more sensitive to fuel size and shape than radiative heating. Another major difference between these modes of ignition is the large surface temperature gradient that forms due to convective heating that is largely missing under radiant heating.

Understanding the ignition process due to convective heating will allow for better prediction of the transition from surface to crown fire and crown fire spread, two aspects of wildland fire behavior that are largely misunderstood.

For more information, contact: Sara McAllister at smcallister@fs.fed.us.



Images: High-speed infrared images show the ignition process for a convective heating temperature of 600°C. Gases first ignite upstream of the fuel cylinder (upper two rows). The flame then propagates back and anchors on solid surface (bottom row). Images by Sara McAllister / FFS.

Buoyant Flame Dynamics and Wildfire Spread



past each other. Behind the advancing flame edge, similar processes of upward and downward flows generate discrete parcels that move through the flame zone from wind or air-flow induced by the rising of parcels at the flame front. The significance of these flame movements is that they force flames to extend out beyond the burning zone — impinging and heating

The underlying causes of convective heating in fine particle ignition and wildfire spread have been found through laboratory experiments to be related to buoyant-inertial instabilities of the flame zone. Buoyancy of flames results from their high temperature ($\sim 1,000^{\circ}\text{C}$; $1,800^{\circ}\text{F}$) which causes expansion and thus, low density. Low-density volumes of hot flame rise and accelerate upward causing the surrounding high-density cool air to descend and flow-in to replace it. The process of replacing a rising parcel with another parcel creates periodic flame patterns in space and time. Across a flame front, regular patterns of peaks and troughs can be seen, where the peak follows a rising parcel and the trough traces descending parcels. This pattern is enhanced by vorticity — the spinning motion of the flames and air caused by their movement

and igniting new fuels ahead. They are highly non-steady, but have predictable average frequencies. Thus, fuel particle ignition and flame spread occurs by non-steady movements of flames driven by their buoyancy.

For more information, contact: Mark Finney at mfinney@fs.fed.us.



Top photo: Peak and trough structure of flame front forms in experimental fires. Bottom photo: A similar peak and trough structure of flames is found in grass fire. Photos courtesy of Mark Finney / FFS. See also the photo on page 14.

Field Characterization of Energy Transport in Wildland Flames

Energy transport in wildland fires not only drives fire spread, but also directly affects how fire impacts plants, animals, humans, homes and the environment. Unfortunately, our understanding of energy transport from spreading wildland fires is limited. The limitations are due to the complexity of the process. Not only do the arrangement, condition, and type of vegetation components change spatially, but the wind is constantly changing, air humidity, air temperature, and solar exposure are also constantly changing. These factors all affect fire intensity and energy release. A



been used to develop new understanding into the relative contribution of radiant and convective heating to wildland fire intensity and spread.

For more information, contact: Bret Butler at bwbutler@fs.fed.us.

multi-year effort to understand the characteristics of effective wildland firefighter safety zones has illustrated the need for additional understanding about energy release from fires, especially under conditions of changing wind and slope. In an effort to better address this need researchers from the Missoula Fire Sciences Laboratory teamed up with fire managers on the Kootenai National Forest and the Northwest Territories in Canada to measure energy release on prescribed burns and experimental burns. The data have



Top photo: Fire researchers ignite a pile arranged to study effect of slope on fire behavior in northwest Montana.

Middle photo: The flames from the same pile have attached to the slope, demonstrating the impact of convective heating under these conditions.

Bottom photo: Experimental fire in Northwest Territories. Photos courtesy of Bret Butler / U.S. Forest Service.

FUEL DYNAMICS

Fuel is always changing, yet models of fire behavior, fire danger, and smoke emissions require an accurate description of that fuel. In 2015, FFS scientists led research to improve understanding of changes in fuel over time. Globally, scientists provided ground-breaking estimates of changes in wildfire danger as climate has changed. Nationally, scientists are providing estimates of wildfire hazard potential to help inform decisions regarding fuel treatments. Regionally, scientists are studying the impacts of mastication on fuels in several areas of the western U.S. to improve understanding of their chemical, physical, and burn characteristics.



Photo: View of Bear Lake in the Pioneer Mountains, Montana. Nearby, the Bear Lake Fire, burning with mixed severity, began on August 20, burning more than 6,400 acres. Photo courtesy of LaWen Hollingsworth / FFS.

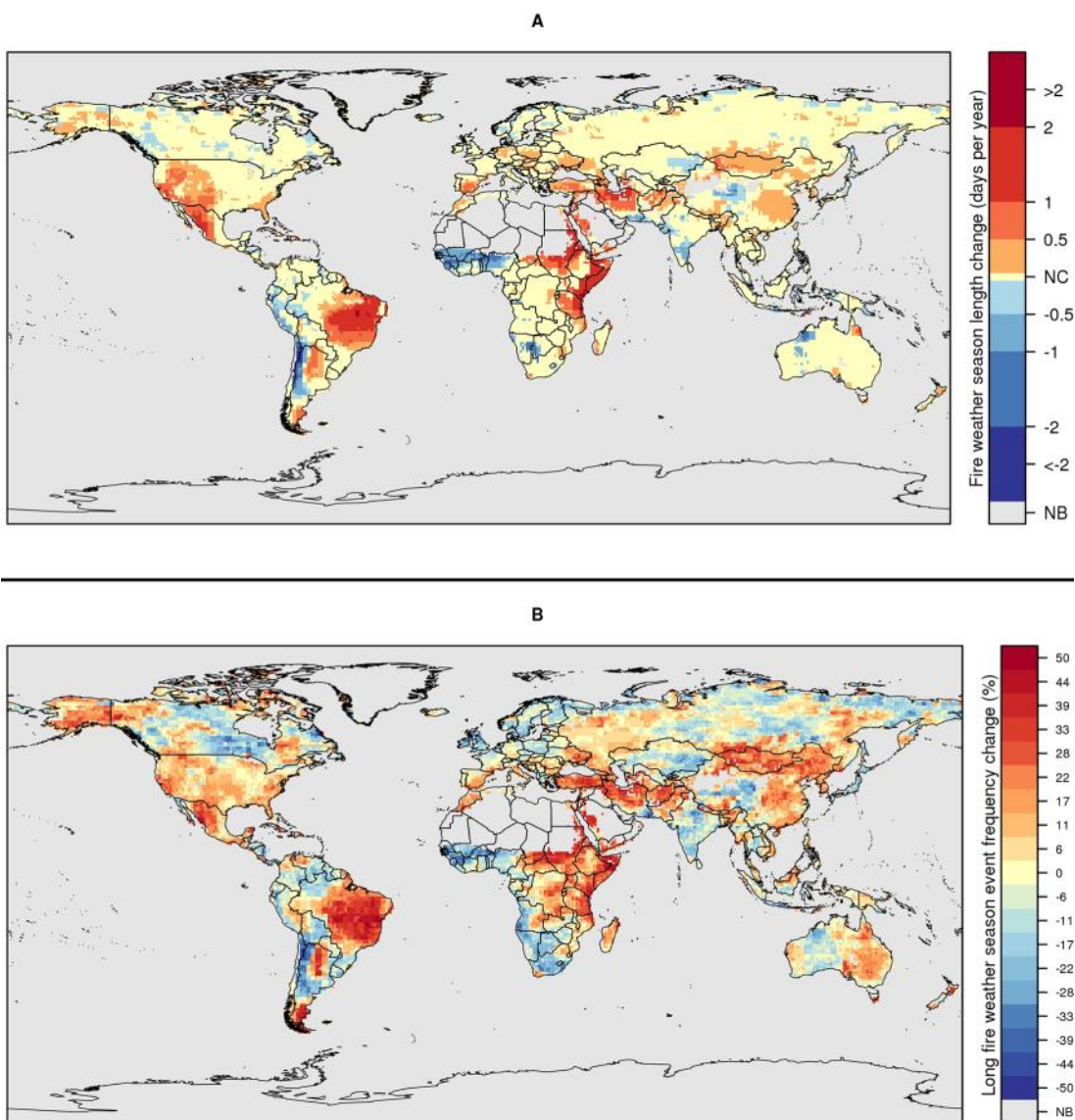
Climate-induced Variations in Global Wildfire Danger from 1979 to 2013

Climate strongly influences global wildfire activity, and recent wildfire surges may signal fire weather-induced pyrogeographic shifts. Here we use three daily global climate data sets and three fire danger indices to develop a simple annual metric of fire weather season length, and map spatio-temporal trends from 1979 to 2013. Matt Jolly and others show that fire weather seasons have lengthened across 29.6 million km² (11.4 million mi²) or 25.3% of the Earth's vegetated surface, resulting in an 18.7% increase in global mean fire weather season length. They also show a doubling (108.1% increase) of global burnable area affected by long fire weather seasons (1.0 sigma above the historical mean) and an increased global frequency of long fire weather seasons across 62.4 million km² (24.1 million mi²) or 53.4% of the Earth's vegetated surface during the second half of the study period. If these fire weather changes are coupled with ignition sources and available fuel, they could markedly

impact global ecosystems, societies, economies and climate.

The results of this work were published in Nature Communications in July 2015. Discover Magazine listed this work as number 31 of the Top 100 stories for 2015.

For more information, contact: Matt Jolly at mjolly@fs.fed.us.



Images: A global map of the changes in the fire weather season length (top) and annual area affected by long fire seasons (bottom). Images courtesy of Matt Jolly / FFS.

Surface Fuel Characteristics, Temporal Dynamics, and Fire Behavior of Masticated Mixed-Conifer Fuel Beds of the Rocky Mountains

Scientists from the Fire, Fuels and Smoke Program (FFS) the Forests and Woodlands Program (FWE), the University of Idaho, and volunteers with the Rocky Mountain Research Station have spent the past year sorting, describing, and burning fuel particles from masticated areas in Idaho, Colorado, New Mexico, and South Dakota. The work was led by Robert Keane (FFS), Pam Sikkink (FWE), and Terri Jain (FWE). It comprises the second year of a three-year JFSP collaborative study to describe the physical, chemical, and burn characteristics of masticated fuels. FFS and FWE technicians, contractors, and volunteers have sorted, measured, and described in detail over 5,600 individual particles this year. Analyses of these particles indicate that the four different mastication



techniques and two different moisture regimes used in this study show that there are significant differences in the dominant size and shape classes produced within each method, moisture, or age group.



Fuel load varies significantly among the 15 sites and is dependent upon the age of the fuel and the mastication method. Moisture studies conducted by Jim Reardon this past year to evaluate how the masticated fuels process moisture indicate that age (that is, old vs. young material) directly relates to the adsorption/desorption process. Chemical analyses of 589 samples for carbon and

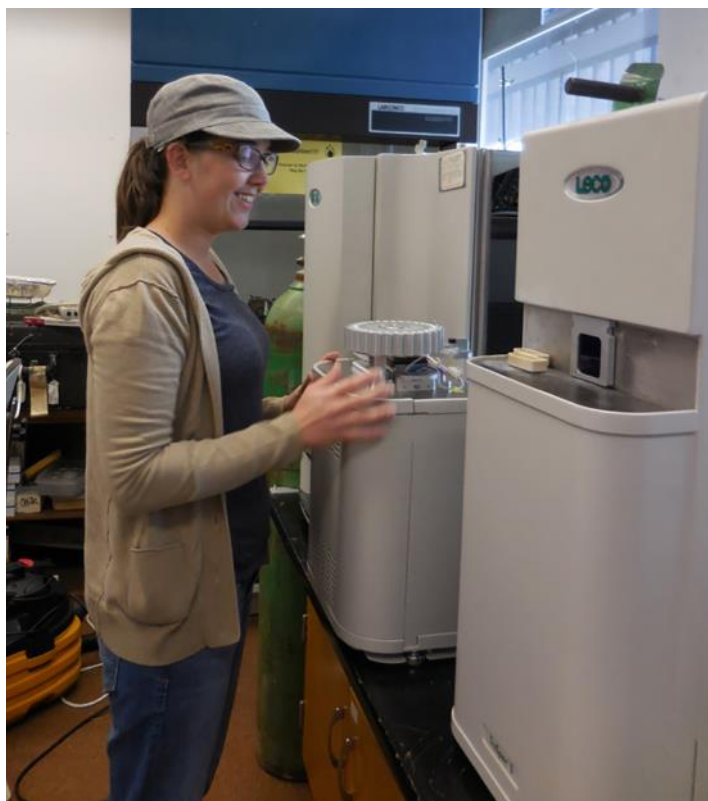
Top photo: Helen Smith and Molly Retzlaff conduct an experimental burn on a fuel bed constructed from chipped masticated material from the Manitou Experimental Forest, Colorado. Bottom Photo: Fuels from the oldest site in Valles Caldera Preserve, New Mexico, site were masticated in 2007-2008. Beds were constructed using average fuel loads of each size and shape from the site and burned on a high slope. Photos courtesy of Pamela Sikkink / USFS.

nitrogen showed that average percentages of these elements also differed significantly for the different ages of materials and their climatic locations (wet and dry sites). Cellulose and lignin tests are in progress and will be used to describe decomposition of the particles on each site. Burn experiments on the masticated fuel beds were conducted by Helen Smith and Molly Retzlaff of the FFS program. They set up 41 fuel beds to burn, basing their fuel loads the average fuel loads of each size class for each of 13 sites included in this study. The burns were done using two different slopes. Most of these burns lit and burned with flame heights of generally less than one meter (3.3 feet); others were more creeping in character and will be difficult to characterize. The



data from these burns is currently being examined by Faith Ann Heinsch from the FFS program to determine whether new fuel models need to be developed for masticated fuel beds.

For more information, contact: Bob Keane at rkeane@fs.fed.us.



Top photo: Jeff Balkanski, a volunteer from France, prepares samples for bomb calorimetry. The “bomb” analyzes heat content, lignin, and cellulose in our samples, providing a measure of the amount of decomposition. Bottom photo: Megan Richardson, FFS technician, processes masticated materials for carbon and nitrogen content using the LECO analyzer, providing important chemical descriptions of the masticated fuels. Photos courtesy of Pam Sikkink / USFS.

Wildfire Hazard Potential Map

The Wildfire Hazard Potential (WHP) map combines probabilistic estimates of wildfire likelihood and intensity developed by RMRS scientists into an easily interpretable five-category index ranging from very low to very high fire potential. Spatial Fire Analyst Greg Dillon developed the WHP map and maintains a website where users can download GIS data, map graphics, and supporting documentation (<http://www.firelab.org/project/wildfire-hazard-potential>).

In December 2014, FMI released an updated version of the WHP map. The new version used the same methods as previously, but with updated input data. The input data used for the 2014 version included LANDFIRE 2010 data layers, and spatial wildfire probability and conditional intensity layers produced by RMRS Research Ecologist, Karen Short, for the Fire Program Analysis system (FPA) in 2014. With this new version, the product name changed slightly from the Wildland Fire Potential map to the Wildfire Hazard Potential. The input probability and intensity layers come from simulations of wildfires, as opposed to the more generic term wildland fire, and the integration of probability and intensity reflects the hazard posed by wildfires. Thus, the new name more accurately describes what the map depicts.

As in previous years, FMI continued to respond to requests for information about, and summaries of, the WHP data from a variety of sources. A notable example was a set of data summaries that FMI provided to the offices of Senator Steve Daines of Montana and Senator Cory Gardner of Colorado to help address questions about acres at risk from wildfire and potentially in need of treatment. Another example included consultation with the Bureau of Indian Affairs (BIA), Fire Use and Fuels staff at the National Interagency Fire Center about a metric that they've developed from the WHP map to help inform fuel treatment placement and prioritization on BIA lands.

For more information, contact: Greg Dillon at gdillon@fs.fed.us.

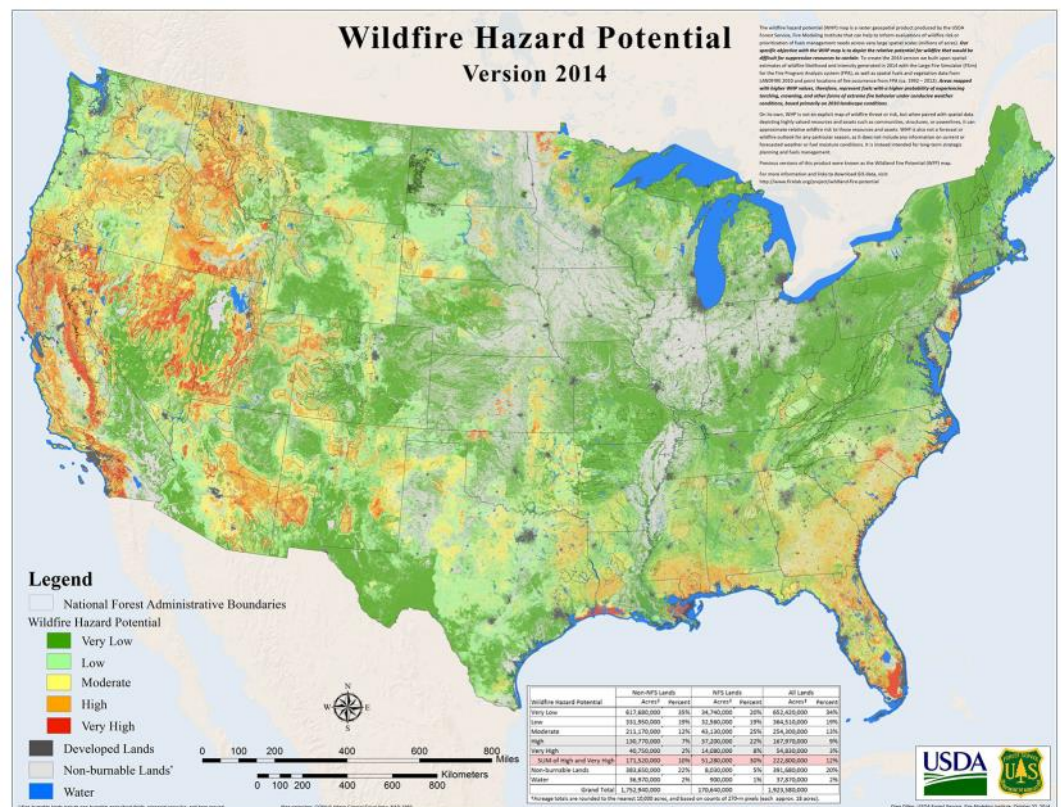


Image: The Wildfire Hazard Potential Map can help to inform evaluations of wildfire risk or prioritization of fuels management needs across very large landscapes. Image courtesy of Greg Dillon / FFS.

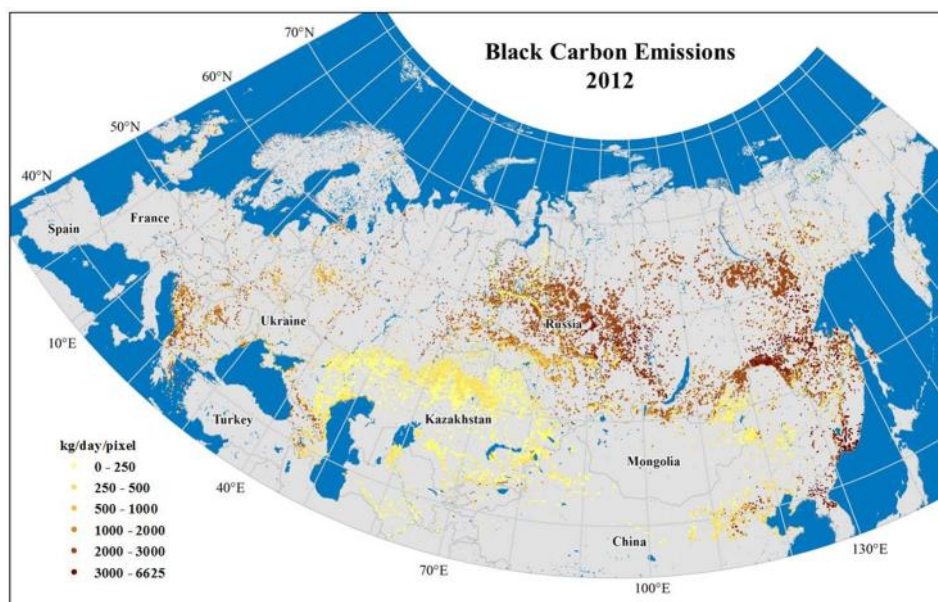
SMOKE EMISSIONS AND DISPERSION

Where there is fire, there is smoke, and the amount of smoke varies in both quantity and chemical content. Smoke can have a large impact on human health, leading to active research in smoke emissions, smoke chemistry, and smoke movement. In 2015, scientists at FFS began working internationally to determine the effect of black carbon resulting from fires in northern Eurasia on climate change, including impacts on Arctic ice. FFS researchers continued to investigate the role of fuel moisture and fuel structure in the combustion of wildland fuels. Results indicate that pollutants generated from fires in many northern Rocky Mountain conifer forests is higher than that predicted using standard combustion models. Scientists are attempting to quantify smoke emissions and their impacts on populations downwind, using Salt Lake City, Utah, as a case study.



Photo: The Spicer Creek Fire on the banks of the Yukon River in Alaska starts picking up steam. Photo by Dan Jimenez / FFS.

Black Carbon from Fires in Northern Eurasia



Northern Eurasia covers 20% of the global land mass and contains 70% of the boreal forest. During certain times of the year, black carbon (BC) in smoke plumes at high latitudes may be transported and deposited on Arctic ice, thereby accelerating ice melting. It is thus imperative to better understand daily sources, transport, and deposition of BC in Northern Eurasia.

Scientists examined daily BC emissions from fires over different land cover types in Northern Eurasia at a 500 m x 500 m (1,640 ft x 1,640 ft) resolution from 2002 to 2013. Black carbon emissions were estimated from MODIS land cover maps and detected burned areas, the Forest Inventory Survey of the Russian Federation, and emission factors of BC for different types of vegetation fires. Our estimated annual burned areas in Northern Eurasia varied considerably from 160,000 km² (~62,000 mi²; 2011) to 490,000 km² (~189,000 mi²; 2003) with an average of 250,000 km² (~96,000 mi²). Grassland dominates the total burned area (61%) and followed by forest (27%). For grassland fires, about three-quarters of the burned area occurred in Central and Western Asia and about 17% in Russia.

More than 90% of the forest burned area was in Russia.

Annual BC emissions from fires varied enormously, but were dominated by forest fires, which accounted for about two-thirds of emissions, followed by grassland fires (15%). More than 90% of the BC emissions from forest fires occurred in Russia. Central and Western Asia is the major region for BC emissions from grassland fires. Overall, Russia contributed 83% of the total BC emissions from fires in Northern Eurasia. While results vary from year-to-year, there are no apparent trends in area burned or BC emissions from 2002 to 2013.

These results are critical in understanding the future impacts of climate change on the fire dynamics in Northern Eurasia and the contribution of black carbon to accelerated melting of Arctic ice.

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Development of Combustion Process-Based Emission Models

Wildland fires emit a substantial amount of atmospheric pollutants including carbon monoxide (CO), methane (CH₄), volatile organic compounds (VOC), nitrogen oxides (NO_x), fine particulate matter (PM_{2.5}), and black carbon particles (BC). These emissions have major impacts on regional air quality and global climate. In addition to being primary pollutants, the photochemical processing of NO_x and VOC leads to the formation of ozone (O₃) and secondary PM_{2.5}. The most important criteria for assessing the impacts of fires on the regional and global environment are accurate, reliable information on the spatial and temporal distribution of fire emissions.

The chemical composition of smoke is quantified using emission factors to compute how much pollutant is emitted by wildland fuel. Emission factors are critical inputs for atmosphere-chemical models used to forecast the impact of fire emissions on atmospheric composition, air quality, and climate. Emission factors are affected by vegetation type and combustion characteristics of a fire, in particular the amount of flaming and smoldering combustion. Some chemical species are emitted almost exclusively by flaming or smoldering, while the emissions of others are substantial from both

processes. The combustion characteristics of wildland fires are believed to be influenced by several factors including: (1) fuel moisture, (2) the structure and arrangement of fuels, (3) fuel chemistry, (4) fuel growth stage and soundness of woody material, and (5) meteorology.

Fuel moisture and structure play an important role in the heating rate, ignition, consumption, and combustion completeness of wildland fuels. CONSUME and FOFEM, two of the most commonly used combustion models, use fuel moisture and fuel structure to simulate combustion completeness. Some laboratory studies have indicated a potential linkage between fuel moisture and emission factors. However, a robust relationship between emission factors and fuel moisture and/or fuel structure has not been demonstrated. Previous lab experiments have had several shortcomings: limited range of fuel moistures, insufficient replicates, and omission of fuel structure. This project seeks to address two key scientific questions.

- 1) Are emission factors for CO₂, CO, CH₄, NO_x, PM_{2.5}, and BC significantly dependent on either fuel moisture or fuel bed structure?
- 2) Can fuel moisture and fuel bed structure serve as independent variables for empirical models that reliably predict these emission factors?

The project focused on a fuel bed composed of simple fuel particles — ponderosa pine needles (PPN). Researchers selected ponderosa pine because it contains a common fuel component, conifer needles, which can be easily arranged into fuel beds of variable structure (bulk density and depth) and moisture contents that are both representative of natural conditions and are easily replicated.

Three hypotheses were tested.

- 1) The combustion efficiency of PPN litter decreases with increasing fuelbed bulk density.



Photo: A typical ponderosa pine needle fuelbed is burned in the experiments. Photo courtesy of Shawn Urbanski / FFS.



high bulk density, shallow fuelbeds between the dry and moist groups, thus leading to differing emission factors for methane. The variability in emission factors for CH_4 from the burning of ponderosa pine needle fuelbeds is largely predicted by the combustion efficiency, which itself is driven by fuelbed bulk density.

Both FOFEM and CONSUME assume that litter fuels, such as ponderosa pine needles, burn almost exclusively via flaming combustion with a high efficiency. This would

- 2) The combustion efficiency of PPN litter decrease with increasing fuelbed depth.
- 3) The combustion efficiency of PPN litter decreases with increasing moisture content.

Researchers discovered that, as expected, the combustion efficiency of ponderosa pine litter decreases as the fuel bed bulk density increases (Hypothesis 1). This resulted in increased emissions of CO and CH_4 . However, fuel bed depth (whether shallow or deep) does not appear to have an effect on how efficiently ponderosa pine litter burns (Hypothesis 2). They also didn't find a consistent relationship between the moisture content of the fuel and combustion efficiency (Hypothesis 3). For the low and mid bulk density fuelbeds — there was no difference in the combustion efficiency of the dry and moist fuelbeds. However, the combustion efficiency was different in

result in relatively low emissions of CH_4 , $\text{PM}_{2.5}$, and volatile organic compounds. Our study finds that the bulk density of litter fuels has a strong influence on the relative amounts of flaming and smoldering and combustion that occurs. This finding indicates that for fuel bed properties typical of many northern Rocky Mountain conifer forests, pollutants generated from fires will be higher than that predicted using standard combustion models due to lower than expected combustion efficiencies.

For more information, contact: Shawn Urbanski at surbanski@fs.fed.us.

Photo: This fire exhibits both flaming and smoldering combustion. Note the rigorous flaming combustion (bottom left) produces little smoke compared to smoldering areas. Photo courtesy of Shawn Urbanski / FFS.

Models for Quantifying Smoke Emissions and Impacts



framework generated an ensemble of stochastic back trajectories arriving at Salt Lake City. The trajectories were combined with the new, high-resolution wildfire emissions inventory. Initial results showed that the WRF-STILT model was able to replicate many periods of enhanced wildfire activity observed in the measurements.

Most of the contributions for the 2007 and 2012 wildfire seasons originated from fires located in Utah and central Idaho. The model results suggested that

Wildfires are known to contribute large quantities of CO₂, CO, and PM_{2.5} to the atmosphere. Wildfires affect not only the area in the vicinity of fire, but may also impact the air quality far downwind from the fire. The 2007, 2012, and 2015 western U.S. wildfire seasons were characterized by significant wildfire activity across much of the Intermountain West and California. In this study, we determined the locations of wildfire-derived emissions and their aggregate impacts on Salt Lake City, Utah, a major urban center downwind of the fires. The USFS Rocky Mountain Research Station's new Wildland Fire Emission Inventory Version 2 model was used to determine the location and timing of wildfire emissions. The influence of wildfire emissions at Salt Lake City were assessed using the Stochastic Time-Inverted Lagrangian Transport (STILT) model driven by wind fields from the Weather Research and Forecasting (WRF) model. The STILT model

during intense episodes of upwind wildfires in 2007 and 2012, fires contributed as much as 250 ppb of CO during a 3-hour period and 15 µg/m³ of PM_{2.5} averaged over 24 hours at Salt Lake City, more than double ambient conditions. Our study has demonstrated that combining the Wildland Fire Emission Inventory Version 2 with the STILT modeling framework provides a powerful tool for quantifying the contribution of wildfires to air pollution impact relative to anthropogenic sources. This is critical for air regulator efforts to develop successful strategies for improving air quality. The preliminary results also indicate that a real-time implementation of the fire emissions-model framework may provide more improved forecasting of wildfire smoke impacts on population centers in the western United States.

For more information, contact: Shawn Urbanski at surbanski@fs.fed.us.

FIRE ECOLOGY

Fire varies across the landscape, requiring ecosystems to adapt to differing fire severity and fire return intervals. In 2015, researchers revisited study areas from 21 years ago to determine if removing cross-sections from fire-scarred trees killed them; it didn't. A computer simulation model is being used to examine interactions of fire and climate change on ecosystems around the world. Researchers performed three different studies on whitebark pine ecosystems. Two of them involved restoring whitebark pine, while the third examined possible impacts of climate change. examined the beneficial effects of adding fire to the landscape to restore whitebark pine ecosystems.



Photo: Looking north from the Tenderfoot Creek Experimental Forest, Montana, managed by FFS.

Condition of Live Fire-scarred Ponderosa Pine Twenty-one Years after Removing Partial Cross-sections

Ponderosa pine is widely distributed in fire-dependent ecosystems across western North America. Some individuals of this long-lived species have survived repeated wounding by frequent, low-severity fires and have a cavity surrounded by fire scars, termed a catface. Our understanding of the historical role of surface fires in ponderosa pine ecosystems is based on the records of fire preserved in these catfaces. This record has been extracted from many dead ponderosa pine trees, but it has also been extracted from thousands of live trees across the western U.S. by removing a partial cross section from one or both sides of the catface with a chain saw. Concern over the effects of removing partial cross sections may limit live-tree sampling and consequently restrict the development of science-based management. Casual observation indicates that sampling wounds generally do not kill trees. However, the effect on tree mortality of removing fire-scarred partial cross sections is poorly quantified. Over the past twenty years, we have been monitoring mortality rates for ponderosa pine trees in the Blue Mountains of northeastern Oregon since we removed a fire-scarred partial cross-section from them. We originally surveyed 138 trees that were alive when we sampled them in 1994-1995 and 387 similarly sized, unsampled living neighbor trees of the same species. The annual mortality rate for sectioned trees from 1994-1995 to 2015 was 2.4% compared to 1.8% for the neighbor trees.

However, many of the trees that died between 2000 and 2005 were likely killed by two prescribed fires. Excluding all trees in the plots burned by these fires regardless of whether they died or not, fire-scar sampling did not have a significant effect on tree mortality during the first two decades after



sampling; the annual mortality rate for sectioned trees was 1.6% compared to 1.3% for neighbor trees. We suggest that sampling live, fire-scarred ponderosa pine trees remains an important and generally non-lethal method of obtaining information about historical fires that can supplement the information obtained from dead fire-scarred trees.

For more information, contact: Emily Heyerdahl at eh Heyerdahl@fs.fed.us.

Photo: Living ponderosa pine tree from which a fire-scarred partial cross section was removed in 1994. The partial cross section can be seen on the right-hand side of the bole. Photo courtesy of Emily Heyerdahl / FFS.

Simulating Climate Change Effects on Landscapes Across the World using the FireBGCv2 Model

The new goal of many land management agencies is to create resilient forests that will be hardy enough to absorb the impacts of current and emergent factors over the coming years such as climate change, fire exclusion, and wildland-urban development. But how will resilience be evaluated? Field studies, while preferable and reliable, will be problematic because of the large time and space scales involved. Therefore, landscape simulation modeling will have more of a role in wildland fire management as field studies become untenable. Starting in 1989, a mechanistic, spatially explicit landscape fire and vegetation model called FireBGCv2 has been developed to explore landscape and ecosystem responses to climate change and to also simulate the effects of a wide gamut of management activities that can be done to create resilient and sustainable landscapes.

FireBGCv2 is computer program that incorporates several types of stand dynamics models into a landscape simulation platform. FireBGCv2 is available for use, but it is designed to be a research tool. It is not yet suitable for management as the complexity of the FireBGCv2 simulation platform makes it unwieldy and difficult to use without extensive training.

Over the past ten years we have used FireBGCv2 to

simulate climate change impacts on a number of landscapes across the U.S. and Australia with some interesting findings. We have employed the model to simulate future streamflows and fish populations (Bitterroot River), grazing intensity effects on fire regimes (central Oregon), impacts of interacting disturbances (Glacier National Park), and species and fire regime shifts (Yellowstone National Park). The model is also being used to simulate human influences on fire regimes in Tasmania, Australia; Jemez Mountains, New Mexico; and the Ochoco National Forest and Ochoco Mountains, Oregon. Perhaps the most important finding is that climate change impacts are highly local and driven by fine-scale factors such as topography, soils, and initial conditions.

For more information, contact: Bob Keane at rkeane@fs.fed.us.

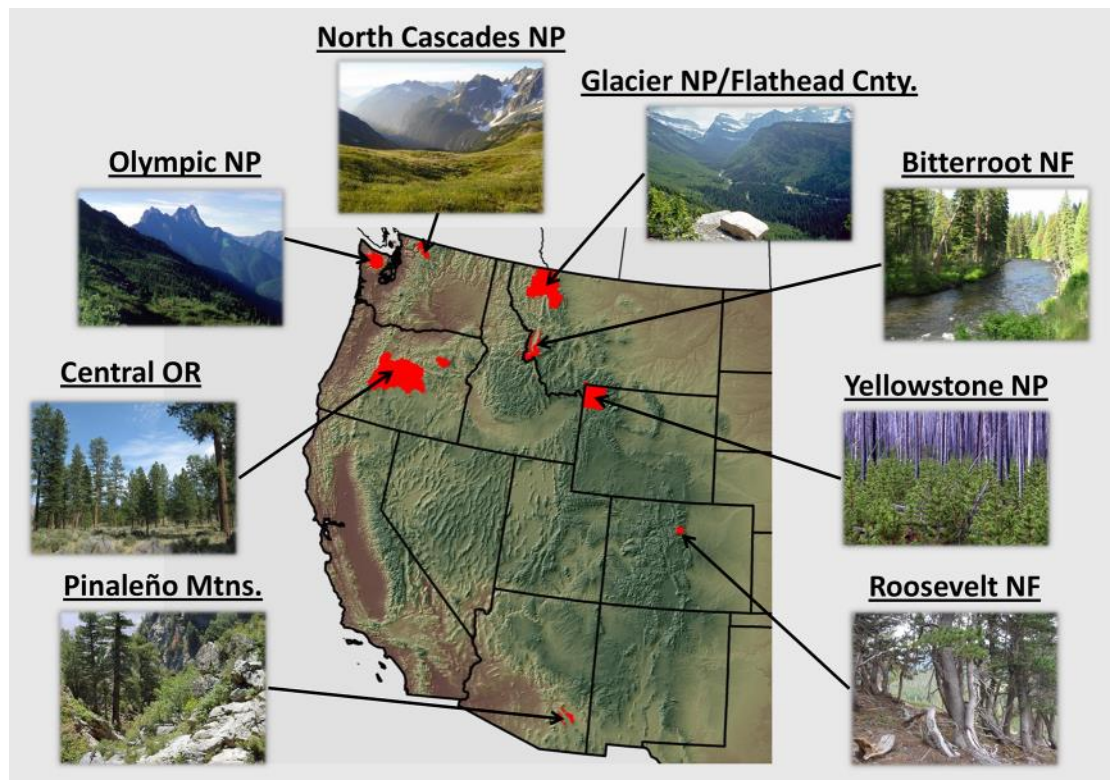


Image: Eight study sites in the western U.S. are used to simulate climate change effects on landscapes. Image courtesy of Bob Keane / FFS.

DAYLIGHT- Effects of New Restoration Technique Called Daylighting Is Evaluated on Whitebark Pine Stands in the Northern Rocky Mountains



Whitebark pine has been rapidly declining on many National Forests in the northwestern United States over the last three decades because of blister rust infections and mountain pine beetle outbreaks, which have been exacerbated by recent warmer climates. Great care should be taken to preserve, protect, and conserve the remaining whitebark pine because their populations are so low that future disturbances, especially those facilitated by climate change, could cause local extinctions of this valuable keystone species that provides food to hundreds of wildlife species. Silvicultural cuttings and prescribed burning have been used to successfully restore declining whitebark pine stands. However, these techniques are costly and are somewhat tricky to implement making them difficult to operationally implement on National Forests with limited budgets and expertise. New cheaper techniques need to be developed that are just as effective as the cutting and burning treatments. Daylighting treatments (cutting competing trees in a circular area around a target tree) have had success in other five-needle pine ecosystems, and many managers are now using daylighting for whitebark pine restoration because they can't afford to thin entire stands. No research study has

documented the effects of daylighting treatments on whitebark pine survival, vigor, and cone production. In this study, we investigate the effects of daylighting treatments, implemented with other silvicultural and prescribed burning treatments, on wildland fuels, tree survival and mortality, and understory vegetation. We will implement this study on at least three sites: Prospect Mountain (Lolo National Forest), Grouse Mountain (Bridger-Teton National Forest), and Mink Peak (Lolo National Forest). We will put ten plots in each unit in each study area, including a control unit where no treatments are implemented. This study will measure fuels, trees, and vegetation at several intervals: pre-treatment, post-treatment, 5-years post-treatment, 10-years post treatment, and 15-years-post-treatment.

For additional information, please reference the Daylight study plan (www.firelab.org/document/daylight-study-plan).

For more information, contact: Bob Keane at rkeane@fs.fed.us.



Top photo: Whitebark pine grows after daylight treatment. Bottom photo: Whitebark pine grows after daylight treatment and prescribed burn. Photos courtesy of Bob Keane / FFS.

Restoring Whitebark Pine Ecosystems, RWPE

Whitebark pine (*Pinus albicaulis*) forests are declining across most of their range in North America because of the combined effects of three factors:

- 1) several major mountain pine beetle epidemics that occurred over the last 70 years,
- 2) an extensive and successful fire exclusion management policy, and
- 3) extensive infections of the exotic white pine blister rust fungus (*Cronartium ribicola*).

The loss of whitebark pine is serious for upper subalpine ecosystems because it is considered a keystone species across most of its range, producing large seeds that are an important food source for more than 110 animal species. This extensive, long-term study, named Restoring Whitebark Pine Ecosystems (RWPE), documents the effects of several ecosystem restoration treatments implement at five high elevation sites in the northern Rocky Mountains. These treatments included prescribed fire, thinning, selection cuttings, and fuel enhancement cuttings. We evaluated fuel consumption, tree mortality, and undergrowth vegetation response measured at

three time periods:

- (1) prior to the treatment, (2) 1- year after the treatment(s), and (3) 5 years post-treatment (10-year post-treatment measurements are available for one site).

Results show that the treatments provided desirable caching habitat for the seed dispersal



vector — the Clark's nutcracker (*Nucifraga columbiana*) — but the measured whitebark pine regeneration rates were quite low due to (1) nutcrackers reclaiming many cached seeds, (2) lack of seed sources in nearby high rust-mortality stands, (3) severity of the site (high snow levels, erosive soils, and cold environments), (4) lack of plant cover, and (5) relatively short time since disturbance.

Intermediate results from this study have been published and presented at various scientific conferences. There is a management guide that presents statistical summaries, treatment descriptions, and photographs by treatment unit at each time interval available at http://www.fs.fed.us/rm/pubs/rmrs_gtr232.pdf. This guide is intended as a reference to identify possible impacts of a restoration treatment at a fine scale by matching a proposed treatment for a stand to the most similar treatment unit presented in this report based on vegetation conditions, fire regime and geographical area. Since data summaries are for individual treatment units, there are no analyses of differences across treatment units or across research sites.

For more information, contact: Bob Keane at rkeane@fs.fed.us.



Top photo: Prescribed fire is used to restore whitebark pine ecosystems. Bottom photo: Silvicultural treatments such as thinning and selection cutting are used to treat whitebark pine ecosystems. Photos courtesy of Bob Keane / FFS.

Examining Effects of Climate Change on Whitebark Pine, WBPCC

Upper subalpine whitebark pine forests are rapidly declining throughout western North America because of the interacting and cumulative effects of historical and current mountain pine beetle outbreaks, fire exclusion policies, and white pine blister rust. Mitigation of these effects through active restoration and management is being attempted. However, many feel that projected



warmer future climates will severely reduce whitebark pine high-elevation habitat, restricting the population to the tops of mountains or north of the U.S./Canada border.

Very few researchers have studied the effects of rapidly changing climate on whitebark pine ecology. There are few studies documenting how whitebark pine has responded to the past two decades of warmer, drier conditions. It is speculated, and modeling studies support, that climate change could “push” whitebark pine “off the top of the mountain” by moving its lower elevation limit above the tallest peaks. However, recent modeling efforts have shown that whitebark pine might be maintained provided that stand-replacing fires predicted during the next 50 years provide a large, competition-free area in which to grow. Whitebark pine also has other advantages – high genetic diversity, moderate to high adaptability, and demonstrated resistance to blister rust. These

competitive advantages must be considered when predicting the future of whitebark pine.

This study is designed to gather the field data necessary to document changes in growth, regeneration, and mortality of whitebark pine and its associates in the upper subalpine fir forests of the U.S. northern Rocky Mountains. From these data, scientists should be able to document the growth, regeneration, and mortality of all trees association with whitebark pine forests and assess if there have been significant changes over the past 20 years. Field crews continued to collect data, during the 2015 field season, throughout Idaho, western Montana, and northern Wyoming, with the goal of completing 100 climate change plots throughout all of the area inhabited by whitebark pine in the lower 48 states. Results from this study can be used to help guide management actions to restore this valuable species across its range.

For more information, contact: Bob Keane at rkeane@fs.fed.us.



Top photo: Whitebark pine seedling cluster at the base of a larger whitebark pine tree. Bottom photo: Whitebark pine seedling regeneration in the U.S. Northern Rocky Mountains. Photos courtesy of Bob Keane / FFS.

FIRE AND FUEL MANAGEMENT STRATEGIES

Land managers make daily decisions about how to best manage the land, yet results may not be apparent for years. FFS scientists and staff are charged with providing scientific background for those decisions that assist managers in understanding how different management strategies affect the landscape as well as human health and safety. In 2015, FFS researchers contributed to this goal in several ways. Fuel treatments are one way to manage ecosystems. FFS researchers are assisting the Helena National Forest in evaluating the effectiveness of various fuel treatments near Helena, Montana. Cultural artifacts are a vital part of U.S. history, yet they can be damaged during fire. FFS researchers are collaborating to better understand the impacts of prescribed and wildland fire on artifacts to provide information on ways to protect them from damage resulting from heat, direct flame, and smoldering. Several FFS employees assisted with prescribed fires around the country. 2015 was a busy fire season in Alaska and the northwestern U.S. FFS employees spent much of the summer on the fireline, in fire camp, and with regional coordinating groups assisting with a number of incidents. Talking to land managers is vital to understanding the questions they face today. This first-hand experience improves our understanding of the issues at hand, and it can be brought back to the lab to improve our research.



Photo: FFS researchers study fires of various intensities in the field. In this photo, fire personnel are evaluating a test ignition. This is part of the process to determine if conditions are appropriate for a prescribed burn at the Horse Pasture prescribed burn at the Dakota Prairie Grassland. Photo courtesy of Bret Butler / FFS.

Evaluating Proposed Fuel Treatment Effectiveness in the Tenmile Watershed of the Helena National Forest

The Upper Tenmile Watershed is located southwest of the city of Helena, Montana, on the Helena National Forest (HNF). The watershed is an important source of drinking water for the city and is also a popular recreational area for nearby residents. The HNF has proposed treating fuels in the Tenmile-South Helena project area which encompasses the 26,000 acre watershed and an additional 35,000 acres to the east of the watershed. The Tenmile-South Helena project proposes hazardous fuel treatments for the purpose of “maintaining consistent water quantity-quality within Helena’s municipal watershed and improving conditions for public and firefighters safety across the landscape in the event of a wildfire” (Helena National Forest, 2014).

In April, 2015 the HNF requested that the Fire Modeling Institute (FMI) conduct a wildfire

probability modeling and risk assessment study to analyze proposed fuel treatments in the project area. The HNF requested this study include modeling the probability of burning, potential fire behavior, and identification of areas where large fires and/or fires potentially destructive to structures were most likely to originate.

This study compared three alternative fuel treatment scenarios regarding their effect on the probability of burning and the potential impacts thereof. Two of the alternatives would apply various combinations of commercial tree harvesting, non-commercial vegetation treatments and prescribed fire (Helena National Forest, 2014) to the Tenmile-South Helena project area. The other treatment scenario, referred to as the ‘existing condition’ alternative, would apply no treatments.

The analyses performed were primarily based on outputs from the large fire simulation model FSim (Finney et al. 2011). FSim combines models of ignition probability, spatial fire growth and suppression with artificially generated weather streams to simulate fire ignition and spread for many thousands of simulation years. It models potential wildfire based on historical weather and fire occurrence data and current fuels data. FSim generates a number of standard

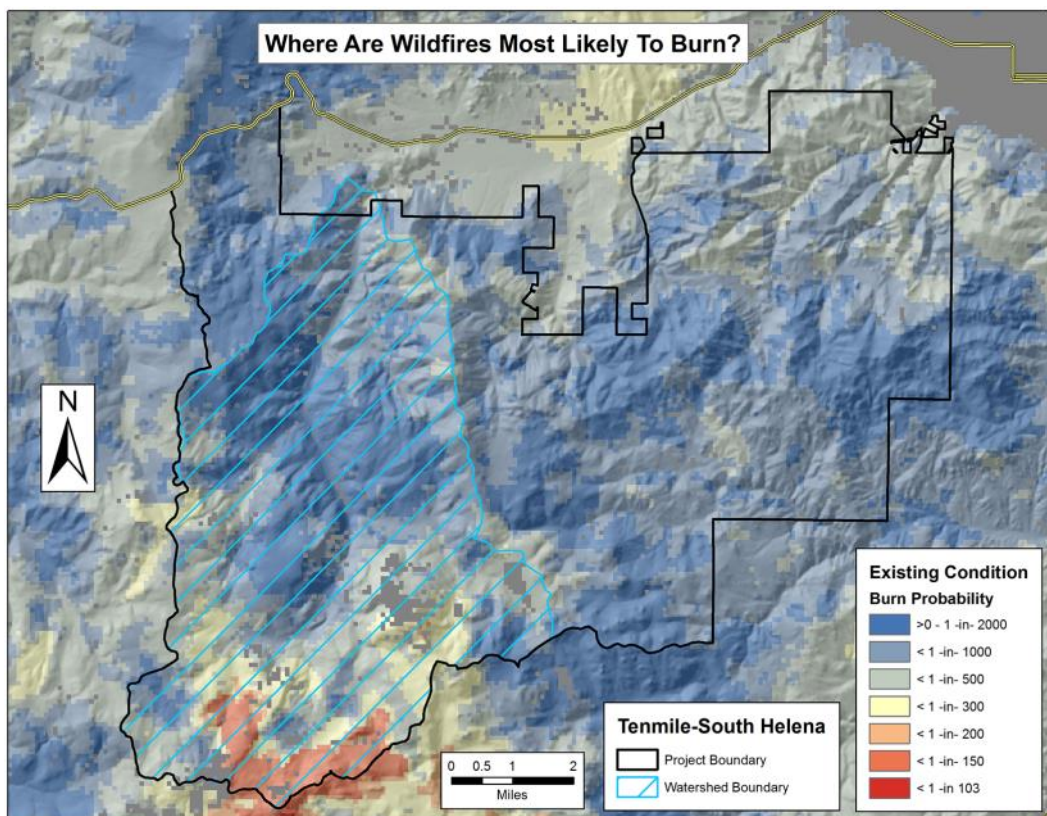
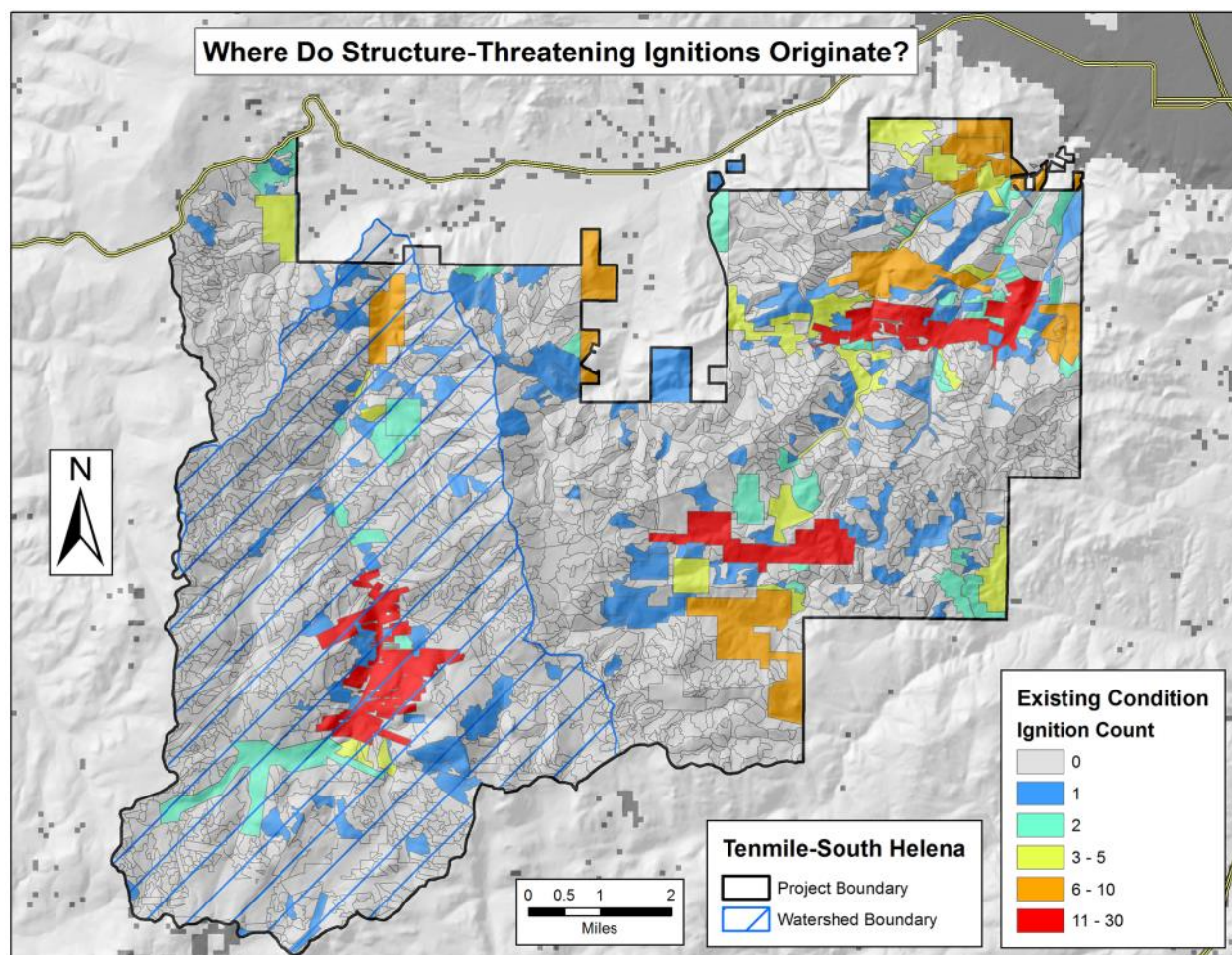


Image: Burn probabilities were generated to aid managers on the Helena National Forest in determining risk and hazard to structures in the area.



outputs including annual burn probability, mean fireline intensity, conditional flame lengths, fire perimeters and a fire size list.

Results were provided to the HNF comparing probability of burning, mean fireline intensity, as well as hazard and risk to structures based on ignition location for each of the three fuel treatment alternatives. This analysis provides insight into the

potential impacts of each alternative on future wildfire behavior and risk. These insights will help the HNF select and defend the most effective fuel treatment option.

For more information, contact: Brett Davis at bhdavis@fs.fed.us.

Image: Analysis results indicate the hazard and risk to structures based on ignition location for one of three proposed fuel treatments. This analysis will help managers on the Helena National Forest select the most effective fuel treatment for the TenMile Watershed project area.

ArcBurn: Linking Field-based and Experimental Methods to Quantify, Predict, and Manage Fire Effects on Cultural Resources

ArcBurn is an experimental fire archaeology project funded by the Joint Fire Science Program. It is a collaborative effort among fire scientists, forest ecologists, earth scientists, archaeologists, tribal members, and fire managers. ArcBurn is designed to help forest and fire managers in the southwestern U.S. use the best available science to make decisions about how to protect cultural resources during fuel treatments, prescribed burning, wildfire suppression, and post-fire rehabilitation. The need for this information is especially critical, as the changing climate is altering wildfire patterns and fire behavior. The ArcBurn project uses both controlled laboratory experiments and instrumentation of prescribed fires to determine critical damage thresholds for cultural resources (archaeological sites, artifacts, and heritage resources). Recorded observations of fire effects, and data on effectiveness of fuels treatments are then used to develop treatment guidelines on best practices for the protection of archaeological resources.

The ArcBurn team is comprised of 13 multi-agency experts, who are crucial for discussing gaps in the current understanding of fire effects on cultural resources. In all, the researchers have interviewed 17 fire and cultural resource managers about best practices and research needs for protecting cultural resources from fire and fire-related activities in the southwestern U.S. This year, the team welcomed new members to develop predictability modeling for erosion and fire effects based on post-burn surveys from southwestern wildfires.

In the past year, ArcBurn project highlights consist of the

continuation of laboratory experiments and public outreach. At the Missoula Fire Sciences Laboratory, experiments included radiant heat testing on volcanic tuff masonry; flame testing on volcanic tuff masonry and ceramics; and smolder testing on volcanic tuff masonry, obsidian, ceramics and chert. Preliminary results suggest that there is a wide range of fire sensitivity among artifact types, and that surface and ground fires are more damaging than crown fires. Smoldering tests are underway for all artifact types. In the past year, members of the ArcBurn team have conducted several professional presentations and completed a number of publications to engage the public.

ArcBurn is collaborating with FRAMES to create a new portal for fire and cultural resources to house useful reports and papers on fire effects on cultural resources, increasing public access. For more information on ArcBurn, please visit the ArcBurn website: <http://www.forestguild.org/Arcburn>.

For more information, contact: Rachel Loehman at rloehman@usgs.gov or Rebekah Kneifel at rrkneifel@fs.fed.us



Photo: This photo shows the pre-burn setup of ArcBurn flame bed for masonry and ceramics. Pine needles (right) are used to ignite the flame. The artifacts lay on a bed of sand, which is overlaid with more pine needles prior to burn. Photo by Rebekah Kneifel.



Top photo: The flaming front approaches masonry in an ArcBurn flame test. Bottom photo: Smoldering tests are performed on all artifact types (masonry, ceramics, chert, and obsidian). The masonry (tan) and obsidian (dark gray) can be clearly seen in the test bed. Photos by Rebekah Kneifel.

Boots on the Ground

Many scientists from the Fire, Fuel, and Smoke program are intimately involved with various aspects of fire management, including both prescribed fires and wildfires. Not only do these activities provide operational experience and the opportunity to observe fire in many different vegetation types but often stimulates research collaboration between FFS and the field. This last year, FFS employees worked on lands managed by the National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), Bureau of Land Management (BLM), Forest Service (USFS), Colville Agency, Yakama Agency, State of Idaho, State of Alaska, and the Clearwater-Potlatch Timber Protective Association.

Prescribed Fire

Last spring, Matt Jolly, Dan Jimenez, and Elliott Conrad ventured to the southeastern United States to participate in multiple prescribed burns as a partnership between The Nature Conservancy, the National Center for Landscape Fire Analysis at the University of Montana, and FFS. They were able to participate in burning seven different units in multiple vegetation types totaling almost 900 acres of degraded pine forests and work on various operational qualifications.

Dan Jimenez and Jim Reardon collaborated with the BLM in eastern Montana to attach temperature sensors to stone and bone artifacts during a



Photos, clockwise from upper left: Dan Jimenez assists with a prescribed burn in Georgia pine forests.; A prescribed fire is lit from the road in the burn unit. Elliot Conrad also assists with the burns. Photos courtesy of Matt Jolly / FFS.



prescribed burn at the Henry Smith Archaeological Site to evaluate fire effects to the artifacts.

Jason Forthofer, Sara McAllister, Dan Jimenez, Russ Parsons, and Elliott Conrad assisted the Eureka District of the Kootenai National Forest with a multi-day prescribed fire that led to further collaboration between FFS and the Kootenai NF to study fire spread and safety zone guidelines by burning two research units. Jason, Dan, Bret Butler, Paul Sopko, Jon Bergroos, and Andrew Gorris assisted with the research burns. Jason and Elliott also helped burn a prescribed fire unit for Missoula BLM.

Wildfires

Jason Forthofer worked on multiple wildfires in Oregon, Washington, and Montana as a Task Force Leader (TFLD), Strike Team Leader Engine (STEN), and finished his training as a Division/Group Supervisor (DIVS). He offered invaluable assistance to evacuate a community in northern Idaho that was in the path of a quickly spreading wildfire.

Greg Dillon worked with a variety of incident management teams including Type 1, Type 2, and Type 3 teams training to be a Geographic Information System Specialist (GISS) on wildfires in Washington, Oregon, and Montana. Greg also worked with the Multi-Agency Coordination Group (MAC) at the Northern Rockies in Missoula for two weeks providing invaluable maps and information. He created a script to automate the creation of new fire perimeters based on the most recent VIIRS and MODIS heat detection points which greatly improved decision-making and fire behavior analyses.

Faith Ann Heinsch travelled to the Last Frontier to work as a Geospatial Analyst (GSAN) supporting wildfires burning on BLM, State of Alaska, and tribal lands. After returning to the lower 48, Faith Ann



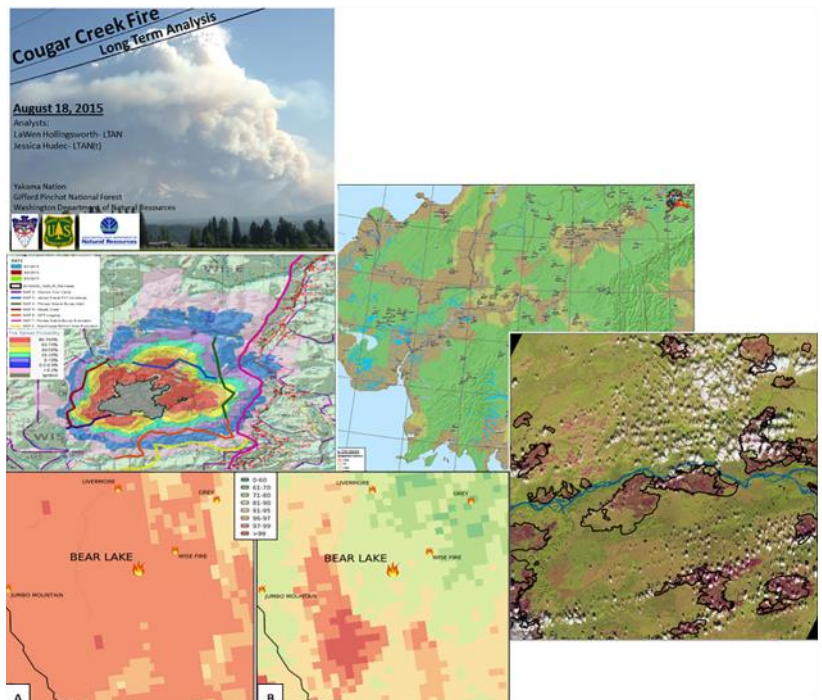
Top photo: Jim Reardon sets up a heat sensor at the Henry Smith Archaeological Site, Montana. Photo by Dan Jimenez / FFS. Middle photo: Video cameras (shown in heat resistant housing) filmed the fire as it burned through the area. Fire effects were then evaluated. Photo by Dan Jimenez / FFS. Bottom photo: An Alaskan Moose eats moss along the side of Chena Hot Springs Road north of Fairbanks, Alaska. Photo by Faith Ann Heinsch / FFS.

continued to work as a Geographic Information System Specialist (GISS) for fires in Oregon and Idaho, including working as a trainer to mentor five personnel in training to be GISSs. She created more 100 maps, learned to work within the ArcGIS Online environment, and worked with two Type 1 incident management teams.

Dan Jimenez worked in the Alaska bush at a remote spike camp for three weeks as a Fireline Emergency Medical Technician (EMTF) providing first aid support to as many as ten 20-person handcrews and miscellaneous overhead along a remote section of the Yukon River.

Jon Bergroos was able to get some operational experience the very first year of having his redcard. He worked with the Plains/Thompson Falls initial attack crew on the Lolo NF and then assigned as part of a 20-person handcrew to the West Fork Fish Creek Fire on the adjacent Ninemile Ranger District.

Matt Jolly worked to support district fire managers on primarily Type 3 incidents as a Geospatial Analyst (GSAN). He supported spatial fire behavior analysis requests for six fires in the Northern



Rockies Geographic Area and he worked as part of the USFS Region 1 Decision Support team to provide up-to-date fire situation analyses to regional fire managers and the Northern Rockies Multi-Agency Coordination Group. He developed new techniques to map season ending events across the geographic area and web-based displays for strategic wildland fire decision making. He also developed new fire danger mapping displays that were used to support decision making in the National Multi-Agency Coordination Group (NMAC) and the USFS Washington Office.

LaWen Hollingsworth travelled to Alaska to work as a supervisory Long Term Fire Analyst (LTAN) at the Alaska Interagency Coordination Center in Fairbanks. She mentored Geospatial Analysts and personnel training to be LTANs as well as provided information on the short-term status of fuels and fire behavior to the Alaska Multi-Agency Coordination Group (AMAC). LaWen also



Top image: Fire behavior analyses were created by LaWen Hollingsworth on various assignments. Images by LaWen Hollingsworth / FFS.
Bottom photo: The Cornet-Windy Ridge Fire burned across Highway 12 in Oregon. Photo by Faith Ann Heinsch / FFS.



Alaska State Department of Forestry initial attack base in McGrath, Alaska. He provided fire behavior analysis support and assessments for 20 separate fires covering a mix of jurisdictions: BLM, FWS, tribal, NPS, and State of Alaska. He also worked with Geospatial Analysts from FWS advising and reviewing modeling efforts. Modeling results were used by the Alaska Multi-Agency Coordination Group (AMAC) to assist with resource allocations and strategic planning. Chuck also worked as an LTAN developing long term plans for the Reynolds Fire and the Thompson Divide Complex in Glacier National Park. The Reynolds Fire was located on the east side of the Park and caused the Going to the Sun Road, between Logan Pass and St. Mary, to be closed to the public for a period of time as well as impacting concessioners, campgrounds, and lodging facilities located in and adjacent to the fire area. The Thompson Divide Complex consisted of the Thompson Fire within Glacier National Park and the Sheep and Granite Fires located on the Flathead National Forest. The Sheep Fire was a critical threat as it temporarily closed the railroad and almost impacted the historic Izaak Walton Inn and Essex, Montana.

worked as an LTAN in western Washington, providing fire behavior analyses for a Type 2 incident management team and mentoring an individual training to be an LTAN. She finished up the season working in Montana, providing short- and long-term fire behavior analyses for agency administrators and a Type 2 incident management team and assisted in preparing a long term plan for a fire burning in a Wilderness Study Area/Research Natural Area in the Pioneer Mountains. This spring LaWen assisted with prescribed burns on the Ninemile RD of the Lolo NF.

Chuck McHugh worked as a Long Term Fire Analyst (LTAN) in Alaska working out of the

For more information, contact: LaWen Hollingsworth at lhollingsworth@fs.fed.us



Top photo: The Sheep Fire burns on the Flathead NF above the Middle Fork Flathead River on August 20, 2015 at 5:36 p.m. as the “fire train” travels across a major train trestle over Sheep Creek in the foreground. The community of Essex, Montana, is approximately 3 miles west of this area. Photo by Charles McHugh / FFS. Bottom photo: Photo of the Whitefish Lake1 Fire in Alaska taken from the air on July 3, 2015, at 3:49 p.m. Photo by Charles McHugh / FFS.

SCIENCE SYNTHESIS AND DELIVERY

Research by FFS scientists and staff is produced in a variety of ways, such as through scientific research projects, data products, and computer applications. Scientific publications are one means FFS researchers disseminate information about our research. More information on our research can be found on our website: <http://www.firelab.org>. A list of scientific publications published in 2015 can be found starting on page 69. Software programs are also created and managed by FFS personnel; these programs are described beginning on page 50. Through the Fire Effects Information System, a website that provides syntheses and reviews of information about fire regimes and fire effects on plants, lichens, and animals, FFS staff produced a number of new and updated products for use by land managers. FFS scientists and staff manage the Tenderfoot Creek Experimental Forest. A new bunkhouse at the site will allow researchers to better utilize their time in the field in a safe and effective manner. Managers often seek out the expertise of FFS staff to apply fire science research to their specific, local issues, such as those employing the Wildfire Risk Assessment Framework.



Image: Western sword ferns grow under redwoods. Photo courtesy of National Park Service.

New and Updated Syntheses in FEIS



The Fire Effects Information System (FEIS, <http://www.feis-crs.org/feis/>) continues to serve managers, scientists, students, and the general public with new and updated online syntheses of scientific knowledge. In 2015, FEIS added fire regime information for all the plant communities in the

United States. These Fire Regime Reports and Fire Regime Syntheses connect LANDFIRE data to all of the 1,078 Species Reviews in FEIS. Fire Regime Reports summarize LANDFIRE data, while Fire Regime Syntheses are peer-reviewed publications that integrate LANDFIRE data with information from the scientific literature to provide in-depth information on historical fire regimes and address contemporary changes in fuels and fire regimes (page 46). FEIS has published Species Reviews online since 1986. These are syntheses of the published literature covering the biology, ecology, and fire effects on plants and animals in the United States. All FEIS publications provide a wealth of information for land managers, with applications in fuels and fire management and post-fire restoration.

Seven new Fire Regime Syntheses covering plant communities in Alaska and California were added to FEIS in 2015, adding value to dozens of Species Reviews with little or no information on historical fire regimes. Six Species Reviews were updated in FEIS in 2015, replacing reviews that were published more than a decade ago and thus adding substantial new information. These include reviews on white spruce, Pacific willow, western sword fern, white alder, wavyleaf soap plant, and sticky whiteleaf manzanita. These new and updated publications included 465 pages of synthesized information documented by 1,835 citations.

In 2015, 578,325 users visited FEIS; this is an increase of 4.1% from 2014. FEIS had visitors from all over the United States, with most visits from California, Texas, Washington, and Oregon. It also



received visits from more than 50 other countries throughout the world.

Literature used for FEIS publications is stored in the Fire Effects Library at the Missoula Fire Sciences Laboratory and documented in the Citation Retrieval System (CRS, <http://www.feis-crs.org/>). CRS now contains 59,518 citations. The FEIS Team is continually adding new citations to CRS; in 2015 they added over 1,000 new citations.

For more information, contact: Kris Zouhar at kzouhar@fs.fed.us.



Top left photo: White alder snags are shown 13 months after the 2002 Wolf Fire in California. Photo courtesy of Jacob Bendix, Syracuse University.

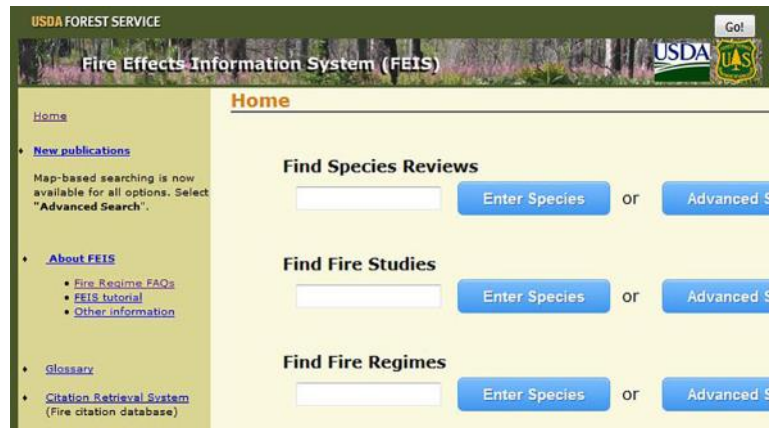
Top right photo: The Angora Creek corridor shortly after the 2007 Angora Fire. Photo courtesy of USFS.

Bottom photo: A giant reed infestation along a valley oak riparian woodland along Stoney Creek in Glenn County, California. Photo © 2009 Neal Kramer.

Finding Information on Fire Regimes in FEIS

Now Fire Effects Information System (FEIS, <http://www.feis-crs.org/feis/>) users can find information on fire regimes for every plant community in the United States. This year, the FEIS Team developed a series of 184 publications describing fire regimes of the United States. Each publication includes a subset of the more than 2,500 Biophysical Settings (BpS) models produced by LANDFIRE. The BpSs are grouped according to similarities in vegetation, modeled fire characteristics, and geographic location.

Most of the fire regimes in FEIS are described by Fire Regime Reports, which show maps of the BpSs covered, summarize the LANDFIRE information on fire frequency and fire severity, and provide links to background information for those BpSs. Fire Regime Syntheses integrate the information in these reports with thorough, well documented analyses of published research on historical fire regimes and contemporary changes in fuels and fire regimes. Each Fire Regime Synthesis includes available information from the scientific literature on historical fire frequency, spatial pattern, extent, and seasonality; historical ignition sources; historical patterns of fire intensity and severity; and the effects of climate change, invasive species, and



disturbances other than fire. Fire Regime Syntheses provide managers with a syntheses of the best science available, identify knowledge gaps and areas of uncertainty, and enable LANDFIRE to incorporate the latest science into data revisions. Since 2013, the FEIS team has published Fire Regime Syntheses for 13 fire regimes in Alaska, California, and Hawaii. See page 72 for information on recent publications.

With the release of a new user interface and database this year, FEIS users have access to all FEIS publications, including Fire Regime Reports and Fire Regime Syntheses, using FEIS's dynamic search capabilities. The new user interface enables users to search for FEIS publications by map location, state, federal land management agency, plant community type, and associated species. The new user interface allows users to answer questions like "What information is available on fire regimes in Alaska?" The new user interface also associates every FEIS Species Review with fire regime information, adding value to these publications.

For more information, contact: Robin Innes at rinnes@fs.fed.us.



Image: With the release of the new user interface, publications on fire regimes are now spatially searchable. Bottom Photo: Fires have produced a mosaic of fire severity in spruce-hardwoods in Yukon-Charley Rivers National Park. Photo courtesy of the National Park Service.

New Bunkhouse at the Tenderfoot Creek Experimental Forest Service Helps Researchers



The Fire, Fuel, and Smoke Science Program (FFS) is pleased to announce that we have a new administrative site for the Tenderfoot Creek Experimental Forest (TCEF). It is complete with bunkhouse, Sweet Smelling Toilet, (a.k.a., concrete pit latrine) and shop/garage building. The facility is located on Lewis and Clark National Forest land just outside the boundary of the TCEF. Prior to this construction, crews of up to 20 people used a “spike camp” during the summer — using a wall tent or tailgate for food preparation and dining room, a temporary pit toilet or port-a-potty, and transporting all potable water. Much energy was spent on managing logistics such as keeping trash and food secure; this new facility will help researchers better utilize their time and ensure a safer living environment.

The site is completely off the grid with power supplied by solar panels or a propane-fueled generator. A wood-burning stove in the main living/dining room and propane-fueled wall furnaces in the bedrooms provide much needed heat. The stove and refrigerator are also propane-fueled and a seasonal water system (powered by solar panels) includes potable water from a well and an ADA-compliant bathroom complete with shower and flushing toilet! Bunkbeds provide sleeping accommodations for six and the couch

folds out to provide space for another person if need be. Ample tent space exists adjacent to the bunkhouse. A small wind turbine may be added in the future to augment the power supply.

This project was initiated with a request for U.S. Forest Service Washington Office Construction dollars by Dr. Ward McCaughey in 2007 and funded in 2010. After Ward’s retirement, then-Scientist-in-charge Elaine Kennedy Sutherland and Manager David Wright from the RMRS Forest and Woodlands Ecosystem Program continued the efforts with development of initial architectural designs. Current Scientist-in-charge Bob Keane and Manager Helen Smith with FFS saw the project to fruition. This being said, we are still working on finishing touches, but the building should be “open for business” for the 2016 field season.

The bunkhouse will be available for use by Federal personnel and their cooperators working on the TCEF. There will be a nominal nightly charge to cover maintenance costs for the site. Look for an announcement of an open house and field trip to be held in 2016 on the FFS (www.firelab.org) and TCEF (www.fs.fed.us/rm/tenderfoot-creek/) websites.

For more information, contact: Helen Smith at hsmith04@fs.fed.us.



Top photo: A new bunkhouse at the Tenderfoot Creek Experimental Forest will provide safer living conditions for researchers. Bottom photo: Completely off the grid, the bunkhouse contains a complete kitchen, including potable water. Photos courtesy of Helen Smith / FFS.

Application of the Wildfire Risk Assessment Framework

In 2015, FMI analysts continued to be involved with application of a wildfire risk assessment framework developed largely by RMRS scientists from both the Fire, Fuel, and Smoke Science Program and the Human Dimensions Program. The risk assessment framework provides a means to assess the potential risk posed by wildfire to specific highly valued resources and assets (HVRAs) across large landscapes. It also provides a scientifically-based foundation for fire managers to think strategically and proactively about how to best manage fire and fuels on their landscapes in a way that integrates with broader land and resource management goals.

At the national scale, Spatial Fire Analyst Greg Dillon continued work on an assessment of wildfire risk across all National Forest System lands in the contiguous U.S. In January 2015 Dillon completed draft calculations of a risk metric called Net Value Change (NVC), but final results are pending completion of new and improved wildfire simulation results. Interestingly, while providing GIS support to the Northern Rockies Multi-Agency Coordination Group in August, Dillon was able to use the draft national NVC map to demonstrate the

potential usefulness of risk assessment products a wildfire incident management and resource prioritization context.

At the local scale, Dillon, along with Fire Behavior Specialist LaWen Hollingsworth and Ecologist Brett Davis, has helped the Lolo National Forest and Bitterroot National Forest make significant progress toward completing risk assessments. In March they helped facilitate a successful workshop with fire managers and resource specialists from both forests to discuss the effects of fire on various resources and assets on the ground. In July, they participated in a workshop led by the TEAMS Enterprise Team to calibrate LANDFIRE fuels data for both forests to improve subsequent wildfire modeling. Lastly, in October, they participated in a series of meetings with fire managers and Forest Leadership Team members from both forests to facilitate the assignment of relative priorities to their resources and assets.

Also in 2015, FMI analysts, along with others from the RMRS Wildland Fire Management RD&A; Fire, Fuel, and Smoke Science Program; and Human Dimensions Program, presented material at two successful workshops for outreach and information sharing about risk assessment concepts and methods. The first was a Wildfire Risk and Fuel Treatment Analysis Workshop. Held in Missoula in January, this workshop had 38 attendees and an additional 50+ on-line participants, representing all Forest Service Regions, the U.S. Department of Interior Office of Wildland Fire, and the U.S. Department of Agriculture



Photo: Workshop participants from U.S. Forest Service Region 4 discuss the applicability of the Risk Framework to their land management planning efforts. Photo courtesy of Erin Noonan-Wright / USFS.

Office of Inspector General. Recordings of all sessions from the 3-day workshop can be found at: <http://nrfirescience.org/event/wildfire-risk-and-fuel-treatment-analysis-workshop>. The second, held in Missoula in July, was a workshop on synthesizing risk assessment outputs to inform spatial fire planning and Forest Plan revision, attended by approximately 25 people. It was organized by the RMRS Wildland Fire Management RD&A and led by Pacific Southwest Regional Fire

Planners. In addition to members of both of those organizations, attendees came from FMI, the RMRS Human Dimensions Program, the TEAMS Enterprise Unit, Washington Office Fire and Aviation Management, the U.S. Department of Interior Office of Wildland Fire, and Pyrologix, LLC.

For more information, contact: Greg Dillon at gdillon@fs.fed.us or LaWen Hollingsworth at lhollingsworth@fs.fed.us.

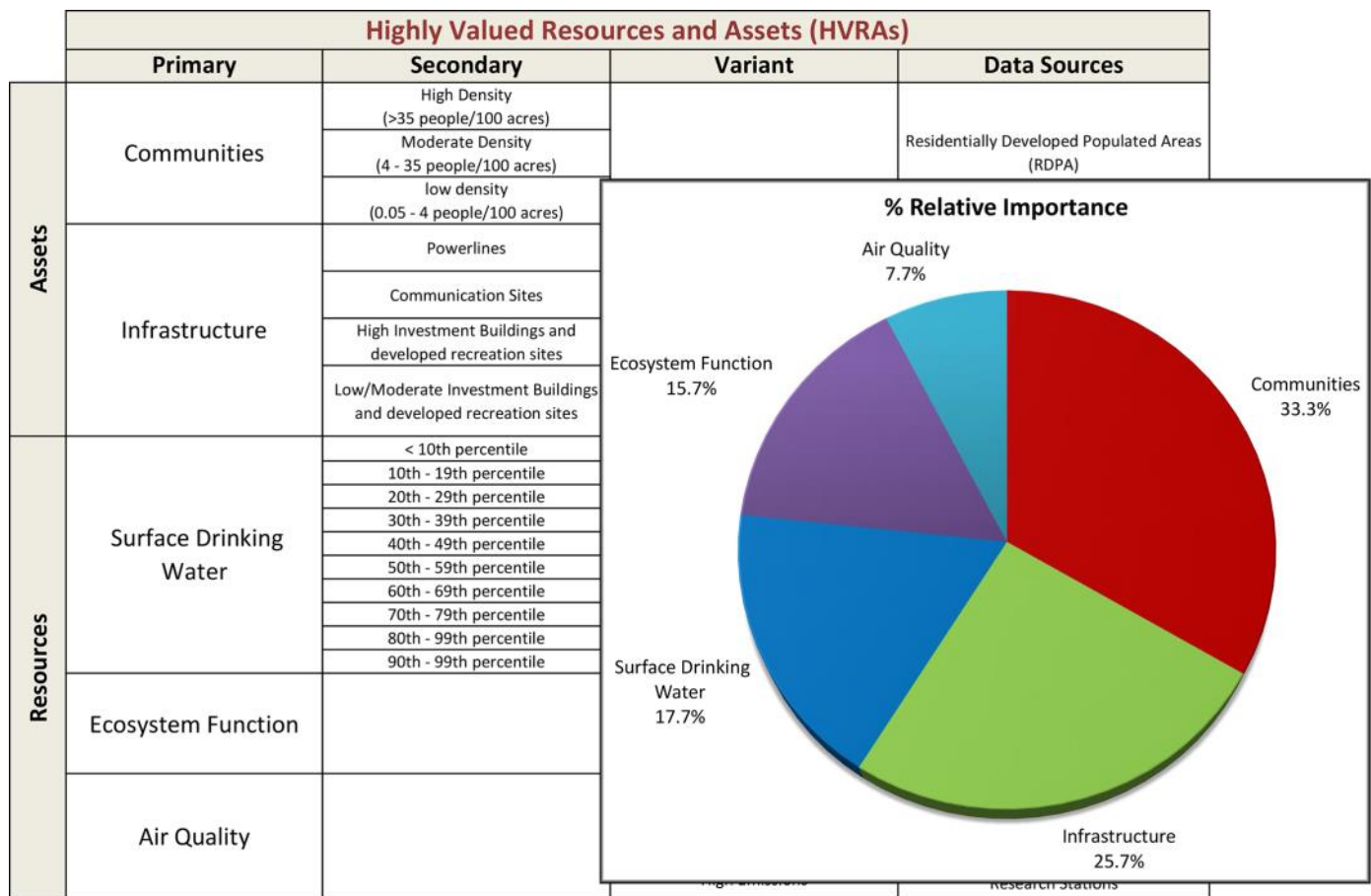


Image: At the workshop, attendees assessed risk surrounding highly valued resources and assets (HVRAs). This information was then synthesized for risk assessment.

APPLICATIONS AND PRODUCTS

In addition to scientific research projects and data products, FFS researchers are responsible for maintaining and updating a number of national computer applications. All of them are available on our website (<http://www.firelab.org>), and they cover the range of fire modeling from fire behavior to fire danger to fire ecology. Several applications are currently being updated. There have been substantial updates to FFI, FlamMap, and the Wildfire Assessment System as outlined in this report. Work on the updated NFDRS 2016 is ongoing.



Image: FFS researchers are responsible for maintaining and updating a number of applications. The logos for the systems are shown in this graphic.

BehavePlus fire modeling system

The BehavePlus fire modeling system is a nationally supported desktop application that models fire behavior, fire effects, and aspects of the fire environment. BehavePlus is used to model surface and crown fire spread rate and intensity, transition from surface to crown fire, fire size, effect of containment efforts, tree scorch height and mortality, fuel moisture, wind adjustment factor, spotting distance, and more. BehavePlus is not limited to a specific application, but rather is designed to be used for any fire management application for which fire model results are useful. It is used by federal, state, and local land management agencies, universities, consultants, and others, both nationally and internationally. Outputs from BehavePlus are used for a range of applications including wildfire prediction, prescribed fire planning, and fuel hazard assessment, as well as communication, education, and training. More information is available at our website: <http://www.frames.gov/behaveplus>.

A Service Level Agreement between Washington Office Fire and Aviation Management (WO F&AM) and FMI ensures FFS staff are available to assist the National Fire Applications Help Desk in answering questions regarding BehavePlus use and operation. In 2015, FFS staff responded to multiple technical support requests. FMI staff also led a workshop on using BehavePlus for prescribed fire for approximately 30 federal and state agency personnel in Harrisburg, Pennsylvania.

BehavePlus is currently being updated to include more than 20 new and improved features, including new analysis variables and special case fuel models. Lessons and documentation are also being updated to reflect changes in the application.

For more information, contact: Faith Ann Heinsch at faheinsch@fs.fed.us.

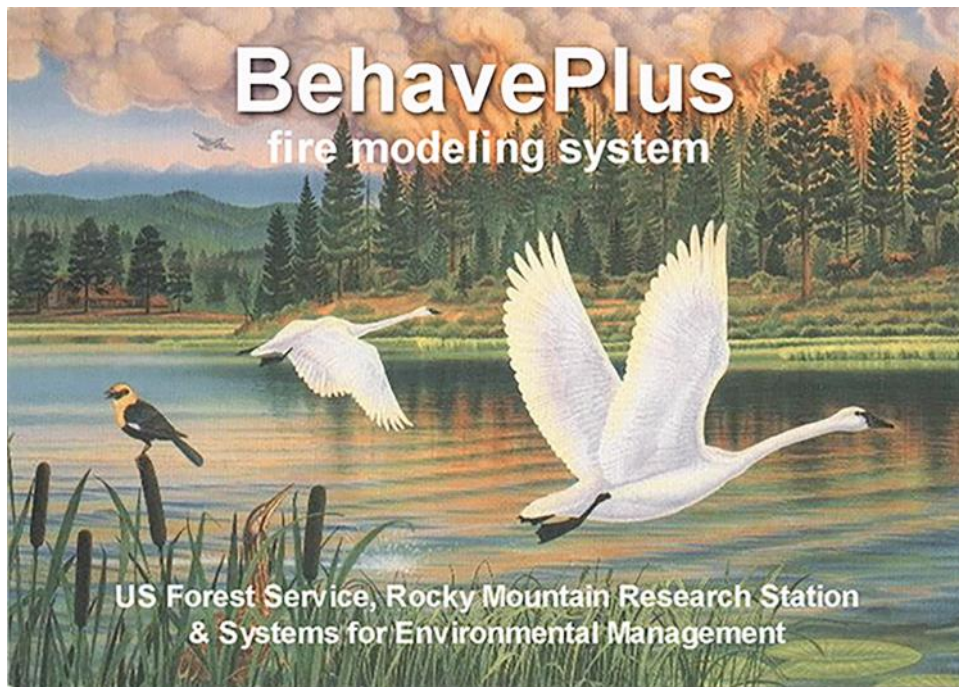


Image: The design for BehavePlus is from the 1992 "Wildfire" painting by Monty Dolack. Trumpeter swans take refuge in the air as a threatening wildfire rages through the forest habitat. This image is used with permission of the artist to represent BehavePlus.

FFI Ecological Monitoring Application

FEAT-FIREMON Integrated (FFI) is an interagency, science-based, ecological monitoring software application that is designed to assist managers in meeting monitoring requirements as mandated by Federal law. It is used in the U.S. Forest Service (USFS), National Park Service, Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (FWS), U. S. Geological Survey, and Bureau of Indian Affairs (BIA), and by tribes, state and local governments, non-governmental organizations, and universities.

FFI is a robust, ecological, vegetation and fuels monitoring tool used to consistently describe ecological systems and monitor change over time. It incorporates the components necessary to conduct a successful monitoring program, including an integral database, analysis and reporting tools, and modular GIS component. In addition to providing local data for managers, FFI data is also aggregated up for regional and national scale programs. For example, the LANDFIRE program uses FFI data to calibrate data layer products. The program can be downloaded from our website at <http://www.frames.gov/ffi>.

In May 2015, the FFI development team released FFI v1.05.03. Changes included a new master species list that includes updates made to the USDA PLANTS database, new species replacement functionality, import/export improvements, protocol updates, bug fixes and user requested updates.

FFI-Lite has been adopted by a number of users in its first year including all Forest Service users in Region 8. In the last year FMI staff converted over 30 databases from the FFI to the FFI-Lite format.

An FMI representative led four training classes in the past year including a standard class, short course and a customized class that focused on data analysis and query functionality. The classes were

attended by 40 participants from USFS, BLM, BIA, FWS, tribes and The Nature Conservancy.

FFI technical support is accomplished through the FFI Google discussion group, email, and phone “help desk”. The FFI technical support lead in FMI recorded over 75 technical support contacts in FY 2015. In a May 2015 survey 92% of respondents said they were highly satisfied or satisfied with the FFI software and 94% they were highly satisfied or satisfied with FFI technical support.

For more information, contact: Duncan Lutes at dlutes@fs.fed.us.



FireFamilyPlus (FFP) is an agency-independent desktop application. It supports the spectrum of analysis tools required by fire managers to successfully use the National Fire Danger Rating System (NFDRS) and the Canadian Forest Fire Danger Rating System from weather climatology data. It can be used to calculate fire danger rating indices and components and summarize both fire and weather data. The program can display data, compute values, and statistically analyze data in graph or report form. FFP can summarize weather climatology to produce climatological breakpoints for fire management decision making. It generates the Fire Danger Rating Pocket Cards required by the 30-Mile Abatement Plan and supports Predictive Services' functions at all the Geographic Coordination Centers. It can be downloaded from our website at <http://www.firelab.org/project/firefamilyplus>.

FireFamilyPlus is the computational and analysis cornerstone for the biennial Advanced Fire Danger Rating course at the National Advanced Fire and Resource Institute (NAFRI) and annual Intermediate Fire Danger Rating (S-491) courses held by the various Geographic Area Training Centers throughout the country. It also provides

climate summaries for techniques taught in the Long Term Fire Risk Assessment course (S-495) at NAFRI.

A Service Level Agreement between Washington Office Fire and Aviation Management (WO F&AM) and FMI ensures FMI staff and Systems for Environmental Management (SEM) programmers are available to assist the National Fire Applications Help Desk in answering questions regarding FireFamilyPlus operation. In 2015, FMI staff responded to more than 30 elevated tickets on FireFamilyPlus technical issues.

Continued progress has been based on suggestions from users and workshops at S-491 training courses. A beta Version 4.2 was made available in July of 2015 that includes the ability to import State fires from the National Association of State Foresters fire records system.

Work has also begun to prepare FireFamilyPlus to support the transition of the legacy National Fire Danger Rating System to NFDRS 2016 which will begin its rollout in 2016.

For more information, contact: Larry Bradshaw at lbradshaw@fs.fed.us.



Image: FireFamilyPlus supports the spectrum of analysis tools required by fire managers to successfully use the U.S. National Fire Danger Rating System (NFDRS) and the Canadian Forest Fire Danger Rating System from weather climatology data.

Fire Order Fire Effects Model (FOFEM)

The First Order Fire Effects Model (FOFEM) is a computer program developed to meet needs of resource managers, planners, and analysts for predicting and planning fire effects. FOFEM simulates four basic effects: 1) consumption of surface and ground fuel, 2) emissions and emission rate of coarse (PM10) and fine (PM2.5), CO, CO₂, CH₄, NO_x and sulfur dioxide (SO₂) for flaming, smoldering and total combustion, 3) soil heating across a range of soil depths over time since ignition, and 4) tree mortality from surface fire, based on flame length or scorch height, and tree species and size. It can be downloaded from our website at <http://www.firelab.org/project/fofem>.

In addition to the desktop application FOFEM is also incorporated in landscape models such as the Emissions Estimation System model used by the California Air Resources Board to model emissions from wildland fire and prescribed burns.

In the past year we've modified several assumptions about herb and shrub consumption, modified the input file format, fixed bugs and, spent substantial effort adding in new soil heating logic and investigating model logic changes necessary for updating emissions simulation. The next FOFEM release is expected in Spring 2016.

For more information, contact: Duncan Lutes at dlutes@fs.fed.us.



Image: The First Order Fire Effects Model (FOFEM) is a computer program developed to meet needs of resource managers, planners, and analysts for predicting and planning fire effects.

Release of FlamMap5

The FlamMap fire mapping and analysis is a PC-based program that describes potential fire behavior for constant environmental conditions (weather and fuel moisture). Fire behavior is calculated for each pixel within the landscape file independently, so FlamMap does not calculate fire spread across a landscape. Potential fire behavior calculations include surface fire spread, crown fire initiation, and crown fire spread. Dead fuel moisture is calculated using the Nelson model and FlamMap permits conditioning of dead fuels in each pixel based on slope, shading, elevation, aspect, and weather. The software can be downloaded from our website at <http://www.firelab.org/project/flammap>.

FlamMap is widely used by the U.S. Forest Service, National Park Service, and other federal and state land management agencies in support of fire management activities. It is designed for use by users familiar with fuels, weather, topography, wildfire situations and the associated terminology. Because of its complexity, only users with the proper fire behavior training and experience should

use FlamMap where the outputs are to be used for making fire and land management decisions.

In March of 2015 a major update to FlamMap5 was made available. This version included:

- An updated context-sensitive Help File.
- Incorporates spotting from torching trees.
- Incorporates gridded wind information from the WindNinja program.
- All outputs and landscapes can be exported as bundled KMZ files for use in Google Earth.
- Ability to clip larger landscape files and save them in the standard LCP or GeoTIFF formats.
- FlamMap now supports the Weather Stream (.WXS) File format.
- Landscape Critique has been included allowing the user to generate a report summarizing landscape characteristics in either a text format (without graphics) or in an Adobe PDF format (with graphics).
- Barriers can now be incorporated into MTT analysis. Barriers can be added from existing shapefiles or created interactively in FlamMap and saved as a shapefile. Barriers can be either filled or unfilled.



Image: The FlamMap fire mapping and analysis is a PC-based program that describes potential fire behavior for constant environmental conditions (weather and fuel moisture).

FuelCalc

FuelCalc is designed to help managers assess changes in ground, surface, and canopy fuel loading as simulated thinning, pruning, piling and prescribed fire treatments are applied. Initial fuel loading can be entered manually or using files exported from FFI. Outputs include canopy fuels (canopy bulk density, crown base height), load of surface and ground fuels, emissions, and fire behavior fuel model. The software can be downloaded from our website at <http://www.firelab.org/project/fuelcalc>.

Recent development includes an updated batch processing tool, better options for creating species-based retention priority lists and incorporating and updating the FOFEM library used in FuelCalc. The next FuelCalc release is expected in spring 2016.

For more information, contact: Duncan Lutes at dlutes@fs.fed.us.

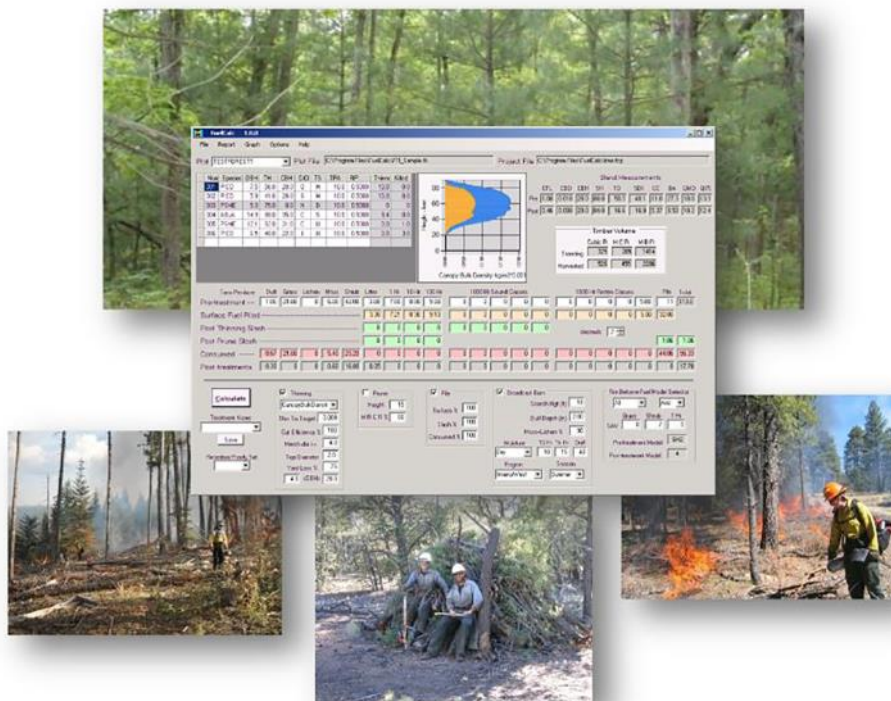


Photo: FuelCalc is designed to help managers assess changes in ground, surface, and canopy fuel loading.

LANDFIRE Fire Modeling Product Workshop Series

Scoping for comprehensive decadal remapping in order capture gradual, cumulative, and broad-scale changes for the entire LANDFIRE mapping area has begun. This remap will capture changes due to drought, invasive species, vegetation succession, disturbance, and loss of open space. The main objective of this effort is to create a new "base map" from which subsequent biennial updates can be used to keep the data current.

To fully evaluate the various elements pertinent to remapping, LANDFIRE is conducting after action reviews and scoping sessions to collect input that affects the scale and approach to this effort. The basic structure of each session evaluates past, current, and potential future approaches toward three elements of the product: requirements, production methods, and applications.

During the latter half of 2014 and early 2015, a series of workshops were held at the Missoula Fire Sciences Lab to incorporate a research-oriented viewpoint into LANDFIRE fire modeling products. The first half of each workshop focused on "briefing" participants about the current LANDFIRE fire modeling product suite. We discussed and documented information from participants on how the products are working, the issues they have found specific to the data, and what could be improved. This structured review

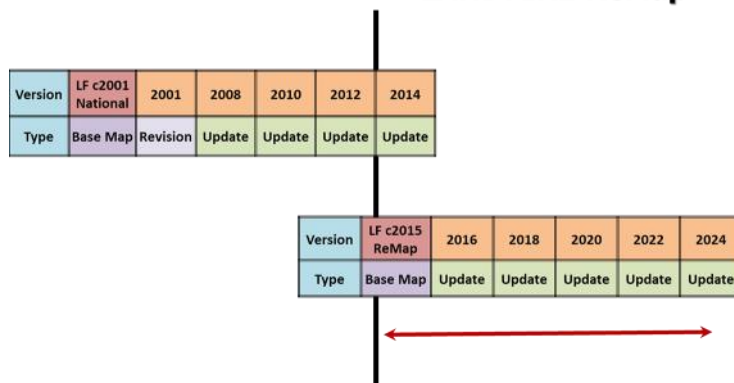


focused on three categories: the current product requirements, the legacy of various versions of these products, and current product applications. The second half each workshop was spent "brainstorming" about future LANDFIRE fire effects products. Here we discussed and documented information from participants regarding potential changes to those products in the future. This structured review also focused on potential changes to the current product requirements; how these products are produced and distributed; and how these products can be best applied.

These sessions provided a wider and more concerted effort toward conducting stakeholder outreach to assess product quality as well as issues related to the production and use of LANDFIRE products over the last ten years. The outcome will be a series of recommendations that respond to the elements listed above in a comprehensive fashion. The effort applies to the entire LANDFIRE mapping area across three major geographic areas including the Coterminous United States (CONUS), Alaska, and Hawaii and various Pacific and Atlantic islands.

For more information, contact: Don Long at dlong01@fs.fed.us.

LANDFIRE ReMap



U.S. National Fire Danger Rating System Development and Support

The U.S. National Fire Danger Rating System (NFDRS) is a system used by wildland fire management agencies to assess current fire danger at local, regional and national levels. It consists of a variety of indices that portray current potential fire danger conditions. FMI staff has been highly involved in the development and application of NFDRS for decades. In 2015, they continued to develop and enhance the base fire danger model and the distribution platforms that make fire danger information available to fire managers.

The Wildland Fire Assessment System (WFAS) is an integrated, web-based resource to support fire management decisions. It serves as the primary distribution platform for spatial fire danger data to a nationwide user base of federal, state, and local land managers. This web-based platform saw over 48,843 users with 208,128 page views during 2015. The system provides multi-temporal and multi-spatial views of fire weather and fire potential, including fuel moistures and fire danger classes from the NFDRS, as well as Keetch-Byram and Palmer drought indices, lower atmospheric stability indicators, and satellite-derived vegetation conditions. It also provides fire potential forecasts from 24 hours to 30 days out.

WFAS developers, working closely with federal fire managers from the U.S. Forest Service and the National Park Service and fire weather forecasters from the Bismarck Weather Forecast Office of the National Weather Service, created an automated fire danger distribution system for the state of North Dakota. This system leverages established fire danger calculations from weather stations state-wide to provide daily assessments of fire danger to local, state and federal agencies. This partnership was forged over the last two years and the system became operational in January 2015. Fire danger maps are produced daily (Figure 2) along with text products that indicate the fire danger by county. In the coming year, this system



will be expanded to include South Dakota, and eventually it will encompass the entire Great Plains.

In 2015, WFAS developers worked closely with researchers from the University of Idaho, the University of Montana, and U.S. Forest Service Region 1 to develop the TOPOFIRE web display and analysis system (<http://topofire.dbs.umt.edu>) for processing and displaying spatial weather data that can be used to support the development of the next generation of NFDRS and WFAS. The system is a NASA Earth Sciences Applications-supported project aimed at streamlining the development and use of spatial data for wildland fire decision making. The system will provide access to a wealth of high-resolution spatial weather data that will significantly enhance WFAS products. NASA saw the value in the project and continued funding of further development and refinement for the next three years.

Development of a new tool to combine airborne and space-borne laser scanner data with passive remote sensing derived canopy fuel products from LANDIFRE is underway. This new tool is being developed in collaboration with the USGS Earth Resources Observation and Science (EROS) Center. This new tool will provide rapid integration of highly detailed LiDAR into fuels maps used for fire behavior predictions. This tool, called CHISLIC (Creating Hybrid Structure from LANDFIRE/Lidar Combinations), will function as a desktop tool that derives its spatial data from web data services provided by WFAS.

WFAS developers in FMI have been producing fire danger forecasts from the National Weather

Service's National Digital Forecast Database (NDFD) for several years. WFAS developers continued to work closely with Predictive Services' meteorologists throughout the country in 2015 to provide point forecasts for key Remote Automated Weather Stations (RAWS) located throughout the United States. WFAS now produces seven-day outlooks daily for over 1,000 weather station points. These outlooks are being used operationally to produce seven-day fire potential forecasts for every geographic area in the continental United States. These seven-day forecasts provide a much longer fire danger outlook than was previously available and are providing fire managers with tools to meet strategic planning needs. The point forecast interface that produces the seven-day fire danger forecasts from the NDFD can be accessed at <http://www.wfas.net>.

Additionally, in the fall of 2015, WFAS developers began producing spatial NFDRS forecasts that were normalized based on historical percentiles. These

maps were used for regional and national strategic planning and were used in daily briefings for the USFS WO Fire and Aviation staff, the National Multi-Agency Coordination Group (NMAC) and the Northern Rockies Multi-Agency Coordination Group (NRMAC). These maps are now produced operationally each day and are provided as new content on the WFAS web interface.

WFAS developers in FMI have also designed and implemented a state-of-the-art web mapping interface for the display and analysis of remotely sensed spatial fire potential data. This new interface allows the rapid assessment of fuel conditions across a landscape, and it provides managers with several tools to assess fuel changes over time. The system is built on a suite of open-source tools that provides a means for efficient storage, display, and analysis of large spatial datasets. This new framework will be a building block for a new, integrated fire danger display and analysis system. The new interface complements the existing static

LANDFIRE national maps and will provide more system flexibility by allowing users to define their own area of interest, link to weather station data in a tabular format, and perform searches for map features. The prototype for the interactive map can be accessed at <http://www.wfas.net>. This web mapping and analysis interface will provide the tools necessary for the rapid and effective dissemination of large spatial datasets to the fire management community and will ultimately serve as the development platform for the next generation of fire danger rating systems.

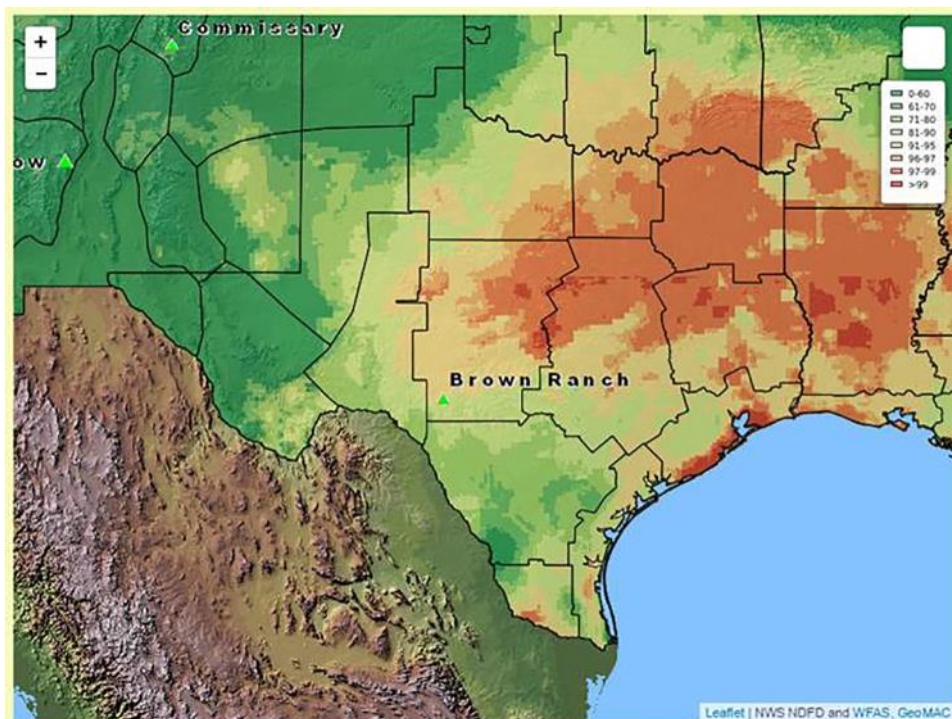


Image: The forecast for Day 0 (current) percentiles for Energy Release Component for 11 August 2015 across Texas. The dark red color indicates the highest fire danger.



In 2015, RMRS fire danger rating system developers continued updating the US National Fire Danger Rating System. This system has remained static for nearly 40 years, despite many scientific and technological advances that could significantly improve the system. These system updates have been approved by the Fire Danger Subcommittee of the National Wildfire Coordinating Group (NWCG) and by the NWCG Executive Board. Developers worked to refine and test the new NFDRS 2016 methodology and to develop computation standards for implementation in WIMS. The new system will be implemented and tested over the next two years and is expected to be fully operational in 2016.

In addition to development and maintenance of the NFDRS, FMI staff participated as core instructors for the National, Advanced Fire Danger Rating System course at NAFRI, Intermediate NFDRS

(S-491) and related Weather Information Management System (WIMS) courses during 2015. Approximately 290 participants from a variety of state and federal government agencies and universities participated in these training sessions.

Lastly, FMI staff provides national technical support for the NFDRS and associated programs through the National Fire Applications Help Desk and responded to over 45 elevated tickets on technical issues in 2015.

For more information, contact: Matt Jolly at mjolly@fs.fed.us or Larry Bradshaw at lbradshaw@fs.fed.us.

Weather Information Management System (WIMS) Support

The U.S. National Fire Danger Rating System (NFDRS) is used by all federal and most state fire management agencies for assessing seasonal fire severity across the nation. The application that hosts the NFDRS is the Washington Office Fire and Aviation Management's Weather Information Management System (WIMS) located at the USDA National Information Technology Center in Kansas City, Missouri. WIMS ingests hourly weather observations from more than 1,800 Remote Automated Weather Stations (RAWS) across the continental United States, Alaska, Hawaii, and Puerto Rico.

In 2015 FMI staff continued leading the science and technical implementation of NFDRS 2016 in the WIMS development environment, including:

- Continued testing of the Growing Season Index in an operational environment. Developed by FMI staff scientist, Dr. Matt Jolly it will replace the current NFDRS live fuel moisture model in 2016.
- Adding the 5 fuel models that will be the core of the NFDRS 2016,
- Enabling WIMS to use the Nelson dead fuel moisture model for all time lag fuel classes.

- Enabling WIMS to calculate hourly NFDRS outputs based on the Nelson model.

They also collaborated with various partners to:

- Monitor the testing phase of the seven-day forecasting scheme at two National Weather Service (NWS) forecast offices (Bismark and Grand Forks, North Dakota) for forecasting NFDRS indices. It is anticipated this tool will be distributed throughout the NWS for the 2016 fire season.
- Implement the FW13 data exchange format into the static F&AM Fire & Weather Web Application for historical weather access.

FMI staff participated in WIMS training classes in Kentucky, Idaho, and California and provided national technical support for WIMS through the National Fire Applications Help Desk. They assisted in resolving 27 elevated tickets on WIMS technical issues in 2015.

For more information, contact: Larry Bradshaw at lbradshaw@fs.fed.us.

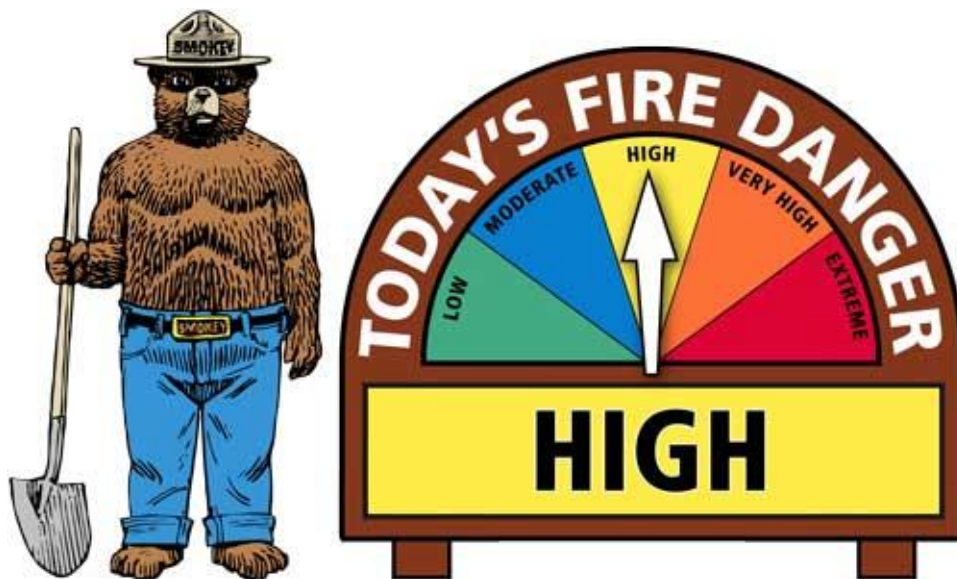


Image: Commonly known as "Smokey's Arm," signs across the U.S. inform the public about fire danger in the local area. Known formally as the Adjective Rating Level, values range from Low to Extreme. Values come from information in WIMS.

THE RESEARCH CONTINUES

Research to enhance current understanding of wildland fire behavior and its effects is ongoing. Scientists and Staff in the Fire, Fuel, and Smoke Science Program are expanding the burn severity project into the eastern U.S., allowing managers to better predict the potential for high severity fires. Tree ring specimens, also known as “cookies” provide critical information about the past. They have been used to determine past fire histories and past climates, among other things. The tree ring specimens housed at the Fire Lab will be moved to the national tree ring archive, making them available to other scientists as well. The FireWorks curriculum has been widely used for many years. It is undergoing a much-needed update, adding a new ecosystems and generalizing many activities so that they can be used anywhere. RxCADRE has been described in past annual reports. In 2016, a special issue of the International Journal of Wildland Fire describes results of the multi-agency, multi-year study.



Photo: Chainsaws are used to cut tree “cookies” from fire-scarred trees and stumps for examination in the lab. Photo courtesy of James P. Riser II / USFS.

FIRESEV East: Expanding the Severe Fire Potential Map to the Eastern United States

In 2013, the FIRESEV project delivered several products, including a Severe Fire potential Map (SFPM), which expanded opportunities for spatial evaluation of fire and burn severity across all phases of fire management from planning to real-time operational and tactical contexts. The SFPM is a digital map covering the contiguous western United States that spatially quantifies the potential for fires, should they occur, to result in high severity fire effects. 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. The current

project expands the SFPM to the eastern US. The result will be a raster geospatial product covering the entire contiguous United States that will be applicable to all scales of fire management analysis and will include an accuracy assessment of the entire SFPM. The project is on target to be completed by October 2016.

More information about the FIRESEV project can be found at <http://www.firelab.org/project/firesev>.

For more information, contact: Bob Keane at rkeane@fs.fed.us or Greg Dillon at gdillon@fs.fed.us.

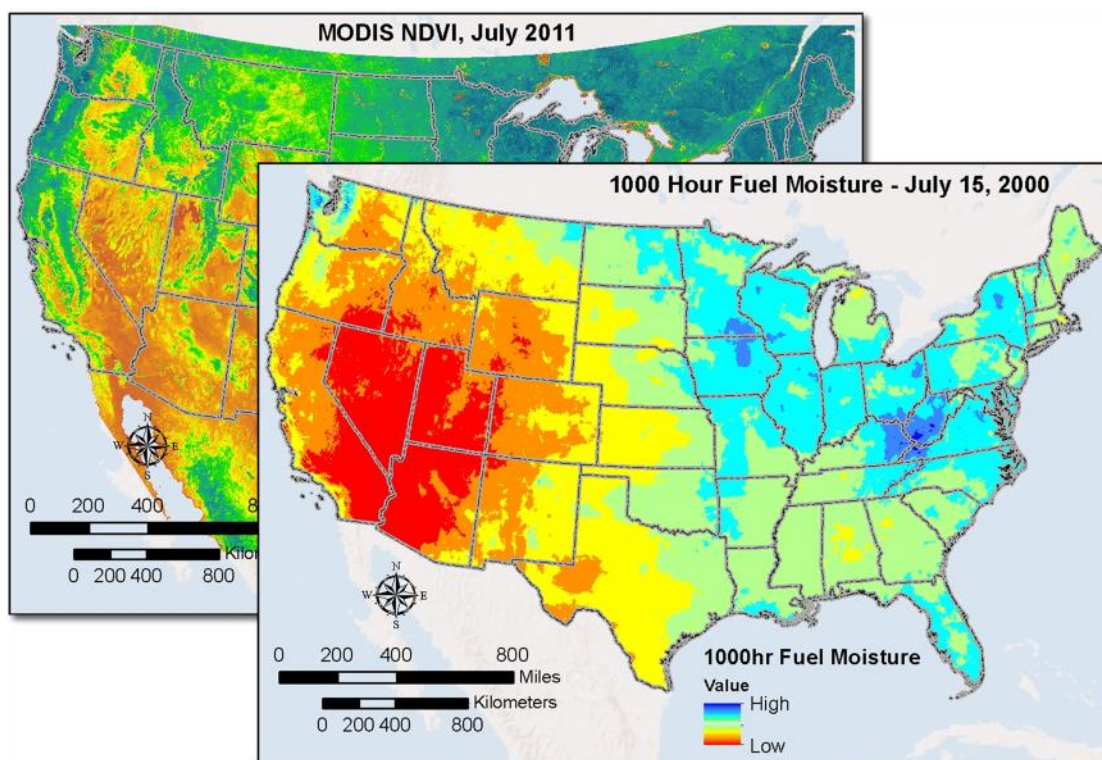


Image: Temporally-specific predictor data for the contiguous United States are used in the FIRESEV project. Data include the Normalized Differenced Vegetation Index (NDVI) and 1000-hour fuel moisture data.

Permanent Archiving of Tree-ring Specimens Collected for Fire History



We are preparing more than 16,000 tree-ring specimens for permanent archiving. These wood samples were collected during the past 20 years to reconstruct historical fire regimes in western North America. While the Forest Service and other funding agencies made a substantial investment in collecting and analyzing these specimens, the value of the wood itself is incalculable. These specimens are unique multi-century records of environmental conditions at specific locations, but in many cases, the specimens themselves cannot be replaced because

old trees are disappearing from the landscape due to ongoing environmental and social changes.

Our goal is to make the specimens available in perpetuity for other researchers to study. While they can be used to confirm the results of the fire histories already reconstructed, they can also be re-analyzed using new instruments and techniques to provide new data and insights, including unanticipated relevance to other fields of study. For example, specimens from this fire history collection have already been reanalyzed for an entirely new purpose - documenting historical tree defense against bark beetles (<http://www.firelab.org/project/fire-and-tree-defense>).

The fire histories reconstructed from these tree-ring specimens have already been publicly archived (<https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/fire-history>), but while this data and metadata are important, the source material itself is also valuable. Over the next several years, this tree-ring specimen collection will be permanently archived at the only federally recognized tree-ring repository in the US, where its importance will grow and it will continue to be used in ways that we cannot currently imagine.

For more information, contact: Emily Heyerdahl at eheyerdahl@fs.fed.us.

FireWorks Expands

FireWorks (www.firelab.org/project/fireworks-educational-program) is an educational program that uses hands-on activities to teach about the physical science of wildland fire, fire ecology, fire history, and people's relationships with fire. FireWorks has been used extensively in the Northern Rocky Mountains since 2000. To meet increasing interest and incorporate the latest science, FireWorks is being expanded to cover more ecosystems, revised to reflect recent research, and linked to current educational standards.

Fire Effects Information System are collaborating with professionals from the Plumas Unified School District and Plumas National Forest to develop a FireWorks curriculum covering ecosystems in the Sierra Nevada and, in particular, the areas burned by the Storrie and Moonlight Fires in the Plumas National Forest. While many FireWorks lessons apply to any location with a history of wildland fire, many others are tailored to particular ecosystems. This project will adapt lessons about individual

species, ecology, and fire history to reflect ecosystems in the Sierra Nevada.

The curriculum for the Sierra Nevada will reflect recent research on fire behavior and ecology, and the 2000 curriculum for the Northern Rocky Mountains will be updated to cover the same information. Innovative lessons are being developed for students at the high school level in both curricula, and all lessons are being linked to current national education standards.

The new, up-to-date curricula for the Sierra Nevada and the Northern Rockies will form the basis for a "generic" FireWorks curriculum to be produced at the Fire Lab. This curriculum will be adaptable for teaching students about the science of wildland fire in any fire-dependent ecosystem.

For more information, contact: Ilana Abrahamson at ilanalabrahamson@fs.fed.us.



Photo: High school science teachers from the Plumas Unified School District modeling how surface fires form scars on trees. Photo courtesy of Ilana Abrahamson / FFS.

IJWF Special Issue: The RxCADRE Interdisciplinary Fire Study



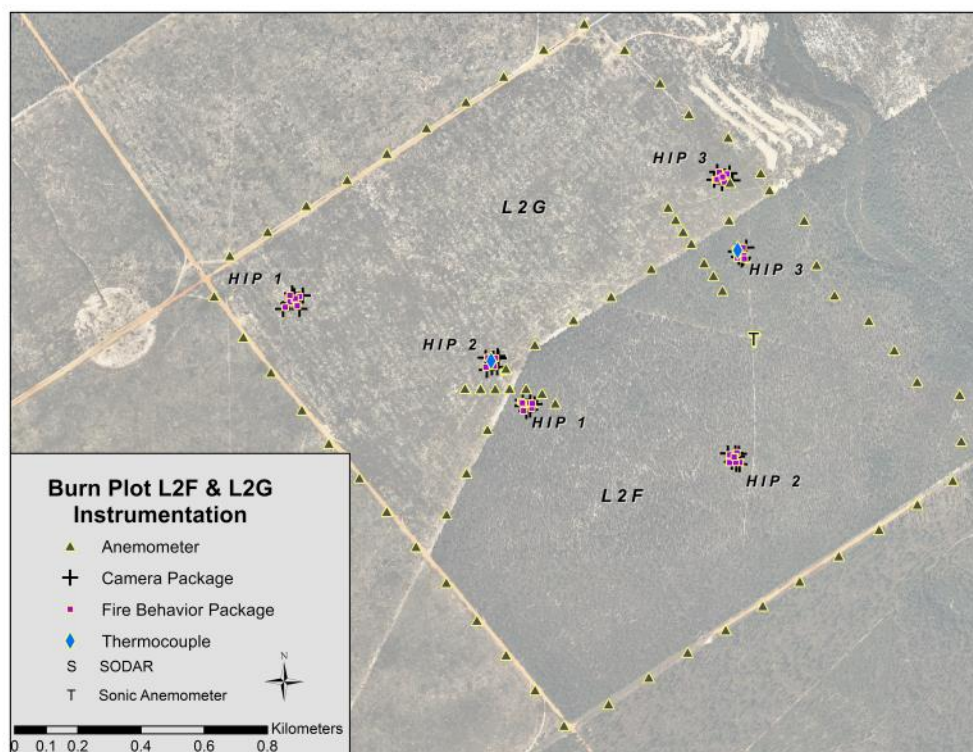
The International Journal of Wildland Fire (IJWF) has released a special issue (<http://www.publish.csiro.au/nid/115/issue/7979.htm>) documenting a landmark study called the Prescribed Fire Combustion and Atmospheric Dynamics Research Experiment (RxCADRE). This study took place from 2008–2012 in Florida.

Building on concepts from early grassfire experiments (1986, Northern Territory, Australia) that helped quantify fuel–fire–atmosphere interactions, RxCADRE was designed to collect complementary data across multiple disciplines before, during and after the active burning periods of prescribed fires in grass-dominated fuels. Unprecedented in scope, the project encompassed measurements of fuels, fuel consumption, fire behavior, smoke and fire effects. High-resolution fire progression and heat release data are critical for

understanding fine-scale fire behavior and fire effects, which in turn are needed to improve computational fluid dynamics-based fire behavior simulators.

Papers in the special issue cover every aspect of the RxCADRE project, from fine-scale fuel measurements to remotely sensed data. The studies involve not only rigorous science but also a high level of coordination and cross-referencing between papers, representing the implicit collaboration throughout the project — no small task when 90 scientists from a broad range of disciplines and organizations, including all of the USDA Forest Service Research Stations, are involved. Colin Hardy, program manager for FFS was a guest editor, and several scientists at the lab authored papers in the special issue.

For more information, contact: Colin Hardy at chardy01@fs.fed.us.



Top photo: RxCADRE sites were heavily instrumented to collect data across multiple disciplines. Bottom image: Sensor layout and general location of burn plots are shown for the RxCADRE measurement site. Photo and image by Dan Jimenez / FFS.

EDUCATION AND OUTREACH

Wildland fire draws the public's attention every summer, but public understanding of fire is limited. The Missoula Fire Lab provides tours, workshops, presentations, and educational curricula and materials to help increase public understanding of the science of wildland fire. In FY15, the Fire Lab's Conservation Education program reached more than 800 students and 100 adults:



FMI and FFS staff provided 10 tours for 250 K-12 students and 34 teachers and other adults. Each tour included presentations and hands-on activities. Students participated in lab investigations of fire spread and used fire-scarred tree sections and feltboards to “tell the stories” of fire’s role in Rocky Mountain forests.

We gave 5 presentations in classrooms and field sites, teaching students at the Elementary, Middle, and High School levels. These presentations addressed 403 students and 26 teachers.

We loaned the FireWorks trunk to 10 teachers, who used it to teach approximately 200 children.

We gave presentations to 26 teachers and agency educators in workshops provided by the Plumas and Stanislaus National Forests.

In July, we provided a tour for a special audience — 8 adults from Missoula’s Opportunity Resources, Inc., a nonprofit corporation that provides training and work opportunities for disabled adults. Presentations during the tour addressed Fire behavior, fire ecology, and fire safety.

In addition to the above, we hosted two intensive educational workshops in FY14 – a week-long summer camp on natural resources for Middle School students in a program for at-risk children in Missoula County, and a 2-day “FireWorks master class” for professional educators. The 25 students and 5 teachers in the natural resources camp learned about history and fuel reduction projects at Garnet Ghost Town. They collected and identified insects and invasive plants in Missoula’s Greenough Park. On the final day of the camp, they learned about fire from presentations by Missoula Rural Fire District and the Missoula

Photo: Educators examine the effects of slope on fire in this exercise as part of the FireWorks master class. Photo courtesy of Ilana Abrahamson / FFS.

Smokejumpers. The day concluded with hands-on learning about fire behavior and fire ecology at the Fire Lab.

The FireWorks master class offered an in-depth exploration of the 30-plus activities in the FireWorks curriculum and trunk. Seventeen educators from Montana, Idaho, Kansas, and North Carolina participated. They conducted experiments in the Fire Lab's burn chamber to learn about ignition, heat transfer, and fuel properties. They "adopted" the characters of various plants and animals to teach each other about different

organisms' adaptations to fire. They participated in role-playing to "model" tree morphology, trees' responses to fires of different severities, and succession in different kinds of forest. Participants from Kansas and North Carolina plan to use the workshop as a springboard for adapting the FireWorks curriculum to teach about fire science in their geographic areas.

For more information, contact: Ilana Abrahamson at ilanalabrahamson@fs.fed.us.



Photo: Teachers and agency fire specialists investigate fire scars and tree rings during the FireWorks master class, June 2015. Photo courtesy of Ilana Abrahamson / FFS.

2015 PUBLICATIONS

The Fire, Fuel, and Smoke Science Program of the U.S. Forest Service Rocky Mountain Research Station focuses on basic and applied research related to wildland fire, including wildland fire processes, terrestrial and atmospheric effects of fire, and ecological adaptations to fire. Results from this research are disseminated in a number of ways, including publications. The following list, separated by the focus areas outlined on pages 1-3, provides an overview of articles published in 2015. Links are provided for publications where possible.

Physical Fire Processes



Finney, Mark A.; Cohen, Jack D.; Forthofer, Jason M.; McAllister, Sara S.; Gollner, Michael J.; Gorham, Daniel J.; Saito, Kozo; Akafuah, Nelson K.; Adam, Brittany A.; English, Justin D. 2015. Role of buoyant flame dynamics in wildfire spread. PNAS. 112(32): 9833-9838. <http://www.treeseearch.fs.fed.us/pubs/48668>

Fuel Dynamics



Keane, Robert E. 2015. Wildland fuel fundamentals and applications. New York: Springer. 182 p.

Smoke Emissions and Dispersion



Evangelizou, Nikolaos; Balkanski, Yves; Cozic, Anne; Hao, Wei Min; Moller, Anders Pape. 2014. Wildfires in Chernobyl-contaminated forests and risks to the population and the environment: A new nuclear disaster about to happen? Environment International. 73: 346-358. <http://www.treeseearch.fs.fed.us/pubs/47004>

Kovalev, Vladimir A. 2015. Solutions in LIDAR profiling of the atmosphere. Hoboken, NJ: John Wiley and Sons, Inc. 304 p.

Kovalev, Vladimir A.; Petkov, Alexander P.; Wold, Cyle E.; Urbanski, Shawn P.; Hao, Wei Min. 2015. Determination of the smoke-plume heights and their dynamics with ground-based scanning LIDAR. Applied Optics. 54(8): 2011-2017. <http://www.treeseearch.fs.fed.us/pubs/49674>

Mao, Y. H.; Li, Q. B.; Chen, D.; Zhang, L.; Hao, W. -M.; Liou, K.-N. 2014. Top-down estimates of biomass burning emissions of black carbon in the western United States. Atmospheric Chemistry and Physics. 14 (14): 7195-7211. <http://www.treeseearch.fs.fed.us/pubs/47014>

*Top photo: Flames exhibit peak and trough structure in experimental fires. Photo courtesy of Mark Finney / FFS.
Middle photo: Whitebark seedlings cluster at the base of a large tree. Photo courtesy of Bob Keane / FFS.
Bottom photo: Smoke rises from the Cougar Creek Fire, WA. Photo by LaWen Hollingsworth / FFS.*

Yue, C.; Ciais, P.; Cadule, P.; Thonicke, K.; Archibald, S.; Poulter, B.; Hao, W. M.; Hantson, S.; Mouillot, F.; Friedlingstein, P.; Maignan, F.; Viovy, N. 2014. Modelling the role of fires in the terrestrial carbon balance by incorporating SPITFIRE into the global vegetation model ORCHIDEE - Part 1: Simulating historical global burned area and fire regimes. *Geoscientific Model Development*. 7(6): 2747-2767. <http://www.treesearch.fs.fed.us/pubs/49671>

Fire Ecology



Flower, Aquila; Gavin, Daniel G.; Heyerdahl, Emily K.; Parsons, Russell A.; Cohn, Gregory M. 2014. Western spruce budworm outbreaks did not increase fire risk over the last three centuries: A dendrochronological analysis of inter-disturbance synergism. *PLOS ONE*. 9(12): doi: 10.1371/journal.pone.0114282. <http://www.treesearch.fs.fed.us/pubs/49669>

Freeborn, Patrick H.; Cochrane, Mark A.; Jolly, W. Matt. 2015. Relationships between fire danger and the daily number and daily growth of active incidents burning in the northern Rocky Mountains, USA. *International Journal of Wildland Fire*. 24(7): 900-910. <http://www.treesearch.fs.fed.us/pubs/49672>

Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin, tech. eds. 2015. Proceedings of the large wildland fires conference; 2014 May 19-23; Missoula, MT. Proceedings RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 345 p. Available online: <http://www.treesearch.fs.fed.us/pubs/49166> [2016, January 13].

Keane, Robert E.; Loehman, Rachel; Clark, Jason; Smithwick, Erica A. H.; Miller, Carol. 2015. Chapter 8: Exploring interactions among multiple disturbance agents in forest landscapes: simulating effects of fire, beetles, and disease under climate change. In: Perera, Ajith H.; Sturtevant, Brian R.; Buse, Lisa J., eds. *Simulation modeling of forest landscape disturbances*. Geneva, Switzerland: Springer International Publishing: 201-231

Keane, Robert E.; McKenzie, Donald; Falk, Donald A.; Smithwick, Erica A.H.; Miller, Carol; Kellogg, Lara-Karena B. 2015. Representing climate, disturbance, and vegetation interactions in landscape models. *Ecological Modelling*. 309-310: 33-47. <http://www.treesearch.fs.fed.us/pubs/48772>

Merschel, Andrew G.; Spies, Thomas A.; Heyerdahl, Emily K. 2014. Mixed-conifer forests of central Oregon: effects of logging and fire exclusion vary with environment. *Ecological Applications*. 24(7): 1670-1688. <http://www.treesearch.fs.fed.us/pubs/49670>

Morgan, Penelope; Keane, Robert E.; Dillon, Gregory K.; Jain, Theresa B.; Hudak, Andrew T.; Karau, Eva C.; Sikkink, Pamela G.; Holden, Zachery A.; Strand, Eva K. 2014. Challenges of assessing fire and burn severity using field measures, remote sensing and modelling. *International Journal of Wildland Fire*. 23(8): 1045-1060. <http://www.treesearch.fs.fed.us/pubs/47843>

Peterson, Birgit; Nelson, Kurtis J.; Seielstad, Carl; Stoker, Jason; Jolly, W. Matt; Parsons, Russell. 2015. Automated integration of lidar into the LANDFIRE product suite. *Remote Sensing Letters*. 6(3): 247-256. <http://www.treesearch.fs.fed.us/pubs/49676>

Riggs, Robert A.; Keane, Robert E.; Cimon, Norm; Cook, Rachel; Holsinger, Lisa; Cook, John; DelCurto, Timothy; Baggett, L. Scott; Justice, Donald; Powell, David; Vavra, Martin; Naylor, Bridgett. 2015. Biomass and fire dynamics in a temperate forest-grassland mosaic: integrating multi-species herbivory, climate, and fire with the FireBGCV2/GrazeBGC system. *Ecological Modelling*. 296(24): 57-78. <http://www.treesearch.fs.fed.us/pubs/47844>

Fire and Fuel Management Strategies



Hollingsworth, L. T.; Johnson, D.; Sikaundi, G.; Siame, S. 2015. Fire management assessment of Eastern Province, Zambia. Washington, D.C.: U.S. Department of Agriculture, Forest Service, International Programs. 88 p. <http://www.treesearch.fs.fed.us/pubs/49673>

Jolly, W. Matt; Cochrane, Mark A.; Freeborn, Patrick H.; Holden, Zachary A.; Brown, Timothy J.; Williamson, Grant J.; Bowman, David M. J. S. 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications*. 6, Article number 7537: doi: 10.1038/ncomms8537. <http://www.treesearch.fs.fed.us/pubs/48648>

Mangeon, Stephane; Field, Robert; Fromm, Michael; McHugh, Charles; Voulgarakis, Apostolos. 2015. Satellite versus ground-based estimates of burned area: a comparison between MODIS based burned area and fire agency reports over North America in 2007. *The Anthropocene Review*. doi:10.1177/2053019615588790. <http://www.treesearch.fs.fed.us/pubs/49675>

McHugh, Charles W.; Hoyt, Stu; Fay, Brett. 2015. Strategic operations planning - it's not just for wilderness! How the strategic operations planner can help. In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin, tech. eds. *Proceedings of the large wildland fires conference; 2014 May 19-23; Missoula, MT*. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 156-162. <http://www.treesearch.fs.fed.us/pubs/49438>

Short, Karen C. 2015. Sources and implications of bias and uncertainty in a century of US wildfire activity data. *International Journal of Wildland Fire*. 24(7): 883-891. <http://www.treesearch.fs.fed.us/pubs/49677>

Short, Karen C. 2015. Spatial wildfire occurrence data for the United States, 1992-2013 [FPA_FOD_20150323]. 3rd Edition. Fort Collins, CO: Forest Service Research Data Archive. Available online: <http://dx.doi.org/10.2737/RDS-2013-0009.3> [2016, January 13].

Science Synthesis and Delivery



Fryer, Janet L. 2014. *Alnus rhombi folia*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/plants/tree/alnrho/all.html> [2016, January 13].

Fryer, Janet L. 2015. (Revised from Reeves, Sonja L. 2006.) *Chlorogalum pomeridianum*, wavy leaf soap plant. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/plants/forb/chlpom/all.html> [2016, January 13].

Fryer, Janet L. 2015. Fire regimes of montane riparian communities in California and southwestern Oregon. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/fire_regimes/CA_montane_riparian/all.html [2016, January 13].

Fryer, Janet L. 2015. Fire regimes of woody riparian communities of the Central Valley, California. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/fire_regimes/CA_valley_riparian/all.html [2016, January 13].



Top photo: Moose peers through the vegetation in the Pioneer Mountains, MT. Photo by LaWen Hollingsworth / FFS.

Bottom photo: State of Alaska Forestry, McGrath Initial Attack Base Flight Deck on July 3, 2015 at 2348hrs. Photo by Charles McHugh / FFS.



- Fryer, Janet L.. 2015. *Salix lasiandra*, Pacific willow. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/plants/tree/sallas/all.html> [2016, January 13].
- Heinsch, Faith Ann; Innes, Robin J.; Hardy, Colin C.; Lee, Kristine M., eds. 2015. Fire, Fuel, and Smoke Science Program: 2014 Research accomplishments. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). 77 p. Available online: <http://www.firelab.org/document/ffs-annual-reports> [2016, January 13]
- Innes, Robin J. 2015. Fire regimes of Alaskan wet and mesic herbaceous systems. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/fire_regimes/AK_wet_herbaceous/all.html.
- Smith, Diane M. 2015. Sustainability and the origins of wildland fire research. In: Arcadia Environment and Society Portal, [Online]. Rachel Carson Center for Environment and Society (Producer). Available: <http://www.environmentandsociety.org/arcadia/sustainability-and-origins-wildland-fire-research> [2016, January 13].
- Zouhar, Kris. 2015. *Polystichum munitum*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/plants/fern/polmun/all.html> [January 13].

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