United States Department of Agriculture

FIRE, FUEL, AND SMOKE SCIENCE PROGRAM
2014 RESEARCH ACCOMPLISHMENTS
Missoula Fire Sciences Laboratory
Rocky Mountain Research Station

Faith Ann Heinsch,
Robin J. Innes,
Colin C. Hardy, and
Kristine M. Lee,
Editors

Forest Service

Rocky Mountain Research Station

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Missoula Fire Sciences Laboratory
Rocky Mountain Research Station
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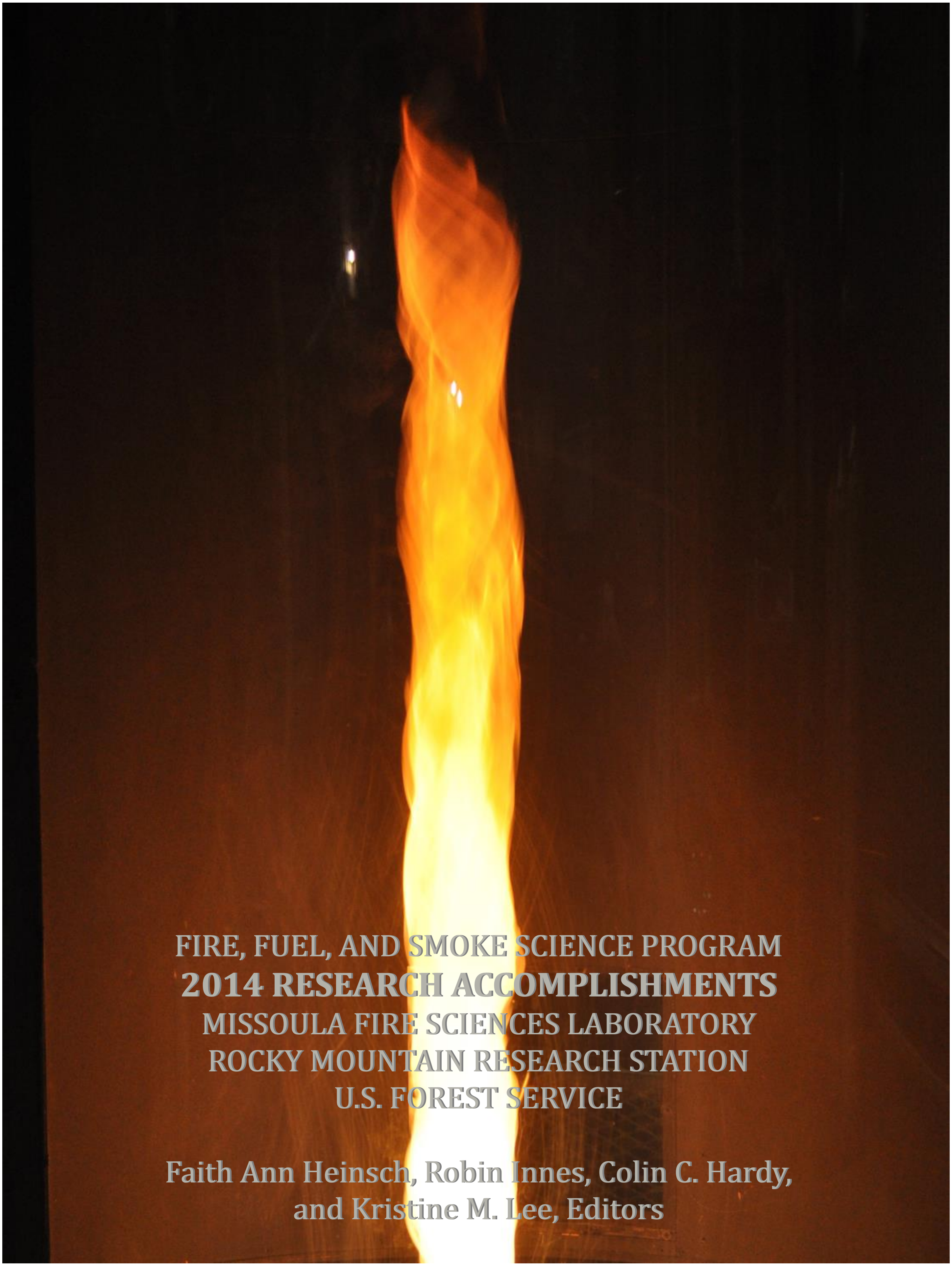
Cover photos, clockwise from top: Schoolhouse Fire. Photo by Duncan Lutes / FFS; Researchers discuss fire scars on a stump in eastern Oregon. Photo by Daniel G. Gavin / University of Oregon. Litter traps are used to collect dead foliage for monitoring fuel. Photo by Bob Keane / FFS. Experimental outdoor crib burn. Photo by Kristine Lee / FFS. Photo on opposite page: Flame structure of a fire whirl. Photo courtesy of Kristine Lee / FFS.



FIRE, FUEL, AND SMOKE SCIENCE PROGRAM
2014 RESEARCH ACCOMPLISHMENTS

MISSOULA FIRE SCIENCES LABORATORY
ROCKY MOUNTAIN RESEARCH STATION
U.S. FOREST SERVICE

Faith Ann Heinsch, Robin Innes, Colin C. Hardy,
and Kristine M. Lee, Editors

Table of Contents

All images and photographs are from the U.S. Forest Service unless otherwise credited.

Photo: Snags and natural regeneration (ponderosa pine and western larch) at the Snowbowl old-growth restoration site, Montana. Picture taken approximately 15 years after timber harvest and prescribed burning. Photo by Helen Smith / 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 designed to improve understanding of wildland fire as well as safe and effective fire, fuel, and smoke management. The research is divided among six general focus areas of study, described on the next page.

Photo: Lighting a prescribed fire as part of RxCADRE, Eglin Air Force Base, Florida. Photo by Dan Jimenez / FFS.

The Fire, Fuel, and Smoke Science Program

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.

Top left photo: Wooden cribs are burned to improve understanding of fundamental fire behavior (burning rate and resident time). Photo by Sara McAllister / FFS. Bottom left photo: Douglas fir cone. Photo by Mary Ellen (Mel) Harte / Bugwood.org. Right photo: Smoke rises from the Rising Eagle Fire near the Carlton Complex, Twisp, Washington. Photo by Faith Ann Heinsch / FFS.

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 www.firelab.org, where information about FFS publications and products is available. The Program's Fire Modeling Institute (FMI, page 67) is an essential component of this focus area.

Top left photo: Prescribed fire, Missoula, Montana. Photo by Karin Riley / University of Montana. Bottom left photo: Snow covers whitebark pine. Photo by Bob Keane / FFS. Right photo: American marten, described in the Fire Effects Information System (FEIS). Photo courtesy of Erwin and Peggy Bauer.

2014 Year in Review: Expanding Our Understanding of Fire

We are celebrating 2014 as another year of tremendous productivity, new innovative science, and highly relevant support to the global fire management community. The mission of our Fire, Fuel, and Smoke Science Program (FFS) is to improve the safety and effectiveness of fire management through the creation and dissemination of basic fire science knowledge. Our core scientific functions and accomplishments are led by individuals assigned to positions classified by the U.S. Office of Personnel Management (OPM) as "scientists." Research executed by scientists is defined by OPM as "systematic, critical, intensive investigation directed toward discovering, disseminating, and applying new or expanded knowledge in a professional discipline." Within FFS, we strive to provide an overall portfolio of Research and Development (R&D) that sets local, national, and international standards of excellence.

To accomplish our work, the Program's 11 scientists organize teams from among our 6 post-doctoral scientists, 20 professionals, 8 term-appointed personnel, as many as 10 temporary employees, numerous resident contractors and cooperators, and scores of external partners and institutions. The program is loosely organized into eight teams, five of which are focused on specific research focus topics. The remaining three teams provide administrative, logistical and technology transfer support. These teams take innovative approaches to discover new information and refine our understanding of the role, behavior, and effects of wildland fire. We are proud to present what these teams have accomplished during 2014.

Program Area Knowledge, Discovery, Development, and Delivery

The FFS scientists and staff pursue research in their specialties through collaborative research within the program and around the world. Within FFS, there are six program areas, outlined on pages 2-3. Research on **Physical Fire Processes** in 2014 ranged from ignition of a single needle or leaf to fuel beds in the wind tunnel, and from small test fuel beds to research burns in the field. Our **Fuel Dynamics** R&D examines how fuel accumulates and decays, how it varies spatially, how to characterize and map fuel, and how fuels respond to disturbance. Research on smoke impacts performed by our **Smoke Emissions and Dispersion** team is international in scope, and our scientists examine these impacts both through fundamental research and by improving models of smoke emissions. This year's accomplishments included estimating smoke dispersion in northern Eurasia and refining models of emission and dispersion. In 2014, our **Fire Ecology** research was focused "closer to home," with work on whitebark pine in the northern Rocky Mountains and western spruce budworm in the interior Pacific Northwest. **Fire and Fuel Management Strategies** were examined across the United States, including fuel monitoring after disturbance in the Northwest to determine fire effects on cultural artifacts of the American Southwest, estimating soil heating effects of oil spills in areas along the Gulf Coast, and improving tools and guidelines for safely managing wildland fire. Globally, our research provides insight into changes in fire danger and improved methods for estimating fire behavior. Finally, our **Science Synthesis and Delivery** spans the world, with websites and educational opportunities based on ecosystems of the northern Rocky Mountains, assistance with fuel treatment planning in the Southwest, documentation of U.S. Forest Service fire research history, support of the U.S. National Fire Danger Rating System, syntheses of information on fire effects, support of fire regime assessments in Zambia, and publications that reach international audiences.

Support of Research at the Station Level

The Rocky Mountain Station is an internationally recognized leader in natural resources research. It is only through the efforts of research teams led by world-renowned scientists such as those 11 in the Fire, Fuel, and Smoke Science Program that this recognition has occurred. Research in the Station has been organized into seven Strategic Research Priorities: Disturbance Ecology, Fire Science, Human-Landscape Interactions, Inventory & Monitoring, Resilient Landscapes, Species Endangerment, and Water & Watersheds. As our program title suggests, we are not just fire research. Rather, projects within FFS are interdisciplinary, directly addressing Fire Science, Disturbance Ecology, Managing Resilient Landscapes, and Human-Landscape Interactions priorities, but also indirectly aligning with the remaining three Strategic Research Priorities. In large part it is through the scientific and administrative direction and management provided by the Station that the Fire, Fuel, and Smoke Science Program is successful.

National Research, Development, and Policy

While scientists and their teams work within the framework of the FFS charter and the RMRS Strategic Research Priorities, they also focus on research needs that influence national research, development, and policy. Our Program's six Focus Areas were developed in the context of the Agency's strategic plan for fire and fuels research and development which guides all fire and fuels research in Forest Service R&D. Wildland fire issues are increasing across the United States, and research we do at the Missoula Fire Sciences Laboratory and in the field is helping to answer large-scale questions.

Safety zones are constructed on fires to provide for firefighter safety. Analysis of past entrapments has led to better understanding of the fire behavior that endangers firefighters. Current guidelines for safety zone construction are based on radiant heating, flat ground, and no wind. However, these conditions are not commonly found on large, intense fires. New research, led by Research Mechanical Engineer Bret Butler, has resulted in a better understanding of conditions important for safety zone size, including the need to consider convective heat, slope, and wind. This research is providing guidance to firefighters regarding what attributes constitute an adequate safety zone, while also suggesting that alternative fire management strategies may be needed if unrealistically large safety zones are required. The results from this work are being used by fire management organizations throughout the world.

The Wildland Fire Investment Planning System (WFIPS) is a system designed to inform national interagency wildland fire planning efforts and budgeting. This next-generation system will replace the Fire Program Analysis System (FPA), providing the best available science. Scientists at FFS, led by Research Forester Mark Finney, are collaborating with others in RMRS and across the country to improve the fire behavior models underpinning the system, including improving both the initial response simulator for determining dispatch requirements and the large fire module, which combines historical wildland fire occurrence and weather data to project how future fire seasons could affect workload and cost.

Research Ecologist Bob Keane has written the first comprehensive book about wildland fuels in their ecological context. Wildland fuels are important inputs for predicting fire behavior, and they are the

Photo: Colin Hardy is the Program Manager for FFS. Photo by Kristine Lee / FFS.

only input that can be actively managed. Fuel treatments are being performed to reduce fire spread and intensity in complex areas, such as the wildland urban interface. Fuel management requires an understanding of fire ecology and what happens to ecosystems "before, during, and after fuels burn." Information from this book – ranging from a fundamental description of fuels to classification and sampling methods – is transforming our understanding of fuel, allowing managers to better understand how fuel affects fire behavior and fire effects modeling as well as to better manage fuels on the landscape.

Our understanding of the fundamentals of fire spread continues to improve through the efforts of Mark Finney, Research Physical Scientist Jack Cohen, and Research Mechanical Engineer Sara McAllister. They have developed a program of research to understand how fire spread occurs with a focus on live fuels and active crown fire. Experiments from ignition of fuel particles to convective heat transfer and burning duration are leading to new insights into fundamental fire behavior. This year, they met with colleagues from the University of California, San Diego; the University of Kentucky; and the University of Maryland to discuss the latest findings on fire behavior fundamentals, research needs and future directions.

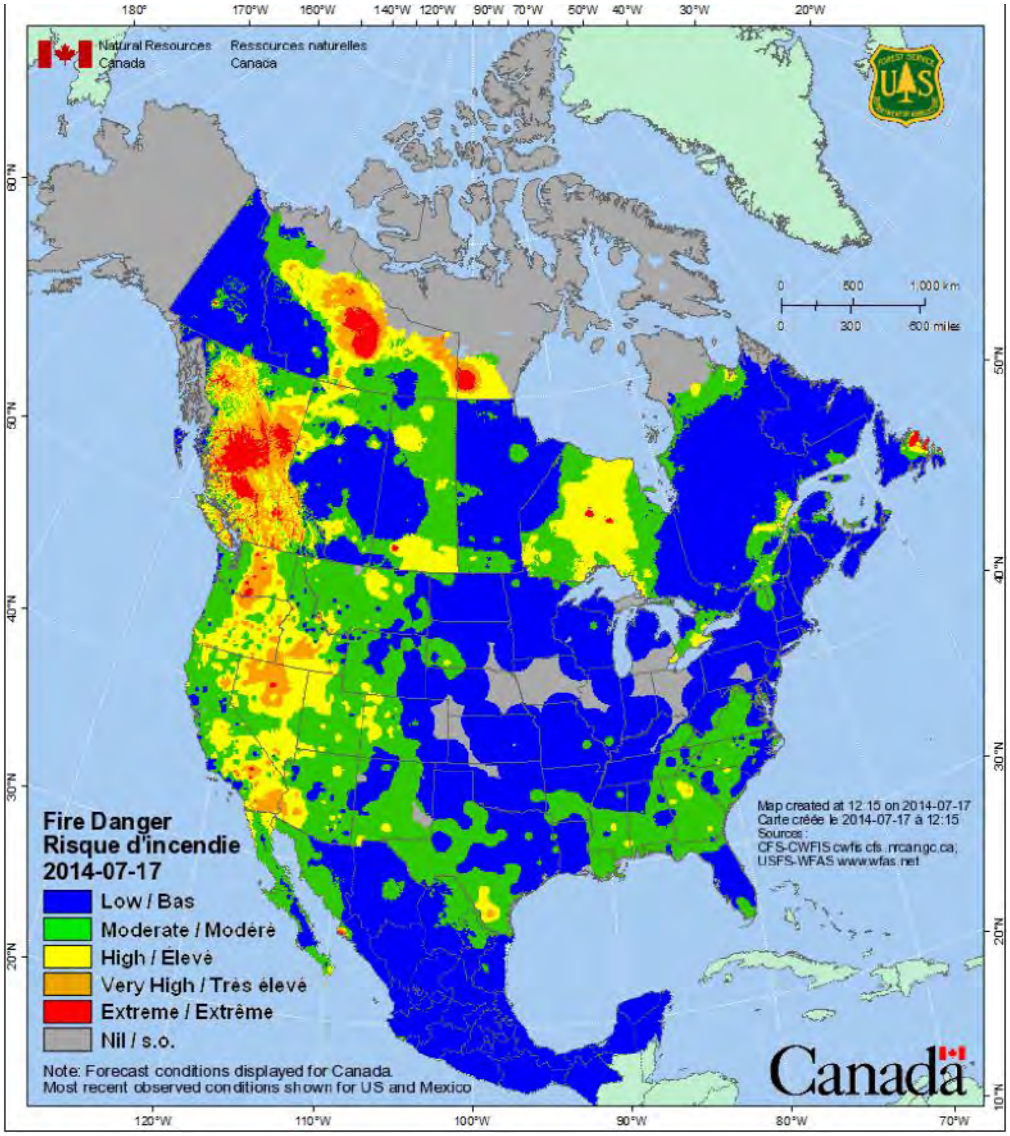
The team led by Bret Butler continues to improve methods for directly measuring energy release, temperatures, and air flow prescribed and natural fires. The data collected from this effort is informing our understanding of the role of radiant and convective energy transport in fire behavior. This cross-disciplinary and collaborative approach will provide information to improve our understanding of fire behavior, which should improve our ability to predict fire spread in the future.

International Collaboration

FFS enjoys a strong international reputation, with active collaborations in, or with, more than 20 countries. Recently, our scientists have participated in invited study tours and invitations to conferences in New Zealand, Portugal, and Greece, where researchers shared ideas and research results, and collaborated with colleagues from around the globe. Our scientists and professionals are invited to participate in activities of the U.S. Forest Service International Programs Office, with Fire Behavior Analyst LaWen Hollingsworth traveling to Zambia and Fire Spatial Analyst Chuck McHugh participating in research in the Bhutan.

International collaboration between Research Chemist Wei Min Hao and

Photo: The view from Snowbowl on the Lolo National Forest. Photo by Helen Smith / FFS.



colleagues at the French Nuclear Energy Commission are investigating the impacts of climate change on current and future fire regimes and air quality in northern Eurasia. The staff interacts regularly with international scientists and students regarding the fire behavior and fire danger systems managed by FFS, including offering workshops, personal assistance, and information.

Our scientists and professionals are regularly invited to participate in international education with Mark Finney, Bob Keane, and Mechanical Engineer Jason Forthofer traveling to Sardinia to teach courses in fire behavior at the University of Sassari.

Our Fire Danger Team was asked by representatives from fire management in Canada and the U.S. to develop a standardized delivery format for fire danger for both countries. Meteorologist Larry Bradshaw and Research Ecologist Matt Jolly worked with their Canadian colleagues to combine daily fire danger maps across the continental United States that are produced through the Wildland Fire Assessment System (WFAS) website with similar maps produced by Natural Resources Canada by the Canadian Wildfire Information System (CFWFIS). As a result, Jolly and Bradshaw produced the first daily maps of adjective fire danger rating across North America.

The WindNinja surface wind model developed under the direction of Research Mechanical Engineer Bret Butler is being used in Canada, Australia, Greece, France, Portugal and other countries. Applications for its use include simulation of insect pheromone dispersion and smoke dispersion. WindNinja is also used in wildland fire growth simulations.

Image: A map of fire danger for the U.S. and Canada on July 17, 2014. On this day fires ignited that ultimately became the Carlton Complex in central Washington. This map is the first of its kind.

Looking Ahead

Researchers in the RMRS Fire, Fuel, and Smoke Science Program will continue to pursue novel approaches in research to develop the fundamental knowledge and tools managers and others around the world need to address modern challenges and maintain healthy, resilient ecosystems. Specifically, FFS scientists are paving the way for a more complete understanding of how the physical, chemical, thermal and combustion characteristics of live and dead fuel vary across space and time. This new knowledge will aid fire managers in planning for prescribed fires and responding to wildland fires. Resurging interest and commitment to laboratory experiments in fire fundamentals are yielding promising results. If successful, these experiments will provide a sound physical basis for understanding and predicting fire behavior and the effectiveness of fuel treatments, dramatically changing our ability to model and manage fire-adapted ecosystems. Ongoing efforts to characterize energy release in “real” prescribed or naturally ignited fires are providing a basis for development of laboratory needs and computer based “virtual” experiments. New descriptions of changes in surface and canopy fuels after major disturbance events, such as fire or mountain pine beetle or spruce budworm infestations, allow for better understanding of the dynamic changes that occur on the landscape. At the same time, we are developing techniques to explore fire, fuel, wind, and vegetation dynamics under a changing climate and at multiple spatial and temporal scales. The Fire, Fuel, and Smoke Science Program is uniquely suited to study these issues through the combination of our unique facilities and our research teams.

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

Photo: A tree nursery at the Sinda National Forest Headquarters, Sinda District, Zambia (page 54). Photo by LaWen Hollingsworth / FFS.

Photo: Upper Sun Creek, part of the Tenderfoot Experimental Forest managed by scientists and staff of FFS. Photo courtesy of Lance Glasgow / FFS.

Partnerships

Fire, Fuel, and Smoke 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 included in this report include collaborations with other federal agencies, tribes, state and local governments, universities, and nongovernmental organizations. In 2014, FFS investigators collaborated with diverse teams of researchers at a number of universities around the country as well as with other federal agencies including the Bureau of Land Management, Bureau of Indian Affairs, National Park Service, 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, and fire ecology. For example, as members of the National Fire Decision Support Center (NFDSC), FFS researchers worked to better understand the fundamental physics of fire, while FFS researchers and other members of the Northern Rockies Fire Science Network (NRFSN) are working together to synthesize and disseminate science to managers and scientists across the northern Rocky Mountains. Partnerships such as these combine each member's strengths to produce more effective and far-reaching research and to develop and deliver new tools and scientific understanding. Developing partnerships and creating cross-disciplinary research teams are critical in addressing the growing number of increasingly complex questions related to wildland fire.

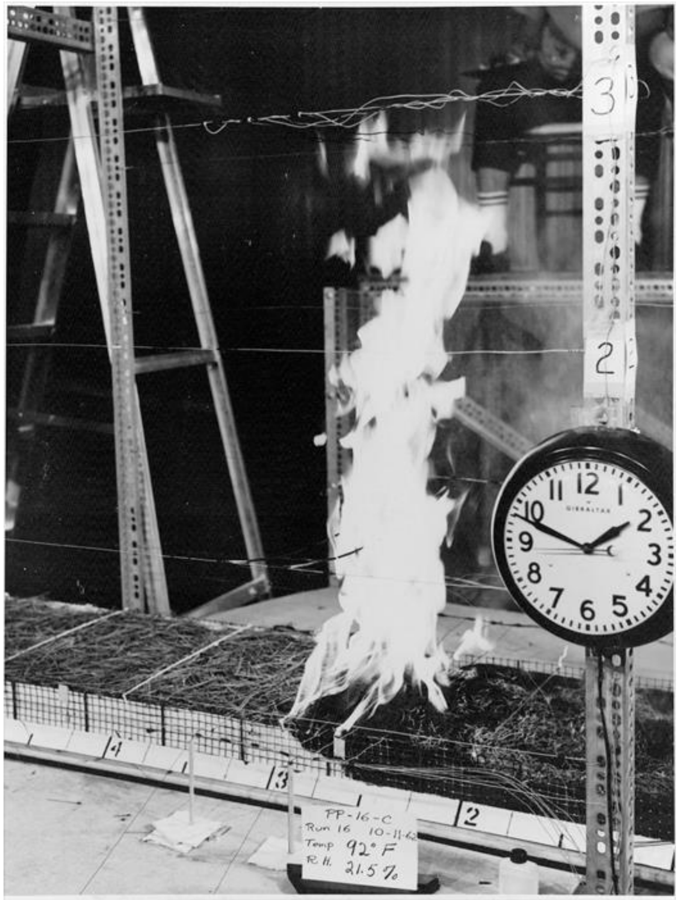
Internationally, FFS researchers have developed partnerships with colleagues from nearly every continent, including North America, South America, Africa, Europe, Asia, and Australia. International partnerships take advantage of FFS researchers' scientific expertise, technological capability, and on-the-ground experience in fire ecology, fire climatology, and fire management. Projects underway or completed in 2014 include an analysis of the impact of forest, shrub, and grassland fires in northern Eurasia on regional and global climate and air quality in northern Eurasia; an evaluation of the effects of climate change on fire danger around the world; and a fire regime assessment in southeastern Zambia. Engagement with the international community is essential for leveraging resources, sharing techniques, and learning innovative practices.

Photo: FFS researchers are partnering with professors from the University of Idaho and other RMRS scientists to study the effects of mastication on fire behavior through time. This masticated fuel bed is located in Los Griegos, New Mexico. Photo by Pam Sikkink / RMRS.

From the Archives: 50 Years Ago: Fire Physics Research

The Missoula Fire Sciences Laboratory (then known as the Northern Forest Fire Laboratory) was established in late 1960. The following year, a new group of scientists, engineers, and skilled technicians joined foresters and researchers in Missoula. All had an interest in fire-related research. It wasn't long before this multi-disciplinary team had several projects well underway. Indeed, by 1964, physicist Hal Anderson and aeronautical research engineer Richard Rothermel were already presenting their research on fire physics to national and international audiences.

In the early 1960s, understanding fire spread was considered nationally important to develop methods and systems for controlling wildland fires. Yet, as Anderson noted in an early report on the research, land managers and researchers alike had little understanding of how complex variables, from weather to vegetation to terrain, affected how fires behaved. The new Fire Lab fuels lab, wind tunnels, and burn chamber allowed researchers to control both the characteristics of the fuel and the weather environment so that researchers could test how fires burn under varying conditions. But first, the researchers had to learn how to use the facility.



The research team conducted 21 preliminary fires to determine the effects of fuel bed width and depth, and tested various measurement techniques and instrumentation. Once they were satisfied that the equipment and techniques were producing consistent results, they burned a series of 32 experimental fires with two types of fuels (ponderosa pine and western white pine needles) under different combinations of fuel moisture, air temperature, relative humidity, and wind.

In August 1964, Anderson and Rothermel presented their research at the Tenth International Combustion Symposium in Cambridge, England. Although the two researchers would continue investigating fire physics and fire behavior into the 1980s, this first round of results would contribute directly to the development of some of the earliest surface rate of spread models developed by the Fire Lab. Just as significant, these early experiments developed techniques for creating fuel beds that could be burned in a variety of

Top photo: Physicist Hal Anderson (standing) and technician Erwin Breuer review data collected from a test fire conducted in 1962. Photo by William Beaufait / U.S. Forest Service. Bottom photo: In this test fire from 1962, wires are connected to thermocouples that record fire activity. Researchers tested fuel bed depth, width, and loading to determine the most suitable size to achieve reproducible results. Photo by Herman Wittman / U.S. Forest Service.

conditions, which were used to test and calibrate the new Fire Lab equipment and facilities. Their innovative research and facilities development paved the way for the fire physics and fire behavior experiments that continue to this day.

For more information, see:

Anderson, Hal E. 1964. Mechanisms of fire spread: Research progress report no. 1. Res. Pap. INT-8. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20 p. On file with: Fire, Fuel, and Smoke Science Program, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Rothermel, Richard C.; Anderson, Hal E. 1966. Fire spread characteristics determined in the laboratory. Res. Pap. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 34 p. http://www.treesearch.fs.fed.us/pubs/42419

For more information, contact: Diane Smith at dianemsmith@fs.fed.us

Top photo: Richard Rothermel photographs residue after a test fire in a model fuel bed in 1962. Photo by Herman Wittman / U.S. Forest Service.
Bottom photo: Hal Anderson, with Richard Rothermel (sitting), explains the Fire Physics program to members of the National Academy of Sciences Committee on Fire Research and other visitors to the Fire Lab in 1963. Photo by Herman Wittman / U.S. Forest Service.

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 2014 occurred in all three settings. In the laboratory, FFS researchers investigated convective and radiant heat transfer from fire using equipment designed at the Missoula Fire Sciences Laboratory. They burned wood particles, wood cribs, live fuels, and high-cellulose cardboard fuel beds to isolate and measure the mechanisms of heat transfer. These experiments were done in the burn chamber and in the wind tunnel to isolate factors involved in how fuels ignite and fire spreads. A unique experiment was conducted at a nearby shooting range to determine if exploding targets, detonated with bullets fired from commonly available modern rifles, could ignite wildland vegetation. Preliminary results indicate it is possible. Wind is a key component of fire spread, and experiments were performed to improve predictions. Finally, research burns in Texas provided data to validate the Wildland-Urban Interface Fire Dynamics Simulator.

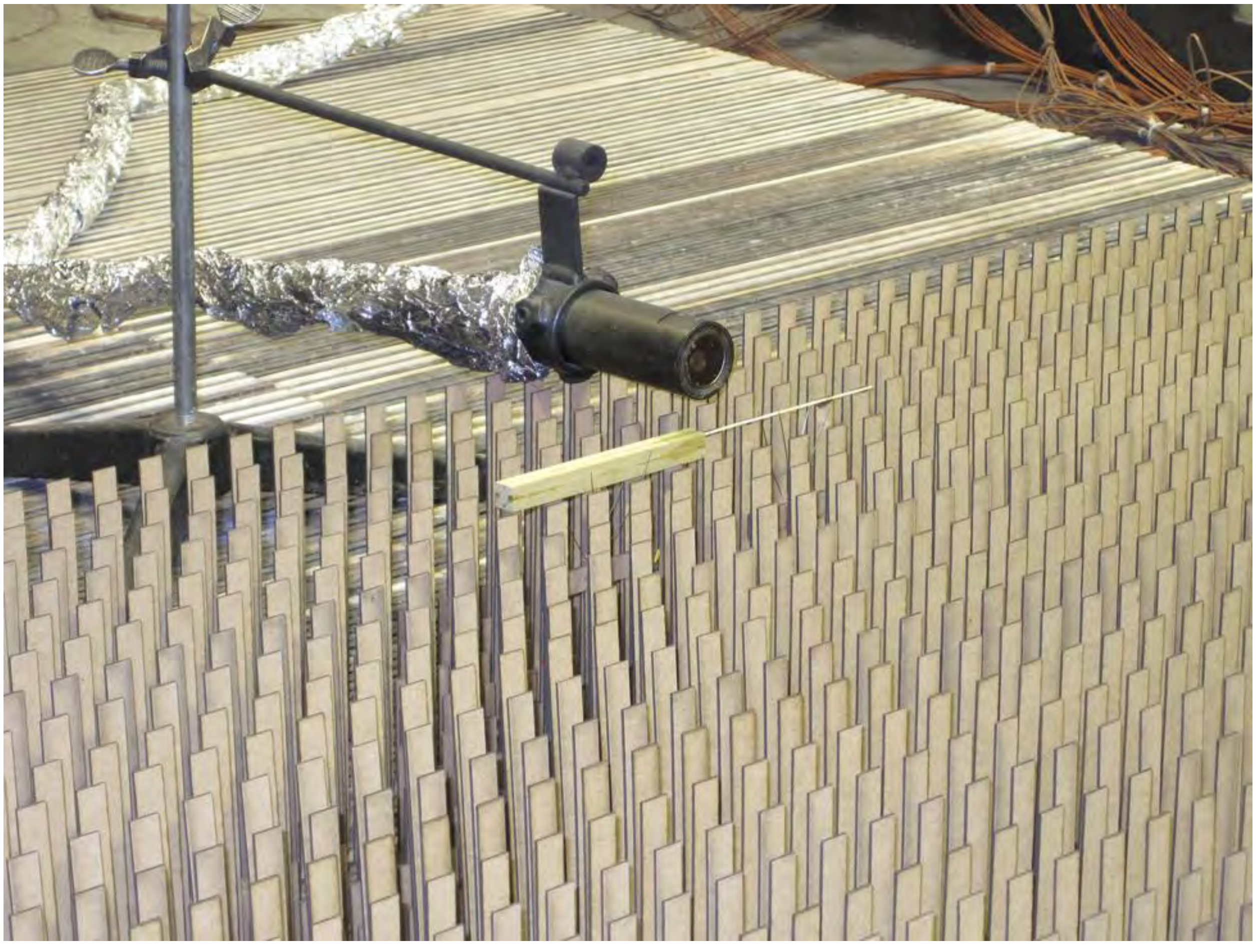


Photo: An instrumented fuel bed composed of laser-cut cardboard. These uniform fuel beds are burned in the wind tunnel to determine rate of spread and other physical characteristics of fire. Photo courtesy of Jack Cohen / FFS.

Understanding Burning Rate and Residence Time 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 surface fires demonstrate spread thresholds, this is of particular concern when discussing the thresholds for crown fire spread, a currently poorly understood aspect of wildland fire. Curiously, no single theory exists for the prediction of flame residence time. 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 studied 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 would apply to the wildland fire context.

Burning rates of cribs with a wide variety of layouts and geometries were explored to determine whether results from structural fire hold in the wildland context. Comparisons included the effect of stick dimension (length and width) ratios and the effect of spacing distance between the crib and the support platform. Cribs tested with geometries similar to those tested in literature matched predicted values well. However, the burning rate of cribs built with sticks of large length-to-thickness ratios (such as long, thin sticks) was considerably lower than predicted, indicating that there is insufficient airflow inside the crib not predicted by current models. The effect of spacing distance between the crib and the support platform was strongly dependent on the stick length-to-thickness ratio, with no difference seen for cubic cribs and a >60% change for cribs with large stick length-to-thickness ratios.

Experiments indicated that cribs with large length-to-thickness ratios required a substantial amount of airflow through the bottom of the crib. As the crib-platform spacing increased, however, the burning rate of the large length-to-thickness ratio cribs increased to more closely match the predicted values. Understanding these effects will be vital when applying crib theory to wildland fires. For example, the effect of crib spacing above the platform will be important when considering ground fuels versus crown fuels. The effect of the length-to-thickness ratio will be important when considering different fuel types (needle litter versus slash fuels).

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

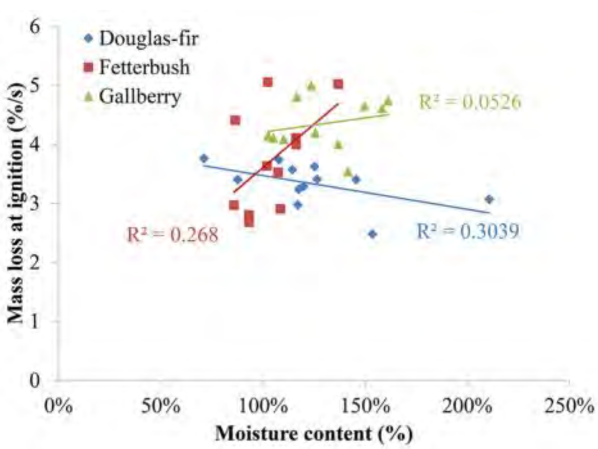
Photo: Change in burning regime for a large length-to-thickness ratio crib as the crib-platform spacing increases. Clockwise from top left: no spacing; 1.27 cm (0.5 in) spacing; 7.62 cm (3 in) spacing; and 2.54 cm (1 in) spacing. Photos by Sara McAllister / FFS.

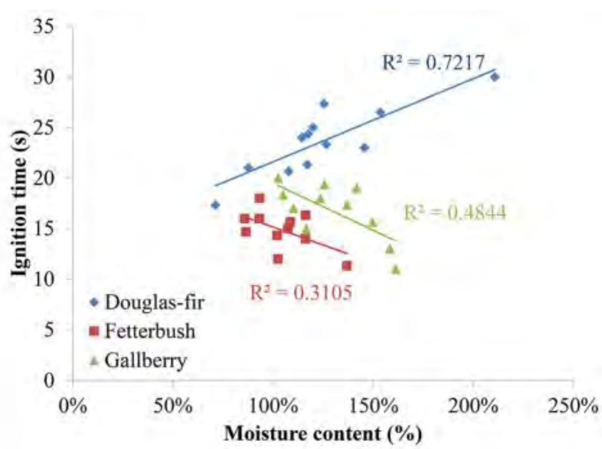
Effect of Season on Ignition of Live Fuels

Fire spread in live fuels has long presented conundrums for managers and defied explanation by researchers. Wildland fires in dead fuels will not spread above some threshold of fuel moisture content, typically assumed to be between 10% and 40%. However, in crown fires, live fuels with moisture contents well above 70% are what carry fire. Unlike dead fuels, live foliage contains as much as half non-structural carbohydrates such as sugars and starches. Its chemical composition changes throughout the growing season. Although easily measured, the apparent moisture content of the fuel can change solely due to changes in dry weight while the relative amount of water stays constant. Clearly there is a complicated, and as yet unknown, relationship between chemical composition and moisture content that has a significant effect on the ignition of live fuels. By better understanding seasonal changes in ignition trends and their causes, resource managers will be better able to predict when crown fire will occur and model its spread.

FFS researchers with collaborators from the Fire and Fuels Program at the Pacific Southwest Research Center, Brigham Young University, and the University of Alabama, Huntsville performed a two-year study of the seasonal changes in the ignition behavior of ten shrub and tree species from southern California, Utah, western Montana, and Florida. Samples were tested monthly to examine the effect of growing season and dormancy on the ignition time and mass lost at ignition. The fuel moisture content was also measured. Large species-to-species variation was seen in the correlations between 1) moisture content and ignition time, 2) moisture content and mass loss rate at ignition, and 3) ignition time and mass loss rate at ignition. Only a few species showed similar behavior to wet wood and other dead fuels. Due to the potential physical and chemical changes that live fuels undergo during the growing season, moisture content is not a particularly useful descriptor of live fuels when discussing ignition behavior.

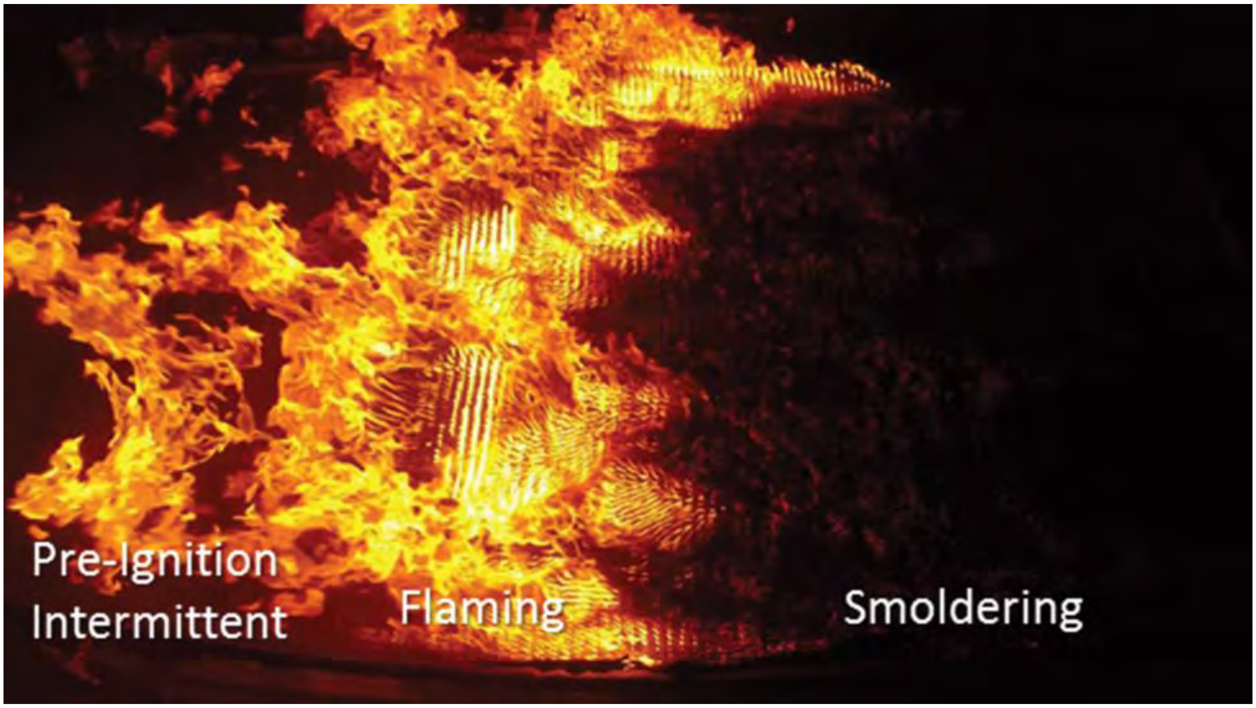
For more information, contact: Sara McAllister at smcallister@fs.fed.us





Top photo (from top to bottom): Douglas fir, fetterbush, and gallberry leaves were burned to examine effects of season on ignition. Photo by Sara McAllister / FFS. Bottom image: On the left, mass loss rate is compared with moisture content. On the right, the effect of moisture content on ignition time is examined. Results show no consistent relationship among species.

Flame Structure in Spreading Laboratory Fires



Experimental evidence now shows that flame impingement is required for ignition of fine fuel particles responsible for the spread of wildland fires. However, the characteristics of the non-steady flame zone that produce convective heating of fuel particles has not been studied. It is not known how to describe, qualitatively or mathematically, the flame dynamics that allow forward spread of wildland fires.

Flame structure studies were conducted and particle heating signals were evaluated by FFS Research Forester Mark Finney and collaborators from the University of Maryland, University of Kentucky, and Los Alamos National Laboratory in laboratory fires spreading through laser-cut cardboard fuel beds and in stationary flames from gas-fed burners. High-speed video and infrared imagery were used to capture flame dynamics to compare with thermocouple measurements.

Flame structure and dynamics were found to be remarkably similar to heated boundary layers that are well known from fluid dynamics research. Flame fronts in stationary and spreading fires were seen to divide into "peak and trough" patterns produced by instabilities of air inflow to the flame zone produced by the upward buoyant force. These instabilities result in paired-streamwise vortices (Görtler vortices) that force flames down into the fuel bed at convergence zones. Secondary instabilities result in apparent forward pulsing that extends flames into the unburned fuels at frequencies that appear to scale inversely with flame length but proportionally to wind speed. Results indicated that buoyant dynamics of the flame zone appear to govern the time-varying heating of fuel particles and the distance ahead of the front that heating takes place.

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Photo: Side view of fire spreading from right to left through laser-cut cardboard fuel beds in the Missoula Fire Sciences Laboratory's wind tunnel. The image shows that smoldering, flaming, and intermittent heating during pre-ignition all occur simultaneously across a small area. The U-shaped depressions are related to the presence of vortices that force the fire downward into the fuel bed. Photo courtesy of Mark Finney / FFS.

Tests of Wildfire Ignition from Exploding Targets

The U.S. Forest Service has banned the use of exploding targets[1] on land managed in much of the western U.S. because of reported association with wildfire ignitions[2]. Exploding targets are composed of two ingredients: ammonium nitrate (AN) and aluminum powder (AL). When mixed, the AN oxidizer reacts with the AL fuel to detonate following a high velocity impact. The targets are intended to be detonated by rifle bullets. Numerous media reports and abundant online video suggest ignition from exploding targets is possible, but manufacturers maintain that exploding targets cannot start fires.

A project was begun to formally address two questions:

1) Can exploding targets be demonstrated to cause ignition, and then, if so,
2) What are the factors that contribute to the ignitions?

Tests conducted in 2014 involved shooting ten targets with various configurations of combustible material located adjacent to the target. Combustible material was enclosed in rectangular wooden cages wrapped in plastic deer fence. Straw bales were also used. Two cages were placed on either side of the target and the target was detonated by shooting it from 70 yards with a rifle bullet. High speed video captured the explosion and allowed qualitative analysis of factors related to ignitions.

Three of the ten tests were observed to produce rapid flaming ignition of the nearby fuel materials. The factor suspected to cause ignition was burning powdered aluminum ejected from the explosion, which could clearly be seen in the high speed video. Residual burning of aluminum was observed on the pedestal holding the target (see photo, bottom left). These results are preliminary but suggest the avenues of further study should involve effects of varying AN/AL mixtures and detonation as they relate to ignition.

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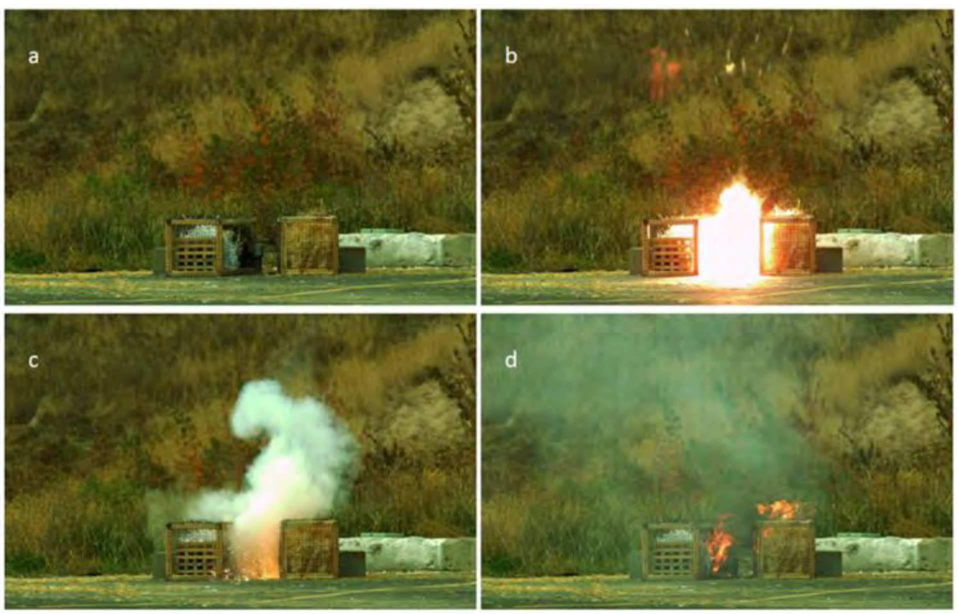

[1] http://www.fs.usda.gov/detail/r2/news-events/?cid=STELPRDB54357272
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http://www.fs.usda.gov/alerts/okawen/alerts-notices/?aid=22964
[2] http://wildfiretoday.com/tag/exploding-targets/

Photo: Image sequence taken with a high-speed video camera showing (a) setup, (b) detonation, (c) glowing material, and (d) ignition of fuel cages. Photo courtesy of Ian Grob / U.S. Forest Service.

Near-Surface Wind Measurements

Wind predictions in complex terrain are important for a number of applications including wildland fire behavior, transport and dispersion of pollutants, and wind energy applications. Fine-scale changes in topography and vegetation substantially alter the flow field. Thus, accurate modeling for these applications in complex topography requires near-surface flow field predictions at a high spatial resolution. Two high-resolution wind models with varying degrees of sophistication have been developed at the Missoula Fire Sciences Laboratory in response to these needs; however, evaluation and improvement of these models are limited by a lack of high-resolution datasets in complex terrain under various weather scenarios. In response to this need, FFS Research Mechanical Engineer Bret Butler, with collaborators from Washington State University and the U.S. Forest Service's Moscow Forestry Sciences Laboratory, collected several high-resolution surface wind datasets over a variety of terrain features and under a range of meteorological conditions. At Big Southern Butte, Idaho, investigators installed more than 50 weather towers that recorded 10-foot average wind speed, wind direction, and gusts, covering an area of approximately 30 square miles. In addition, they installed four Sonic Detection And Ranging instruments (SODARs), two radar wind profilers, approximately six sonic anemometers, and numerous balloon sondes. The datasets will be used to investigate terrain-induced effects on wind flows, such as mechanical channeling and thermally driven slope flows, as well as to develop and evaluate high-resolution numerical wind and weather prediction models in complex terrain. Preliminary exploration of the data revealed unique local-scale mechanically and thermally driven flow features that will be of interest in future model evaluations. Preliminary model evaluations indicate that wind predictions from routine weather forecasts can be improved in complex terrain by downscaling the data to a fine resolution with the WindNinja model.

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Photo: FFS Physical Scientist Cyle Wold downloads wind speed and direction data from an anemometer at an elevation of 9,500 feet in the Lemhi Range, Idaho. Photo courtesy of Bret Butler / FFS.

Vegetation Clearance Distance to Prevent Wildland Fire Damage to Power Transmission and Telecommunication Lines and Towers

Wildland fire management teams may be faced with the potential for fires to damage power transmission or telecommunication lines. Damage can be severe enough to cause failure of the system, which can then have critical implications for public safety. One method to minimize the potential for this damage is to clear vegetation away from lines, poles, and towers. In the past, clearing distance guidelines have been developed by asking, "What is required to prevent fires caused by electricity arcing from the line to the ground?" The question of what is required to minimize the risk of thermal damage to the transmission or telecom system from a nearby fire is different, and as yet unstudied. This study attempts to address that question.

This effort is being conducted jointly between the FFS and U.S. Forest Service Rocky Mountain Region (Region 2) and is funded by the U.S. Forest Service, Xcel Energy Corporation, and the Joint Fire Science Program. The primary objective is to define the vegetation clearing distances required to minimize thermal damage to lines, poles, and towers. The study employs three methods:

1) collection of anecdotal information about damage to power and telecommunication infrastructure;
2) computer simulations of thermal impact on support towers and poles, overhead conductors, and ground-based enclosure; and
3) correlation of data from simulations with literature and observations.

This study is based on measurements from a range of fires in different forest types, focusing on the highest intensity fires. Findings suggest that the vegetation clearance distances needed are nominally 4 times the vegetation height for wood structures (poles), 3-4 times the vegetation height for fiberglass poles, and 1-1.5 times the vegetation height for steel poles. Clearances for transmission lines are 0.5 to 2 times the vegetation height depending on the material. Distances for transformer and junction boxes should be roughly 2 times the vegetation height for grass and brush and nominally 1 vegetation height for forests. This study accounts for frontal flame spread in low wind and flat to moderate slopes. Laboratory experiments and actual fire events have shown that as slope increases above 30%, the fire intensity and rate of spread increase significantly. Thus, conditions where slopes are greater than 30% or winds are greater than 10 mi/h should be accompanied by a significant increase in clearing distance.

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Photo: A downed power transmission pole and line on the French Fire in California in 2014. Photo courtesy of Bret Butler / FFS.

Camp Swift Research Burns

On January 15, 2014, three experimental burns were conducted at Camp Swift Military Installation, approximately 15 km (9.3 miles) north of Bastrop, Texas. The FFS Fire Fundamentals Team, led by Research Mechanical Engineer Bret Butler and Mechanical Engineer Dan Jimenez, participated in the interagency research project with partners from the National Institute of Standards and Technology, U.S. Forest Service, Texas Forest Service, San Diego State University, Colorado State University, and the University of Washington.

The overall goal for the project is to evaluate the Wildland-Urban Interface Fire Dynamics Simulator (WFDS), a physics-based fire behavior model, using data collected in a full-scale prescribed fire setting. Researchers also collected information on fuel break effectiveness that can be used directly by first responders and homeowners.

These research burns were conducted in homogeneous grass fuel ecosystems located in central Texas. They were selected using fuel attributes, local weather, and plot layout. Multiple sampling methodologies and technologies were utilized during the research burns to collect fire behavior data regarding the fire front as well as flanking and backing fire spread. The Fire Fundamentals Team deployed a number of fire behavior packages, thermocouple rakes, and *in situ* camera boxes to collect flame geometry and fire information. Multiple meteorological wind sensors were deployed both at ground level and aloft. Unmanned aerial vehicles (UAVs), outfitted with electo-optical and modified infrared payloads, monitored fire behavior from a remote sensing platform. Data from the UAVs were processed with geo-rectification to coincide with the ground-based *in situ* measurements to be used in validating the WFDS program.

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Top photo: Fire burns through an area of energy sensors in grass near Bastrop, Texas (south of Houston). Photo by Bret Butler / FFS. Bottom left photo: FFS employees Mark Fosburg, Cyle Wold, and Emily Lincoln set up equipment for in situ monitoring of fire behavior. Photo by Dan Jimenez / FFS. Bottom right photo: A research burn spreads through the sensor area. Photo by Dan Jimenez / FFS.

Fuel Dynamics

Fuel is always changing, yet models of fire behavior, fire danger, and smoke emissions require an accurate description of that fuel. In 2014, FFS scientists conducted research to improve estimates of fuel loading, fuel moisture, fuel chemistry, and impacts of insect attacks on fuels. All experiments combined laboratory work with field work to better understand fuel dynamics. Scientists are studying methods of calculating fuel loading for use in physics-based fire behavior models. In the Great Lakes area, crown fire activity occurs most often in spring between snowmelt and green-up, when live fuels are changing most rapidly. FFS scientists examined the chemistry and moisture content of live fuels in Wisconsin to determine their effects on spring crown fire activity. Finally, researchers evaluated methods for determining fuel treatment effectiveness.

Photo: View from Carlton Ridge, Montana. Photo courtesy of U.S. Forest Service.

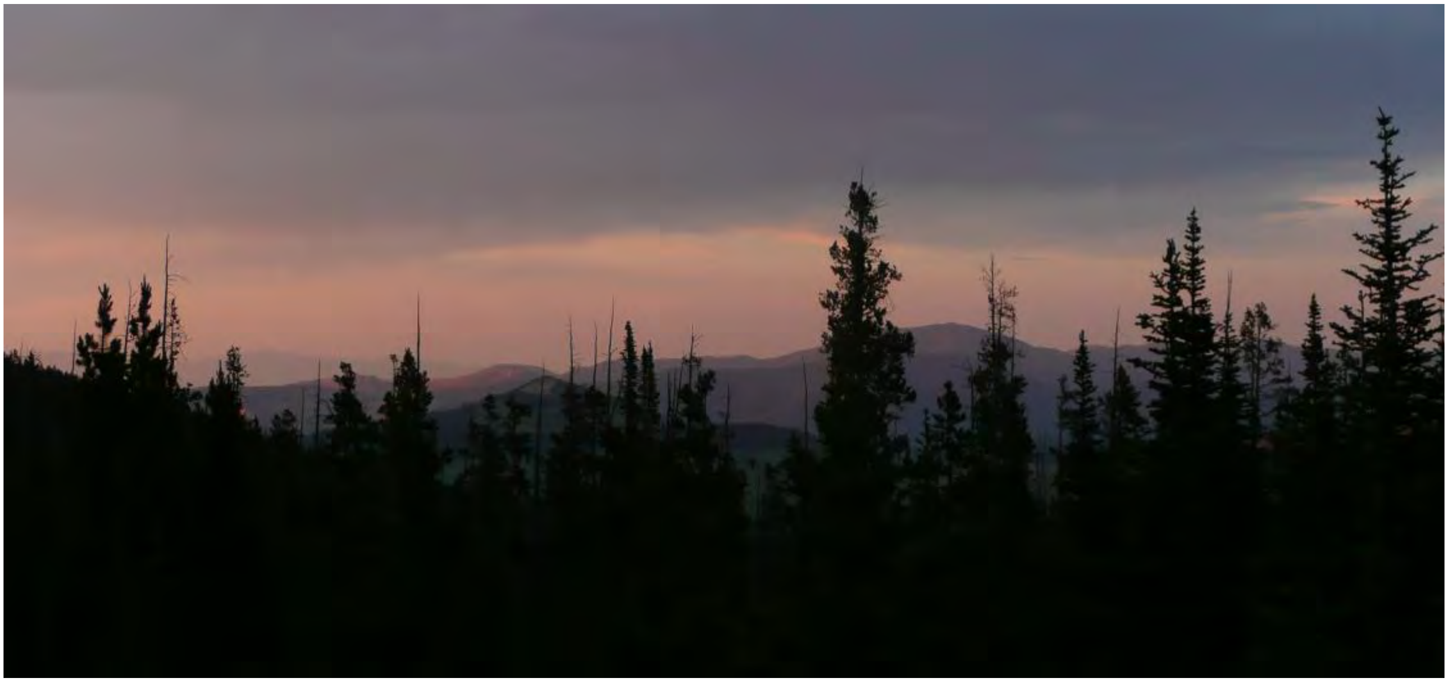
Describing and Scaling Physio-chemical Properties of Live and Dead Fuels to Parameterize Physics-based Fire Behavior Models

Considerable effort is expended to determine fuel loadings and to map those loadings across the landscape, yet there is little or no work being done to determine how to incorporate those measurements into the next generation of fire behavior models, such as physics-based models. Identifying critical spatial and temporal fuel characteristics required by these models may help to refine field sampling procedures and ensure a tight coupling between how fuels are measured and how those measurements are then used to assess potential fire behavior.

FFS Research Ecologist Matt Jolly, FFS Research Forester Russ Parsons and other FFS researchers at the Missoula Fire Sciences Laboratory are developing a three-part project that describes and scales the physio-chemical properties of live and dead fuels to parameterize physics-based behavior fire models. For the first part of this project, litter and foliage samples from a variety of grass, shrub, and tree species common throughout the Rocky Mountains will be analyzed to provide a full suite of seasonal physical and chemical fuel properties and determine their flammability. This research may help to explain linkages between physical and chemical fuel properties, as well as provide much needed input parameters to support the testing and application of physics-based fire models. The second part of this project will develop methods to integrate field-measured fuels data into physics-based fire models. This will entail developing methods for integrated heterogeneous fuel beds into physics-based models, such as FIRETEC and the Wildland-Urban Fire Dynamics Simulator (WFDS), with the ultimate goal of developing a standard set of surface fuel models that allows for the flexibility of integrating a range of field measurements. This will help bridge the gap between large-scale spatial fuel mapping projects such as LANDFIRE and these emerging physics-based fire models.

The final component of this project is to perform model simulations to evaluate the sensitivity of physics-based fire models to key physio-chemical inputs at scales from leaves to plots in an effort to determine important fuel characteristics and to refine field sampling protocols to accommodate

Photo: Complex vegetation in Cabin Gulch, Helena National Forest, Montana. Photo by LaWen Hollingsworth / FFS.



these models. Using laboratory burns, researchers will be able to determine how well physics-based models using these fuel characteristics are able to predict fire heat release.

In 2014, branch samples were collected for 11 different tree species found through the Rocky Mountains. Many physical and chemical characteristics, such as moisture content, density, heat content, surface-area-to-volume ratios, and flammability, were measured for each sample. More than 1,000 samples were measured during the field season. Preliminary results are consistent with previous studies that show that canopy fuel flammability is most heavily influenced by surface-area-to-volume ratios. However, there are significant species-level differences in the allocation of fine branchwood. These results challenge traditional assumptions used to calculate canopy fuel components such as canopy bulk density. Our results will improve both canopy bulk density calculations used to support operational fire behavior models and biomass allocations in fire models based on computational fluid dynamics. Future work will integrate these findings into WFDS to evaluate the impacts of species-specific physio-chemical differences on crown fuel flammability and crown fire spread.

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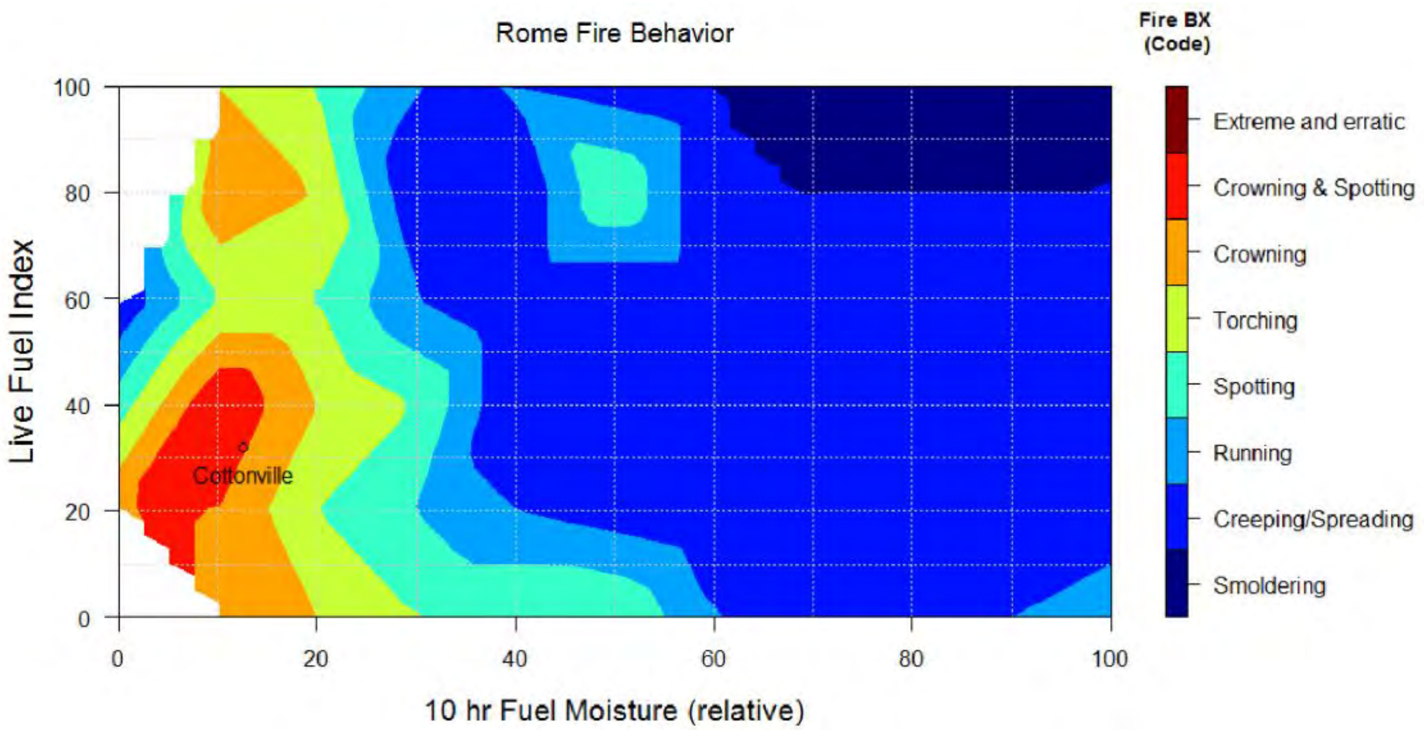
Photo: Sunset at the Tenderfoot Creek Experimental Forest, central Montana. The experimental forest is managed by FFS researchers. Photo courtesy of Lance Glasgow / FFS.

Physiological Drivers of the 'Spring Dip' in Red Pine and Jack Pine Foliar Moisture Content and Its Relationship to Crown Fire in the Great Lakes

Both firefighters and fire scientists have observed a period of peak crown fire activity in the Great Lakes area during spring when a dip in foliar moisture content occurs. For decades, the cause and timing of this 'dip' have been poorly understood. It is therefore important to understand the drivers of this dip in order to improve wildland firefighter preparedness and situational awareness during a period of dynamic fuel changes.

Working with local firefighters, FFS Research Ecologist Matt Jolly led a group of collaborators from the Wisconsin Department of Natural Resources, the Minnesota Department of Natural Resources, the Michigan Department of Natural Resources, the Huron-Manistee National Forest, the Eastern Area Fire Science Consortium, and the University of Wisconsin-Stevens Point, to develop a sampling scheme to determine the causes of spring moisture

Photo: Ground-level view of a typical red pine crown fire. Photo courtesy of Matt Jolly / FFS.



content changes and to determine their effect on flammability. Foliar samples were taken from red pine and jack pine at seven sites in three states throughout the 2014 growing season and needle moisture, chemistry, heat content, and flammability were determined in the laboratory. During that time, local firefighters documented fire behavior on wildland fires throughout the study area.

Results indicated that foliar chemistry, rather than absolute foliar water content itself, drove the apparent changes in measured live foliar moisture content. Results confirmed that the period of highest flammability occurred during the moisture content dip and was coincident with the timing of the most extreme fire behavior observed by local firefighters. Fire seasons in the Great Lakes occur shortly after snowmelt and the timing of both snowmelt and this needle moisture dip can vary by more than a month from year to year. These data are being used to develop tools that can assess crown fire potential in these dynamic forests based on live and dead fuel moisture conditions. Additionally, in collaboration with scientists from Los Alamos National Laboratories, our field sampling results were used to perform a series of numerical experiments using the fire behavior model FIRETEC, which is based on computational fluid dynamics. Changes in foliar density can lead to dramatic increases in the energy release and area burned by fires during the spring dip period. This information will help Great Lakes firefighters better prepare for and respond to wildland fires.

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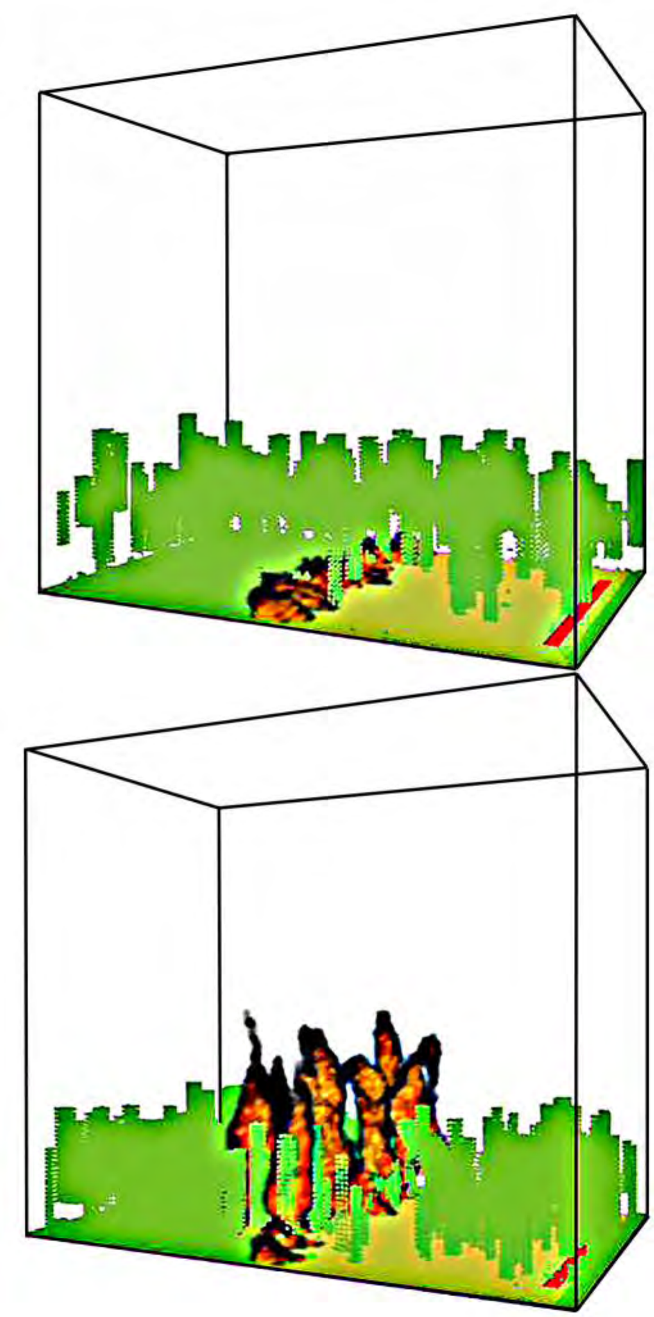
Image: Graph showing the likelihood of crown fire based on fine dead fuel moisture and phenological conditions estimated from the Live Fuel Index. The Cottonville Fire noted on the graph was the largest fire ever recorded in that part of Wisconsin.

Evaluating Fuel Treatment Effectiveness at Stand Scales Using STANDFIRE

Increasingly intense fire seasons, rapidly changing ecosystems, and an expanding wildland-urban interface all increase the hazard that fires pose to communities, watersheds, and ecosystems. Fuel treatments offer managers an opportunity to proactively mitigate threats to firefighters and communities as well as to maintain or restore healthy ecosystems, typically by altering forest canopies before a wildfire incident occurs. Unfortunately, fire that spreads through forest canopies is very complex, and many aspects of such fire behavior are still poorly understood. Therefore, it is difficult to identify the most hazardous stands, and managers cannot be certain that treating a stand will reduce fire hazard.



FFS Research Ecologists Russ Parsons and Matt Jolly, along with Rocky Mountain Research Station (RMRS) scientist Carolyn Sieg, FFS Forester Greg Cohn, RMRS Operations Research Analyst Nick Crookston, and Pacific Northwest Research Station Scientist William Mell, are partnering with researchers at Oregon State University, Colorado State University, Los Alamos National Lab, and the French National Institute of Agricultural Research in a project to explore what makes fuel treatments effective. The project, STANDFIRE, is a platform through which new fire science can be tested, assessed, and incorporated into fuel treatment analysis.

STANDFIRE has three goals:

1) to improve understanding of how fire spreads through forest canopies,
2) to think critically about how to measure the success of a fuel treatment, and
3) to develop and test new approaches for predicting the impact of a fuel treatment.

Most of the time, it is too difficult and dangerous to test how fires burn through forest canopies in real forests, so computer models play a key role in helping us understand this critically important phenomenon. In this project, researchers are working with new physics-based fire behavior models (HIGRAD-FIRETEC and WFDS), which allow them to simulate fire spreading through three dimensional forests to test how different aspects of fuel, such as spacing between trees, can change how fire spreads. They are experimenting with different ways of representing

Image: Example three-dimensional fire simulations for a forest stand, before (bottom) and after treatment (top), carried out with STANDFIRE, a platform for fire science development and analysis.

fuels, and examining the potential impact of other fuel properties, such as fuel chemistry, on fire behavior.

How do researchers and managers know if a treatment will be successful? The answer depends on many factors, but an important one is how to measure “success.” To learn more about how different people describe a successful fuel treatment, the researchers organized a workshop in 2014, gathering an international group of researchers and managers to develop clear, measurable, and adaptable benchmarks for fuel treatment success. The workshop revealed the importance of defining measures of success during the planning process and testing multiple potential treatments against those measures. With the ideas generated by this engaged group of researchers, analysts, and managers, scientists have begun to develop and test new stand-scale metrics that can be used by managers to both define fuel treatment goals and evaluate how well a fuel treatment has achieved those goals.

These researchers have taken the knowledge of fire behavior, fuel dynamics, and management needs gained in our research to develop a new software platform that can help predict fuel treatment impacts, through detailed simulations at the scale of individual forested stands. Physics-based fire behavior models have been paired with an existing nationwide forest harvest and growth model (the Forest Vegetation Simulator) to look at the impact of different fuel treatment methods and examine how that impact changes over time.

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Photo: Fuel treatment project in Douglas fir and lodgepole pine on the Helena National Forest, Montana. Photo by LaWen Hollingsworth / 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 2014, FFS researchers investigated 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 at FFS are also working internationally to determine the effect of climate change on air quality and fire regimes in northern Eurasia.

Photo: Smoke rises from the Lone Mountain 1 Fire, North Cascades National Park, Washington. Photo by LaWen Hollingsworth / FFS.

Development and Validation of Combustion Process-based Emission Models

Wildland fires emit a substantial amount of atmospheric pollutants including carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane organic compounds (NMOC), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and black carbon (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 NMOC leads to the formation of ozone (O_3) and secondary $PM_{2.5}$. Assessing the impacts of fires on regional and global environments requires 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 input 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 short-comings: 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 CO_2, CO, CH_4, 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 first phase of the project is now complete. It focused on a fuel bed composed of simple fuel particles – ponderosa pine needles. 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.

Researchers discovered that, as expected, the combustion efficiency of ponderosa pine litter decreases as the fuel bed bulk density increases. 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. They also didn't find a

Photo: In this experiment, ponderosa pine needles were used to examine assumptions of popular combustion models. Photo courtesy of U.S. Forest Service.

consistent relationship between the moisture content of the fuel and combustion efficiency.

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 result in relatively low emissions of CH_4, $PM_{2.5}$, and volatile organic compounds. Researchers discovered that the bulk density of litter fuels has a strong influence on the relative amounts of flaming, smoldering and combustion that occurs. This finding indicates that pollutants generated from fires in many northern Rocky Mountain conifer forests will be higher than that predicted using standard combustion models because combustion efficiency is lower than predicted.

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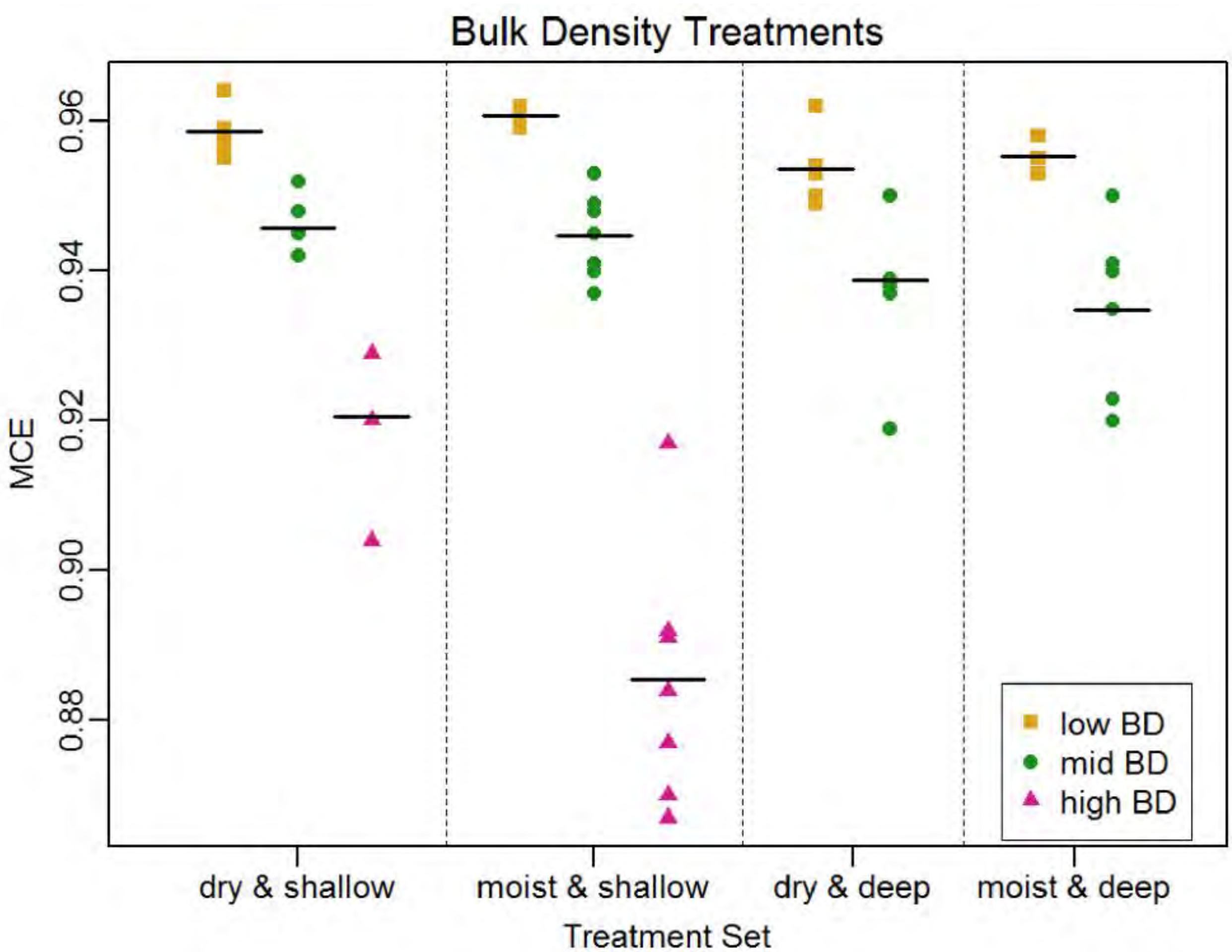
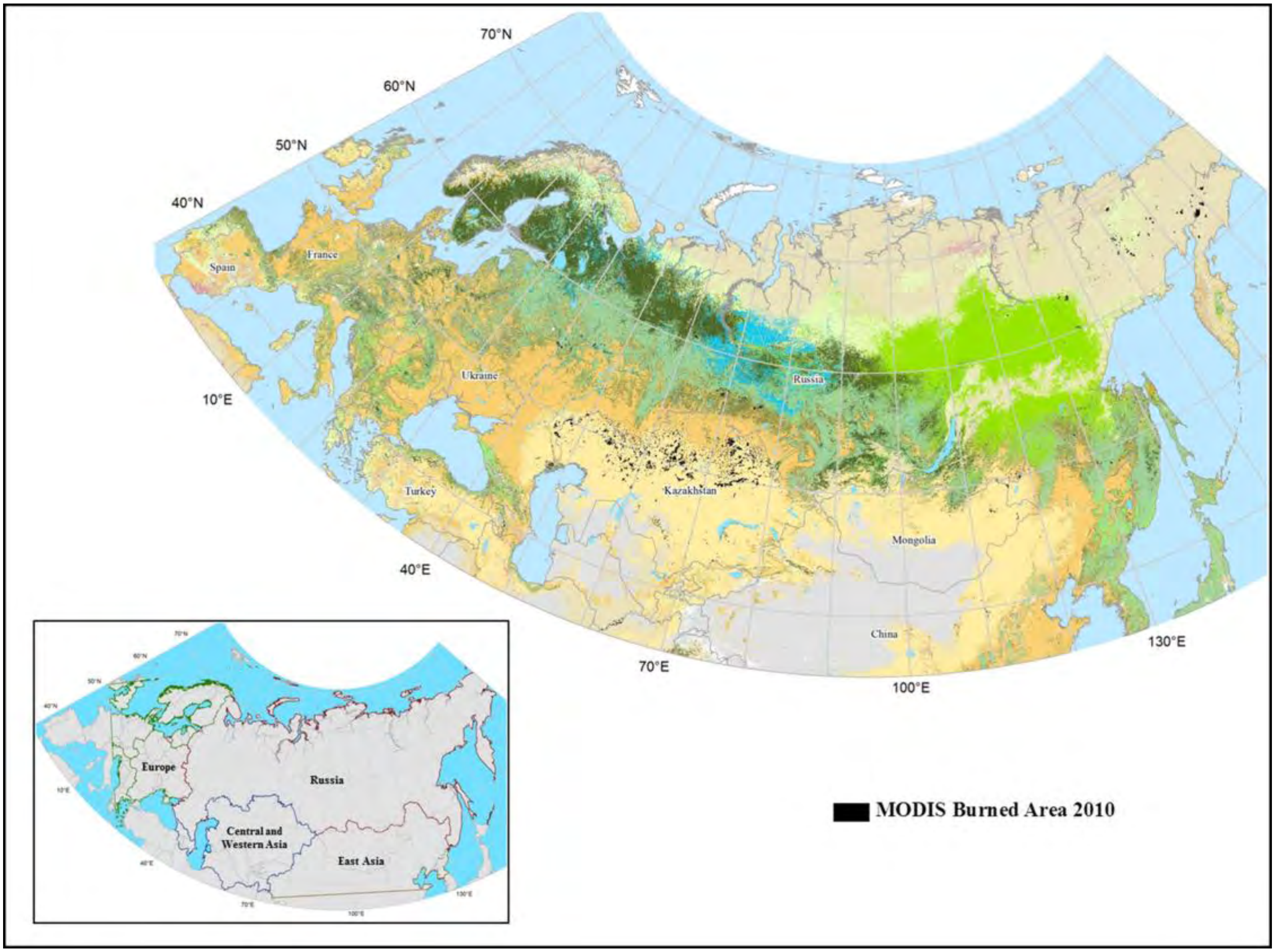


Image: This image displays the effects of both bulk density and fuel bed depth on emission factors (MCE) for ponderosa pine. Higher bulk density (BD) results in less efficient combustion (lower MCE). Fuel bed depth had no effect in this experiment.

Climate Change Impacts on Fire Regimes and Air Quality in Northern Eurasia

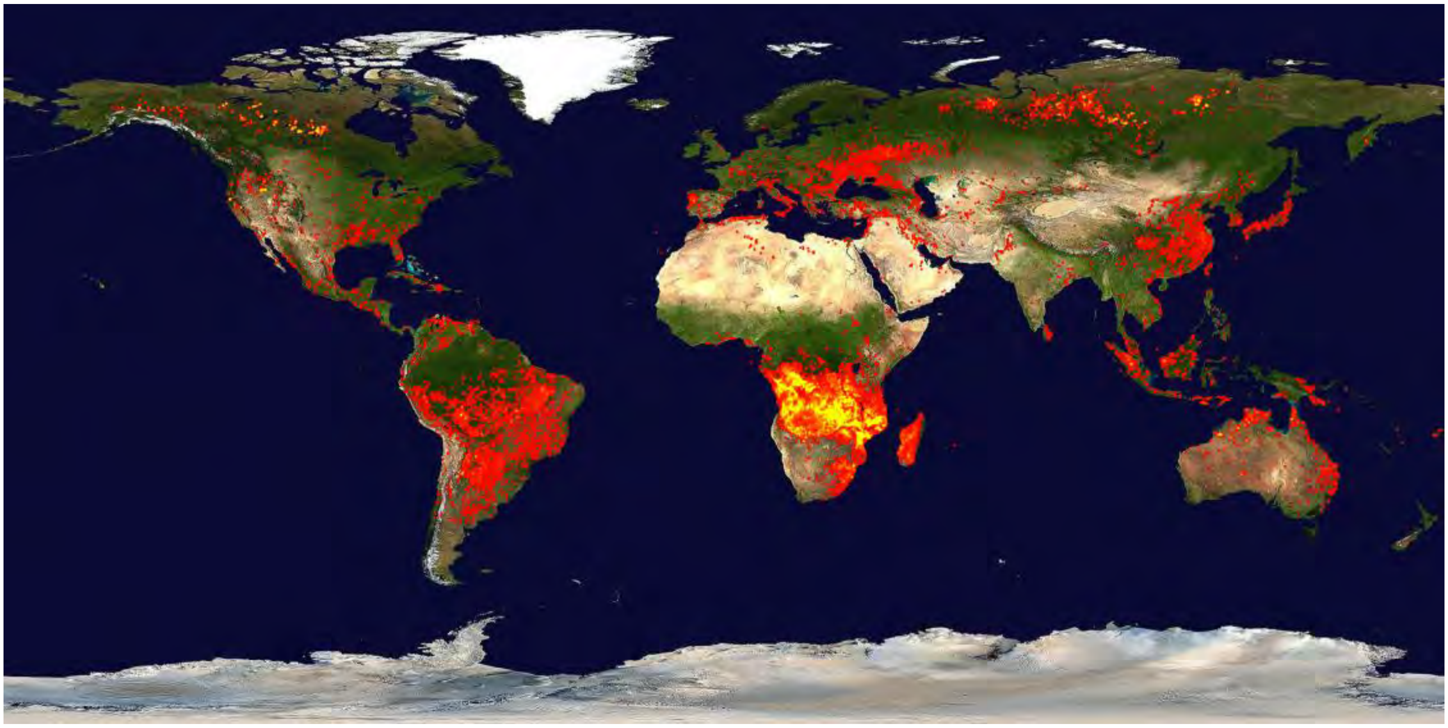


Global surface temperatures have increased about 0.89°C during the period from 1901 to 2012, and Northern Eurasia has experienced the greatest temperature increase. This region is projected to continue experiencing the largest temperature increase globally. High-latitude boreal and temperate ecosystems are particularly sensitive to climate change, and fire – a major disturbance in these ecosystems – responds rapidly to climate change.

The RMRS Smoke Emission and Dispersion Research Team has been investigating the impacts of climate change on current and future fire regimes and air quality in Northern Eurasia. Led by Research Chemist Wei Min Hao, the team is studying climate impacts on changes in vegetation type and conditions, frequency of fires, length of fire season, spatial-temporal distribution of the area burned, and smoke emissions.

This joint project is carried out in cooperation with the French Nuclear Energy Commission (CEA), France's premier national science and engineering laboratory. The joint project leveraged the team's strengths in fire science, satellite remote sensing, and

Image: MODIS-detected burned area in Northern Eurasia in 2010 as used in the simulation model.



fire emissions and the CEA's expertise in carbon cycling, atmospheric chemistry, and supercomputing. Researchers studied and simulated the current land cover and fire regimes using the state-of-the-art global dynamic vegetation model, which is part of the French Earth System Model. The simulation was accomplished by downloading global climate data and the global climate model over a high speed Internet2 connection, and then simulating the climate model for Northern Eurasia using the team's high-performance computing system. Results revealed that temperature is one of the major factors affecting annual area burned. This research supports development of a model to predict future fire regimes for Northern Eurasia as climate continues to change.

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Image: MODIS 10-day global fire detection for August 9-18, 2013. Image courtesy of NASA.

Fire Ecology

Fire varies across the landscape, requiring ecosystems to adapt to differing fire severity and fire return intervals. In 2014, researchers also looked at the beneficial effects of adding fire to the landscape to restore whitebark pine ecosystems. Studies of western spruce budworm revealed that they did not increase fire risk in the interior Pacific Northwest. Studies have also shown that fire danger has increased globally during the past 35 years in response to climate change.

Photo: Prescribed fire at Mink Peak on the Lolo National Forest, Montana, will reduce competition for whitebark pine, shown in the foreground. Photo by Molly Retzlaff / FFS.

Effects of New Restoration Technique "Daylighting" Are Evaluated for Whitebark Pine in the U.S. Northern Rocky Mountains

Whitebark pine forests cover a major portion (approximately 10-15%) of the northern Rocky Mountain forested landscape. Unfortunately, whitebark pine has been rapidly declining on many National Forests in the northwestern United States during the past three decades because of blister rust infections, mountain pine beetle outbreaks, and fire exclusion. This valuable keystone species provides food to hundreds of wildlife species, including the grizzly bear, red squirrel, and Clark's nutcracker, and whitebark pine's preservation, protection, and conservation are vital. In addition, this high-elevation forest acts as a nursery for less hardy vegetation, regulates snow melt, and reduces soil erosion.

Whitebark pine populations are so low that future disturbances, especially those facilitated by climate change, could cause local extinctions. Tree thinning and prescribed burning have been used to successfully restore declining whitebark pine stands. However, these techniques are costly and somewhat difficult to implement on National Forest land. New, effective, and less expensive techniques need to be developed for operational use. One such restoration technique is called daylighting, in which competing trees that surround the whitebark pine tree are removed. This technique has been successfully applied to other five-needle pine ecosystems, and managers are now applying it to whitebark pine restoration. This research, designed and implemented in collaboration with the Lolo and Bridger Teton National Forests, is designed to document the effects of daylighting treatments on whitebark pine survival, vigor, and cone production.

Researchers are investigating the effects of daylighting treatments, thinning, and prescribed fire on wildland fuels, tree survival and mortality, and

Photo: Prescribed fire is used as part of daylighting treatments to improve whitebark pine survival. Photo by Bob Keane / FFS.

understory vegetation before and during treatment. Monitoring of the sites will continue for 15 years after treatment. The research is being performed at Prospect Mountain and Mink Peak on the Lolo National Forest as well as Grouse Mountain on the Bridger-Teton National Forest. In 2014, research plots at Mink Peak were thinned and burned using prescribed fire. Thinning and burning were used to create the daylighted area surrounding the selected whitebark pine trees thereby reducing competition from other conifer species and limiting whitebark pine mortality. Measurements of the project's success at Mink Peak will begin in early 2015. The Prospect Mountain plots were thinned, with prescribed burning scheduled for 2015.

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

Photo: Daylighting treatments, including this prescribed fire at Mink Peak on the Lolo National Forest, Montana, will reduce competition for whitebark pine, improving its chances for survival. Photo by Bob Keane / FFS.

Western Spruce Budworm Outbreaks Did Not Increase Fire Risk During the Past Three Centuries in the Interior Pacific Northwest

Forests of ponderosa pine, Douglas-fir, and grand fir in the interior Pacific Northwest are subject to fire and to outbreaks of western spruce budworm. By feeding on the needles of its preferred host species, Douglas-fir and grand fir, caterpillars of this insect defoliate the crowns of some trees, thereby decreasing tree growth and killing some trees. Both disturbances are widespread, but interactions between them are not well understood and may have been altered by recent changes in land use and fire regimes. Researchers used two approaches to study interactions between these ecologically and economically significant disturbances: tree rings and computer models. Tree rings revealed many historical fires and outbreaks of western spruce budworm outbreaks along a 1,000-mile transect from central Oregon to western Montana, but no consistent relationship in their timing. Western spruce budworm was associated with the ends of multi-year droughts whereas fire was associated with single drought years. The computer model revealed that defoliation by western spruce budworm reduces the potential for fires burning on the surface to spread to tree crowns as well as for fires to spread between tree crowns, suggesting that areas heavily defoliated by western spruce budworm may inhibit crown fire spread and may thus promote non-lethal surface fires.

For more information, contact: Emily K. Heyerdahl at eheyerdahl@fs.fed.us, Russ Parsons at rparsons@fs.fed.us, or Greg Cohn at gcohn@fs.fed.us

Top photo: Douglas-fir tree with top killed by western spruce budworm defoliation. Photo by Greg Cohn / FFS.
Bottom photo: Aquila Flower (Western Washington University) and Branden Rishel (University of Oregon) discuss fire scars on a stump in eastern Oregon with Emily Heyerdahl (FFS). Photo by Daniel G. Gavin / University of Oregon.

Assessing the Impacts of Recent Climate Change on Global Fire Danger

Wildfires occur at the intersection of dry weather, available fuel, and ignition sources. Weather is the most variable and largest driver of regional burned area. Temperature, relative humidity, precipitation and wind speed independently influence wildland fire spread rates and intensities. The alignment of multiple weather extremes, such as the co-occurrence of hot, dry, and windy conditions, leads to the most severe fires. Global temperatures have increased by ~ 0.2°C per decade over the last three decades, possibly leading to an acceleration of the global water cycle with more intense rainfall events and more severe and widespread droughts and regional humidity variations. Although climatic changes are implicated in global fire variations, a comprehensive assessment of the interactions of recent climatic changes that lead to an expansion or contraction of the fire season is lacking.

In a NASA-funded study, FFS Research Ecologist Matt Jolly, in collaboration with researchers from South Dakota State University, the University of Tasmania, the Desert Research Institute, and the U.S. Forest Service Region 1, used global climate data from three reanalysis platforms and three different fire danger rating systems to explore the relationships between recent climatic changes and global fire weather season length. They found that fire weather seasons have lengthened across 27.8M km^2 (23.8%) of the Earth's vegetated land surface, resulting in a 16.3% increase in global mean fire weather season length. They also showed a near doubling (90.7%) of global burnable area affected by anomalously long fire weather seasons (>1.0 σ above historical mean) and an increased frequency of long fire weather seasons across 62.4M km^2 (53.4%) of the globe's vegetated areas during the second half of the study period. If coupled with ignition sources and available fuel, these fire weather conditions may profoundly alter global pyrogeography, and they may have pronounced global socio-economic, ecological and climate impacts.

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

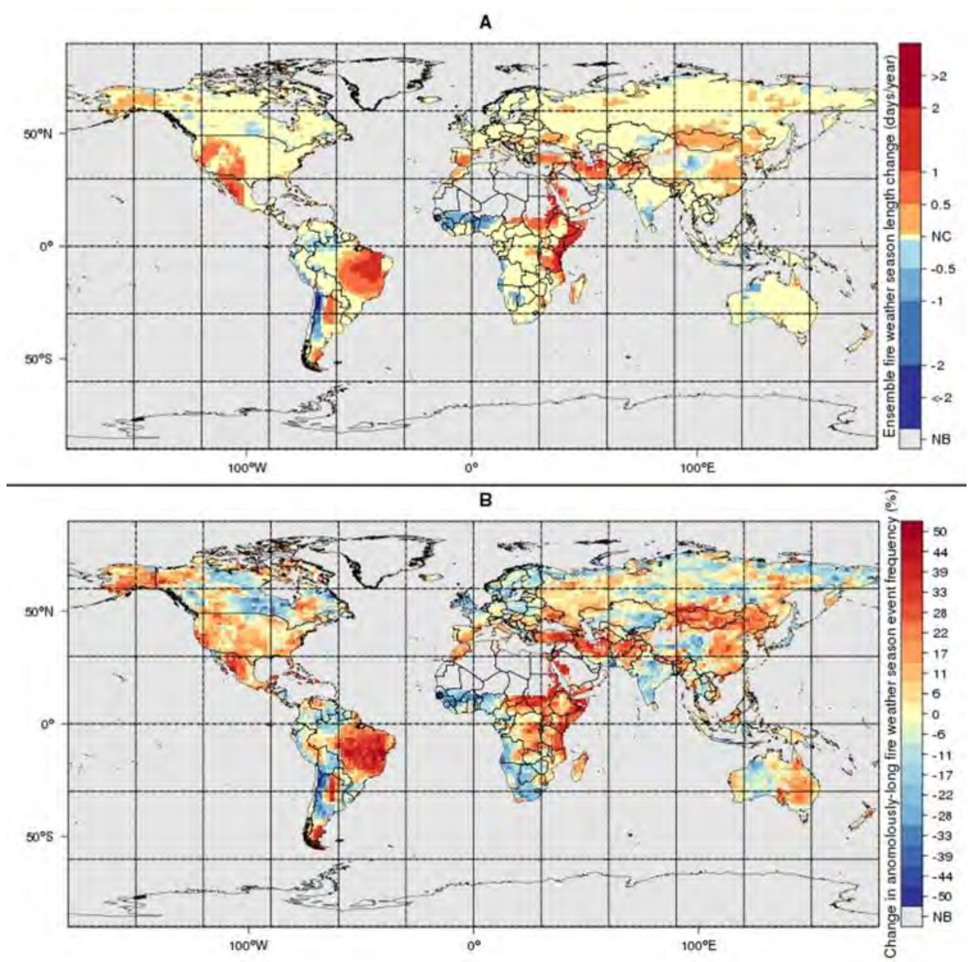


Image: Global patterns of fire weather season length changes from 1979-2013. Panel A shows trends in fire weather season length. Panel B shows changes in the number of unusually long seasons between 1979-1996 and 1996-2013. Red areas show places where seasons are getting longer (A) or there is an increased frequency of long seasons (B). Blue areas show places where seasons are getting shorter (A) or there is a decreased frequency of long seasons (B).

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 2014, FFS researchers contributed to this goal in several ways. Oil spills are difficult to clean, and one potential method is burning the oil on-site. Researchers are studying the impacts of burning on soil in a unique set of laboratory and field experiments. 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. To improve firefighter health and safety, FFS scientists linked slope, wind, and fire intensity to firefighter safety zone size to make recommendations for safe separation distances from fires to avoid firefighter injury due to direct exposure to hot, toxic gases and thermal injury to skin.

Ecosystems change over time, but disturbances can alter them quickly. Two studies are aimed at improving understanding of how ecosystems respond to disturbance and how these disturbances affect future fire behavior. The first study, in the northern Rocky Mountains, is a 10-year study examining surface and canopy fuel conditions after disturbance (fire or mountain pine beetle). The second study throughout the Rocky Mountains, investigates the characteristics of masticated fuels, their change with time, the effects of moisture, and how potential fire behavior may change with time.

Photo: Fire researcher monitor fire as it passes by sensors in a study designed to improve estimates of safety zone size. Photo by Paul Sopko / FFS.

When petroleum is spilled on land, clean up can be difficult. Sites may be inaccessible to mechanical containment, recovery, and clean up, and the equipment may cause environmental damage. In situ burning may be a viable alternative for removing this spilled petroleum.

Although in situ burning of spilled oil may be a useful tool, its effects on vegetative communities and long-term site recovery are important concerns. Burning oil may produce temperatures that heat soils. This soil heating may affect the soil's ability to supply water and nutrients needed by plants. In this study, researchers are investigating the effects of burning petroleum fuel oil (diesel) and crude oil on soils. Laboratory burning of soil monoliths (vertical slices of undisturbed soil) has been conducted at three soil moisture levels. Results from this study will improve understanding of the soil temperature distribution during burning and corresponding effects on soil respiration. A video outlining this study can be found at http://videos.firelab.org/ffs/Other/Reardon2014/Reardon-soilburn.mp4.

For more information, contact: Jim Reardon at jreardon@fs.fed.us

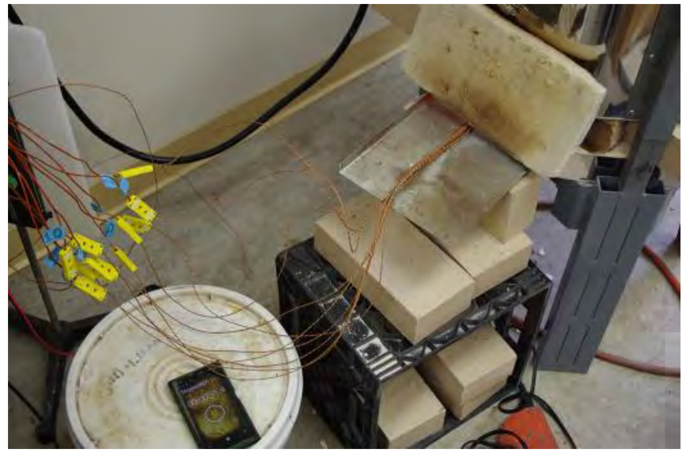
Top photo: Soil monoliths are used in the lab to investigate the effect of burning petroleum fuel oil and crude oil on soil. Photo courtesy of U.S. Forest Service. Bottom photo: In situ controlled burn of crude oil in Iberville Parish, Louisiana. Photo courtesy of U.S. Coast Guard.

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

The ArcBurn project uses both controlled laboratory experiments and instrumentation of prescribed and wild fires to determine critical damage thresholds for cultural resources (archaeological sites and artifacts and heritage resources). Data on fire effects, and observations and data on effectiveness of fuels treatments, are then used to develop treatment guidelines for best treatment practices and protection of archaeological resources. 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 fire, wildfire suppression, and post-fire rehabilitation. ArcBurn is funded by the Joint Fire Science Program, and is a collaborative effort among fire scientists, forest ecologists, earth scientists, archaeologists, tribal members, and fire managers. Information generated is especially critical as the changing climate is altering wildfire patterns and fire behavior.

ArcBurn project highlights in the past year include deployment of instrumentation on archaeological sites within a large prescribed fire, laboratory experiments, and outreach. At the Missoula Fire Science Laboratory, experiments have included an outdoor 'crib' burn that measured fire effects and heat exposure on ancient architectural stone, a muffle furnace pilot study on ceramics and obsidian, and a kiln test on ceramics. The crib burn measured the effects of both radiant and convective heating, while the muffle furnace and kiln measure the effects of radiant heat alone. Our preliminary results suggest that there is a wide range of fire sensitivity among artifact types, and that ground and surface fires are more damaging than crown fires.

Top photo: Ceramic shards were burned to examine the effects of both prescribed and wildland fire on cultural artifacts. Bottom photo: An outdoor crib burn was conducted in 2014 to examine the effects of heat on architectural stone, shown in the bottom center of the image. Thermocouples were inserted in the stone to measure how heat is transferred through the stone. Afterwards, the stone was inspected for damage. Photos by Rebekah Kneifel / FFS.



The ArcBurn team has developed a multi-agency advisory team of 13 experts, who are crucial for discussing gaps in 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. ArcBurn is also 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 (http://www.frames.gov/partner-sites/arcburn/), 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

Top photos: Ceramic shards are placed on a bed of sand, instrumented, and exposed to radiant heat in a kiln (left). The ceramic shards are later inspected for damage. The artifacts are exposed to radiant heat of varying temperatures in the kiln (right). Bottom photo: Artifacts were also exposed to heat in a muffle furnace to measure the effects of both radiant and convective heating. Photos by Rebekah Kneifel /FFS.

While researchers have been active in the lab, field-based crews have also collected data for the ArcBurn project. The team has made giant strides in the past year in fire instrumentation. The team developed protocols for monitoring fire behavior, heat flux, and the resulting fire effects on archaeological sites during both wildland and prescribed fires. These protocols were applied in two fires in north-central New Mexico: the San Juan prescribed fire (7,300 acres, October 2013) and the Pino wildland fire (4,300 acres, September 2014).

The Fire Fundamentals Team (FFT, page 20) instrumented a total of eight archaeological sites with fire behavior packages and in situ camera boxes to monitor fire behavior and effects on a wide range of artifacts, including field houses and pueblos as well as stone, obsidian and ceramic lithics. The sites varied in fuel load, slope, aspect, and weather. Ignition patterns were varied to alter the overall fire behavior at individual cultural sites, resulting in a wide range of fire intensity. Post-fire analysis revealed that previous fuel treatments had varying levels of effectiveness in protecting artifacts.

Results from this study suggest that treatments such as larger ignition buffers around archaeological sites, tailored ignition patterns, off-site removal of slash and heavy fuels, and minimal treatment of live fuels can protect archaeological sites from damage resulting from heat, direct flame, and smoldering.

For more information, contact: Rachel Loehman at rloehman@usgs.gov or Bret Butler at bwbutler@fs.fed.us

Top photo: Fire crews and members of the Jemez Pueblo tribe install fire behavior packages near artifacts prior to the San Juan prescribed fire in New Mexico. Tribal members are actively involved in the project. Middle photo: Interagency Hotshot Crews monitor the Pino Fire near the research sites, providing ground support to the researchers. Bottom photo: Fire burns past a Fire Behavior Package located near the center of this photograph. Photos by Dan Jimenez /FFS.

Firefighter Safety: New Research on Safety Zones

Analysis of firefighter entrapments from the past 90 years suggests that advances in understanding of fire, changes in fire management policy, and better firefighter work practices can save lives. Data from the last 30 years suggest that firefighter injuries and deaths can be attributed almost uniformly to aircraft accidents, driving accidents, heart attacks, and fire entrapments. The term safety zone was first introduced into the official literature in 1957 in the aftermath of the Inaja Fire, which killed 11 firefighters in California. Since then, identification of safety zones has been an integral task for all wildland firefighters. The work that resulted in the current guidelines used officially in the U.S. was based on radiant heating, flat ground, and no wind — conditions that are not realistic for most high-intensity fires.

This current project explores the impact of wind and slope on safety zone size and location. In 2014, the group conducted a series of wildland fire field campaigns. The mission focus and scope targeted in situ fire behavior data collection on wildland fires to validate the new firefighter safety zone guidelines. The team travelled to wildland fires in Arizona, New Mexico, Utah, Nevada, Oregon, and California over a four-month period in an effort to collect wildland fire data at sites with sloped terrain, a heavy fuel component, and moderate to high fire intensity. This work will continue into the 2015 fire season.

Ultimately, measurements, literature review, and simulations suggest that current guidelines should be modified to account for flame size, slope, and wind. This work has resulted in new understanding about how energy is released from fires and its implications for firefighter safety. In many cases when wind or slope influence fire behavior, the size of the safety zone must be increased significantly. In some cases, alternate fire management tactics will be needed to keep firefighters safe. Clearly, the answer is incomplete and additional work is needed to provide the best possible guidelines.

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

Top photo: Firefighters exit the area where safety zone sensors were deployed on a fire in Nevada in 2014. Photo by Dan Jimenez / FFS.
Bottom photo: Fire researchers observe a fire burning through the sensor location in Alberta. Photo by Bret Butler / FFS.

Monitoring Surface and Canopy Fuel Conditions after Stand-Replacing Disturbance Events in the Northern Rocky Mountains

Conventional wisdom in fire management holds that forested stands containing trees that are killed by insects, disease, or fire will remain at high fire hazard for decades after the disturbance. The foliage and fine woody material that falls from the trees killed by the disturbance agents will be highly flammable and create landscapes that have high risk for abnormally severe fire, including crown fire. This assumption, however, is currently being debated for many ecosystems across the western United States. There may be only a small period of time when the disturbance-killed tree foliage is markedly more flammable than the remaining live foliage, especially during moisture conditions when surface fuels can burn.

Dead foliage may fall to the ground within a year or two. Therefore, some think that the fine woody material from dead trees will fall to the ground and create surface fuel conditions that could foster wildfires of high intensity and severity. Recent litterfall studies have shown that only small amounts of fine fuel are deposited each year and much of this material is lost to duff in a decade or two.

To help resolve these uncertainties, researchers are investigating the effect of disturbance events, namely fire and beetles, on future fire hazard and risk in conifer forests of the northern U.S. Rocky Mountains. The study includes four sites that have experienced fire, and 11 sites disturbed by mountain pine beetle. The sites contain Douglas-fir, lodgepole pine, ponderosa pine, whitebark pine, subalpine fir, spruce, and/or larch. During the next 10 years, scientists and staff will annually measure stand and fuel characteristics at every site. They are measuring surface fuel deposition and the resulting decomposition rates for 11 forest types across the northern U.S. Rocky Mountains after wildfire events and after beetle epidemics to quantitatively describe fuel dynamics. At the end of the study, they will quantify fire behavior for each plot using collected or measured tree and fuels data, local weather summaries, and other data using the BehavePlus fire modeling system for predicting surface fire behavior and NEXUS for estimating crown fire behavior. Researchers will summarize and report fuel deposition and decomposition rates in these disturbed

Top photo: Litter traps are used to collect dead foliage for monitoring.
Bottom photo: Litter traps were installed at this site after stand-replacing fires to measure fuel characteristics. Photos by Bob Keane / FFS.

stands during the 10-year period and the describe fire hazard in these stands for each of the 10 years.

Results from this study will inform managers and researchers about the effects of stand-replacement disturbances on fuel, future fire behavior, and future fire effects. This research may lead to new methods of prioritizing fuel treatments after major insect, disease, or fire events, and it will provide important parameters and values for fuel sampling efforts.

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

Photo: Sampling is performed each year at 15 sites, including this site disturbed by mountain pine beetles. Photo by Bob Keane / FFS.

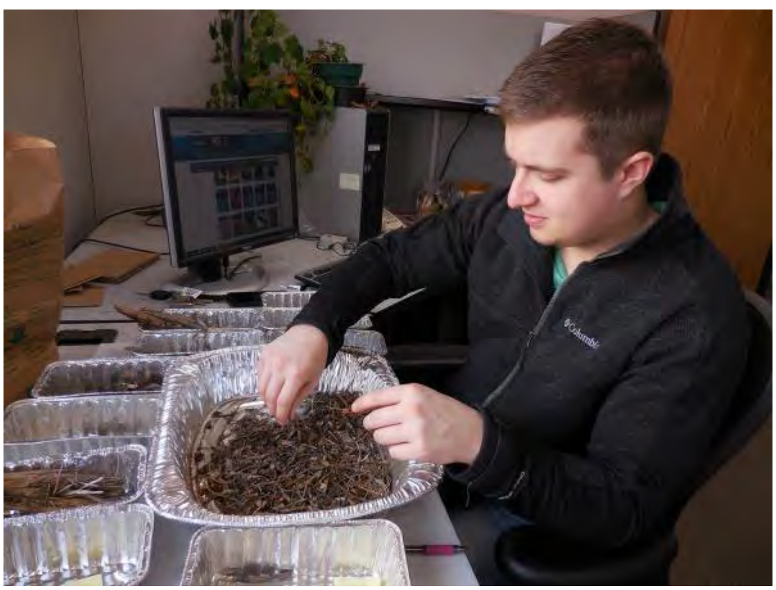
Surface Fuel Characteristics, Temporal Dynamics, and Fire Behavior of Masticated Mixed-Conifer Fuel Beds of the Southeast and Rocky Mountains

Fuel mastication, or the mechanical modification of live and dead surface and canopy biomass, to reduce the potential of extreme fire behavior is becoming the preferred fuel treatment for many fire hazard reduction projects in areas where reducing fuels using prescribed fire is challenging. For mixed-conifer ecosystems, much research has been done concerning how fire in masticated fuel beds affects soils, how compressed fuels affect fire behavior, and how different ways of masticating fuels affect vegetation response. However, little is known about how fuel particle and fuel bed characteristics and properties change over time. To answer these questions, scientists, technicians, and volunteers from the RMRS Fire, Fuel and Smoke Science Program, the RMRS Forest and Woodland Ecosystems Science Program, and the University of Idaho spent the summer and fall of 2014 gathering field data and collecting fuel particles from masticated areas in Idaho, Colorado, New Mexico, and South Dakota. The collection sites were located in mixed-conifer forests from dry to wet climates, and were treated with three distinctly different methods of mastication. Each sample area contains a range of ages of masticated materials that will help determine how fuel particles and fuel bed characteristics change over time.

At 15 sites within the four states, they measured fuel bed depths for masticated fuel, duff, and recent litter fall to examine the spatial variation of fuel distribution that is created during the mastication process. Next, samples were collected from 20 subplots (0.5 m x 0.5 m size) at each site. The samples were then transported to the Missoula Fire Sciences Lab, where samples from each site were sorted into shape and size classes to characterize fuel loads and particle characteristics. Subsamples of particles were randomly selected to determine length, width, dry weight, particle density, and surface characteristics. Particles from the same subsample were then ground up to examine the chemical content of carbon, nitrogen, lignin, and cellulose. A total of 30 samples from several sites were characterized in 2013- 2014.

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

Top photo: Sample frame from the Valles Caldera site, New Mexico, where mastication occurred in 2008. Area of large frame is 1 m^2. All material was collected from the small sample frame (0.5 x 0.5 meter) down to mineral soil and is being analyzed for particle characteristics and chemical properties. Bottom photo: A masticator (yellow) grinds or flails fuel into chips as part of a fuel treatment. Photos by Pam Sikkink / RMRS.



Top left photo: Jonathan Sandquist (left) and John Byrne (right) of RMRS Forests and Woodland Ecosystems Program measure masticated fuel, Boise Basin, Idaho. Top right photo: Nikki Stirling, FFS volunteer, measures fuel depth, Manitou Experimental Forest, Colorado. Bottom left photo: Forestry Technician Joe Frament sorts masticated materials. Bottom right photo: Art Sikkink, FFS volunteer, grinds particles for chemical analysis. Photos by Pam Sikkink / RMRS.

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: www.firelab.org. A list of scientific publications published in 2014 can be found starting on page 70. Software programs are also created and managed by FFS personnel; these programs are described in detail in the Fire Modeling Institute's annual report, available on our website. There have been substantial updates to the Wildfire Assessment System as outlined in this report. An educational website has been created to assist students in the Flathead Valley, Montana, in understanding the effects of fire and climate change on the ecosystems of the Crown of the Continent. The U.S. Forest Service's rich history of 100 years of fire science research is being collected and synthesized for the first time. Synthesis of past research is another important component of science delivery. 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. Managers often seek out the expertise of FFS staff to apply fire science research to their specific, local issues, such as those for Fort Huachuca and the eastern province of Zambia.

Image: Current and historical research is highlighted on our website, www.firelab.org.

The Fire Effects Information System (FEIS, http://www.feis-crs.org/beta/) provides scientific information for resource management, restoration, rehabilitation, and fire management. In 2014, FEIS continued to improve its service to managers with new and updated products and a new user interface under development.

FEIS is producing a collection of new literature reviews called Fire Regime Syntheses. These syntheses supplement information in FEIS Species Reviews and complement fire regime products developed by LANDFIRE. Each Fire Regime Synthesis covers a group of Biophysical Settings, the vegetation units used by LANDFIRE that represent vegetation that may have been dominant on the landscape prior to Euro-American settlement. By bringing information together from the scientific literature and LANDFIRE's Biophysical Settings models, FEIS's Fire Regime Syntheses provide up-to-date information on the characteristics of historical fire regimes as well as contemporary changes in fuels and fire regimes, and enable LANDFIRE to incorporate the latest science into their data revisions. These syntheses also identify regions and plant community types with little or no fire history data. Three Fire Regime Syntheses were added to FEIS in 2014. Each synthesis is linked to related FEIS Species Reviews.

FEIS also continues to provide online syntheses of scientific knowledge on more than 1,100 species of plants and animals in the United States and their relationships with fire. Five Species Reviews were updated in 2014. Notable among these are reviews covering black spruce, common manzanita, and tussock cottongrass.

In 2014, FEIS had 555,521 visitors from over 50 countries and all of the United States, with most visits from California, Texas, Washington, Oregon, and New York. Of the reviews available in FEIS, 99.3% received a visit in 2014. Sixteen of the 40 most commonly viewed syntheses cover invasive plants, and 5 of the 40 most frequently viewed syntheses cover mammals (mule deer, white-tailed deer, elk, moose, and coyote).

The Information Team continued to work with the U.S. Forest Service Digital Visions Enterprise, LANDFIRE, and LANDFIRE-TNC to develop an improved user interface for FEIS. The improvements will make fire regime information accessible for all ~1,100 FEIS Species Reviews and for ~2,500 LANDFIRE Biophysical Settings. They will be implemented in 2015.

For more information, contact: Jane Kapler Smith at jsmith09@fs.fed.us

Top photo: Crowning fire in a black spruce stand during the lightning-ignited 2004 Taylor Complex Wildfire, southeastern interior Alaska. Photo used with permission of Wildlandfire.com. Bottom photo: Tussock cottongrass grows from post-fire nutrient-rich soils in Gates of the Arctic National Park. Photo courtesy of the National Park Service.

“Imagining Fire Futures” Educational Website

In IMAGINING FIRE FUTURES, funded by the National Science Foundation, students in a high school or college class use model results to develop a vision of the future for Flathead County, Montana. This is a rural area in the northern Rocky Mountains where more than half of the landscape is covered by wildland ecosystems that have evolved with and are shaped by wildland fire.

In FIRE FUTURES, each student adopts a “character”— human, other animal, or plant—whose interests he or she represents throughout the online activity and in the class’s subsequent Community Planning Meeting. The student uses the website to learn about the character’s habits and needs, examines predicted conditions as modeled by large-scale fire simulation models (FireBGCv2 and FSIM), and then selects the scenario most likely to produce good habitat for their character. Students select scenarios based on their characters’ preferences for climate, wildland-urban interface development, fuel treatment, and inclusion of wildfire. Sample model results are shown on the next page.

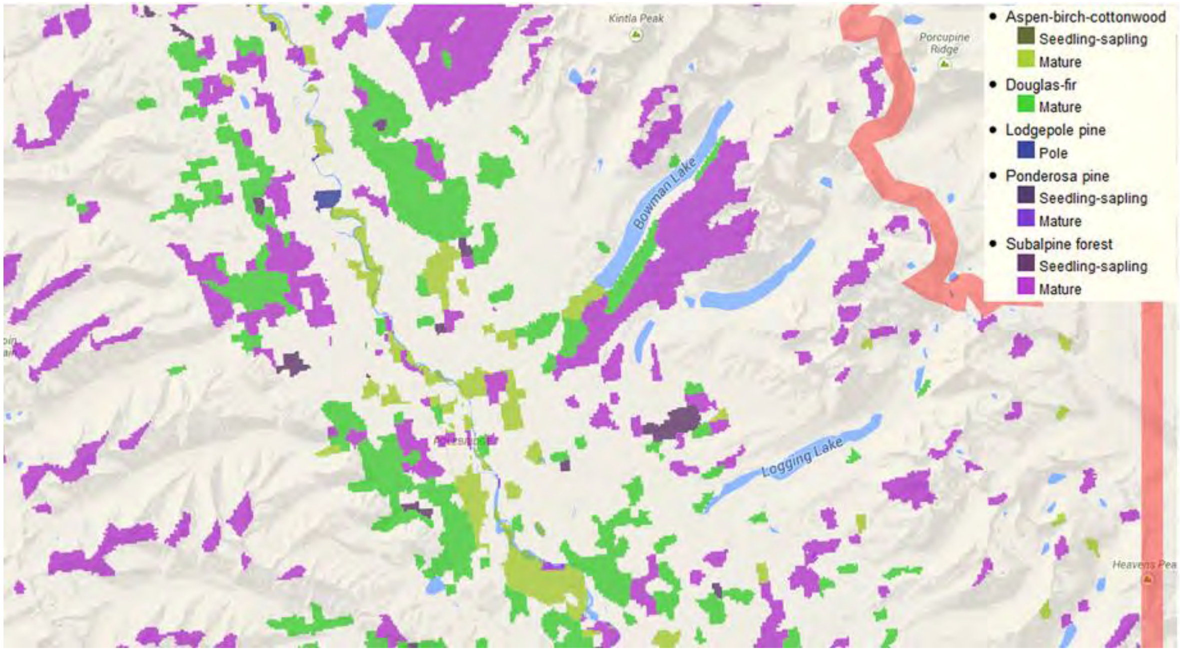
Throughout the activity, students complete “quizzes” that challenge them to demonstrate or improve their ability to interpret graphs, read maps, and apply new information to practical problems. Each student also completes a journal that contains:

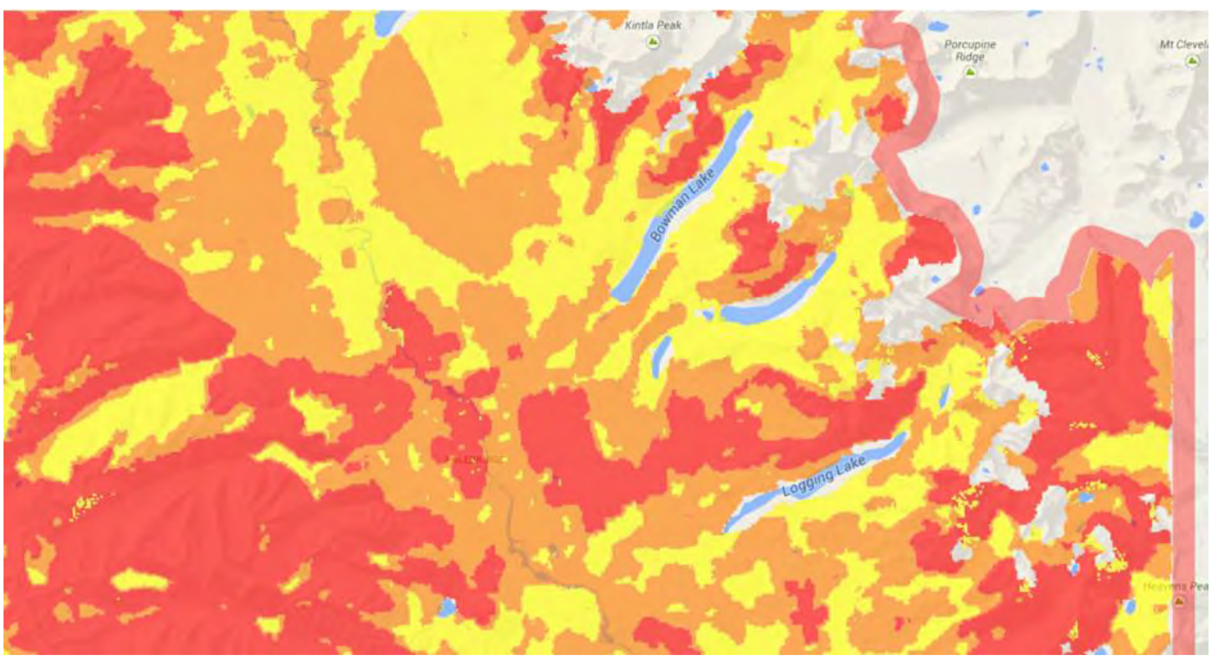
- data about his or her character and its habitat
- interpretation of the data
- evaluation of future habitat for meeting the character’s needs, and
- reflections on the adequacy of the model predictions.

After completing the online activity, available at http://feis-crs.org/firefutures/, students collaborate in a Community Planning Meeting to develop a vision of the future that could optimize habitat and wildland fire potential for all species living in Flathead County, Montana.

For more information, contact: Jane Smith at jsmith09@fs.fed.us

Top image: A model of the cottonwood tree used on the Imagining Fire Futures website.
Bottom image: The website homepage, located at http://feis-crs.org/firefutures/.





Top image: Estimated tree distribution in Glacier National Park in the year 2060 without the influence of climate change.
Bottom image: Potential fire frequency in the same area in the year 2060 with the influence of climate change.

A Century of Wildland Fire Research

For more than 100 years, U.S. Forest Service researchers have focused on better understanding, predicting, and controlling wildland fire. With U.S. Forest Service Research and Development funding, this multi-year research project has been documenting the history of their studies. Using documents collected in the National Archives, the Library of Congress, the University of Montana, the Forest Service Library, and the Fire Lab's own records, this project synthesizes the Forest Service's century-long commitment to understanding wildland fire nationwide.

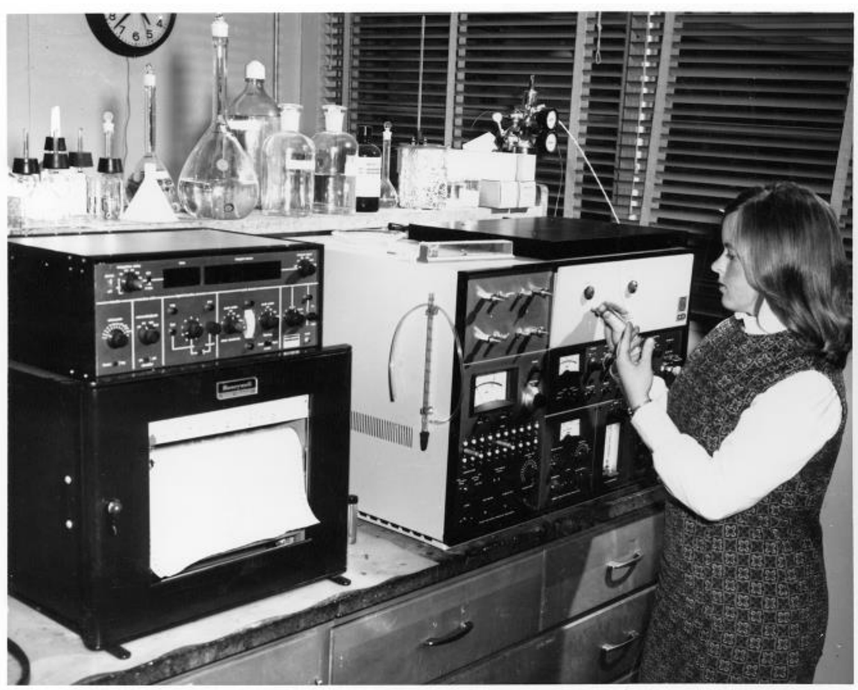
In 1915, all research programs conducted by the Forest Service became part of the agency's newly established Branch of Research and, in 1916, the Washington Office reported on the agency's four wildland fire-related studies:

1) Development of a scientific basis for forest fire hazard and liability. This national research study set out to "develop a uniform, scientific, and practical method" for rating fire hazard and liability. Conducted as a historical survey of fire records and weather records, the ultimate goal was to develop a scientific basis for distribution of fire-protective funds by identifying where fire danger and financial risk were the greatest and preparing accordingly.
2) Relation of meteorological conditions to fire hazard and fire protection. In cooperation with the U.S. Weather Bureau, this ongoing national project focused in part on defining "climatic units" within the National Forests; developing a means to predict fire danger based on these units; obtaining meteorological data to apply to fire studies; and identifying the effect weather and other conditions have on a fire's rate of spread. These early fire danger-rating studies documented everything from the moisture content of leaf litter to regional fire records.
3) Principles underlying methods of fire protection. Designed to study the best methods of fire prevention and control, this early research worked on developing special fire-fighting

Photo: Meteorological and fire investigations built on the work initiated in the early 20th century. In 1959, Howard (Red) Halpin (left) and C.E. (Mike) Hardy (right) scouted the Brackett Creek Fire in the Gallatin National Forest and checked a portable fire weather station.

equipment such as portable fire extinguishers using chemical retardants, and documenting the effects of light burning (i.e., prescribed burns) as a protective measure against fire.

4) Determination of fire damage. Initiated on the Deschutes National Forest, Oregon, this research sought to develop uniform principles for estimating fire damage, including the relative damage done in different types of forests under varying conditions. Researchers also collected data from other forests based on this model.



These early studies continued to grow over the next 100 years, and laid the foundation for much of the wildland fire-related research conducted to this day.

For more information, contact: Diane Smith at dianemsmith@fs.fed.us

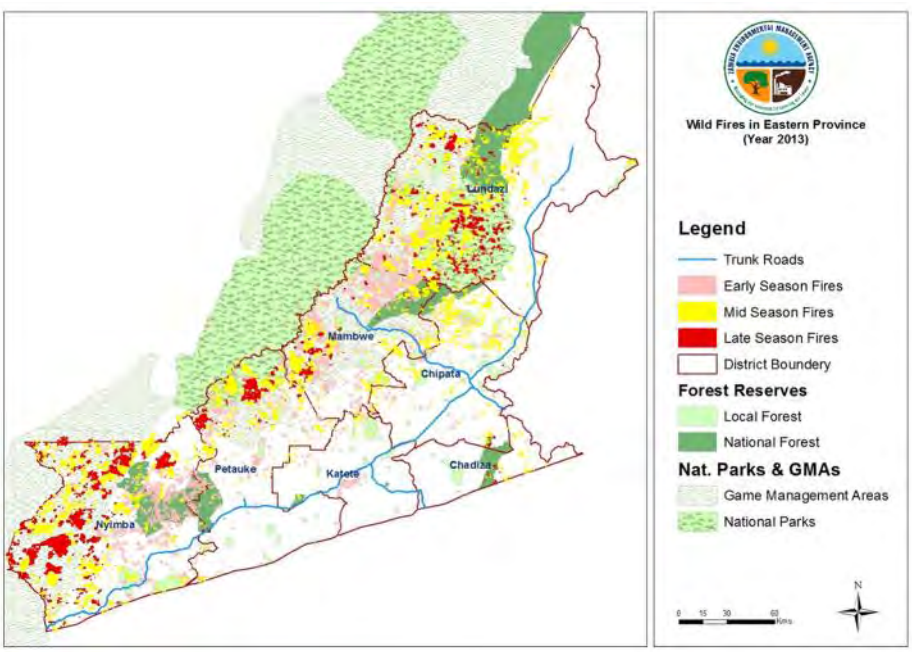
Top photo: The Missoula Fire Sciences Lab, established in 1960 as the Northern Forest Fire Laboratory, continued research in both retardant development and application. In this 1969 photo, a mobile unit applies retardant to a section of the Newman Ridge fire. Bottom photo: The Fire Lab also built on early research identifying fuel moisture and other properties. Roberta (Bobbie) Bartlette uses a gas chromatograph unit to identify fuel properties in 1969. Photos by Herman Wittman / U.S. Forest Service.

Living with Fire: A Fire Regime Assessment of the Eastern Province, Zambia

A team of four individuals, supported through the U.S. Forest Service International Programs, convened in October 2014 to conduct a fire regime assessment in the Eastern Province of Zambia. The team, which included a multinational assemblage from the United States and Zambia, was tasked with the following objectives:

1) gain preliminary insights into the current status of fire management and fire use in the province,
2) assess the role of fire in the regeneration and maintenance of the dominant vegetation present in the terrestrial ecosystems of the province, and
3) provide recommendations for fire management training and equipment needs for the Zambia Forestry Department and partner agencies.

The Eastern Province, and Zambia by extension, is dominated by vast tracks of fire-prone vegetation including woodland savannas and grasslands. Bush fire is a frequent process on the landscape, estimated to annually burn approximately 25% of Zambia's land base. Fire is a readily available and inexpensive tool that impoverished rural populations in Zambia can utilize to participate in a multitude of traditional activities such as clearing vegetation for agriculture, improving pastures for grazing, burning crop residues, hunting, and stimulating the growth of non-timber forest products (NTFPs). Indeed, the presence of fire-adapted plants and paleoecological studies indicate that fire has been used by humans in this landscape for millennia



Top photo: Chief Nyalugwe's Palace, Paramount Chief for Nyimba District [includes team members Gift Sikaundi (2nd from left), Sylvester Siame (2nd from right), LaWen Hollingsworth (far right), and Catherine Tembo from USAID (4th from right), village leaders, and Chief Nyalugwe (left center in leopard)] Photo by Darren Johnson / U.S. Forest Service. Bottom Image: Seasonality and aerial extent of fires as detected by MODIS Active Fire Data.

(and, as such, is culturally ingrained) and has helped to shape much of the existing Zambian landscape. Fire is used as a tool by the Zambian people throughout the dry season, but the effects can be more substantial late in the dry season when herbaceous fuels are fully cured and fires can quickly spread into adjacent villages or protected areas.

The team travelled 1,550 miles (2,500 km) throughout the Eastern Province to meet with officers from the Zambia Wildlife Authority (ZAWA) and Zambia Forestry Department (ZFD) who manage protected areas including national parks, game management areas, national forests, and local forests. The team also met with village leaders and community members throughout the Eastern Province to document the use of fire by villagers. The team also met with various ministry and government officials in Lusaka, the capital.

It is essential that contemporary fire management strategies, if they are to be effective, consider not only the technical aspects of fire management but also the communities and the environment in which they live. The team provided a list of recommendations in the technical report, released in January 2015, that will highlight future formal fire management training needs for ZAWA and ZFD personnel and promote development of community-based fire management plans, increased establishment of community tree nurseries, and improved outreach to communities that lessen social and ecological effects of fire.

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

Top photo: Recently burned area near Msipazi, Chipata District. Photo by LaWen Hollingsworth / FFS.
Bottom photo: Vwenkhu Village, Lundazi District. Photo by Darren Johnson / U.S. Forest Service.

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

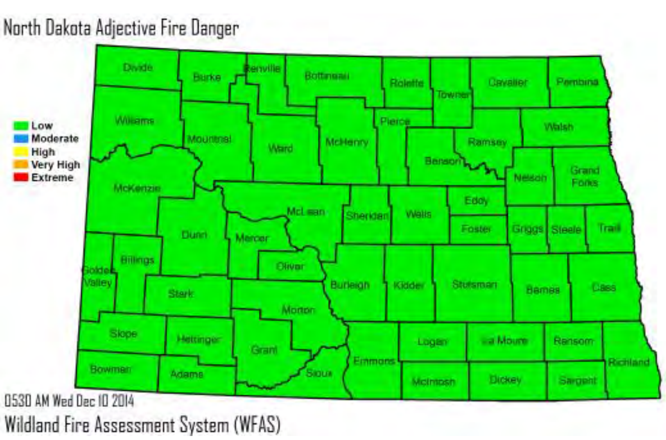
The U.S. National Fire Danger Rating System (NFDRS) is a system used by wildland fire management agencies to assess current fire danger at local, regional, and national levels. It consists of a variety of indices that portray current potential fire danger conditions. Fire Modeling Institute (FMI) staff have been highly involved in the development and application of NFDRS for decades. In 2014, 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 41,100 users with nearly 200,000 page views during 2014. 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.

WFAS developers, working closely with federal fire managers from the U.S. Forest Service and the National Park Service as well as 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 statewide 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 2014.

Fire danger maps are produced daily for the state of North Dakota 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 2014, 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 will continue funding further development and refinement of the system over the next three years.



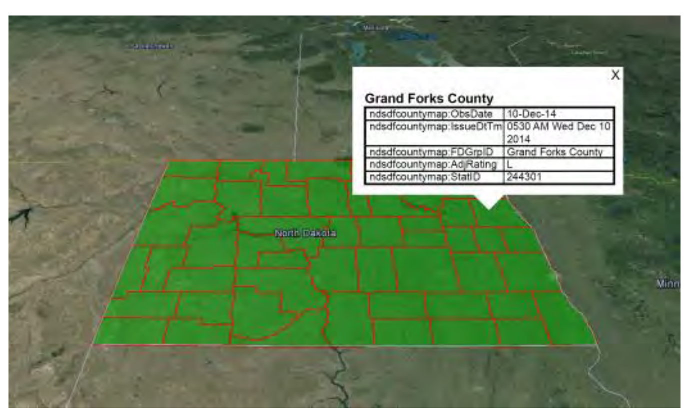


Image: Static, county-based fire danger map for North Dakota (left) and dynamic fire danger map overlaid on Google Earth (right) for early December 2014. These maps are produced daily as part of the North Dakota fire danger rating system prototype.

Development of a new tool to combine airborne and spaceborne 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 U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center and will provide rapid integration of highly detailed LiDAR into fuels maps used for fire behavior predictions. Called CHISLIC (Creating Hybrid Structure from LANDFIRE/Lidar Combinations), it 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 seven-day fire danger forecasts from the National Weather Service's National Digital Forecast Database (NDFD) for several years (http://www.wfas.net/). WFAS developers continued to work closely with Predictive Services' meteorologists throughout the country in 2014 to provide point forecasts for key Remote Automated Weather Stations (RAWS) located throughout the United States. WFAS now produces seven-day outlooks daily for more than 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.

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 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 search for map features. The prototype for the interactive map can be accessed on the WFAS website. 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.

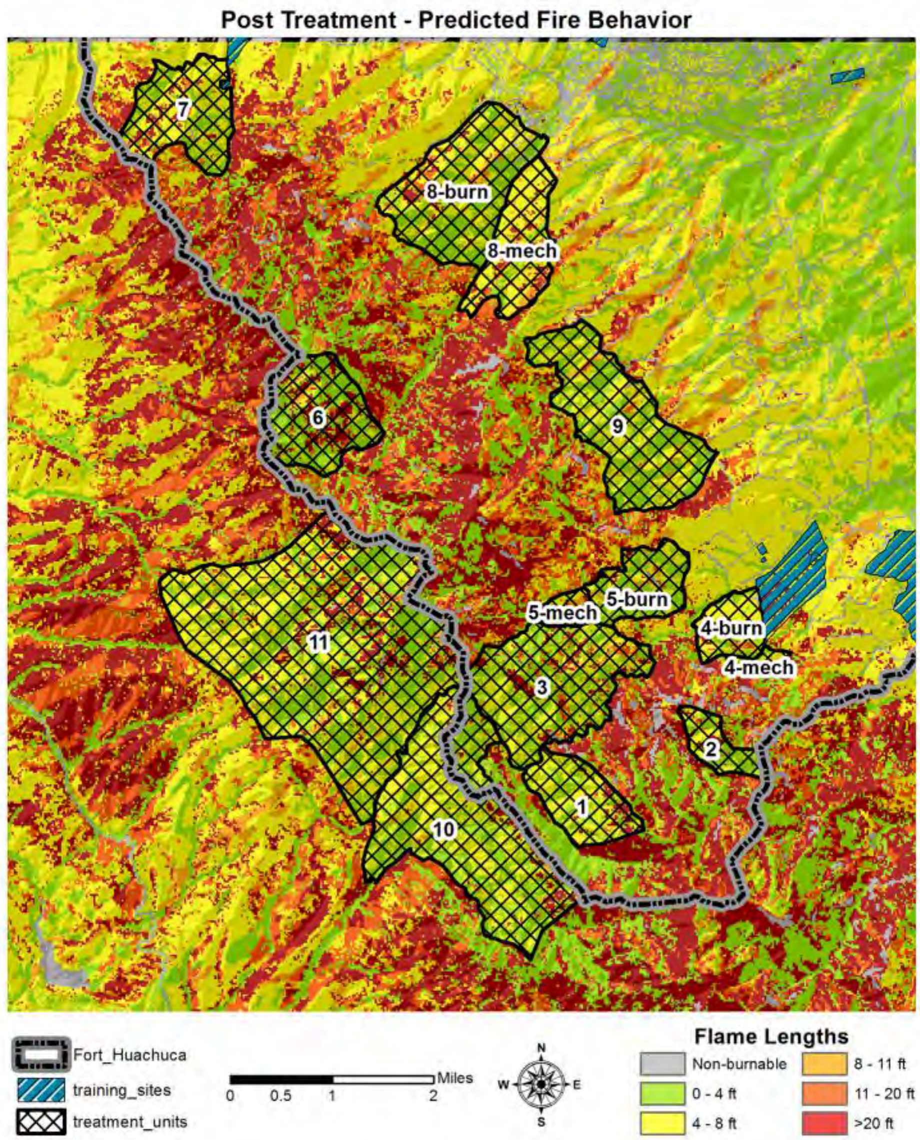
For more information, contact: Matt Jolly at mjolly@fs.fed.us or Larry Bradshaw at lbradshaw@fs.fed.us

Image: U.S. National Fire Danger Rating System information is available for the United States at http://www.wfas.net.

Fort Huachuca 10-Year Fuels Treatment and Implementation Plan

Within the Fort Huachuca military installation in southeastern Arizona, there are 11 Protected Activity Centers (PACs) identified for the threatened Mexican spotted owl. The PACs include a variety of vegetation types including multi-storied conifer and pine-oak systems in addition to grasslands. These PACs provide nesting and roosting habitat as well as foraging habitat for the Mexican spotted owl both within the PAC and in adjacent areas. A wildfire has the potential to alter multi-storied structure within the PACs, resulting in unknown consequences to the Mexican spotted owl.

The objective of this project was to develop a fuels treatment plan, based on landscape fire simulations, that allows Fort Huachuca to treat minimum area for maximum benefit and produce forest structure and fuel characteristics that reduce the likelihood that future wildfires will cause large, rapid changes in biophysical conditions in and around designated PACs, while still maintaining habitat for all other threatened and endangered species and their prey.



Approximately 6,014 acres (2,434 ha) within Fort Huachuca have been grouped into nine treatment units based on a desire to modify fire behavior in these units because they are adjacent to PACs. Most units are proposed for mechanical thinning followed by prescribed fire as this combination of silvicultural treatments offers the best combination of removing ladder fuels, increasing canopy gaps where appropriate, and decreasing fine woody debris. Two additional units were identified west of Fort Huachuca on the Coronado National Forest as numerous PACs in Fort Huachuca lie near this ownership boundary.

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

Image: Predicted fire behavior following proposed treatments within Fort Huachuca. Flame lengths were derived from FlamMap as predicted for dry conditions and southwest winds.

WindNinja: Simulating High-Resolution Winds in Support of Fire Growth Simulations and Fire Management Strategy Planning

Improving land managers' capability to manage wildland fire has significant implications for human safety, ecological processes (such as forest recovery or water management), and disaster response. Managers require information both during an actively burning fire and after the fire (including erosion potential, growth rates, etc.). Wildland fire intensity and spread are strongly dependent on local environmental variables such as fuel type, fuel moisture, terrain, and surface winds. Similarly, post-fire, wind-blown dust depends strongly on the local surface wind field. The critical spatial scales for these dependencies range from centimeters to kilometers. Because of its inherent temporal and spatial variability, especially in mountainous terrain, the surface wind field is particularly difficult to characterize. This presents a unique challenge to fire management teams charged with determining optimal fire management strategies. Traditionally, fire managers have relied upon expert judgment, measurements from nearby weather stations, or weather forecasts to estimate local winds. A tool or model to predict near-surface winds at fine resolution can vastly improve the information available to fire managers.

Recognizing this need, FFS scientists have spent the past decade developing a computer model to simulate small-scale, near-surface winds. Model development has been dictated by several constraints imposed by the unique nature of wildland fire management, including short decision time frames, remote locations with little or limited internet access, limited computing resources, and ease of use by non-expert users. In response, the WindNinja model was developed to obtain three-dimensional surface wind fields. This approach appears somewhat risky since it deviates from traditional meteorological modeling approaches. However, it has ultimately demonstrated its utility as a decision support tool for modeling surface wind flow in support of wildland fire management.

Recently, WindNinja was updated to allow users to initialize wind calculations using a variety of meso-scale National Weather Service models. Essentially WindNinja is a physically-based model that estimates small-scale wind data from available coarse-scale data provided by the National Weather Service. The tool allows users to access high-resolution wind forecast data in any location in the United States. Outputs from the model can be used as inputs to both the FlamMap mapping and analysis system and the FARSITE fire area simulator. Fire behavior estimates and growth prediction improve significantly when WindNinja winds are included.

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

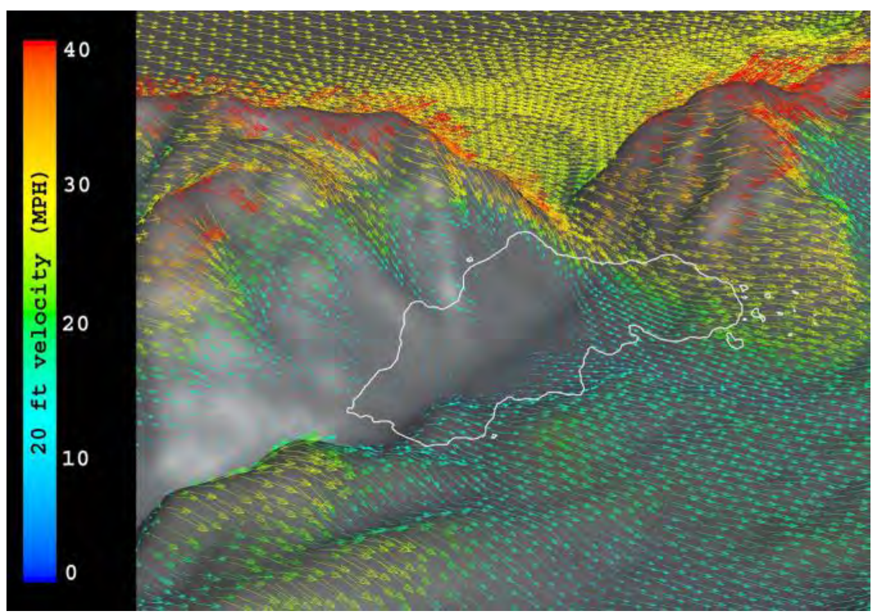


Image: Wind vectors simulated using WindNinja are often used in modeling spatial fire behavior.

The Research Continues

Research to enhance current understanding of wildland fire behavior and its effects is ongoing. Staff in the Fire, Fuel, and Smoke Science Program are working with the National Wildfire Coordinating Group to update the U.S. National Fire Danger Rating System. Scientists are evaluating the effects of climate change on whitebark pine. The first comprehensive book outlining the science of wildland fuel was published. Finally, a report outlining the process of writing and improving science syntheses is in production.

Photo: RMRS scientists and staff participate in prescribed burns to gain valuable field experience. This prescribed fire was on Blue Mountain, Missoula, Montana. Photo by Karin Riley / University of Montana.

Updates to the U.S. National Fire Danger Rating System

In 2014, RMRS fire danger rating system developers sought and gained approval to update the U.S. National Fire Danger Rating System (NFDRS). 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. The new system will be implemented and tested over the next two years and is expected to be fully operational in January 2016.

Approved changes to the NFDRS include:

1) incorporating the Growing Season Index (GSI) to compute live fuel moistures;
2) incorporating the Nelson model to compute fine dead fuel moisture; and
3) reducing the number of fuel models in NFDRS.

More information can be found in a recorded presentation located at http://www.nwcg.gov/branches/et/fenc/subcommittees/fds/index.htm.

For more information, contact: Matt Jolly at mjolly@fs.fed.us or Jon Wallace at Jon_Wallace@fws.gov

Photo: Remote Automated Weather Stations, such as this one in Missoula, Montana, provide key inputs to the U.S. National Fire Danger Rating System.

Evaluating Effects of Climate Change on Whitebark Pine

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 management is being studied as part of DAYLIGHT project (page 34). 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. This may confound restoration attempts such as those studied in the DAYLIGHT project.

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. 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

Photo: Whitebark pine seedling cluster. Photo courtesy of Anna Schoettle / U.S. Forest Service.

Book: Wildland Fuel Fundamentals and Application

Wildland fuels may be the most important consideration in fire management, not just because they are important inputs for predicting fire behavior and effects, but also because fuels are the only factor that can effectively be controlled by direct and indirect management actions. To address these issues, Research Ecologist Bob Keane has written the first comprehensive synthesis of wildland fuels in their ecological context — *Wildland Fuel Fundamentals and Application*. This book provides fire scientists and managers with a comprehensive understanding of fuels ecology and science to realistically evaluate fire effects and behavior in the diverse ecosystems and landscapes of the world.

Expensive fuel treatments are being planned in fire-dominated landscapes across the world to minimize fire damage to people, property and ecosystems, so it is incredibly important that people understand wildland fuels to develop more effective fuel management activities. The amounts and kinds of fuels burned in a fire dictate how dangerous a fire can get, how much smoke is generated, how ecosystems will respond to fire, and how society will respond to the fire. By modifying the fuel bed, managers hope to minimize adverse consequences to protect ecosystems, people, and property.

A comprehensive description and understanding of wildland fuels is vital for crafting effective treatments and novel ways to manage wildfires. This book will provide fire managers and scientists information needed to understand how fuels are used in fire behavior and effects predictions and management.

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

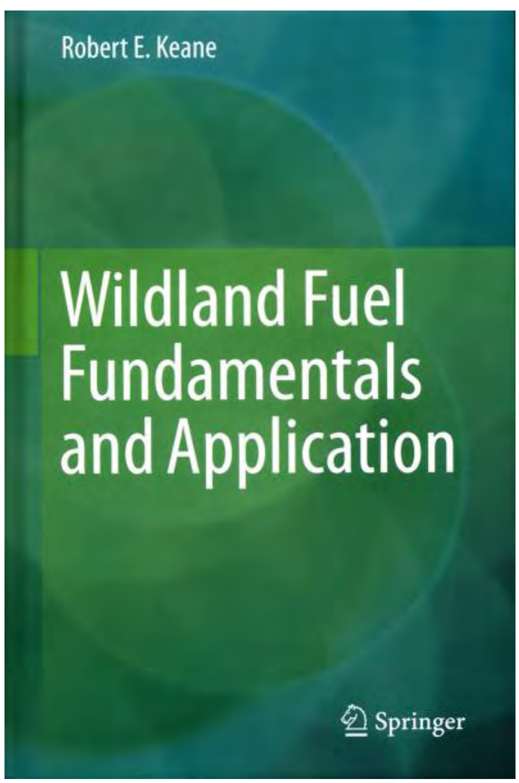


Image: Book cover for Wildland Fuel Fundamentals and Application, the first comprehensive book on fuel, and its impact on fire behavior and fire effects.

Strengthening Science Syntheses on Fire: Increasing Their Usefulness for Managers

A science synthesis for fire managers summarizes and interprets a body of information, presents its meaning in an objective, unbiased way, and describes its implications for decision makers. Ecologist Jane Kapler Smith searched the literature on synthesis and informatics, and interviewed 35 people who plan, write, and/or use syntheses on fire. Her research suggested several ways to strengthen syntheses on fire and other natural resource issues, among them:

- Include managers, scientists, and science delivery specialists in planning, developing, and delivering syntheses.
- If a synthesis has unique regional components, include someone from each region in the planning team and consider these needs in writing and packaging.
- Use managers as authors, co-authors, or reviewers to ensure management implications are fully developed and clearly explained.
- Use existing communication networks within the management community for marketing and delivery.
- Include syntheses in professional training courses.
- Improve use of technology to provide syntheses, research and monitoring results, and other information so managers can easily find the information they need and apply it to resource management decisions

Sponsored by the Joint Fire Science Program, this research will be published in a General Technical Report, due to be released in 2015.

For more information, contact: Jane Kapler Smith at jsmith09@fs.fed.us

Image: Decisions about the information to include in a synthesis depend on the objectives and the information available. Highly inclusive criteria may admit information that is unreliable or has limited generalizability, while highly exclusive criteria may leave valuable information by the wayside.

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, and presentations, as well as educational curricula and materials to help increase public understanding of the science of wildland fire. In 2014, the Fire Sciences Lab's Conservation Education program reached more than 1,000 students and 150 adults:

Students

Fire Modeling Institute (FMI) and Fire, Fuel, and Smoke Science Program (FFS) staff provided 10 tours for 336 students and 49 teachers and other adults. Tours included hands-on activities, including lab investigations of fire spread and use of feltboards to "tell the stories" of fire's role in Rocky Mountain forests.

Staff delivered seven presentations in classrooms and field sites, teaching students at the Elementary and Middle School levels. These presentations addressed 420 students and 25 teachers/ faculty.

FMI staff loaned the FireWorks trunk to eight teachers, who used it to teach more than 300 children, and gave presentations to 54 teachers and agency educators in workshops provided by the International Association for Wildland Fire, the Lolo National Forest, and the Glacier Institute.

In addition, FFS hosted two intensive educational workshops this past year – a week-long summer camp on natural resources for Middle School students as part of a program for at-risk children in Missoula County, and a two-day "FireWorks master class" for professional educators. The 29 students and three teachers in the natural resources camp learned about history and fuel reduction projects at Garnet Ghost Town. They visited the National Bison Range, where they learned about the historical and current relationship of the Salish and Kootenai Tribes with the Jocko River. On the Lolo National Forest, they learned about insect and fish ecology. On the final day of the camp, they learned about fire from presentations by Montana Department of Natural Resources and Conservation, Missoula Rural Fire, Lolo National Forest, and the Missoula Smokejumpers. The day concluded with hands-on learning about fire behavior and fire ecology at the Fire Lab.

Photo: Students at the natural resources summer camp visited Garnet Ghost Town to learn about the history of the area and fuel reduction projects. Photo by Kristine Lee / FFS.

Educators

The FireWorks master class offered an in-depth exploration of the 30-plus activities in the FireWorks curriculum and trunk (http://firelab.org/project/fireworks-educational-program). Sixteen 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. The educators "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: Jane Smith at jsmith09@fs.fed.us

Photo: Teachers and agency fire specialists investigate fuel properties in the FireWorks master class, June 2014. Photo courtesy of Jane Kapler Smith / FFS.

Fire Modeling Institute

The Fire Modeling Institute (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 (RMRS) 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 – provide different roles and 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. 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).

FMI's 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.

Application

In 2014, 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 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 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, this year, the Information Team provided many new and updated products in FEIS and continued to work with the U.S. Forest Service Digital Visions Enterprise Team, FMI-LANDFIRE, and The Nature Conservancy-LANDFIRE to develop an improved user interface for FEIS that will be released in 2015. In addition, the release of BehavePlus 6, FireFamilyPlus 4.2, FOFEM 6.3, and the next version of FuelCalc are expected in 2015. The new U.S. National Fire Danger Rating System (NFDRS) is expected in 2016.

Photo: Estimating understory cover within a 1-meter quadrat during the FEAT-FIREMON Integrated (FFI) training course. Photo courtesy of Nikole Swaney / The Nature Conservancy.

Information

The Fire Effects Information System (FEIS, http://www.feis-crs.org/beta/), the core project for the Information Team, provides scientific information for resource management, restoration, rehabilitation, and fire management. In 2014, FEIS continued to improve its service to managers with new and updated products and a new user interface under development. In 2014, staff produced a collection of Fire Regime Syntheses, which supplement the FEIS Species Reviews. FEIS also continues to provide online syntheses of scientific knowledge on more than 1,100 species of plants and animals in the United States and their relationships with fire. Five Species Reviews were updated in 2014. Notable among these are reviews covering black spruce, common manzanita, and tussock cottongrass.

Support

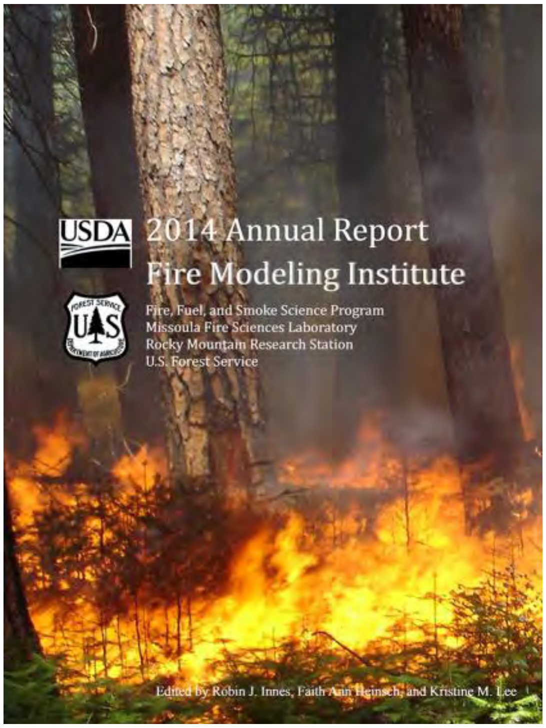
Each year, FMI staff provide support services for users of FFS applications and products, and in 2014, they reported more than 350 technical support contacts regarding their operation. FMI staff also provide field support during wildfire incidents. In 2014, FMI staff worked nearly 880 hours providing fuels and fire behavior modeling, operations, and planning support to fire managers throughout the West.

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 National Wildfire Coordinating Group courses.

Photo: Crowning fire in a black spruce stand during the lightning-ignited, 2004 Taylor Complex in southeastern interior Alaska. A fire regime synthesis of Alaskan black spruce communities was published in 2014. Photo used with permission of Wildlandfire.com.

The staff at FMI work with a range of national and international partners, including other agencies, state and local governments, academia, and nonprofit groups to accomplish its tasks. For example, they worked with officers from the Zambia Wildlife Authority and Zambia Forestry Department to document fire use by villagers throughout the Eastern Province of Zambia to provide a fire regime assessment for the province. In another project, they worked with the U.S. Fish and Wildlife Service, Coronado National Forest, and Fort Huachuca, a military installation in Arizona, to provide a 10-year fuels treatment and implementation plan. The plan is intended to produce forest structure and fuel characteristics that reduce the likelihood that future wildfires will cause large, rapid changes in biophysical conditions in and around Mexican spotted owl activity centers.

For more information, contact: Kristine Lee at kristinelee@fs.fed.us



Top photo: The FMI annual report summarizes all of the work done by the staff of the Fire Modeling Institute. It is available on the FFS website.
Bottom photo: FMI staff provide assistance on wildland fires, including the Seepay Fire near Dixon, Montana. Photo by LaWen Hollingsworth / FFS.

2014 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 2014. Links are provided for publications where possible.

Physical Fire Processes

Ager, Alan A.; Buonopane, Michelle; Reger, Allison; Finney, Mark A. 2013. Wildfire exposure analysis on the national forests in the Pacific Northwest, USA. Risk Analysis. 33(6):1000-1020. http://www.treesearch.fs.fed.us/pubs/46997

Ager, Alan A.; Day, Michelle A.; McHugh, Charles W.; Short, Karen; Gilbertson-Day, Julie; Finney, Mark A.; Calkin, David E. 2014. Wildfire exposure and fuel management on western US national forests. Journal of Environmental Management. 145: 54-70. http://www.treesearch.fs.fed.us/pubs/46998

Brillinger, David R.; Finney, Mark A. 2014. An exploratory data analysis of the temperature fluctuations in a spreading fire. Environmetrics. 25(6): 443-453. http://onlinelibrary.wiley.com/doi/10.1002/env.2279/abstract

Canfield, Jesse M.; Linn, Rodman R.; Sauer, Jeremy A.; Finney, Mark; Forthofer, Jason. 2014. A numerical investigation of interplay between fire line length, geometry, and spread rate. Agricultural and Forest Meteorology. 189-190: 48-59. http://www.treesearch.fs.fed.us/pubs/47001

Forthofer, Jason M.; Butler, Bret W.; Wagenbrenner, Natalie S. 2014. A comparison of three approaches for simulating fine-scale surface winds in support of wildland fire management: Part I. Model formulation and comparison against measurements. International Journal of Wildland Fire. 23(7): 969-981. http://www.treesearch.fs.fed.us/pubs/47006

Forthofer Jason M.; Butler, Bret W.; McHugh, Charles W.; Finney, Mark A.; Bradshaw, Larry S.; Stratton, Richard D.; Shannon, Kyle S.; Wagenbrenner, Natalie S. 2014. A comparison of three approaches for simulating fine-scale surface winds in support of wildland fire management. Part II. An exploratory study of the impact of simulated winds on fire growth simulations. International Journal of Wildland Fire. 23(7): 982-994. http://www.publish.csiro.au/nid/114/paper/WF12090.htm

McAllister, Sara; Finney, Mark A. 2013. Convective ignition of forest fuels. In: 8th U. S. national combustion meeting; 2013 May 19-22; Park City, UT. Livermore, CA: Western States Section/Combustion Institute: 3698-3709.

McAllister, Sara; Finney, Mark A. 2013. Effect of crib dimensions on burning rate. In: Bradley, D.; Makhviladze, G.; Molkov, V.; Sunderland, P.; Tamanini, F., eds. Proceedings of the seventh international seminar on fire and explosion hazards (ISFEH7); 2013 May 5-10; Providence, RI. College Park, MD: University of Maryland, Research Publishing. http://www.treesearch.fs.fed.us/pubs/44351

Saito, Kozo; Finney, Mark A. 2014. Scale modeling in combustion and fire research. Journal of the Combustion Society of Japan. 56(177): 194-204.

Photo: Flame from exploding target. Photo courtesy of Ian Grob / FFS.

Salis, Michele; Ager, Alan A.; Finney, Mark A.; Arca, Bachisio; Spano, Donatella. 2014. Analyzing spatiotemporal changes in wildfire regime and exposure across a Mediterranean fire-prone area. Natural Hazards. 71(3): 1389-1418.

Fuel Dynamics

Jolly, W. Matt; Hadlow, Ann M.; Huguet, Kathleen. 2014. De-coupling seasonal changes in water content and dry matter to predict live conifer foliar moisture content. International Journal of Wildland Fire. 23(4): 480-489. http://www.treesearch.fs.fed.us/pubs/47011

Mueller, Eric; Skowronski, Nicholas; Simeoni, Albert; Clark, Kenneth; Kremens, Robert; Mell, William; Gallagher, Michael; Thomas, Jan; Filkov, Alexander; Houssami, Mohamad El; Hom, John; Butler, Bret. 2014. Fuel treatment effectiveness in reducing fire intensity and spread rate - An experimental overview. In: Wade, Dale D.; Fox, Rebekah L., eds; Robinson, Mikel L., comp. Proceedings of 4th fire behavior and fuels conference; 2013 February 18-22; Raleigh, NC; 2013 July 1-4; St. Petersburg, Russia. Missoula, MT: International Association of Wildland Fire: 360-362. http://www.treesearch.fs.fed.us/pubs/46781

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Photo: Black cottonwood growing from a burned out root. Photo by Jane Kapler Smith / FFS.

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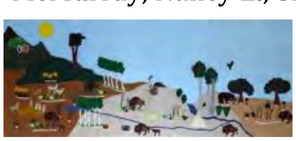

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