THE FIRE CONTINUUM CONFERENCE
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PREPARING FOR THE FUTURE OF WILDLAND FIRE

S1.1. Annually Updated Rangeland Plant Functional Type Percent Cover Maps at 30m Resolution for Improved Fuel Mapping
Presenter: Matthew Jones
Additional Authors: Brady Allred
David Naugle

Interannual variation in vegetation growth and species composition in response to climate, disturbance, and proliferation of annual grasses across rangeland systems results in significant interannual variation in surface fuels. These high-frequency changes in fuel loads have substantial effects on firefighter safety, fire behavior, smoke emissions, and fuel treatment effectiveness. Current fuel mapping processes are not sensitive to these interannual variations due in part to a lack of high temporal and spatial resolution land cover maps. To address this need we produce annual, 30 meter, continuous land cover maps for U.S. rangelands from years 1984 to 2017. We use over 30,000 vegetation plots from the NRCS National Resources Inventory and BLM Assessment, Inventory and Monitoring program spanning years 2004-2016 to train and validate machine learning regression models and capitalize on a cloud-based platform for planetary-scale geospatial analysis with massive computational capabilities (Google Earth Engine). The resulting annual maps provide percent cover within each 30m pixel of annual herbaceous, perennial herbaceous, shrubs, bare ground, litter, trees, and rock for western U.S. rangelands, inclusive of the Great Plains. Incorporating these maps into the fuel mapping process will increase the accuracy of fuels assessments, improve fire model results, and increase the efficacy of decision support systems. The historical record also allows assessment of pre- and post-fire vegetation conditions, efficacy of past treatments, and the ability to couple pre-fire fuel load estimates with fire behavior and implemented management strategies to better understand fire processes and management across U.S. rangelands.

S1.2. A geospatial approach to account for interannual variability in rangeland fuels
Presenter: Matt Reeves, Research Ecologist, USDA, Forest Service, Rocky Mountain Research Station
Additional Authors:

Every manager knows that grasses and shrubs grow more in wet years, and less in dry years. These responses to climate manifest themselves in surface fuels and the inter-annual variability often exceeds 100%. This seasonal/annual climate response in fuel loads substantially alters fire behavior as well as associated smoke emissions, with profound implications for firefighter safety, fuel treatment effectiveness, and air quality throughout much of the country. Yet, current fuel mapping processes, such as LANDFIRE, are unresponsive to these annual or seasonal fuel changes. The inability to incorporate the inter-annual weather response of rangeland fuel loads into decisions support systems significantly limits the effectiveness of numerous efforts critical to core agency goals. Thus, decision support systems are operating with inaccurate fuels data.

In this project we address this problem by offering a new generation of fuel maps from 2000 – 2017 and account for the significant interannual variability in rangelands fuels. The resulting product is consistent and seamless across the coterminous US at 30 m resolution and yields surface fire behavior fuel model data as well as actual loadings of 1, 10, 100 – and 1000 hr time lag fuels for both woody and herbaceous fuels from 2000 – 2017. These data offer significant improvements in timeliness and realism over the relatively static LANDFIRE fuel data layers.

Keywords: Remote sensing, rangelands, fuel, variability

Bio: Matt Reeves is a Research Ecologist with the USDA, Forest Service, Rocky Mountain Research Station, in Missoula Montana. Prior to becoming a Research Ecologist, he led the LANDFIRE fuels team during its inaugural 4 years of existence. His career has focused on developing remote sensing, simulation modeling, and geographic analysis to develop decision support systems and evaluate the effects of climate and management on rangeland vegetation and fuels.

S1.3. Updating of LANDFIRE Vegetation and Fuel Data using Transition Modeling
Presenter: Donald Long, Fire Ecologist, USDA Forest Service
Additional Authors:

One of the main objectives for the LANDFIRE project has been to deliver updated vegetation and fuel products to reflect disturbance and the resulting change in vegetation and fuel that has occurred on the landscape. Since delivery of the initial LANDFIRE National circa 2001 products, this biennial updating process has resulted in the creation of a four vegetation and fuel products representing circa 2008, 2010, 2012, and 2014 conditions.

This process characterizes landscape change uses a variety of disturbance mapping, vegetation transition, and fuel mapping techniques. Disturbance mapping emphasizes a remote sensing approach along with locally derived vegetation management activities data in order to characterize disturbance type, disturbance severity, and disturbance time frame. Vegetation transition is a process that is used to couple disturbance and the vegetation upon which it has occurred, along with simulation models, in order to predict and map the resulting vegetation composition and structure. These data are leveraged in order to predict and map change in fuel attributes of the vegetation.

This presentation will outline the process LANDFIRE has implemented to produce these updated products and illustrate the relative efficacy of the effort with comparisons to other more recent vegetation and fuel mapping products.

Bio: Donald Long is a fire ecologist at the Forest Service Region 1 Regional Office in Missoula, MT. working in the Ecosystem Assessment and Planning Program. He earned a B.S. degree in forest science from the University of Montana in 1981 and completed a master of science in forest resources at the University of Idaho in 1998.

S1.4. Improving national shrub and grass fuel maps using remotely sensed data to support fire fuel assessments
Presenter: Jim Vogelmann, Research Ecologist, USGS EROS

Additional Authors: Shi, Hua, Research Scientist, Inuteq, USGS Earth Resources Observation and Science Center
Hawbaker, Todd, Research Ecologist, US Geosciences and Environmental Change Science Center, USGS
Reeves, Matthew, Research Ecologist, US Forest Service

Shrub and grassland ecosystems in the western United States are especially prone to fire events, yet available geospatial data for assessing fire risk in these areas are inadequate. During this investigation, we assessed relationships among intra- and inter-annual variability in greenness, biomass, and fire in the Great Basin using Landsat and MODIS data. In early phases of the study, we demonstrated that: (1) Intra- and inter-annual spectral variability in these ecosystems is high; (2) Spectral variability is highly correlated with climate variables, especially precipitation; (3) Fire activity is more likely in areas where the spring normalized difference vegetation index (NDVI) values are high and late summer NDVI values are low; and (4) Programs such as STARFM and their derivatives can be effectively used to combine the temporally rich attributes of MODIS data (which has relatively low spatial resolution for LANDFIRE applications) with spatially detailed Landsat data (which has relatively low temporal resolution for intra-annual fire applications). During later phases of the project, we generated maps that indicate areas likely to be at high risk to fire using May data prior to the fire season, which can be used by the fire community for planning their fire seasons. We also demonstrated that we can model grass and shrub biomass using a combination of field efforts and correlative analysis using Landsat data, which ultimately relates to fire behavior. One of the limitations in using Landsat for assessing shrub and grass condition in the past has been related to time gaps between cloud-free data acquisitions, limiting our ability to the assess intra-annual changes that characterize rangelands. Merging of the Landsat data with data from high-temporal frequency MODIS sensor has helped enable the generation of multiple data sets within a growing season, which has helped fill in critical gaps in coverage and enabled characterization of vegetation condition at various times of the year. Looking towards the future, a USGS project known as Land Change Monitoring Assessment and Projection (LCMAP) is designed to further facilitate the use of Landsat data for assessing landscape changes. As part of the project, USGS is developing and disseminating what is referred to as "Analysis Ready Data", which standardizes processing of the Landsat data facilitates their use for operation large area monitoring. The data from this project will be very appropriate for monitoring grass and herbaceous cover in the western US.

Keywords: Shrub, grassland, Landsat, MODIS, fuel

Bio: Dr. Jim Vogelmann is a Research Ecologist at the USGS Earth Resources Observation and Science Center in Sioux Falls, South Dakota, where he has worked for the past 23 years. His research interests have focused on large area mapping and monitoring land characteristics using remotely sensed data.

S1.5. Operational periodic updating of LANDFIRE fuels data

Presenter: Kurtis Nelson, Physical Scientist, USGS EROS
Additional Authors:

The Landscape Fire and Resource Planning Tools (LANDFIRE) Program has been providing consistent and comprehensive surface and canopy fuels data over the entire US for more than a decade. These data have been updated nominally every 2 years to incorporate the effects of landscape disturbance and natural succession. Updating the fuels data is a multi-step process that incorporates newly

acquired satellite imagery, landscape disturbance data contributed by a variety of sources, modeled vegetation transition responses, and locally calibrated rulesets. Each resulting updated version is utilized in a fire behavior modeling system to compare the modeled outputs with previous versions of LANDFIRE fuels data, providing both a qualitative and quantitative analysis of changes represented in the updated data. Each of these processes is semi-automated with analyst guidance and verification.

LANDFIRE is currently undergoing its first comprehensive re-mapping effort to establish new baseline products on which future updates can be based. Utilizing new imagery, plot data sources, tools, and more than ten years of experience mapping nationwide vegetation and fuels, the LANDFIRE Remap seeks to improve and update the original LANDFIRE layers and address as much of the feedback received over the years as possible. The LANDFIRE Remap is expected to be a three to four year mapping effort with periodic updates built into the mapping process such that newly released data will be as current as feasible upon release. Research is ongoing to develop the next generation of LANDFIRE updating procedures with the goal of reducing time between updates, improving responsiveness to feedback, and enhancing partnerships with programs that contribute to or utilize LANDFIRE data.

Keywords: LANDFIRE, fuels, updating, remote sensing, landscape disturbance

Bio: Kurtis Nelson is a physical scientist with the US Geological Survey's Earth Resources Observation and Science Center. His background is in remote sensing, GIS, fire behavior, and vegetation and fuels mapping. He has worked with the LANDFIRE program for many years but also works with the Monitoring Trends in Burn Severity project and supports the Burned Area Emergency Response teams for the US Department of the Interior by providing burn severity maps for use in their assessments.

S2.1. Using landscape modeling to quantify ecological variability as a means to assess resilience
Presenter: Robert Keane, Research Ecologist, US Forest Service Rocky Mountain Research Station Missoula Fire Sciences Lab
Additional Authors: Holsinger, Lisa Spatial Data Analyst, US Forest Service
Loehman, Rachel, Research Ecologist, USGS

Ecological resilience is a somewhat nebulous concept that is now being used to guide US land management into the uncertain future. However, there are few operational means of assessing the resilience of a landscape or ecosystem. We present a graphical construct that forms the foundation for a protocol that we propose to use for quantifying resilience. In this protocol, we use historical ecology as the benchmark or reference to compare to contemporary conditions to assess resilience. However, managing for resilience based on historical conditions is somewhat tenuous in the Anthropocene with rapid climate change, extensive human land use, and exotic introductions. To account for this, we augment our method to integrate projected future conditions with past conditions to direct the management of ecosystems and landscapes. We use simulation results from a landscape model to illustrate the theory, concepts, and methods presented.

Keywords: HRV, future range variation, simulation modeling, FireBGCv2

Bio: Robert E. Keane has been a Research Ecologist with the USDA Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory since 1994. His most recent research includes 1) developing ecological computer simulation models for the exploring landscape, fire, and climate dynamics, 2) conducting basic research in wildland fuel science, and 3) investigating the ecology and restoration of whitebark pine. He received his B.S. degree in forest engineering from the University of Maine, Orono; his M.S. degree in forest ecology from the University of Montana, Missoula; and his Ph.D. degree in forest ecology from the University of Idaho, Moscow.

S2.2. Can fire and fuel management maintain or restore ecological resilience under a changing climate?

Presenter: Rachel Loehman, Research Ecologist, USGS
Additional Authors: Holsinger, Lisa, Ecologist, USFS Rocky Mountain Research Station
Flatley, Will, University of Central Arkansas, Associate Professor
Keane, Robert, Research Ecologist, USFS Rocky Mountain Research Station

Gradual changes in landscape composition and structure are predicted with shifting climate patterns. Climate-driven species shifts often occur in the context of increased landscape disturbance that can catalyze abrupt changes in composition, structure, and function. In the southwestern US, a hundred-plus years of livestock grazing, logging, and fire exclusion have altered pre-European settlement fire frequencies that have resulted in increased surface fuel loads, tree densities, and ladder fuels and reduced structural and spatial heterogeneity of vegetation, especially in dry conifer forests with frequent-fire regimes. Fires in the current era are likely to be more intense with larger patches of high severity than historical fires, reducing biodiversity, ecological function, and resilience. We used the spatial fire-vegetation landscape simulation model FireBGCv2 to model long-term fire and forest responses to climate changes and management activities in the Jemez Mountains of northern NM, a landscape fundamentally and perhaps persistently altered by recent, extensive areas of uncharacteristic high severity fire. We found that a range of plausible future management scenarios failed to prevent substantial shifts in dry forest composition, structure and biomass, especially under hot-dry conditions associated with high-emissions climate models. Notable ecological changes included expansion of woodlands and shrublands into areas middle elevations previously occupied by ponderosa pine forests, a shift toward early successional forest structure where trees persisted, and a dramatic decline in biomass. Management (including fire suppression, prescribed fire, and mechanical treatments) had some buffering effect on wildfire severity and burned area, but direct climate impacts on vegetation species outpaced any positive impacts of treatments on species composition, structure, and persistence. We infer that the resilience of Jemez Mountains dry forests – or their capacity to absorb perturbations but maintain key ecological relationships – was not maintained by conventional management activities under hot-dry future climate conditions, suggesting that alternative strategies may be necessary to maintain desired fire and forest patterns in this and similar southwestern landscapes.

Keywords: resilience, spatial modeling, southwest, Jemez, climate change, management

Bio: Rachel Loehman is a Research Ecologist with the USGS. Her work focuses on disturbance ecology, interactions of climate, wildland fire, and ecosystems, and fire effects.

S2.3. Evaluating ecological shifts across levels of wildfire suppression on US northern Rocky Mountain landscapes

Presenter: Kathy Gray, Professor of Statistics, California State University-Chico
Additional Authors: Keane, Robert, Research Ecologist, US Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

Davis, Brett, Ecologist, US Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory
Holsinger, Lisa, Ecologist, US Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

Wildfires are becoming major concerns across the western US because, over the last 20 years, they have increased in frequency, intensity and size in many areas, and fire suppression costs are increasing exponentially. A new approach to fire management may be to blend suppression with fuel treatments to create the resilient landscapes of the future. This would involve explicitly determining the various levels of suppression, wildland fire use, and fuel treatments needed to manage landscapes for ecological resilience. This study used the landscape model FireBGCv2 to simulate ecological dynamics on three landscapes in the US northern Rocky Mountains to determine tipping points in fire suppression levels under two climate (historical, future RCP8.5) and four fuel treatment scenarios (none, <3% treated per annum, 10% treated, and all lands treated every year). We used the historical range and variation (HRV) of conditions as the benchmark for resiliency, and compared all simulations to the HRV base case. We found that approximately 30-60% of fires can be suppressed (40-70% allowed to burn) and some landscapes will still be within HRV. Aggressive fuel treatment can raise that suppression level another 10-30% depending on the landscape. Findings from this effort indicate that each landscape must be individually evaluated to determine the right mix of wildfires, WFU, and fuel treatments.

Keywords: Ecological thresholds wildland fire use; FireBGCv2; landscape modeling

Bio: Kathy Gray currently resides in Chico, CA. She has worked in the Department of Mathematics and Statistics at CSU-Chico as a professor since 2007. She received her PhD in Statistics from the University of Montana in 2007.

S2.4. Can herbivore management be used to reinforce fuel reduction programs?

Presenter: Robert Riggs, Owner, Riggs Ecological Research
Additional Authors: Keane, Robert, USFS Rocky Mountain Research Station Missoula Fire Sciences Laboratory
Cimon, Norm, Owner, Info Synchronicity LLC

A landscape's response to shifting climate can depend on several mediating factors. Fire suppression, forest management, and large-herbivore grazing are such factors. Among those, herbivory can modify flash-fuel loads and succession pathways, and potentially fire behavior and vegetation patterns. Nevertheless, managers often have difficulty articulating a specific grazing regime to its expected consequences at spatial scales and time horizons usually considered relevant to strategic planning. In this presentation we use two FireBGCv2 simulation experiments to explore how different grazing regimes could function in an eastern Oregon landscape under contrasting regimes for fire suppression, forest management, and climate change. The first experiment crosses five grazing regimes (none, only wildlife, only livestock, wildlife and livestock, wildlife and 2x livestock) with three climate scenarios (Historical, A2 or B2 warming) and two fire-suppression regimes (none, 90% effective), but it excludes any timber harvest and/or prescribed burning. The second experiment crosses the same grazing and climate scenarios with two fuel-reduction strategies (none, selection harvest coupled with prescribed fire) while assuming constant 90% effectiveness for wildfire suppression. Thus, taken together the two experiments compare grazing-regime functions in a passive-reactive forest management context (Experiment I) to those functions

in a more pro-active forestry context (Experiment II). The first experiment: (1) confirms suppression of flash fuels and fire behavior by grazers at the fine scale of forest and grassland stands; (2) predicts those effects to be much greater in forest than in grassland; but also that (3) those effects are confirmed only when all three of the landscape's large herbivore populations are accounted for; and (4) while stand- and site-scale effects of grazing do "scale up" to affect the landscape's fire-return interval, those effects do not scale up to similarly affect the average size of fires, landscape-scale respiration, metabolism, or carbon dynamics over extended time. In the second experiment, the coupling of pro-active fuels reduction with constant fire-suppression effectiveness precludes most of the significant grazing effects seen in the first experiment. As implemented here, FireBGCv2 predicts that current grazing can suppress undergrowth fuels and modestly suppress fire behavior on forest sites. Barring any increase in the number of grazers (or an ability to mimic their population cycles), however, the dominant factors regulating the landscape's broader fire ecology remain the climate, fire-suppression effectiveness, and forest fuel management.

Keywords: climate, grazing, fire behavior, fuel reduction

Bio: Bob has degrees (BS, MS) in Wildlife Resrouces from University of Idaho, and a PhD in Range Science from Utah State University. His professional work has focused on describing and modeling wildlife habitats in managed forests and rangelands, notably for 16 years as a research biologist with Boise Cascade Corporation, and more recently as an independent researcher in his own firm.

S2.5. Evaluating future success of whitebark pine ecosystem restoration under climate change using simulation modeling

Presenter: Lisa Holsinger, Ecologist, US Forest Service Fire Sciences Lab
Additional Authors:

Major declines of whitebark pine throughout its range in western North America from the combined effects of mountain pine beetle (Dendroctonus ponderosae) outbreaks, fire exclusion policies, and the exotic disease white pine blister rust caused by the pathogen Cronartium ribicola, has spurred many restoration actions. However, projected future warming and drying may compromise the long-term success of today's restoration activities and potentially exacerbate the species' further decline. We tested the success of restoration treatments under a warming climate using a comprehensive landscape simulation model. The spatially explicit, ecological process model FireBGCv2 was used to simulate whitebark pine populations on two US Northern Rocky Mountain landscapes over 95 years under two climate, three restoration, and two fire management scenarios. Major findings from this modeling effort are that (1) whitebark pine can remain on some upper subalpine high mountain landscapes in a future climate albeit at lower basal areas (50% decrease), (2) restoration efforts, such as thinning and prescribed burning, are vital to ensure future whitebark pine forests, and (3) climate change impacts on whitebark pine vary by local setting. Whitebark pine restoration efforts will mostly be successful but only if future populations are somewhat resistant to WPBR. Results were used to develop general guidelines that address climate change impacts for planning, designing, implementing, and evaluating fine-scale restoration activities.

Bio: Lisa Holsinger is an ecologist specializing in geospatial analysis and fire modeling with a joint position at the RMRS Aldo Leopold Wilderness Institute and the Missoula Fire Sciences Lab.

S2.6. Assessing alternative management strategies for whitebark pine under future climate change

Presenter: Kathryn Ireland, Data Analyst, WWF Northern Great Plains Program
Additional Authors: Robert Keane, Supervisory Research Ecologist, USDA Forest Service Rocky Mountain Research Station, Missoula Fire Sciences Laboratory
Andrew Hansen, Professor, Department of Ecology, Montana State University
Lisa Holsinger, Ecologist, USDA Forest Service Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

Climate change is expected to lead to declines in many subalpine tree species and for some species this process is already underway. Whitebark pine (Pinus albicaulis), a keystone species in subalpine forests of the northern Rocky Mountains, is expected to be an early responder to climate change. Widespread mortality of whitebark pine from an outbreak of mountain pine beetles (Dendroctonous ponderosae) that began in 1999 is thought to be linked to unprecedented climate warming. Additionally, potential shifts in whitebark pine distribution using statistical models project a large loss of suitable habitat by 2100. Evaluation of the potential outcomes of different management alternatives under climate change is a critical need for management of whitebark pine, and other climate-vulnerable species. We developed three spatially-explicit management alternatives for whitebark pine in the Wind River Range of northeastern Wyoming, including: (1) no active management, (2) current management, and (3) climate-informed management which used projected climate suitability for WBP and competing tree species to place management actions. Using the FireBGCv2 simulation model, we evaluated the effect of these management alternatives on whitebark pine populations under projected future climate conditions. Management activities had negligible impact on maintenance of whitebark pine forests under future climate conditions. We found an overall decline in the area occupied by forest land cover across all future and management scenarios. But, whitebark pine expanded its distribution in the study area, especially under the hottest, driest climate scenario. Increases in whitebark pine distribution were primarily driven by seedlings and saplings, resulting in a landscape conversion towards younger size classes of trees under future climates. A pronounced increase in fire frequency appears to have led to loss of competing tree species and large classes of trees, resulting in establishment of whitebark pine seedlings but an inability to mature due to frequent burns.

Keywords: whitebark pine, climate change, management, Greater Yellowstone Ecosystem, FireBGCv2, simulation modeling

Bio: Katie Ireland is a data analyst with the World Wildlife Fund, where she works on grassland conservation within the Northern Great Plains. Prior to joining WWF, she worked as a research scientist in the Ecology Department at Montana State University. She received her PhD in Forest Science from Northern Arizona University and her master's in Ecology from Montana State University. Her work has focused on fire-climate-forest interactions. Today, she is going to talk about the work she did at Montana State University, where she used FireBGCv2 to evaluate management alternatives for whitebark pine communities in the GYE under future climate.

S3.1. Modernizing wildland fire performance measurement: A brief history and future directions
Presenter: David Calkin, Research Forester, USFS, RMRS
Additional Authors:

A common saying around performance measurement is what you measure is what you get. To date performance measurement within US federal fire management has been limited by a lack of quality data and analytics. Further existing performance measures have typically not aligned with stated fire management objectives. The 2014 Quadrennial Fire Review reiterated many previous analyses by independent consultants and governmental oversight agencies simply stating that “The FS and the DOI lack sufficient data, with sufficient fidelity and reliability to inform strategic and programmatic decision making”. This lack of information challenges the Agencies ability to demonstrate to the American taxpayers that wildfire suppression spending represents a wise and efficient investment. In this presentation I will review existing federal fire management performance measures such as the ‘stratified cost index’ and initial attack success to demonstrate how current measures neither promote improved effectiveness nor facilitate organizational learning. I will then discuss characteristics of a performance measurement system that better align decisions, actions and outcomes with organizational fire management mission and objectives and describe current efforts to develop and promote improved measures.

Keywords: Performance Management

Bio: Dave is the team lead of the Fire Management Science group (https://www.fs.fed.us/rmrs/groups/wildfire-risk-management-team) of the National Fire Decision Support Center working to improve risk based fire management decision making through improved science development, application, and delivery. Dave’s research incorporates economics with risk and decision sciences to explore ways to evaluate and improve the efficiency and effectiveness of wildfire management programs.

S3.2. Leveraging evidence-based management and key performance indicators to improve responder safety
Presenter: Matthew Thompson, Research Forester, Rocky Mountain Research Station
Additional Authors:

This presentation will highlight new methods to quantify responder exposure and their translation into key performance indicators (KPIs). KPIs are widely used in strategic planning and management settings, and serve as measures of success in areas that are critical for achieving organizational objectives. The KPIs highlighted in this presentation fill critical information gaps and provide the evidence and type of accountability loops necessary for effective risk management and continual improvement. The discussion will focus primarily on suppression actions, and attempt to illustrate how the Forest Service could develop a more robust set of KPIs related to the safety and effectiveness of its wildland fire response operations.

Bio: Research Forester, Human Dimensions Program, Rocky Mountain Research Station, USDA Forest Service

S3.3. Aviation analytics to inform strategic planning and risk management in large fire support
Presenter: Crystal Stonesifer, Ecologist, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: Calkin, Dave, Research Forester, USDA Forest Service, RMRS
Thompson, Matthew, Research Forester, USDA Forest Service, RMRS

As a part of the Agency's Life First initiative, US Forest Service employees who engage in fire management activities were asked to identify areas of unnecessary exposure. A key area of concern that emerged from the field was exposure related to the Agency's use of aviation resources in fire management. Research has demonstrated that aviation assets, particularly large airtankers, are frequently used outside of the range of conditions where they are considered to be most effective; this suggests that airtanker use in large fire support is often a reactionary response to increased fire activity when it is no longer safe for ground resources to engage, or the effectiveness of ground resources is diminished. In 2017, the Washington Office led an effort to form a Risk Management Assistance Team (RMAT) to help guide fire managers as they work to implement the findings of Life First by addressing unnecessary firefighter risk. Today, we will provide a high-level overview related to the RMAT mission and fire season accomplishments, including additional focus on RMAT efforts to track aviation use and associated exposure in real-time. This work demonstrate the wide-ranging utility of real-time tracking of aviation actions and strong potential for these data to help better inform risk-based decisionmaking related to aviation use in fire management.

Keywords: airtankers, risk management, firefighter exposure

Bio: Crystal Stonesifer is an Ecologist with the USDA Forest Service, Rocky Mountain Research Station in Missoula, MT. She graduated from the University of Montana with an MS in Resource Conservation and has been with the station for 7 years, and her primary areas of research interest and expertise center around fire management, including related data systems, aviation use, decision-support, and risk management.

S3.4. The Wildfire responder triangle: integrating safety, probability of success, and values at risk for operational response.
Presenter: Jessica Haas, Ecologist, USDA Forest Service Rocky Mountain Research Station
Additional Authors: Dunn, Christopher, Forest Economist, Oregon State University
O'Connor, Kit, Ecologist, USDA Forest Service RMRS
Thompson, Matthew, Research Forester, USDA Forest Service RMRS
Calkin, David, Research Forester, USDA Forest Service RMRS

Effective fire-fighting response should be assessed through three primary factors: 1) hazards to firefighter and public safety, 2) the values at risk, and 3) the probability of a successful containment strategy. These three factors can be thought of as a fire responder triangle. We demonstrate the utility of the fire responder triangle through a case study of the Park Creek and Arrastra Fires in Montana, USA. We integrated the Potential Control Locations model, a regional wildfire risk assessment and snag hazard locations from broad scale bug kill to develop the prototype for a spatially explicit wildfire responder triangle. We show how this triangle varies under different wildfire management strategies and how it can be incorporated into incident safety assessments, long term plans and strategic operation planning.

Bio: Jessica R Haas is an ecologist with the US Forest Service Rocky Mountain Research Station, where she has worked for the past nine years on wildfire and natural hazard mitigation science. Her work with the Rocky Mountain Research Station has been used nationally to support wildfire and natural hazard mitigation efforts for the major land managers such as the US Forest Service, BLM, The Nature Conservancy, as well as various state forestry departments throughout the western United States. She received her Masters of Science degree in Resource Conservation in 2010 from the University of Montana, where she studied the vulnerability of national parks to climate change and ex-urban development.

S3.5. The spatial and temporal dynamics of responder exposure to snag hazards following mixed-severity fires

Presenter: Christopher Dunn, Research Associate, Oregon State University
Additional Authors: O'Connor, Christopher, PhD, Ecologist, Rocky Mountain Research Station, US Forest Service, Missoula, MT, USA
Calkin, Dave, PhD, Research Forester, Rocky Mountain Research Station, US Forest Service, Missoula, MT, USA
Reilly, Matthew, PhD, Post-doctoral Scholar, Humboldt State University, Arcata, CA, USA
Thompson, Matthew, PhD, Research Forester, Rocky Mountain Research Station, US Forest Service, Missoula, MT, USA

The complexity of the fire environment has increased dramatically in recent decades because of historical management strategies, a changing climate, and expanding wildland urban interface. As the fire management system looks to new strategies for overcoming the wildfire paradox and meeting the challenges of the contemporary fire environment, minimizing risk to fire responders becomes increasingly important. Snags are one of a multitude of hazards encountered routinely by fire responders, and risk of injury or death has increased commensurate with an increase in snag abundance in recent decades as more area burns at greater severity in landscapes with higher tree densities. To characterize this exposure, we modeled the spatial and temporal dynamics of snags for a 50-year period across six burned landscapes. We created spatially explicit post-fire snag lists from pre-fire tree lists, classified burn severity maps, and probability of mortality models. Temporal snag dynamics were then estimated using the NecroDynamics model for each pixel across the burned landscapes. At each annual time step, we classified snag hazard into one of four hazard ratings, and then summarized this hazard across space and time. Here we summarize key findings within the context of one of several metrics we are integrating into a responder exposure index (REI) as we expand the available spatial data layers that support improved risk-informed decision-making.

Keywords: snag hazard, responder exposure, wildfire risk, fire management

Bio: Christopher Dunn is currently a post-doc with Dave Calkin's lab at the Rocky Mountain Research Station in Missoula, Montana but operates out of the College of Forestry at Oregon State University. For seven years between his undergraduate and graduate studies, he worked in fire suppression and fuels management, and now integrates these experiences into his scientific research often bridging the gap between fire ecology and management. Today he researchers the safety and effectiveness of large fire management, developing new tools supporting strategic land and fire management strategies that improve the safety and effectiveness of wildfire response.

S3.6. Previous burn scars- a blessing or a curse? Responder mobility as a hazard in the post-fire environment.
Presenter: Christopher O'Connor, Forest Ecologist, USDA Forest Service RMRS
Additional Authors: Dunn, Christopher, Research Associate, Wildfire Ecology and Management, Oregon State University
Reeves, Matthew, Research Ecologist, US Forest Service Human Dimensions Program, Rocky Mountain Research Station
Lankston, Robb, Analyst, USFS Rocky Mountain Research Station

Previous burn scars are often considered useful landscape features for wildfire containment. Reduced quantities and altered spatial arrangements of surface fuels in recently burned areas can slow or impede the growth of subsequent fires but may also pose a series of safety challenges for fire responders on the ground. While standing snags are an obvious safety concern, often overlooked are the surface shrub components that can severely hinder mobility, obscure line of sight, and when fully cured may produce fire behavior more severe than the pre-fire condition. The type, density, and rate of shrub growth within burn scars is highly dependent on fire severity, reproductive strategies, species dynamics, and biophysical site conditions. In this study we use the Rangeland Vegetation Simulator to develop a 20-year spatial and temporal model of post-fire shrub growth dynamics for three species of concern in a series of burn scars in central Oregon. Model results demonstrate the variability in shrub spatial distribution, height, and biomass as a function of time since fire. These results are one component of a spatially explicit responder exposure index (REI) that is part of a suite of new tools designed to support risk-informed decision making for fire planning and response.

Keywords: Fire responder hazards, burn scar, shrub growth

Bio: Dr. Kit O'Connor is an ecologist with the Wildfire Risk Management Group at the US Forest Service Rocky Mountain Research Station. His current work is focused on developing spatially explicit risk-based tools that support integrating operational fire response with sustainable landscape planning, fire responder safety, and efficient resource use. His research background in disturbance ecology draws from forest ecology, fire science, entomology, dendrochronology, ecological risk assessment and spatial analysis and modeling. He holds a BS from Penn State University, an MS from the University of Quebec at Montreal, and a PhD from the University of Arizona.

S4.1. What We Already Know About the Social Components of Wildfire Risk
Presenter: Sarah McCaffrey, Research Social Scientist, USFS - Rocky Mountain Research Station
Additional Authors: Butler, William, PhD, Associate Professor, Florida State University
Essen, Maureen, Social Science Analyst, USFS - Rocky Mountain Research Station

Studies to understand the social components of wildfire risk are not new; however, studies centered on understanding how the variety of individuals and organizations exposed to wildfire risk can better co-manage this risk are limited. The Co-management of Wildfire Risk Transmission (CoMFRT) project aims to highlight ways to better co-manage this risk among the diversity of stakeholders involved. This cross-scalar project has a number of components, many rely on collecting new data to address associated research questions and objectives. The literature synthesis is intended to contribute to this team-based project differently in two ways: 1) provide professionals, managers, and agency administrators clarity on what is already known in existing literature on specific related topics and 2)

inform project data collection efforts especially related to interdisciplinary project integration. The presentation will discuss preliminary findings from the two main sections of the synthesis, what is known to date about 1) community wildfire risk mitigation and 2) cross-boundary environmental or natural resource management. It will conclude with observations of research gaps found and potential research needs identified. Finally, recommended questions to guide future research in each of the categories and for the CoMFRT project will be shared.

Keywords: Wildfire risk, social science, synthesis

Bio: Sarah McCaffrey, Ph.D. is a Research Forester for the USDA Forest Service. Her research focuses on the social aspects of fire management. This work has included projects examining wildfire risk perception, social acceptability of prescribed fire and thinning, incentives for creation and maintenance of defensible space, and social issues that occur during and after fires such as evacuation decision making and agency-community interaction during fires. More recent work examines how stakeholders conceive of and move toward becoming a fire adapted community. She received her PhD in Wildland Resource Science in 2002 from the University of California at Berkeley.

S4.2. Co-producing research and responses to address wildfire risk
Presenter: Carina Wyborn, Research Associate, University of Montana
Additional Authors:

Effective strategies to address wildfire risk draw on a range of interdisciplinary expertise, and must be appropriately tailored to the context of use. Academic research on wildfire risk will only go so far if it remains disconnected from those who seek to use this research to improve their efforts in policy and management. Knowledge co-production is an iterative research process that actively engages those with a stake in a problem to shape knowledge and values in order to support policy and management. Co-production processes aim to create knowledge tailored for use in a specific context, while remaining legitimate, rigorous and relevant. This paper will present a brief overview of the theory and practice of co-production, pointing to ways that this approach can be used to support efforts to prepare for the future of wildland fire. It will then outline a case study of co-production, to illustrate how this approach is being applied by the Co-Management of Wildfire Risk Transmission project to investigate the social dimensions of wildfire risk transmission. The paper will highlight how the research team is working with partners within the US Forest Service and with local stakeholders to develop a shared understanding of the barriers and potential strategies to address wildfire risk at a landscape scale. It will highlight the opportunities and challenges presented by a co-production approach, and will outline lessons learned so far by the research team.

Keywords: science engagement; co-production; science policy; knowledge to action

Bio: Carina holds a dual position as a research associate in the College of Forestry and Conservation at the University of Montana, and as the research advisor for the Luc Hoffmann Institute. She is an interdisciplinary social scientist with background in science and technology studies, and a focus on climate adaptation and biodiversity conservation.

S4.3. Cross-Boundary and Adaptive Governance to Facilitate Adaptation to Wildfire Risk
Presenter: Maureen Essen, Social Science Analyst, USFS - Rocky Mountain Reserach Station
Additional Authors: Yung, Laurie, PhD, Professor of Natural Resource Social Science, University of Montana

Wyborn, Carina, PhD, Research Associate, University of Montana

Governance of social-ecological systems is a complex web of formal and informal institutions, organizations, actors, laws, rules, policies, and social norms. To further complicate the picture, governance arrangements vary spatially, with a diverse suite of options operating in different landscapes, at a variety of scales focusing on different desired states. Often times, governance options can not only change the social landscape, but also the biophysical landscape.

This presentation will discuss an on-going multi-team based project, the Co-management of Wildfire Risk Transmission (CoMFRT), a research-management partnership aimed at understanding options to decrease wildfire risk by facilitating adaptation and co-management of wildfire in different types of fire-prone communities. The paper will outline governance related project components intended to identify conditions and activities that support and undermine adaptive governance and cross-boundary co-management of wildfire to better support the National Cohesive Strategy. Research design, including methodology, research questions, and governance related outputs will be shared. This effort will be integrated with a number of other CoMFRT project components to improve understanding of community resilience to wildland fire, safely allow more fire on the landscape, and reduce the cost and risk of fire management.

Keywords: Wildfire risk, social science, governacne, adaptation, Cohesive Strategy

Bio: Maureen (Mo) Essen is a social science analyst at the USFS Rocky Mountain Research Station office in Missoula, MT. She manages and works on projects related to the governance of public lands and social-ecological systems. The bulk of her current work centers on adaptive approaches to wildfire management.

S4.4. Wildfire Collaboration Networks: An Empirical Study of Network Governance of Wildfire Risk in North Central Washington

Presenter: Cody Evers, PhD Student, Portland State University
Additional Authors: Jacobs, Derric; PhD; Research Associate; Portland State University
Nielsen-Pincus, Max; PhD; Assistant Professor, Portland State University

Wildfire risk management includes a broad range of organizations, agencies, businesses, and other social groups. Each is confined by jurisdictional boundaries, technical capacity, and mission scope. Given the scale and diversity of biophysical and social factors that contribute to wildfire risk, organizations must collaborate in order to effectively reduce risk. While beneficial in principle, collaboration is not cost-free. Seeking out and maintaining new collaborative opportunities require time, money, trust, and a common framing of wildfire risk and its drivers. The Cohesive Strategy promotes collaboration and strategic alignment between risk management actors in order to achieve wildfire management goals. Nonetheless, there is only limited empirical work that systematically describes these organizational actors, where they work, and how they collaborate together. This is particularly true at the scale at which most risk management actions need to occur in order to address increased risk from wildfire. In this presentation, we present preliminary results of an organizational survey that seeks to document the 'network governance' of wildfire risk in North Central Washington, a fire-prone region that has an established history of wildfire co-management and collaboration. This survey represents the first in a series of regional assessments that will continue over the next year. Early results paint a system notable for its breadth of actors.

The density of collaborative interactions varies by social sector and geographic area. This work reveals both synergies and gaps in existing the risk management system.

Keywords: risk management; collaboration; network governance; social network analysis

Bio: Cody Evers is a doctoral student and NSF IGERT research fellow at Portland State University in the Department of Environmental Science and Management. He has been involved in wildfire research for nearly a decade through projects funded by the NSF, USDA, and JFSP. His dissertation uses social-ecological network modeling to evaluate scale-matching between the social and ecological aspects of wildfire risk governance.

S4.5. Network analysis of wildfire transmission and implications for risk governance

Presenter: Alan Ager, Research Forester, USFS, Missoula Fire Science Lab
Additional Authors: Barros, Ana, Research Associate, Oregon State University
Day, Michelle, Research Associate, Oregon State University
Evers, Cody, Research Associate, Portland State University

We characterized wildfire transmission and exposure within a matrix of large land tenures (federal, state, and private) surrounding 56 communities within a 3.3 million ha fire prone region of central Oregon US. Wildfire simulation and network analysis was used to quantify the exchange of fire among land tenures and communities and analyze the relative contributions of human versus natural ignitions to wildfire exposure. Among the land tenures examined, the area burned by incoming fires averaged 57% of the total burned area. Community exposure from incoming fires ignited within from surrounding land tenures accounted for 67% of the total area burned. The number of land tenures contributing wildfire to individual communities and surrounding WUI varied from 3 to 20. Community firesheds, i.e. the area where ignitions can spawn fires that can burn into the WUI covered 40% of the landscape, and were 5.5 times larger than the combined area of the community and WUI. For the major land tenures within the study area, the amount of incoming versus outgoing fire was relatively constant, with some exceptions. The results provide a multi-scale characterization of wildfire networks within a large, mixed tenure and fire prone landscape, and illustrate the connectivity of risk between communities and the surrounding wildlands. We use the results to discuss potential conflicts among social and ecological goals in US federal wildland fire policy. We trace these conflicts to scale mismatches in local wildfire risk policy and governance that result from disconnected planning systems and disparate fire management objectives among the large landowners (federal, state, private) and local communities. Local and regional risk planning processes can adopt our concepts and methods to better define and map the scale of wildfire risk from large fire events and incorporate wildfire network and connectivity concepts into risk assessments.

Bio: Alan Ager is a Research Forester with the Missoula Fire Science Lab.

S4.6. Demographic analysis of transboundary wildfire exposure in the western US

Presenter: Palaiologos Palaiologou, Geographer, USDA Forest Service International Visitor Program: Oregon State University
Additional Authors: Ager, A. Alan, Research Forester, USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, USA
Evers, Cody, PhD student, Portland State University, Department of Environmental Sciences and Management, USA

Nielson-Pincus, Max, Assistant Professor, Portland State University, Department of Environmental Sciences and Management, USA
Ringo, Chris, Faculty Research Assistant, Oregon State University, Department of Crop and Soil Science

Disentangling the problem of managing transboundary wildfire exposure requires new modeling tools and approaches that consider the social context of fire-prone areas and the biophysical risk. Large federal landowners need to understand population demographics to design investment strategies for reducing transboundary risk. Vulnerable populations have limited capacity for reducing wildfire hazard in the wildland-urban interface. This research is aimed at improving the efficiency of existing hazardous fuel investment by considering both social and biophysical factors in the prioritization of investments. Three study areas (Wenatchee, WA, Central Sierras, CA, and Santa Fe, NM) were used to build social vulnerability profiles that considered social drivers that affect community investments, adaptive capacity and population exposure. FSim fire behavior simulations were used to estimate large-scale national forest community exposure hotspots. Biophysical risk patterns were differentiated between human and natural caused ignitions. Social indicators were derived from American Census Survey databases at block group level and used to estimate a composite Social Vulnerability Index through principal components. Results were used to analyze how different land tenures affected communities and block groups with different social vulnerability. In addition, we performed a coupled examination of individual social variables with biophysical risk to understand if different social conditions relate to high exposure and fire transmission. The goal of this research is to provide new methods for prioritizing community wildfire protection investments to restore resilient landscapes, reduce suppression costs, and leverage fuel management and firewise activities investments.

Keywords: Transboundary wildfire exposure, Coupled Natural and Human Systems, Social vulnerability

Bio: Palaiologos Palaiologou is a Geographer with a Ph.D. in Wildfire Effects and Behaviour, from the University of the Aegean, Department of Geography, Greece. His research interests include wildfire effects and coupled human and natural systems for wildfire risk governance. He has been involved in a number of EU-funded research projects on forest fires, dealing with integration of new technologies into wildfire suppression. Since 2016, he lives in the USA, working as a visiting scholar for the International Visitor Program of the US Forest Service, invited by Dr. Alan Ager, in collaboration with Portland State University and Oregon State University.

S5.1. Fire regime shifts under climate change depend on the timeframe and ecological context

Presenter: Sean Parks, Research Ecologist, Aldo Leopold Wilderness Research Institute, Rocky Mountain Research Station, US Forest Service
Additional Authors:

Fire regimes will undoubtedly respond to a changing climate. Longer fire seasons and more frequent and extreme drought are expected as the climate warms. When considering the existing spatial distribution of vegetation and fuel loads, these changes will likely result in increased area burned and fire severity in the near-term for nearly all vegetation types and biophysical settings. Over longer timeframes, however, climate change will alter species distributions and rates of biomass accumulation (i.e. productivity). Such changes strongly suggest that "more frequent and more severe fire" is a generalization that is unlikely to play out in many regions over longer timeframes.

For example, ecosystems that historically experienced infrequent, stand-replacing fire (e.g. lodgepole pine forests) may exhibit increased fire frequency, but fire severity may decrease as species establish that are that are more suited to the emerging climate (and the increased fire frequency). Also, some ecosystems that historically experienced frequent surface fire (e.g. dry pine forests near the forest/shrub ecotone) may exhibit a decrease in fire frequency due to reduced productivity and the disturbance regimes associated with encroaching shrub communities. These examples highlight that expected shifts in fire regimes are highly dependent on the timeframe of interest and the ecological context. Given that some ecosystems are fairly stable even under a warming climate, shifts in fire regimes and vegetation characteristics may not occur until triggered by a disturbance event such as a stand-replacing fire or severe insect outbreak. Consequently, the exact timing and magnitude of fire regime shifts is somewhat ambiguous for any given spatial unit (i.e. stand or pixel), but generalizations applicable to large geographic areas are possible and will be highlighted in this presentation.

Keywords: Altered fire regimes; climate change

Bio: Sean is a Research Ecologist with the Aldo Leopold Wilderness Research Institute, Rocky Mountain research Station in Missoula, MT. He is interested in spatial interactions between past wildland fire and subsequent fire events. He is specifically interested in how past fires regulate subsequent fires in terms of fire size, severity, ignition potential, etc. Sean is also keenly interested in better understanding how climate shapes fire regimes, which is particularly relevant given that climate change will inevitably result in changes to fire regimes.

S5.2. Fire During High-velocity Climate Change Can Trigger Ecological Transformation
Presenter: Shelley Crausbay, Lead Scientist, Conservation Science Partners
Additional Authors: Higuera, Philip, Associate Professor, University of Montana

In the 21st century, we are experiencing increased risk of fire, bigger fires, more extreme fires, interactions with other disturbances, and altered post-disturbance climate. Historically, disturbances like fire have catalyzed rapid ecological change in western forests by causing widespread mortality and initiating successional pathways that ultimately arrive back at the pre-fire forest type. Disturbance can, alternatively, initiate a new successional pathway that does not lead back to the pre-fire forest but instead shepherds in ecological transformation – a persistent state change in ecosystems. Understanding and predicting when and where fire can initiate transformation is an important research and management goal. We used paleoecological techniques to ask whether forested ecosystems occurring in the Pacific Northwest of North America since glacial retreat were resilient to fires or whether fires initiated ecological transformation. We studied forest history with sediment cores from small hollows located ~1 km apart in the Puget Lowland ecoregion of western Washington, USA. We developed high-resolution stand-scale paleorecords of vegetation and fire that span nearly the past 14,000 yr to study how fire was associated with transformation or resilience in forest vegetation at the stand scale (1–3 ha). Rate of change in pollen/spore assemblages was similarly low across sites, but at both sites, rates of change increased significantly following fire events. During times of low climate velocity, forest composition was resilient to fires, which initiated successional pathways back to the dominant vegetation type. In contrast, during times of high climate velocity (the early Holocene) forests were not resilient to fires, and large-scale ecological transformations were triggered. These records provide clear evidence that disturbance, in the form of an individual fire event, can be an important catalyst for rapid transformation, accelerating the vegetation shifts expected with ongoing climate trends. The catalyzing role of fire at times of high climate velocity arises because fire accelerates population turnover when climatic conditions are unfavorable for seedling establishment of dominant species. These inferred mechanisms have broad relevance (i.e., to any ecosystem where high-severity disturbances are possible), and three criteria are met: the life span of the dominant species exceeds the time scales of climate change; mature individuals can persist through climate conditions under which germination of the same species is unlikely; and propagules are available from species that are better suited to post-disturbance climate. Paleoecology can strengthen our understanding of how fire can initiate a persistent ecological transformation.

Bio: Shelley is a plant community ecologist and paleoecologist. She is a Lead Scientist at Conservation Science Partners. Her work focuses on 1) ecological transformation with climate change, 2) how water availability determines ecological patterns, 3) how drought and other disturbances influence species turnover, and 4) stakeholder engagement to make science actionable.

S5.3. Climate-induced variations in global severe fire weather conditions
Presenter: W. Matt Jolly, Research Ecologist, USFS, RMRS, Fire Sciences Laboratory
Additional Authors: Freeborn, Patrick, Research Physical Scientist, USFS, RMRS, Fire Sciences Laboratory

Surface weather conditions are a major drivers of wildland fire size and intensity. Climatic changes over the last four decades are thought to be influencing these burning conditions both regionally and globally but few studies have comprehensively explored how climatic changes may be affecting fire weather severity during the fire season. Here we explore how these climatic changes impact two metrics of wildland fire weather: the weather-mediated length of the fire season and the within-season fire weather severity. We show that these metrics are strong predictors of burned area across the Western US and other fire-adapted global ecosystems. We leverage these two metrics to assess climatic changes across the globe in an effort to map areas that are experiencing significant changes in both fire weather season length and fire weather severity. These results will help us better understand how climatic variations are manifesting themselves as tangible changes in observed fire activity and it will improve our understanding of the complex interactions between long-term climatic changes, short-term weather variations and wildland fire-induced carbon cycle feedbacks.

Keywords: Climate, Fire, Global

Bio: William Matthew “Matt” Jolly is a Research Ecologist in the Fire, Fuel and Smoke Science Program of the US Forest Service, Fire Sciences Laboratory in Missoula, MT. He received a BA in Environmental Science from the University of Virginia and a PhD in Forestry from the University of Montana. He is also the project administrator for the research and development team of the Wildland Fire Assessment System (WFAS) and is continually evaluating and developing tools for landscape-scale fire danger assessment. His research explores how wildland fuel characteristics vary across space and time and how these variations impact wildland fire potential. Ultimately, his work will lead to improved wildland fire danger and behavior prediction tools.

S5.4. Effect of reduced warm-season cloud cover on aridity and fire danger in coastal California
Presenter: A. Park Williams, Bioclimatologist, Lamont-Doherty Earth Observatory of Columbia University
Additional Authors: Pierre Gentine, Department of Earth and Environmental Engineering; Columbia University
Max A. Moritz, Bren School of Environmental Science and Management; University of California
Dar A. Roberts, Department of Geography; University of California, Santa Barbara

In coastal California, cloud shading is critical to drought-limited and flammable ecological systems because it reduces atmospheric water demand during the rainless warm season. Over the past 40-70 years, cloud observations from many coastal Californian airfields indicate major declines in warm-season (May–September) daytime cloud frequency, which appear to be linked lifting of the altitude of condensation due to the urban heat island effect. At Burbank, Santa Monica, and Santa Ana Airports, which are positioned adjacent to flammable coastal mountains that ring Los Angeles, warm-season daytime cloud frequency has declined by approximately half since the early 1970s. Reductions in daytime cloud frequency have caused increases incoming solar radiation, evaporative demand, and, presumably, fire danger, but these effects have not been quantified. We used 10 years of sub-hourly meteorological, surface radiation, and cloud observations (N > 101,000) at a coastal site in southern California to statistically model the effects of changes in cloud cover on warm-season evaporative demand.

Forcing our model with cloud observations from 31 coastal airfields throughout California, including several near wildlands regularly at fire risk, we estimate that reduced cloud frequency and increased cloud-base height since the early 1970s significantly enhanced warm-season daytime solar radiation and atmospheric water demand at the majority of sites, especially in the greater Los Angeles and San Diego areas. At Burbank, Santa Monica, and Santa Ana Airports, the increases in warm-season daytime solar radiation and atmospheric moisture demand (as represented by Penman-Monteith reference evapotranspiration) were 17–31 W m-2 and 3–6%, respectively. Within the coastal grass and chaparral ecoregions of central and southern CA, annual wildfire area was significantly and positively correlated with summer atmospheric water demand during 1984-2017 and an increase in summer atmospheric water demand of just 5% corresponded to a tripling in wildfire area. Reduced warm-season cloud cover in and around coastal California's large cities has very likely had important consequences for ecological systems and fire danger over the past half century that have been under-recognized and deserve further study.

Bio: I am a bioclimatologist whose research straddles the fields of climatology and ecology. I am especially interested in the climatological causes and the ecological consequences of drought. My research aims to improve understanding of drought and its effects on terrestrial systems, including forests, the carbon cycle, agriculture, and humanity. My ultimate goal is to advance scientific knowledge in ways that are relevant to policy makers and future scientific endeavors, and also interesting to the public and other scientists.

S5.5. Reexamining the drivers of recent wildfire activity in the Pacific Northwest U.S.
Presenter: Zachary Holden, Scientist, U.S. Forest Service Region 1
Additional Authors: Swanson, Alan, Data Scientist, School of Community and Public Health Sciences, University of Montana
Luce, Charles, Research Hydrologist, U.S. Forest Service Rocky Mountain Research Station
Jolly, William, Research Ecologist, Missoula Fire Sciences Laboratory, Missoula, MT

Maneta, Marco, Assistant Professor, Department of Geosciences, University of Montana
Parsons, Russell, Research Ecologist, Missoula Fire Sciences Laboratory, Missoula, MT
Affleck, David, Department of Forestry and Conservation, University of Montana

Wildfire increases in the Pacific Northwest United States (PNW) have generally been attributed to warming temperatures, either through effects on winter snowpack or summer evaporation. However, near surface air temperature and evaporative demand are strongly influenced by moisture availability and, these interactions and their role in regulating fire activity have never been fully explored. We analyze relationships between wildfire area burned and hydroclimatic predictors using newly developed gridded snow, temperature and soil water balance datasets. We show that previously unnoted declines in summer precipitation across large portions of the PNW are strongly associated with burned area variations. The number of wetting rain days (WRD) during the fire season strongly regulated the temperature and subsequent evaporative demand (VPD) previously implicated as a driver of annual wildfire area burned. We decompose the relative influence of declining snowpack, rising temperatures and declining precipitation on observed fire activity increases. After accounting for interactions, the net effect of interannual rain-free periods wildfire area burned was substantially larger than the influence of both winter snowpack or VPD. Our findings suggest that precipitation during the fire season exerts the strongest control on burned area either directly through its wetting effects or indirectly through feedbacks to VPD. If these trends persist, decreases in summer precipitation and the associated summertime aridity increases would lead to more burned area across the Northwest US with far-reaching ecological and socio-economic impacts.

Keywords: Climate, wildfire area burned, climate change

Bio: Zack Holden is scientist for Region 1 of the U.S. Forest Service and affiliate faculty in the Geography department at the University of Montana. He received his PhD in natural resource management from the University of Idaho in 2008. His current work focuses on modeling mountain weather and climate and their influence on wildland fire ecology and management.

S5.6. Extensive Burning Reduces Future Landscape Flammability in North American Boreal Forests: Implications for Anticipating 21st-Century Fire-Regime Shifts

Presenter: Adam Young, Research Assistant & NASA Research Fellow, Dept. of Forest, Rangeland, and Fire Sciences, University of Idaho
Additional Authors: Higuera, Philip, Associate Professor, Dept. of Ecosystem and Conservation Sciences, University of Montana
Abatzoglou, John, Associate Professor, Dept. of Geography, University of Idaho
Boschetti, Luigi, Associate Professor, Dept. of Natural Resources and Society, University of Idaho
Duffy, Paul, Environmental Statistician, Neptune and Co, Inc.
Hu, Feng Sheng, Harry E. Preble Dean, College of Liberal Arts and Sciences, University of Illinois at Urbana-Champaign

In North American boreal forests, annual area burned is projected to increase by 50-300% in direct response to 21st-century climatic change. These and other projections of climatically driven fire-regime changes, however, generally do not account for post-fire successional dynamics (e.g., reduced biomass, deciduous dominance for years to decades), which can have important impacts on future landscape flammability. In this study, we characterized the relative influence of tree cover on annual area burned, and then modeled post-fire changes in tree cover over years to decades to

understand how post-fire vegetation changes influence future burning. Specifically, we constructed two sets of predictive models at a 1000 km2 spatial resolution for North American boreal forests (study area = 4.74×10^6 km2): (1) a fire model predicting annual area burned as a function of summer climate (i.e., P-PET and temperature) and percent tree cover, and (2) a tree-cover model predicting changes in tree cover from 1-65 years after fire. To quantify fire-climate-vegetation linkages, we used a combination observational climate (CRU), a remote sensing product of tree cover (MOD44B), and fire perimeters from Canada and Alaska (1950-2015), along with statistical modelling tools including linear modelling and boosted regression trees.

Our fire models had relatively strong predictive power, capturing on average 90% (SD = 17%) of observed annual area burned exceeding 100 km2 from 2002-2016. Total summer moisture deficit (i.e., P-PET) had the highest relative influence (bootstrapped mean = 43%, SD = 9%) among all explanatory variables, followed by tree cover, which had an average relative influence of 18% (SD = 7%). The nature of the relationship between tree cover and annual area burned was also highly nonlinear, with a notable decrease in annual area burned when tree cover is less than 15-25%. Our post-fire vegetation models highlight reduced tree cover of 6-22% in the first five years following extensive burning (i.e., >100 km2), with recovery to pre-fire conditions occurring between 30-40 years. Such reductions in tree-cover due to extensive burning could shift some areas below the 15-25% tree-cover threshold, suggesting fire-vegetation feedbacks can significantly moderate the direct link between climate and fire activity in the future. Together, these findings suggest a possible negative feedback between climatically induced increases fire activity and post-fire vegetation change, and future work will focus on linking the fire and tree-cover models to generate future projections of fire activity that explicitly account for post-fire vegetation changes.

Keywords: Climate change, fire regimes, boreal forests

Bio: Adam is a Ph.D. Candidate in the Department of Forest, Rangeland, and Fire Sciences at the University of Idaho, Moscow, Idaho. Adam's dissertation work is focused on understanding how climate and vegetation control past, present, and future fire regimes in boreal forest and tundra ecosystems of North America.

S5.7. Analyzing Risk of Regeneration Failure in the Managed Boreal Forest of North-Western Quebec

Presenter: Tadeusz Splawinski, Postdoctoral research scientist, Université du Québec en Abitibi-Témiscamingue
Additional Authors: Cyr, Dominic, Biologist, Natural Resources Canada, Canadian Forest Service
Gauthier, Sylvie, research scientist, Natural Resources Canada, Canadian Forest Service
Jette, Jean-Pierre, forestry engineer, Direction de l'aménagement et de l'environnement forestiers Ministère des Forêts, de la Faune et des Parcs
Bergeron, Yves, Professor, Chaire industrielle en aménagement forestier durable, Université du Québec en Abitibi-Témiscamingue

Changes in fire regime can affect the post-disturbance regeneration potential of boreal forest tree species, thereby modifying successional pathways and leading to changes in abundance and composition. This could adversely affect the sustainability of forest management, especially in regions currently characterized by a short fire cycle and low productivity. We model the effect of current and climate-induced changes in fire cycles and harvesting rate on the regeneration failure potential of pure black spruce and jack pine stands in a region of North-western Quebec characterized by a high annual area burned and where fire activity is projected to strongly increase. Simulations were carried out over a 50-year period under three reproductive maturity thresholds per species. Results show a progressive increase in the area affected by natural regeneration failure over the course of the simulation period under both climate scenarios. Changes in fire cycle had the greatest effect on the regeneration failure rate, followed by age at maturity and harvest rate. We suggest that proactive forest management practices and strategic planning that includes fire risk can reduce the likelihood of regeneration failure following fire. This includes intensive stand management such as plantation establishment and pre-commercial thinning, and retention strategies following harvest logging.

Keywords: Black spruce, jack pine, regeneration failure, fire cycle, climate change.

Bio: Dr. Tadeusz B. Splawinski is a postdoctoral research scientist at the Université du Québec en Abitibi-Témiscamingue, Canada. His background and research interests include: forest ecology, post-fire regeneration dynamics of boreal tree species, silviculture, natural resource management, systems modelling, and geology.

S5.8. Simulation of extreme wildfire events and impacts across spatial and temporal scales with statistical and dynamical models

Presenter: A. LeRoy Westerling, Professor, University of California, Merced
Additional Authors: Hurteau, Matthew, Professor, UNM
Jones, Gavin, Postdoctoral Researcher, U Wisconsin
Keyser, Alisa, Postdoctoral Researcher, UNM
Liang, Shuang, PhD Student, UNM
Peery, Zachariah, Professor, U Wisconsin

Applications such as climate change adaptation planning and endangered species habitat management require scenario analyses and simulation capable of capturing interactive effects of climate, development and landscape management on the risk of extreme events at multiple spatial scales. We describe here a set of integrated statistical models of large fire occurrence, size and severity that we have recently implemented at 1/16 degree lat/lon and 30 m grid nested resolutions with monthly and annual time steps. We also introduce adaptations of these models to incorporate dynamic habitat suitability and vegetation modeling. These models were used to create libraries of extreme fire event simulations for a range of climate, population and fuels management scenarios for planning activities in California for adaptive management of habitat, transportation and energy sector fire risks, and are being extended to applications in the northern US Rocky Mountains.

Keywords: wildfire, climate change, drought, habitat

Bio: Dr. LeRoy Westerling is Associate Professor of Management at UC Merced and co-Director of the Sierra Nevada Research Institute and Center for Climate Communication. His research interests include applied climatology and seasonal forecasting for wildfire management, climate change impacts on wildfire and related aspects of mountain hydrology, paleo reconstructions of climate-wildfire interactions, and simulation of extreme events. Dr. Westerling holds a B.A. from the University of California, Los Angeles; and a Ph.D. from the University of California, San Diego, and has published extensively on wildfire and climate in the western United States.

S5.9. Climate- and vegetation-driven changes in area burned in the Sierra Nevada
Presenter: Matthew Hurteau, Associate Professor, University of New Mexico
Additional Authors:

The area burned by wildfire tends to be synchronous with climate on a regional basis. At this scale, there is a strong relationship with temperature and precipitation patterns. Empirical data demonstrate that in the western US, area burned has increased substantially and this correlates with increased temperature, earlier snowmelt, and increased fuel aridity. Projections of future area burned built on these relationships show a substantial increase under projected climate in the Sierra Nevada Mountains. However, the relationship between climate and area burned neglects the influence of vegetation on area burned. We sought to account for the vegetation feedback in area burned under projected climate by using a forest simulation model. We ran simulations under projected climate from three global climate models across three transects (southern, central, northern) in the Sierra Nevada. At each decadal time-step we used the simulated area burned during the prior decade to estimate a distribution of area burned for the subsequent decade using generalized Pareto distributions of log-area burned (dynamic). We also ran simulations with area burned distributions driven only by projected climate (static). We found that mean cumulative area burned across all three transects in the absence of the vegetation feedback was 1805 km2 (se = 102.1) by year 2100. When we accounted for the effects of wildfires in the previous decade on vegetation, the mean cumulative area burned was 1545 km2 (se = 83.4) by year 2100. The largest decrease in cumulative area burned when accounting for the vegetation feedback occurred in the southern transect (-21.8%), followed by the northern (-14.5%) and southern (-9.8%) transects. The larger reductions in area burned for the southern and northern transects resulted in late-century aboveground carbon stocks that were approximately 3% higher for the dynamic simulations. The late-century difference between the dynamic and static simulations was negligible for the central transect. Our results demonstrate the importance of accounting for the influence of prior fire events on the vegetation community and how that factor feeds back to limit area burned. Further, our simulations account for the influence of projected climate on forest recovery following wildfire and forest growth and how these system attributes influence area burned.

Keywords: Climate change, wildfire, carbon, Sierra Nevada

Bio: Matthew Hurteau is an Associate Professor of Quantitative Ecology at the University of New Mexico. He has a BS in Forestry from Northern Arizona University and a PhD in Ecology from the University of California, Davis. His research focus is on climate change mitigation and adaptation in forest systems. He uses empirical and simulation data to better understand how changing climate and disturbance influence species distributions, productivity, and carbon dynamics.

S5.10. The Climate Change altered wildland fire regime for Canada in the 21st Century: Possible Implications.
Presenter: Mike Flannigan, Professor, University of Alberta
Additional Authors:

Wildland fires are a frequent occurrence in many regions of the world including Canada. These fires are the result of interactions between climate/weather, ignitions, fuels and people. Our climate and associated day-to-day weather are changing rapidly due to human activities that may have dramatic and unexpected impacts on regional and global fire activity. Specifically for Canada, a warmer world means a longer fire season, more lightning activity, and most importantly drier fuels. Existing studies

suggest regional increases in fire occurrence and area burned although there is significant temporal and spatial variability. Future trends in fire severity and intensity are more difficult to project due to the complex and non-linear interactions between weather, vegetation and people. However, recently results suggest that wildland fire intensities will increase in the future. The consequences of climate change on the wildfire regime for Canadian society and fire management will be explored.

Keywords: climate change, fuel moisture, lightning, fire season, fire intensity

Bio: Dr. Mike Flannigan is a professor with the Department of Renewable Resources at the University of Alberta and is the Director of the Western Partnership for Wildland Fire Science located at the University of Alberta. Dr. Flannigan's primary research interests include fire and weather/climate interactions, including the potential impact of climatic change, lightning-ignited forest fires, landscape fire modelling and interactions between vegetation, fire and weather.

S5.11. Mid-21st-century climate changes increase predicted fire occurrence and fire season length, Northern Rocky Mountains, United States

Presenter: Karin Riley, Research Ecologist, US Forest Service, Rocky Mountain Research Station
Additional Authors: Loehman, Rachel A., PhD, Research Landscape Ecologist, US Geological Survey, Alaska Science Center, Anchorage, AK

Climate changes are expected to increase fire frequency, fire season length, and cumulative area burned in the western United States. We focus on the potential impact of mid-21st-century climate changes on annual burn probability, fire season length, and large fire characteristics including number and size for a study area in the Northern Rocky Mountains. Although large fires are rare they account for most of the area burned in western North America, burn under extreme weather conditions, and exhibit behaviors that preclude methods of direct control. Allocation of resources, development of management plans, and assessment of fire effects on ecosystems all require an understanding of when and where fires are likely to burn, particularly under altered climate regimes that may increase large fire occurrence. We used the large fire simulation model FSim to model ignition, growth, and containment of wildfires under two climate scenarios: contemporary (based on instrumental weather) and mid-century (based on an ensemble average of global climate models driven by the A1B SRES emissions scenario). Modeled changes in fire patterns include increased annual burn probability, particularly in areas of the study region with relatively short contemporary fire return intervals; increased individual fire size and annual area burned; and fewer years without large fires. High fire danger days, represented by threshold values of Energy Release Component (ERC), are projected to increase in number, especially in spring and fall, lengthening the climatic fire season. For fire managers, ERC is an indicator of fire intensity potential and fire economics, with higher ERC thresholds often associated with larger, more expensive fires. Longer periods of elevated ERC may significantly increase the cost and complexity of fire management activities, requiring new strategies to maintain desired ecological conditions and limit fire risk. Increased fire activity (within the historical range of frequency and severity, and depending on the extent to which ecosystems are adapted) may maintain or restore ecosystem functionality; however, in areas that are highly departed from historical fire regimes or where there is disequilibrium between climate and vegetation, ecosystems may be rapidly and persistently altered by wildfires, especially those that burn under extreme conditions.

Keywords: burn probability; climate change; climatic fire season length; fire occurrence; FSim; Northern Rocky Mountains

S5.12. Assessing fuel treatment effectiveness during wildfires under future climate conditions
Presenter: Carrie Minerich, Graduate Research Assistant, University of Idaho
Additional Authors: Kolden, Crystal, Associate Professor, University of Idaho
Abatzoglou, John, Associate Professor, University of Idaho

As climate change leads to increased wildland fire frequency and extreme fire behavior in the western United States, managing fire risk in the expanding wildland-urban interface (WUI) is an on-going challenge. With WUI expansion predicted to grow as much as 111% in the West in the 30-year period ending 2030, a common way to mitigate fire danger in the WUI is by implementing fuel reduction treatments. Federal land management agencies in the western United States spent US$2.7 billion between 2001 and 2006 on fuel treatments despite there being limited research on the effectiveness of these treatments under future climate conditions. One place impacted by a large expanding WUI, high fire frequency, and a changing climate is Angeles National Forest in southern California. The Charlton-Chilao masticated fuel treatment on the Angeles National Forest was implemented in 2007 in a Ponderosa pine-dominated forest. In 2009, the Station Fire intersected the fuel treatment. We compared the change in fire behavior between historic and future climate conditions to assess how the Charlton-Chilao fuel treatment would have altered a fire analogous to the Station Fire, but under future climatic extremes. We first quantified the change in fire behavior associated with the Charlton-Chilao fuel treatment during observed 2009 Station fire conditions, specifically flame length and crown fire potential. We then modeled fire behavior with downscaled, mid-21st century global climate model outputs to analyze future fire behavior projections associated with the Charlton-Chilao fuel treatment. The difference in historic and future projected fire behavior has important implications to increase cost-effectiveness of fuel treatment programs by providing suggestions on how to modify fuel treatments to better withstand predicted future fire behavior.

Keywords: climate, fuel treatments, WUI, downscaled global climate model

Bio: Carrie has a Bachelor of Science degree in Environmental Biology from Fort Lewis College in Durango, Colorado. She is a member of the Tri-Beta Biological and Xi Sigma Pi honor societies and formerly served as president of the Student Association of Fire Ecology. Carrie has 10 years of natural resource management experience and is currently a graduate student at the University of Idaho.

S6.1. NASA Applied Science Efforts: Collaborations in Earth Observation Data, Information, Models and Tools Supporting Wildland Fire Management
Presenter: Vincent Ambrosia, Associate Prgram Manager, NASA Applied Science Program - Wildland Fire, NASA
Additional Authors: Soja, Amber J., Associate Program Manger, Wildland Fire, NASA Applied Science Program
Friedl, Lawrence, Director, NASAApplied Science Program, Earth Science Division, Science Mission Dorectorate, NASA HQ

In 2011, NASA solicited applications and applied research projects using Earth observations (EO) to improve decision-making activities and actions on topics related to wildland fires. Nine projects were selected, that focused on advancing organizations' use and application of Earth observations in analysis and assessments, management strategies and actions, business practices, and policy analysis and decisions associated with wildland fires. In 2018, the NASA Wildfire program will be concluding, and we will present the overall review of the efforts and in the special session, highlight these nine

projects which have made significant advances in the integration of EO in tools and decision support endeavors of the wildland fire management community.

Keywords: Earth Observations, NASA, wildfire, remote sensing, decision support tools

Bio: Vince Ambrosia is a NASA Applied Science Associate Program Manager for Wildland Fire. He supports the Group on Earth Observations (GEO) as the NASA Wildland fire community representative on the Global Wildfire Information System (GWIS) initiative. He has received numerous awards related to EO for wildfire including the 2009 NASA Outstanding Public Service Medal for efforts focused on emergency wildfire observations with UAS / sensors in 2006-2009; the 2009 Federal Laboratory Consortium for Technology Transfer, Interagency Partnership Award, and the 1999 ASPRS Best Remote Sensing Paper Award in Photogrammetric Engineering & Remote Sensing (PE&RS) for: “"An Integration of Remote Sensing, GIS, and Information Distribution for Wildfire Detection and Management. He holds a BS in Geography from Carroll University (Waukesha, WI) and the MS from the University of Tennessee- Knoxville (1980).

S6.2. A topographically resolved wildfire danger and drought monitoring system for the conterminous United States

Presenter: Zachary Holden, Scientist, U.S. Forest Service Region 1
Additional Authors: Swanson, Alan, Data Scientist, University of Montana
Jolly, William, Research Ecologist, Missoula Fire Sciences Laboratory, Missoula, MT
Maneta, Marco, Assistant Professor, Department of Geosciences, University of Montana
Warren, Dyer, Computer Scientist, School of Community and Public Health Sciences, University of Montana
Parsons, Russell, Research Ecologist, Missoula Fire Sciences Laboratory, Missoula, MT
Burgard, Mitchell, Fire technology transfer specialist, U.S. Forest Service Rocky Mountain Research Station

Information on fire danger and drought that resolves fine-scale topographic variation may help to inform fire management decisions and land management planning. With support from the National Aeronautics and Space Administration (NASA) we developed Topofire, a web-based mapping system designed to provide topographically resolved information on evapotranspiration, drought, fuel moisture and wildfire danger for the contiguous United States. We developed 8 arc second (~250 meter) resolution daily gridded radiation, temperature, humidity, and snow water equivalent data and used these grids to produce soil water balance models and fuel moisture inputs to National Fire Danger Rating System. Historical climatologies were developed for 1979-2015 and outputs are produced for the previous day and a four day forecast period. Aspect-scale differences in shortwave radiation contribute to warmer air temperatures on south-facing slopes and greater snow accumulation and delays in melt timing on north-facing slopes, resulting in large delays in fuel conditioning on shaded slopes. These datasets will help advance our understanding of the role of topography in wildland fire spread and ecological effects. Integration of these data with national programs like the Wildland Fire Assessment System and the Wildland Fire Decision Support System could support more proactive management of wildland fires in the future.

Keywords: wildfire danger, climate, topography, microclimate

Bio: Zack Holden is scientist for Region 1 of the U.S. Forest Service and affiliate faculty in the Geography department at the University of Montana. He received his PhD in natural resource management from the University of Idaho in 2008. His work focuses on modeling mountain weather and climate and their influence on fire ecology and management.

S6.3 WRFX - Numerical framework for operational coupled fire-atmosphere-fuel moisture forecasting

Presenter: Adam Kochanski, Research Assistant Professor, Atmospheric Sciences Department, University of Utah
Additional Authors: Jan Mandel, Professor, Director of the Center for Computational Mathematics, University of Colorado, Denver
Sher Schranz, Senior Program Development/Project Manager, CIRA
Martin Vejmelka, Engineering manager, CEAI, Inc.

We present an integrated wildland fire modeling framework, coupling a high resolution, multi-scale weather forecasting model, with a semi-empirical fire spread model and a prognostic dead fuel moisture model. The fire-released heat and moisture fluxes are fed into the atmospheric model in order to render the fire impacts on local meteorology, and the fire-modified winds are used to drive the fire progression. The system renders plume dynamics and simulates plume rise and dispersion, treating the fire smoke either as a passive tracer or a mixture of chemical species. In order to render the diurnal and spatial fuel moisture variability, and its impact on the fire behavior, plume rise, and smoke dispersion, the system is coupled with a fuel moisture model, driven by the atmospheric component of the system. As a consequence, the forecasted fire and plume dynamics are linked to the weather conditions via the local winds and the fuel moisture.
The sub-kilometer model resolution enables detailed representation of complex terrain and small-scale variabilities in surface properties. The fuel moisture model takes advantage of an advanced data assimilation scheme. It assimilates surface observations of the 10h fuel moisture from remote automated weather stations and generates spatial fuel moisture maps, which are used to initialize the fuel moisture model. The dead fuel moisture is traced in three different fuel classes (1h, 10h and 100h fuel), which are combined to provide the total dead fuel moisture content at the fire model resolution (tens of meters).
The fire simulations are initialized by a web-based control system allowing a user to define a fire location as well as basic simulation properties such as simulation length, type of meteorological forcing and the model resolution. The fire can be started anywhere in CONUS, and operational meteorological products such as HRRR, or NAM are used to initialize and force the weather model. The meteorological, as well as fuel and elevation data, are downloaded and processed automatically for the selected location. The system monitors execution on a cluster and manages an archive organizing all the forecasts. The simulation results are processed while the model is running, and are displayed as animations on a dedicated visualization portal.

Keywords: Smoke, WRF-SFIRE, WRF-FIRE, fire forecasting, plume rise

Bio: Adam Kochanski is a Research Assistant Professor at the University of Utah Atmospheric Sciences Department, working on coupled fire-atmosphere modeling. He is a co-developer of the community fire-atmosphere model WRF-SFIRE, WRF-SFIRE-CHEM and the coupled fire-atmosphere forecasting system WRFX.

S6.4. Monitoring Great Basin Shrub and Grasslands using Landsat and MODIS data for Fire Applications

Presenter: Jim Vogelmann, Research Ecologist, USGS EROS
Additional Authors: Shi, Hua, Research Scientist, Inuteq, USGS Earth Resources Observation and Science Center
Hawbaker, Todd, USGS Geosciences and Environmental Change Science Center
Reeves, Matthew, Research Ecologist, US Forest Service
Dittmeier, Ray, Scientific Software Engineer, SGT Corporation, USGS Geosciences and Environmental Change Science Center

The forests of the western United States are highly prone to wildland fire. Based on Monitoring Trends in Burn Severity (MTBS) data, approximately 249,500 sq km burned at least once during the 1984-2017 time frame for the US area between the eastern Rocky Mountains and the Pacific Ocean. It is largely unappreciated that in the western US, many more fires occur in shrublands and grasslands than in forests in the western US. Using the 2011 National Land Cover Dataset as a basis for life-form stratification, approximately 70.6% of the fires have been located on shrub and grasslands, and 35.7% have occurred on forest lands. Unfortunately, to date, available geospatial data for assessing fire risk in these grass and shrub areas have been limited. During this investigation, we assessed relationships among intra- and inter-annual variability in greenness, biomass, and fire in the Great Basin using Landsat and MODIS data. These shrub and grass areas are exceedingly difficult to characterize using remotely-sensed data because the intra- and inter-annual spectral variability in these ecosystems is high, and it requires high-temporal resolution data to adequately characterize these areas. In this study, we used the STARFM program to combine the temporally rich attributes of MODIS data (which has relatively low spatial resolution for LANDFIRE applications) with spatially detailed Landsat data (which has relatively low temporal resolution for intra-annual fire applications). We generated a series of temporal STARFM MODIS-TM mosaics for each year from 2000 through 2017 for May, June, July and August to characterize changing grass and shrub ecosystems throughout the Great Basin. Using this information, we generated maps that indicate areas likely to be at high risk to fire using May data prior to the fire season. We believe that this type of information would be useful to the fire community for planning upcoming fires seasons. We also demonstrated that we can model grass and shrub biomass using a combination of field efforts and correlative analysis using Landsat data, which ultimately relates to fire behavior.

Keywords: Great Basin, MODIS, Landsat, grass, shrubs, seasonality, fire fuel

Bio: Jim Voglemann has been working at the USGS-EROS Center for over 20 years, where he has used Landsat and other sources of remotely sensed data for characterizing landscapes and for assessing land cover change.

S6.5. Enhanced Wildland Fire Management Decision Support Using Lidar-Infused LANDFIRE Data

Presenter: Birgit Peterson, Geographer, USGS
Additional Authors: Jolly, W. Matthew, Research Ecologist, USFS
Nelson, Kurtis, Physical Scientist, USGS
Parsons, Russ, Research Ecologist, USFS
Seielstad, Carl, Professor, University of Montana

Wildfire is an important component of many ecosystems. As such, improving the understanding of wildfire behavior and impacts is critical to both policy makers and land managers. To adequately

model and analyze fire behavior, accurate information about the three-dimensional canopy structure and wildland fuel across the landscape is necessary. While various remotely sensed data are invaluable for assessing these canopy characteristics over large areas, lidar data are especially suited for quantifying three-dimensional canopy structure. However, the use of lidar measurements to derive the required canopy structure (e.g., canopy height and cover) data is still rather limited. This can largely be attributed to two underlying issues. First, within the United States, the LANDFIRE program has become the default source of large-scale fire behavior modeling inputs because it provides consistent, nationwide data regarding the distribution of vegetation structure and canopy fuels across the landscape. However, the LANDFIRE program has not incorporated lidar data because they are not consistently available for the country (although the current ReMap effort aims to leverage lidar data where possible). Second, where lidar data are available, these data are underutilized for fire behavior applications, partially because of a lack of local personnel trained to process and analyze lidar data. Our project addressed both of these issues by developing the Creating Hybrid Structure from LANDFIRE/lidar Combinations (CHISLIC) tool. CHISLIC generates a suite of vegetation structure and wildland fuel metrics from lidar data and infuses these into existing LANDFIRE data sets. CHISLIC thereby ensures: 1) vegetation and fuels maps based on the best data available, and 2) data continuity through the linkage with the LANDFIRE program. We describe the methods used within CHISLIC to derive key vegetation canopy characteristics from airborne and space-based lidar observations. We will also show how the CHISLIC tool provides data to land managers and policy makers so they can better understand and manage wildland fire.

Keywords: fuels, lidar, LANDFIRE

Bio: Birgit Peterson has been affiliated with the USGS Earth Resources Observation and Science Center for the last 10 years, working primarily with the LANDFIRE program. Her main interests have been vegetation type and structure mapping using remotely sensed data, and is especially interested in integrating airborne and spaceborne lidar into the mapping process.

S6.6. Conservation Impacts of a Near Real-time Monitoring and Alert System for the Tropics

Presenter: Karyn Tabor, Director of Early Warning Systems, Conservation International
Additional Authors: Musinsky, John, Staff Scientist, Battelle Ecology
Cano, Carlos A., Manager of Monitoring Systems, Conservation International
Ledezma, Juan Carlos, Scientific Manager, Conservation International Bolivia
Mendoza, Eddy, Land Use Planning Manager, Conservation International Peru
Rasolohery, Andriambolantsoa, GIS Manager, Conservation International Madagascar
Sajudin, Ermayanti R., Hima Lestari International

Forest monitoring and alert systems based on remotely sensed data are among the most recently developed tools to help manage and protect forest resources are near real-time. The use of satellite and airborne remote sensing to quickly and accurately detect activities associated with deforestation has great potential for catalyzing local response teams responsible for assessing and interdicting threats to tropical forest ecosystems. To better understand the utility of near real-time monitoring technologies in improving environmental protection and management, from 2008 to 2016 Conservation International conducted a series of surveys and interviews with users of these systems in four countries where wildfires threaten tropical forest ecosystems: Madagascar, Indonesia, Bolivia and Peru. Users reported that near real-time forest monitoring systems made significant contributions to improving the ability of conservation and forest management organizations to respond to and reduce the impacts of fire, deforestation, and other illegal or undesirable forest activity. Understanding the types of applications for which users successfully employed forest monitoring data, the challenges they faced in accessing, analyzing or disseminating these data, and the lessons learned from our attempts to develop and deploy near real-time forest monitoring systems is useful to institutions interested in successfully incorporating near real-time monitoring into their work.

Keywords: monitoring, alert systems, fire, deforestation, conservation, forest management

Bio: Karyn Tabor is the Director of Early Warning Systems for the Betty and Gordon Moore Center for Science at Conservation International. She directs the development of decision-making tools delivering time-sensitive information for improved fire/natural resource management. She has extensive expertise building tools and models that use satellite observations and climate projections to support conservation decisions.

S6.7. Development and Application of Spatially Refined Remote Sensing Active Fire Data Sets in Support of Fire Monitoring, Management and Planning

Presenter: Janice Coen, Project Scientist, National Center for Atmospheric Research
Additional Authors: Wilfrid Schroeder, NOAA
Brad Quayle, USDA Forest Service
Scott Conway, USDA Forest Service
Leland Tarnay, USDA Forest Service
Louis Giglio, University of Maryland

Current wildfire monitoring, management, and planning requires informed decisions supported by remote sensing data, including fire detection and fuel mapping. These products support tactical response and strategic planning to avert or mitigate impacts either directly or through input into models and other information systems.

This project has built upon new remote sensing active fire detection products derived from spatially-refined datasets (e.g., S-NPP/VIIRS 375 m), providing significantly improved fire information. Remote sensing fire products are fully operational, being delivered through operational sites, and being used in decision-making systems in the U.S. and abroad. Early project outcomes showed how an integrated fire detection-coupled weather-wildland fire modeling system based upon 12-hourly VIIRS fire detections could be used to model a wildland fire from detection throughout its lifetime, using a sequence of simulations initialized with updated fire mapping data. In practice, detections may be missing or obscured, leading to decreased fidelity, but the project's next stage showed how forecasts could be improved with additional fire mapping data, both from additional sensors (e.g., Landsat-8 30 m and FireBIRD TET-1) and adjacent VIIRS passes that sometimes provide an additional observation. Recent advances include development of a fire detection algorithm for the Sentinel-2/MSI sensor, being ported to the USDA FS Geospatial Technology and Applications Center in anticipation of the 2018 U.S. fire season.

Project members continue to engage the user community, while porting satellite fire products and modeling framework to operational environments, applying the system in forecast mode faster than real time to anticipate fire behavior and conditions hazardous to firefighter safety. Also, additional applications are being developed in partnership with land management units, based on coincident development of remote sensing-enhanced fuel datasets that provide improved information on fuel type and structure. These enable users to identify conditions of rapid fire growth and test the impact of fuel mitigation strategies on wildfires in complex weather, fuel, and terrain environments. These applications will be discussed.

Keywords: remote sensing of fires, fire modeling

Bio: Dr. Janice Coen is a Project Scientist at the National Center for Atmospheric Research in Boulder, Colorado. She received a B.S. in Engineering Physics from Grove City College and an M.S. and Ph.D. from the Department of Geophysical Sciences at the University of Chicago. She investigates wildland fire behavior and its interaction with weather using coupled weather - fire models and by analyzing infrared imagery of wildland fires. She has served as Associate Editor for the International Journal of Wildland Fire, on the Editorial Board of Environmental Modelling & Software, and on the Board of Directors of IAWF.

S6.8. Development of a new open-source tool to map burned area and burn severity

Presenter: Joshua Picotte, Fire Specialist, ASRC Federal InuTeq, contractor to USGS EROS
Additional Authors:

Accurate and complete geospatial fire occurrence records are important in determining post-fire effects, emissions, hazards, and fuel loading inventories. Currently the Monitoring Trends in Burn Severity (MTBS) project maps the fire perimeter and burn severity of all large fires on public lands. Although the MTBS project maps a large proportion of the fire acreage, it maps a smaller proportion of the actual number of fires in the U.S thereby creating a data gap. To fill this data gap, fire scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science Center (EROS; Sioux Falls, SD) proposed creating an open-source Fire Mapping Tool (FMT; available at https://mtbs.gov/qgis-fire-mapping-tool) as part of a two-phase National Aeronautics and Space Administration (NASA) Applied Fire Science Program grant. Phase II developed the FMT to map burn perimeters and severity. This paper will focus on Phase II and will explain the algorithms that enhance the FMT's functionality, demonstrate fire mapping procedures, and provide an example comparison between MTBS analyst fire products and those mapped using the FMT. The overall goal in the production of the FMT was to provide a freely available tool that can be used to map fires anywhere in the world.
Keywords: burn severity, QGIS, MTBS

Bio: Joshua Picotte is a fire specialist at USGS EROS in Sioux Falls, SD whose primary projects include Monitoring Trends in Burn Severity (MTBS) and LANDFIRE. He is currently assisting in the automation of the MTBS fire identification and mapping procedures.

6.9. Linking Remote Sensing and Process-Based Hydrological Models to Increase Understanding of Wildfire Effects on Watersheds and Improve Post-Fire Remediation Efforts

Presenter: Mary Ellen Miller, Research Engineer, Michigan Tech Research Institute
Additional Authors: Elliot, William, Research Civil Engineer, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 1221 South Main Street, Moscow ID 83843, USA.
Robichaud, Peter, Research Engineer, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 1221 South Main Street, Moscow ID 83843, USA.
Billmire, Michael, Research Scientist, Michigan Tech Research Institute
Banach, David, Assistant Research Scientist, Michigan Tech Research Institute

We have built the Rapid Response Erosion Database (RRED, http://rred.mtri.org/rred/) to facilitate the use of earth observations and spatially explicit process based models in post-fire assessment and remediation planning. Post-fire flooding and erosion poses a serious threat to life, property and

natural resources. Increased runoff and sediment delivery due to the loss of surface cover and fire-induced changes in soil properties are of great concern. Remediation plans and mitigation treatments must be developed and implemented before the first major storms in order to be effective. Soil burn severity maps derived from remote sensing and field observations are one of the primary sources of data for assessing fire induced changes to soils and vegetation. Slope, climate, pre-fire soil properties and land cover are also important parameters. Spatially-explicit process-based models can account for these parameters, but they are currently under-utilized because they are difficult to set up and require spatial inputs (digital elevation models, soils, and land cover). RRED provides comprehensive support for post-fire hydrological modeling by allowing users to upload spatial soil burn severity maps, and within moments returns spatial model inputs. RRED delivers a 10m or 30m USGS DEM, land cover derived from the LANDFIRE project, and soil data derived from SSURGO and STATSGO datasets. Land cover and soil layers are delivered in both burned and not burned conditions alleviating days of data preparation. A new QGIS open source interface to WEPP (QWEPP) is currently being developed to further facilitate modeling. The inclusion of historical burn severity maps (Monitoring Trends in Burn Severity project) within RRED will help land managers predict cumulative watershed effects. Fire, runoff, and erosion risks are highly heterogeneous in space, creating an urgent need for rapid, spatially-explicit assessment. RRED has been used by Burned Area Emergency Response teams on over a dozen recent wildfires and is being used to help plan fuel treatments in order to protect valuable water reservoirs from future high severity fire effects.

Keywords: Erosion, Forestry, Hydrology, Hazards, Forest fire, Databases, Soil, Land Cover

Bio: Dr. Miller has over 15 years of experience solving problems in the fields of GIS, Environmental Remote Sensing and Modeling. Her research interests include developing practical methods of supporting land management with remote sensing and environmental modeling, large scale mapping of vegetation, land cover and land use change, and developing and improving environmental models. Current projects include developing an erosion modeling database to support post-fire remediation and fuels planning, mapping wetland connectivity and vegetation in the Great Lakes Basin, and mapping land cover and historical fire occurrences in the Arctic Tundra.

S6.10. Post-Wildfire Decision Support with NASA RECOVER

Presenter: Keith Weber, GIS Director, Idaho State Univ. - GIS Center
Additional Authors: Schnase, John, NASA Goddard Space Flight Center
Carroll, Mark, NASA Goddard Space Flight Center
Blair, Kindra, ISU GIS Center

RECOVER (Rehabilitation Capability Convergence for Ecosystem Recovery) is a fire-specific decision support system (DSS) that automatically brings together in a single analysis environment the actionable information necessary to support wildfire decision-making. RECOVER is the result of a close collaboration between NASA's Applied Sciences Program, Idaho State University's GIS Research and Training Center, and the Bureau of Land Management (BLM). RECOVER uses rapid resource allocation capabilities to automatically collect Earth observation data, derived decision products, and historic biophysical data so wildfire management agencies have at hand a complete and ready-to-use dataset within an online GIS analysis environment customized for each specific wildfire. RECOVER is transforming this information-intensive process by reducing from days to a matter of minutes the time required to assemble and deliver crucial wildfire-related data. This

presentation describes the NASA RECOVER project and its numerous automation techniques using ArcGIS.

Keywords: decision support, post-fire, managent, GIS, remote sensing

Bio: Mr. Weber is the GIS Director at Idaho State University (ISU) and has held this position since founding the GIS Center in 1998. He has been involved in the Geospatial technologies industry since 1989, is a Certified GIS Professional (GISP), recipient of Esri's SAG award in 2000 and again in 2013, as well as URISA's ESIG award in 2014. He is past-President of the NR Chapter of URISA and former Vice-President of the Intermountain Chapter of ASPRS. Keith is the principal investigator for NASA's RECOVER wildfire decision support system, and the Science Advisor for the NASA DEVELOP node at ISU.

S6.11. Socioeconomic Impacts of Geospatial Data in Wildfire Emergency Response Planning: A Case Study using the NASA RECOVER Decision Support System

Presenter: William Toombs, Graduate Research Assistant, Idaho State University - GIS Training and Research Center
Additional Authors: Weber, Keith, Director, Idaho State University - GIS Training and Research Center
Schnase, John L., Senior Computer Scientist, NASA Goddard Space Flight Center - Computational and Information Sciences and Technology Office
Stegner, Tesa, Professor of Economics, Idaho State University
Lindquist, Eric, Associate Professor, Boise State University - School of Public Service
Lippitt, Frances, Graduate Research Assistant, Boise State University - Lindquist Policy Research Group

Decision making in the post-fire environment benefits from rapid assembly of and access to the actionable information needed to develop stabilization and rehabilitation plans. Beyond the unpredictability of wildfire behavior, uncertainty in wildland fire management largely stems from inaccurate or missing data. Decision support systems (DSS) employing satellite imagery and geospatial data can significantly reduce the uncertainty in post-fire planning.
The NASA RECOVER DSS provides geospatial data as actionable information to support the development of post-fire rehabilitation plans. To accomplish this, RECOVER makes extensive use of Earth observing satellite system imagery and derived products along with a suite of other geospatial data layers. RECOVER is an interactive, GIS-based web map enabling the user to instantly gain actionable information for a given fire event. What previously may have required several days of data collection can now be completed in only five minutes.
This project used the RECOVER DSS as a case study to assess the socioeconomic impact of geospatial data for emergency management. To date, the RECOVER DSS has been applied by the Bureau of Land Management, Bureau of Reclamation, Federal Emergency Management Agency, National Park Service, Forest Service, National Weather Service, Idaho Fish and Game, Idaho Department of Lands, Utah Division of Forestry, Fire & State Lands, Whatcomm (Washington State) Conservation District, California National Guard, and the California Department of Transportation to assist in rehabilitation planning for 60 wildfires. Many of the decision makers who used RECOVER were interviewed, enabling estimates of the socioeconomic value of Earth observations for post-fire rehabilitation planning. The success and long-term feasibility of RECOVER was assessed using the policy theory of diffusion and innovation by recording the adoption rate of RECOVER by land management agencies, as reflected by decision makers' responses regarding plans for continued use of the capability. These interviews revealed that although the time- and cost-savings for decision makers and support staff is

significant, the potential value of better informed decisions on rehabilitation planning through improved resource allocation or treatment efficacy, is far greater.

Keywords: Post-fire Rehabilitation Planning, GIS, Land Management

Bio: Mr. Toombs is a doctoral student in political science and a graduate research assistant at the GIS Training and Research Center at Idaho State University. William's research focuses on natural resource and environmental policy. William has a MA in History from Pittsburg State University and a BS in History from Portland State University.

S6.12. Leveraging spatio-temporal data to improve wildland fire management decision support systems: a NASA Wildfires partner perspectiv

Presenter: W. Matt Jolly, Research Ecologist, USFS, RMRS, Fire Sciences Laboratory
Additional Authors: Holden, Zack, USFS, Region 1
Parson, Russell A., Research Ecologist, USFS, RMRS, Fire Sciences Laboratory
Warren, Dyer, Computer Scientist, School of Community and Public Health, University of Montana
Peterson, Birgit, Geographer, USGS Earth Resources Observation and Science Center
Nelson, Kurtis, Physical Scientist, USGS Earth Resources Observation and Science Center
Seielstad, Carl, Associate Professor, Univ of Montana, National Center for Landscape Fire Analysis, College of Forestry and Conservation

Wildland fire managers throughout the world depend on a variety of data and supporting systems to guide decision-making. Many of these systems are antiquated and leverage decades-old technology. Recent climatic and human population changes are leading to fire environments that are increasingly complex. As costs of fighting wildfires soar and more people are exposed to fire risks, better solutions are needed to support complex decision making. Here we introduce two decision support systems used in wildland fire management, the US National Fire Danger Rating System and the Wildland Fire Decision Support System and we detail how results from two NASA-funded Wildfires projects (TOPOFIRE and CHISLIC) can be incorporated into these decision support systems to meet emerging needs of wildland fire management. Specifically, we focus on how these two projects can integrate into the USFS Wildland Fire Assessment System (WFAS) to provide complimentary information to best describe high resolution, wildland fire potential changes across landscapes and over time and how this information can be used to guide decisions that can minimize firefighting costs while keeping firefighters and the public safe.

Keywords: fire weather, decision support systems, TOPOFIRE, CHISLIC

Bio: William Matthew “Matt” Jolly is a Research Ecologist in the Fire, Fuel and Smoke Science Program of the US Forest Service, Fire Sciences Laboratory in Missoula, MT. He received a BA in Environmental Science from the University of Virginia and a PhD in Forestry from the University of Montana. He is also the project administrator for the research and development team of the Wildland Fire Assessment System (WFAS) and is continually evaluating and developing tools for landscape-scale fire danger assessment. His research explores how wildland fuel characteristics vary across space and time and how these variations impact wildland fire potential. Ultimately, his work will lead to improved wildland fire danger and behavior prediction tools.

S7.1. Long-term trends in fire behavior and changes in population at risk

Presenter: Ana G. Rappold, Statistician, US EPA
Additional Authors: Geoffrey Colin Peterson, ORISE/EPA
W. Matt Jolly, USFS

Air pollution regulations and technological advances have successfully reduced emissions of air pollutants from many anthropogenic sources in recent decades. During the same period, emissions from wildfires have increased, becoming the largest sources of air pollution in some geographic regions. In this work, we contrast long-term trends in fire risk with changes in population and emissions from all other sources of air pollution. Specifically, we examine spatial and temporal variability in the distribution of fire-weather parameters and characterize long-term trends in fire risk within wildland urban interface and by region to identify communities that have experienced rapid changes in population health vulnerability as well as the physical risk of wildland fire.

Additionally, the daily forecasting of fire behavior risk metrics allows for the development of tools aimed to identify populations at risk prior to the fire incidence thus enabling public health response.

Keywords: fire risk

Bio: Dr. Rappold is a Statistician with EPA, Office of Research and Development, Environmental Public Health Division. She is a scientific lead of the project aimed to integrate public health messaging with environmental models and understanding their effectiveness to reduce burden in population. She has conducted a number of clinical and epidemiological research studies of health effects from air pollution and has authored a number of studies specific to smoke impacts on health.

S7.2. Communicating Risk: Air Quality Index, Wildfire Guide, and Online PM Medical Course

Presenter: Susan Stone, Senior Environmental Health Scientist, US Environmental Protection Agency
Additional Authors: Cascio, Wayne, Acting Director National Exposure and Environmental Effects Laboratory, US Environmental Protection Agency
Sacks, Jason, Epidemiologist, US Environmental Protection Agency
Damon, Scott, Health Communications Specialist, US Centers for Disease Control and Prevention

Abstract:
Particulate matter (PM) or particle pollution, the primary pollutant of concern in smoke, has been associated with respiratory and cardiovascular morbidity, including hospital or emergency department visits for asthma, acute coronary syndrome (myocardial infarctions and unstable angina), heart failure, arrhythmia, and stroke, as well as mortality. This presentation will discuss tools and resources that EPA has made available to better communicate risk associated with exposure to PM, as well as other air pollutants. The three main topics we will discuss are the presentation of EPA’s Air Quality Index on the redesigned AirNow web site, current revisions to the wildfire guide, and newly available online PM medical course.
EPA's Air Quality Index (AQI) is the nationally uniform U.S. index for informing the public about daily air quality and associated health risks if any. The AQI is forecasted daily and also available in real-time. This presentation will show the redesign of the AirNow website that will make the AQI more accessible and useful to the public, including new infographics, during smoke events.
This presentation will also describe ongoing revisions to the 2016 document Wildfire Smoke: A Guide for Public Health Officials (https://www3.epa.gov/airnow/wildfire_may2016-revised.pdf), and new, related fact sheets. This guide, which was last revised in 2016, is designed to help local public health

officials prepare for smoke events, to take measures to protect the public when smoke is present, and communicate with the public about wildfire smoke and health. The members of the team updating the guide are from a number of federal and state agencies.
Lastly, the presentation will highlight an online medical course, Particle Pollution and Your Patients' Health (https://www.epa.gov/pmcourse), which is a continuing education course designed for family medicine physicians, internists, pediatricians, pulmonologists, cardiologists, nurse practitioners, nurses, asthma educators, and other medical professionals. Successful completion of the course results in the accrual of continuing education credits from the Centers for Disease Control and Prevention. It is an evidence-based training course that:

- Describes the biological mechanisms responsible for the cardiovascular and respiratory health effects associated with particle pollution exposure.
- Provides practical education tools to help patients understand how particle pollution exposure can affect their health and how they can use the Air Quality Index to protect their health.

Office of Research and Development Disclaimer: The views expressed are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

Keywords: Air Quality Index (AQI), Health Effects of Smoke, Emergency Response, Public Health Guidelines, Continuing Medical Education

Bio: Susan Stone is a Senior Environmental Health Scientist, who led the team that reviewed the national ambient air quality standards (NAAQS) for ozone, concluding in 2015. Ms. Stone is also the Air Quality Index (AQI) team leader, has coauthored many of EPA's public information documents about the AQI, the health effects of criteria pollutants, and she has given presentations across the U.S. and internationally on these subjects. She leads a multi-agency team that updated the document Wildfire Smoke: A Guide for Public Health Officials in 2016, continues to work on associated fact sheets and the next version of the Guide, and lead the development of the web course for health providers, Particle Pollution and Your Patients' Health. She was co-lead for the National Scale Activity Survey (N-SAS), and a co-author of two epidemiological studies of the health impacts of smoke from a fire in Eastern North Carolina, and also a wood smoke controlled human exposure study. Susan Stone has an M.S. from the Gillings School of Global Public Health at the University of North Carolina at Chapel Hill.

S7.3. Cardiovascular and cerebrovascular emergency department visits associated with wildfire smoke exposure in California in 2015

Presenter: Ana G. Rappold, Statistician, US EPA
Additional Authors: Zachary S. Wettstein, BA; School of Medicine, University of California San Francisco
Sumi Hoshiko, MPH; Environmental Health Investigations Branch, California Department of Public Health
Jahan Fahimi, MD, PhD; Department of Emergency Medicine, University of California San Francisco
Robert J. Harrison, MD, MPH; Department of Medicine, University of California San Francisco; Occupational Health Branch, California Department of Public Health
Wayne E. Cascio, MD; National Health and Environmental Effects Research Laboratory, Office of Research and Development, United States Environmental Protection Agency

Wildfire smoke is known to exacerbate respiratory conditions; however, evidence for cardiovascular and cerebrovascular events has been inconsistent, despite biological plausibility.
Time series analysis was conducted for daily cardiovascular and cerebrovascular emergency department (ED) visits and wildfire smoke exposure in 2015 among adults in eight California air basins. A quasi-Poisson regression model was used for ZIP code-level counts of ED visits, adjusting for heat index, day of week, seasonality, and population. Satellite-imaged smoke plumes were classified as light, medium, or dense based on model-estimated concentrations of fine particulate matter. Relative risk (RR) was determined for smoky days for lag days 0-4. Rates of ED visits by age- and sex-stratified groups were also examined. Rates of all-cause cardiovascular ED visits were elevated across all lags, with the greatest increase on dense smoke days and among those 65 years and older at lag 0 (RR 1.15, 95%CI [1.09, 1.22]). All-cause cerebrovascular visits were associated with smoke, especially among those 65 years and older, (1.22 [1.00, 1.49], dense smoke, lag 1). Respiratory conditions were also increased, as anticipated (1.18 [1.08, 1.28], adults 65+, dense smoke, lag 1). No association was found for the control condition, acute appendicitis. Elevated risks for individual diagnoses included myocardial infarction, ischemic heart disease, heart failure, dysrhythmia, pulmonary embolism, ischemic stroke, and transient ischemic attack.
Analysis of an extensive wildfire season found smoke exposure to be associated with cardiovascular and cerebrovascular ED visits for all adults, particularly for those over 65.

Keywords: smoke, cardiovascular impacts, respiratory impacts

Bio: Ana G. Rappold, Ph.D.
Dr. Rappold is a Statistician with EPA, Office of Research and Development, Environmental Public Health Division. She is a scientific lead of the project aimed to integrate public health messaging with environmental models and understanding their effectiveness to reduce burden in population. She has conducted a number of clinical and epidemiological research studies of health effects from air pollution and has authored a number of studies specific to smoke impacts on health.

S7.4. Comparison of Aspiration and Inhalation Exposure Methods for Predicting Pulmonary Toxicity of Biomass Smoke

Presenter: Yong Ho Kim, NRC Senior Research Associate, U.S. Environmental Protection Agency
Additional Authors: King, Charly, Environmental Engineer, U.S. EPA
Krantz, Todd, Environmental Engineer, U.S. EPA
George, Ingrid, Environmental Scientist, U.S. EPA
Hargrove, Marie, Postdoc Fellow, ORISE
McGee, John, Enviornmental Engineer, U.S. EPA
Copeland, Lisa, Biologist, U.S. EPA

We have previously assessed lung toxicity of biomass smoke particulate matter (PM) from flaming versus smoldering phases of five different fuels (oak, peat, pine, pine needles, and eucalyptus) following a single aspiration exposure (100 μg of PM) in mice, and reported that the greatest lung toxicity was for eucalyptus smoke (from smoldering and flaming phases) or peat smoke (from flaming phase), while the least lung toxicity was for oak smoke (from smoldering and flaming phases). Since the aspiration exposure method is not a natural or physiologic exposure route however, our findings may not be readily transferable to real-world exposure situations. Thus we conducted inhalation exposures on a subset of the biomass smoke fuels (oak, peat, and eucalyptus) under smoldering and flaming conditions, and compared the results with the previous findings. Mice were exposed to the biomass smoke for 1 hour/day for 2 days and then assessed for lung toxicity at 4

and 24 h after the second exposure. PM levels were actively controlled to yield approximately 40 and 4 mg m-3 for the smoldering and flaming smoke, respectively. The resulting carbon monoxide (CO) levels ranged from approximately 60 to 110 ppm. Deposited PM mass in entire respiratory tract of mice was calculated to be approximately 75 and 7 µg of PM for the smoldering and flaming, respectively (determined by multiple-path particle dosimetry (MPPD) model). The peat (flaming and smoldering) and eucalyptus (smoldering) smoke significantly induced lung toxicity (neutrophil influx) at 4 h and the toxic outcome was further increased at 24 h after exposure to the peat (flaming) smoke. No lung toxic responses were observed at any of the oak smoke exposure conditions. Compared with our previous findings, we found good correlation of the lung toxicity potencies (neutrophil influx per PM mass) between the inhalation and aspiration methods in mice exposed to the peat ($p < 0.001$) and eucalyptus ($p = 0.0056$) smoke, suggesting that the aspiration exposure method provides a comparable prediction of pulmonary toxicity from biomass smoke inhalation. Overall, our findings suggest that wildland fire smoke in the rich regions of peat and eucalyptus fuels may induce greater health effects than smoke from oak fires, and that on a mass basis, there is a greater health risk from flaming smoke compared to smoldering emissions. [This abstract does not represent EPA policy]

Keywords: lung toxicity, inhalation, instillation, aspiration, smoldering, flaming, biomass smoke

Bio: Yong Ho Kim is a National Research Council Senior Research Associate in the U.S. Environmental Protection Agency (EPA). He has extensive experience in studying interactions of inhaled particles with lung cells and their toxicological implications. His current research primarily focuses on adverse health effects of wildfire smoke from different fuel types or combustion conditions.

S7.6. The chemical composition of aerosols from wildland fires: Current state of the science and possible new directions
Presenter: Michael Hays, Physical scientist, U.S. Environmental Protection Agency
Additional Authors:

Wildland fires emit a substantial quantity of aerosol mass to the atmosphere. These aerosols are a complex mixture of organic matter and refractory elemental or black carbon and also comprise minor concentrations of inorganic matter from soils and plant micronutrients. Identification and quantification of both the bulk chemical constituents and individual chemical components in aerosols emitted from wildfire is important to understanding public health effects, climate change, and supports the dispersion, apportionment, and air quality models most relevant to generating sound regulatory policy. While current analytical chemistry technology is offering unprecedented information about aerosol composition, a large fraction of organic aerosol released during wildland fires often remains unidentified. This presentation aims to examine the current state of the science with regard to the bulk chemical and molecular level properties of organic aerosol particles emitted from biomass burning with a specific focus on wildland fires. We discuss the novel hyphenated chromatography-mass spectrometry and absorption spectroscopy tools being used to measure functional group chemistry, individual molecular constituents, and optical properties of wildland fire aerosols. We also propose the use of additional analytical-chemical technology that may assist in further unraveling unidentified aerosol matter from the globally important wildland fire aerosol source.

Keywords: PM, smoke, spectroscopy, carbon

Bio: Dr. Michael D. Hays is a physical scientist at the U.S. Environmental Protection Agency's Office of Research and Development. His primary research interests include combustion chemistry, air pollution, and emissions characterization science. He has performed studies on anthropogenic and biogenic emissions sources with a specific focus on the chemical characterization of submicron aerosol particles and their gas-phase chemical precursors. Dr. Hays has also focused on the development of analytical methods for the physical and chemical characterization of fine carbonaceous aerosols. His analytical-chemical research interests include thermal desorption and extraction, and the application of hyphenated chromatography-mass spectrometry techniques.

S7.7. Influence of Combustion Factors on Biomass Emissions

Presenter: Brian Gullett, Acting Division Director, U.S. Environmental Protection Agency
Additional Authors: Aurell, Johanna, PhD, Senior Research Engineer, University of Dayton Research Institute
Holder, Amara, PhD, Senior Research Scientist, U.S. EPA, Office of Research and Development

The effect of combustion quality on the character of emissions from wildland fires remains relatively unknown. While "good" combustion is expected to minimize emissions, this remains minimally documented. As a consequence, emission factors, or the amount of a pollutant per amount of biomass burned, are typically quantified in terms of "flaming" and "smoldering" modes. In reality, a continuum between flaming and smoldering exists throughout the active part of a fire. Recent research is starting to define this continuum of emission type and quantity versus combustion quality, commonly measured by a "modified combustion efficiency," or MCE. Inclusion of this more robust fire quality and emissions relationship into models will better enable prediction of the temporal nature of the smoke evolution.

Field sampling and laboratory combustion studies are examining the effect of combustion intensity (the burn rate) and quality (MCE) on the type and amount of emissions. Laboratory tests will be varying fuel area density, volume density, moisture, and orientation along with ventilation rate, impingement air (wind), and relative humidity. Emission measurements will include continuous monitoring of CO, CO_2, NO_x, PM by size, and black carbon. Batch measurements for PM elements, carbonyls, volatile organic compounds, polycyclic aromatic hydrocarbons, and semivolatile organic compounds will be taken. Emission results will be compared with combustion measurements including MCE as well as mass loss rates and infrared measurements of temperature across the flame field. This laboratory work is expected to identify the variance of pollutant types and their emission factors as a function of combustion variables. Results will be compared with field results and current emission factors in inventories.

This abstract has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication.

Keywords: smoke, emissions, combustion, quality, pollutants

Bio: Brian is an ST level scientist at EPA's Office of Research and Development. His work on formation mechanisms of chlorinated dioxins and furans led him into the field of open combustion measurements. Currently he is serving as the Acting Director of the Air and Energy Management Division of the National Risk Management Laboratory located in Research Triangle Park, North Carolina.

S7.8. Status of EPA's National Emissions Inventory for Wildland Fire
Presenter: Amara Holder, Mechanical Engineer, U.S. EPA, Office of Research and Development
Additional Authors: Rao, Venkatesh, PhD, Environmental Scientist, U.S. EPA Office of Air Quality Planning and Standards
George, Ingrid, PhD, Chemist, U. S. EPA Office of Research and Development

Wildland fire (WLF, including both prescribed and wild fires) emission estimates contribute significantly to atmospheric particulate matter (PM), volatile organic compounds (VOC), black carbon, and certain air toxics levels in the National Emissions inventory (NEI). The NEI is published every three years by the U.S. Environmental Protection Agency (EPA), with the most recent inventory completed for 2014. New to the 2014 NEI, EPA worked with States, Local Agencies, and Tribes (SLT) to gather fire activity data and determine completeness through survey questionnaire responses. These data were combined/reconciled with national fire activity data sources using the SmartFire2 system to estimate day-specific geo-coded emission estimates. Final daily fire activity data were processed through the BlueSky Framework to estimate fuel loading, fuel consumption, and smoke emissions with the Fuel Characteristic Classification System, CONSUME model, and Fire Emission Production Simulator, respectively. An exception was made for fires in Hawaii and Puerto Rico, which were processed using the Fire Inventory from the National Center for Atmospheric Research (FINN) module. As an improvement from previous year's inventories, the 2014 NEI reports emissions by flaming and smoldering combustion phases to improve the accuracy of the inventory for use in air quality modeling. One limitation in reporting emissions this way is the limited availability and inconsistency of emission factors for each pollutant by combustion phase. Therefore, a series of laboratory burns and field measurements were undertaken to provide updated emission factors and speciation profiles for PM and VOC emissions by combustion phase. This presentation will detail the methods used to estimate the 2014 WLF emissions for the NEI and explore these recently obtained emission factors and their potential impact on future NEIs.
The views expressed in this abstract are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

Keywords: Smoke, Emissions, Chemical Composition

Bio: Amara Holder received a PhD in Mechanical Engineering from UC Berkeley where she studied the impact of PM characteristics on the toxicity of diesel particulate matter. She has been with the U.S. Environmental Protection Agency since 2011, where she studies the particulate matter characteristics from a wide variety of combustion sources and atmospheric processes.

S7.9. Implications of Burned Area Approaches in Emission Inventories for Modeling Wildland Fire Pollution in the Contiguous U.S.
Presenter: Shannon Koplitz, , US EPA
Additional Authors: Nolte, Christopher, US EPA
Pouliot, George, US EPA
Vukovich, Jeffrey, US EPA
Beider, James, CSRA

Wildland fires are a major source of fine particulate matter (PM2.5), one of the most harmful ambient pollutants for human health globally. Within the U.S., wildland fires can account for more than 30% of total annual PM2.5 emissions. In order to represent the influence of fire emissions on atmospheric composition, regional and global chemical transport models (CTMs) rely on fire emission inventories

developed from estimates of burned area (i.e. fire size and location). Burned area can be estimated using a range of top-down and bottom-up approaches, including satellite-derived remote sensing and on-the-ground incident reports. While burned area estimates agree with each other reasonably well in the western U.S. (within 20-30% for most years during 2002-2014), estimates for the southern U.S. vary by more than a factor of 3. Differences in burned area estimation methods lead to significant variability in the spatial and temporal allocation of emissions across fire emission inventory platforms. In this work, we implement fire emission estimates for 2011 from three different products - the USEPA National Emission Inventory (NEI), the Fire INventory of NCAR (FINN), and the Global Fire Emission Database (GFED4s) - into the Community Multiscale Air Quality (CMAQ) model to quantify and characterize differences in simulated fire-related PM2.5 and ozone concentrations across the contiguous U.S. due solely to the emission inventory used. Preliminary results indicate that the estimated contribution to national annual average PM2.5 from wildland fire in 2011 is highest using GFED4s emissions (0.63 μg m-3) followed by NEI (0.44 μg m-3) and FINN (0.20 μg m-3), with comparisons varying significantly by region and season. Understanding the sensitivity of modeling fire-related PM2.5 and ozone in the U.S. to fire emission inventory choice will inform future efforts to assess the implications of present and future fire activity for air quality and human health at national and global scales.

Keywords: burned area, emission inventories, CMAQ, wildland fire pollution

Bio: Shannon Koplitz is a post-doctoral scientist with the US EPA. Her work focuses primarily on understanding the environmental and human health impacts of wildland fires. To this end she uses chemical transport models along with data from satellites and surface monitoring networks to investigate how wildland fires affect atmospheric composition.

S7.10. Improving EPA's Fire Emissions Inventory: A Dive into MODIS Fire Detections

Presenter: George Pouliot, , Computational Exposure Division, National Exposure Research Laboratory, U.S. Environmental Protection Agency
Additional Authors: James Beidler, CSRA, Research Triangle Park
Thomas Pierce, Computational Exposure Division, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park

Biomass burning has been identified as an important contributor to the degradation of air quality because of its impact on ozone and particulate matter. EPA's National Emission Inventory (NEI) relies on the SMARTFIRE information system to develop estimates of emissions from wildland fires. The Hazard Mapping System (HMS) dataset for identifying fire locations has been available from the National Oceanographic and Atmospheric Administration (NOAA) as an operational product from 2003 to the present. EPA has used this dataset as well as other datasets to develop wildfire and prescribed fire emission inventories for multiple years using SMARTFIRE. In the HMS dataset, fires are detected from multiple satellite sensors. One sensor that is used for detecting and locating fires is the Moderate Resolution Imaging Spectrometer (MODIS), which is located on two polar orbiting satellites (Aqua and Terra). Researchers have noted a prevalence and abundance of fire detections along the southern Louisiana coast that do not appear to be realistic. An analysis of the HMS MODIS detections over the southern Louisiana coast has identified this dataset as the source of the anomalous fire detections. Reprocessing of the entire MODIS data archive is periodically performed to incorporate better calibration, algorithm refinements, and improved upstream data into all MODIS products. We have found that the MODIS collection 6 products, which were created in February 2015, do not have these anomalous fire detections over Louisiana. In addition, the MODIS collection

6 product has additional quality assurance and improved geolocation. Replacing the HMS MODIS fire detections with the Collection 6 Global Monthly Fire Location Product (MCDML) results in an 18% decrease in the area of wildfires (3.0 vs 2.5 million acres) in 2013 across the contiguous U.S. In addition, estimated prescribed fire area decreases by 15% (8 to 6.8 million acres). The revised estimate of fire area results in a 32% decrease in PM2.5 emissions from both prescribed and wildland fires for 2013

Disclaimer: The views expressed in this abstract are those of the authors and do not necessarily reflect the views or policy of the U.S. Environmental Protection Agency.

Bio: Dr. George Pouliot is a physical scientist in the National Exposure Research Laboratory at the Environmental Protection Agency in Research Triangle Park, NC. He received his Ph.D. from North Carolina State University in 2000. He works in the Computational Exposure Division and his areas of research include the estimation and modeling of emission sources such as biogenic sources., fire sources, mobile sources, residential wood combustion that depend on meteorology. He most recently developed the method used in the 2014 national emissions inventory to estimate emissions from crop residue burning.

S7.12. Modeled Smoke Impacts on Ozone and Particulate Matter Evaluated with Field Study and Routine Air Quality Measurements
Presenter: Shannon Koplitz, , US EPA
Additional Authors: Baker, Kirk, PhD, Physical Scientist, U.S. Environmental Protection Agency

Highly instrumented field studies provide a unique opportunity to evaluate multiple aspects of photochemical grid model representation of fire emissions, dispersion, and chemical evolution. Fuel information and burn area for a specific fire coupled with near-fire and downwind chemical measurements provides information needed to constrain model predicted fire plume transport and chemical evolution of important pollutants such as particulate matter (PM2.5) that have deleterious health effects. Most local to regional scale field campaigns to date have made relatively few transects through plumes from fires with well characterized fuel type and consumption. While more comprehensive field studies are being planned for 2018 and beyond (WE-CAN and FIREX), existing measurement data from multiple field campaigns including 2013 SEAC4RS, satellite data, and routine surface networks are used to assess how a regulatory modeling system captures fire impacts on local to regional scale PM2.5. A comparison of Community Multiscale Air Quality (CMAQ) model estimated speciated PM2.5 from specific fires with routine surface measurements at rural locations in proximity to the 2013 Rim fire, 2011 Wallow fire, and 2011 Flint Hills fires indicate PM2.5 organic carbon tends to be overpredicted at rural surface sites downwind from the 2011 Flint Hills prescribed fires while results were mixed at rural sites downwind of the 2013 Rim fire and 2011 Wallow fire. These results suggest differences in fuel characterization (e.g., emission factors, emissions speciation, burn period, etc.) between these areas may contribute to differences in model prediction. Remotely sensed AOD and aircraft transects made downwind of the 2013 Rim fire suggest the model does well at predicting local to regional scale transport and also the vertical extent of the plume. However, the model tends to underestimate regional downwind AOD compared with satellites and ground-based estimates during the Rim fire period.

Bio: Shannon Koplitz is a post-doctoral scientist with the US EPA. Her work focuses primarily on understanding the environmental and human health impacts of wildland fires. To this end she uses chemical transport models along with data from satellites and surface monitoring networks to investigate how wildland fires affect atmospheric composition.

S7.13. Characterization of Aerosol Polar Organic Compounds of Smoldering and Flaming Combustion of Red Oak, Irish Peat, and Eucalyptus
Presenter: Mohammed Jaoui, Physical Scientist, US EPA
Additional Authors: Kim Yong Ho, NHEERL/EPA
King Charly, NHEERL/EPA
Gilmour Ian, NHEERL/EPA
Landis S. Matthew, NERL/EPA

Wildland fires occur in many seasons and regions around the world, and significantly enhance local and regional ambient aerosol concentrations. Human exposure to gas phase and aerosol compounds from wildland fire smoke result in deleterious human health outcomes, water contamination, and degrade atmospheric visibility. We investigated the chemical composition of particulate matter emitted from the combustion of three fuel types: eucalyptus (EU), Irish peat, (IP) and red oak (RO). The effect of combustion conditions (smoldering and flaming) on organic aerosol composition was investigated. Experiments were conducted in an automatic tube furnace system that controls fuel combustion and biomass smoke concentration during testing. Particulate matter, generated during each combustion experiment, was collected onto glass fiber filters, solvent-extracted and derivatized using one step derivatization that characterize -OH and -COOH groups. Using a detailed analysis of mass spectra obtained from GC-MS of silylated derivatives in EI and CI modes, we identified typical biomass burning compounds (e.g., levoglucosan), as well as compounds that are known to affect optical properties of aerosols such as nitro aromatic compounds. Initial attempts have been made to quantify the concentrations of these compounds based on authentic or surrogate compound calibrations. A comparison between smoldering and flaming as well as between EU, IP, and RO was conducted. Some of these organic compounds may be useful atmospheric markers associated with EU, IP, and RO combustion. This study supplements the health studies of biomass burning with compound identification through established, tested, reliable GC-MS methods. This study also highlights the potential emission of light absorbing constituents from IP, RO and EU combustion and their importance in the atmospheric visibility.

Keywords: Wildland fire, eucalyptus, Irish peat, red oak, organic aerosol

Bio: Currently, Mohammed Jaoui is as research physical scientist providing leadership and guidance in atmospheric sciences. His research interests are in the study of the formation and removal of gas and aerosol-phase constituents important in ozone, air toxics, and particulate matter chemistry. Physical and chemical parameters for important process are examined experimentally under highly controlled conditions. The results of the laboratory studies are then applied to describe and predict pollution formed in ambient atmospheres using air quality models, such as the Community Multiscale Air Quality (CMAQ) model.

S7.14. Improving the vertical distribution of wildland fire emissions in the CMAQ modeling system
Presenter: Joseph Wilkins, Physical Scientist, U.S. EPA
Additional Authors: Poulliot, George, Physical Scientist, U.S. EPA,Office of Reserach and Development, Computational Exposure Division
Poulliot, George, Physical Scientist, U.S. EPA, Office of Reserach and Development, Computational Exposure Division

Vuckovich, Jeffrey, Physical Scientist, U.S. EPA, Office of Air Quality Planning and Standards, Air Quality Assessment Division
Pierce, Thomas, Associate Director, U.S. EPA,Office of Reserach and Development, Computational Exposure Division

The area burned by wildland fires (prescribed and wild) across the contiguous United States (U.S.) has expanded by nearly 50% over the past 20 years, now averaging 2 million hectares per year. Chemical transport models are extensively used by environmental decision makers to examine the impact of air pollution on human health, and to devise strategies for reducing or mitigating exposure of humans to harmful levels of air pollution. Since wildfires are occurring more frequently and burning more intensely, the exposure of humans to fine particulate matter (PM2.5) and ozone (O3) is projected to grow. Currently, there is little consensus on fire pollution vertical transport methods. The height to which a biomass burning plume in injected into the atmosphere, or plume rise, is not only difficult to qualitatively determine, but comes with quantitative difficulties due to poor understanding of physical constraints within models. Many air quality models rely on plume rise algorithms to determine vertical allocation of emissions using various input models or in-line plume height calculations, to determine plume height vertical structures and invoke transport of emissions. In this work, we test basic plume rise methods currently being used in chemical transport modeling, to determine where CMAQ current capabilities can be improved. We investigate expected necessary improvements needed for allocating the vertical distribution of smoke, separately characterizing smoldering and flaming fires, identifying agricultural vs prescribed fires, and adjusting the diurnal profile of smoke emissions.

Keywords: Plume rise, fire modeling, emissions

Bio: Dr. Joseph L. Wilkins is a graduate of the University of Louisville gaining his B.S. in Physics and Atmospheric Science. Dr. Wilkins attended graduate school at Saint Louis University, where he gained his Masters and PhD in Meteorology with a concentration in Atmospheric chemistry, air quality, and modeling. Currently Dr. Wilkins works at the U.S. Environmental Protection Agency as a Post-Doc; conducting experimental and modeling research primarily focused on pollution, transport of pollution, biomass burning, plume rise, and plant health.

S7.15. Comparison of Ozone Measurement Methods in Biomass Burning Plumes

Presenter: Russell Long, Research Chemist, United States Environmental ProtectionAgency
Additional Authors: Whitehill, Andrew, U.S. EPA
Landis, Matthew, U.S. EPA
Maribel Colon, U.S. EPA
Andrew Habel, JTI

The most widely used method for measuring ozone in ambient air is based upon UV photometry. Several instruments employing the UV photometric method have been designated by the U.S. EPA as Federal Equivalent Methods (FEM) and can be used for regulatory monitoring purposes. However, the UV photometric method is prone to interference from water vapor, VOCs and other UV absorbing compounds that exist in ambient air and that are commonly found in biomass burning plumes. Two newly introduced and recently designated ozone analyzers have the potential to overcome the interference issues associated with the widely used UV photometric method. The first utilizes NO-chemiluminescence (NO-CL) to measure ozone in the atmosphere where the reaction between ambient ozone and NO produce light proportional to the ozone concentration. The NO-CL

method was promulgated as the new Federal Reference Method (FRM) for ozone in 2015. The second represents a variation of the UV photometric method, known as the "scrubberless" UV (UV-SL) method that specifies removal of ozone and only ozone from the sample air for the zero reference by a gas-phase reaction with NO rather than via a conventional solid chemical scrubber. Both methods, either through measurement principle, or sample treatment processes may effectively eliminate interferences to an insignificant level. The EPA has performed research on methods for the measurement of ozone in both laboratory and ambient settings including evaluation in biomass burning plumes. This presentation presents the results of both laboratory and ambient based evaluations of FRM and FEM analyzers for ozone including inter-comparison between the different methods during prescribed fires at the Konza (March and November 2017) and Tallgrass (November 2017) prairies in Kansas and at the Sycan Marsh (October 2017) in Oregon.

Disclaimer:
Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.

Keywords: Ozone, measurement, methods, biomass, burning, plume

Bio: Dr. Russell Long, serves as the lead at the U.S. EPA for ground-based, gas-phase federal reference methods research supporting the EPA National Ambient Air Quality Standards. Dr. Long has served as the EPA lead for activities under the NASA DISCOVER-AQ (2011-2014) and KORUS-AQ (2016) missions and NOAA UWFPS study (2017) and was responsible for the overall planning, deployment and operation of the EPA gas-phase, PM, and small sensor networks. Dr. Long actively participates as a member of EPA's wild land fire research team with responsibilities for planning, deployment and operation of in situ and remote-sensing, gas-phase and PM measurement technologies.

S7.16. EPA Wildland Fire Sensor Challenge: Preliminary Results from the Stage I Evaluation

Presenter: Mattthew Landis, Senior Research Environmental Health Scientist, U.S. EPA Office of Research and Development, National Exposure Research Laboratory
Additional Authors: Hagler, Gayle, Assistant Laboratory Director, U.S. EPA Office of Research and Development
Baker, Kirk, Physical Scientist, U.S. EPA Office of Air Quality Planning and Standards
Urbanski, Shawn, Research Physical Scientist, U.S. Forest Service, Rocky Mountain Research Station
Long, Russell, Research Chemist, U.S. EPA Office of Research and Development
Whitehill, Andrew, Post Doctoral Research Fellow, U.S. EPA Office of Research and Development
Krug, Jonathan, Research Physical Scientist, U.S. EPA Office of Research and Development

Wildland fires can emit substantial amounts of air pollution that may pose a risk to those in close proximity (e.g., first responders, nearby residents) as well as downwind populations. Quickly deploying air pollution measurement capabilities in response to incidents has been limited to date by the cost and complexity of implementation. Emerging technologies including miniaturized direct-reading sensors, compact microprocessors, and wireless data communications provide new opportunities to detect air pollution in real time. The U.S. Environmental Protection Agency (EPA) partnered with the National Oceanic and Atmospheric Administration; U.S. Forest Service; National Aeronautics and Space Administration; Centers for Disease Control and Prevention; National Park Service, and Tall Timbers Research Station to sponsor the Wildland Fire Sensor Challenge (https://www.challenge.gov/challenge/wildland-fire-sensors-challenge/). EPA and partnering

organizations share the desire to advance wildland fire air measurement technology to be easier to deploy, suitable to use for high concentration events, durable to withstand difficult field conditions, with the ability to report high time resolution data continuously and wirelessly. The Wildland Fire Sensor Challenge encouraged innovation worldwide to develop sensor prototypes capable of measuring particulate matter (PM2.5), carbon monoxide (CO), carbon dioxide (CO_2), and ozone (O_3) during wildfire episodes, with one or multiple awardees to be determined based upon performance testing. Ten solvers from four countries submitted sensor pods by the January 2018 deadline for evaluation as part of the challenge. The results for Phase I testing of the sensors (February - March 2018) including sensor accuracy, precision, linearity, and operability will be presented and discussed.

Disclaimer
Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.

Keywords: Smoke, sensor, challenge

Bio: Dr. Matthew S. Landis

- Received Ph.D. (1998) in Environmental Health Science - Air Quality from the University of Michigan
- Senior Environmental Health Research Scientist with U.S. EPA Office of Research and Development
- Principal Investigator in the Air Climate and Energy Program and point of contact for the Wildland Fire Research Program
- Over 80 published papers and book chapters
- Research interests include wildland fire emissions, biogeochemical cycling of heavy metals, particulate matter characterization, atmospheric wet & dry deposition, and source apportionment modeling

S8.1. Risk Interdependence and Alignment of Social and Ecological Networks in Fire-prone Forests
Presenter: Matthew Hamilton, Postdoctoral Research Fellow, University of Michigan
Additional Authors: Fischer, A. Paige, PhD, Assistant Professor, University of Michigan
Ager, Alan, PhD, Research Forester, US Forest Service RMRS

Large wildfire events highlight the importance of governance systems that address wildfire risk at landscape scales and among multiple land owners and institutions. These governance systems feature numerous collective action problems, because the likelihood that a wildfire spreads to a given location depends on forest management practices on adjacent and sometimes distant lands. A growing body of empirical work demonstrates that environmental governance outcomes depend upon how well patterns of interaction among actors (e.g., organizations) align with patterns of ecological connectivity, such as wildfire transmission. However, the factors that facilitate or inhibit this alignment remain poorly understood. It is crucial to improve understanding of the conditions under which organizations establish or maintain linkages with other organizations with whom they are interdependent because of ecological linkages. This presentation explores the concept of "risk interdependence archetypes," which distinguish between types of costs and benefits of risk mitigation associated with different spatial configurations of ecological connectivity in governance systems characterized by extensive overlap among organizations' jurisdictions. I'll discuss how colleagues and I have been using tools and perspectives from network science to study risk

transmission networks (developed through simulation of wildfires over a large landscape) and a governance network (created from interviews with 154 representatives of 87 organizations involved in efforts to mitigate wildfire risk in the Eastern Cascades, USA). We found that alignment of the governance network with the fire transmission network is more likely when organizations can capture a greater share of the benefits of risk mitigation. Importantly, not all forms of risk interdependence increase the likelihood of alignment, implying that organizations have limited capacity for interaction and may prioritize certain high-payoff forms of alignment over others. While performance of risk governance systems may depend upon alignment of social and ecological networks, we show that alignment is shaped by organization-level strategies for interaction with other organizations.

Keywords: Risk interdependence, social-ecological networks, Oregon

Bio: Matt Hamilton is a postdoctoral research fellow at the School for Environment and Sustainability at the University of Michigan. Current research focuses on applications of network science tools and perspectives to understand how people (or organizations) work together to solve environmental problems.

S8.2. Wildfire Exposure and Community Capacity to Manage Wildfire Risk: A Coupled Biophysical and Social Analysis of Wildfire Risk in Communities across the Western United States

Presenter: Cody Evers, PhD Student, Portland State University
Additional Authors: Ager, Alan, PhD, Research Forester, Rocky Mountain Research Station, United States Forest Service
Evers, Cody, PhD Candidate, Portland State University

Coordinated approaches to planning and implementing wildfire risk mitigation strategies that cross ownership and management boundaries are found in many policies and programs worldwide. However, mismatches between biophysical manifestations of risk and the social potential to address risk may limit the effectiveness of the "all lands, all hands" approach to address the risks communities face from wildfire. Wildfire risk may be elevated if the sources of risk are too many to effectively coordinate mitigation. Yet substantial local capacity to coordinate risk reduction may make success stories out of at-risk communities, or visa-versa turn what would appear a problem into a disaster waiting to happen. We conducted an analysis of simulated housing exposure to wildfire in 60 communities in the western United States coupled with key informant assessments of the social capacity of those communities to mitigate wildfire risks. The research aims to highlight the relationships between biophysical and social determinants of wildfire risk at the community scale. The results generally demonstrate (1) the number of sources of wildfire risk influences the extent a community is exposed to wildfire, and (2) local expressions of competence in managing wildfire risk are associated with to lower exposure communities. We suggest that investments in ongoing community risk planning and networking across communities, especially moderate capacity communities, may help to leverage existing capacity into a self-reinforcing cross-boundary wildfire risk management system. The analysis provides an improved social-ecological understanding of wildfire risk, but also highlights new questions about the causal pathways between capacity and exposure.

Keywords: Cohesive Strategy, key informant survey, scale mismatches, recursive partitioning, wildfire simulation

Bio: Cody Evers is a doctoral student and NSF IGERT research fellow at Portland State University in the Department of Environmental Science and Management. He has been involved in wildfire research for nearly a decade through projects funded by the NSF, USDA, and JFSP. His dissertation uses social-ecological network modeling to evaluate scale-matching between the social and ecological aspects of wildfire risk governance.

S8.3. Assessing and Managing Wildfire Risk Across Diverse Forest Ownerships in a Fire-Prone Landscape

Presenter: Susan Charnley, Research Social Scientist, USDA Forest Service, Pacific Northwest Research Station
Additional Authors:

This presentation reports on research that investigated how federal, state, and private corporate forest owners in a fire-prone landscape of southcentral Oregon manage their forests to reduce wildfire hazard and loss to high-severity wildfire. The research used a combination of social science methods and agent-based landscape modeling to assess how landowners perceive and manage wildfire risk, and to evaluate trends in forest structure and fire metrics by ownership as an outcome of these perceptions and management practices. We found a high degree of variation in forest management decisions and behaviors to reduce wildfire losses between and within ownership groups. This diversity contributed to heterogeneous forest conditions across the landscape, and was driven mainly by forest management legacies, economics, and attitudes toward wildfire (fortress protection vs. living with fire). Contrary to common perceptions among land managers interviewed, modeling results indicated that, in general, U.S. Forest Service management had the most favorable outcomes for forest resilience to wildfire, and private corporate management the least. However, some state and private corporate forest ownerships have the building blocks for developing fire-resilient forests. Heterogeneity in social–ecological systems is often thought to favor social–ecological resilience. We found that despite high social and ecological heterogeneity in wildfire risk management and forest conditions in our study area, most forest ownerships did not exhibit characteristics that make them resilient to high-severity fire currently or in the future under current management. Our coupled social and biophysical approach to assessing wildfire risk management enabled us to understand connections among the social, economic, and ecological components of a multi-ownership, fire-prone ecosystem. Our approach also underscored the importance of looking beyond the present to future trajectories of landscape change to fully understand the implications of current wildfire management practices for promoting forest resilience to wildfire. We identified how wildfire risk management in this multi-ownership landscape might improve through interventions to address key constraints in the system. Strategies include retaining and developing market infrastructure for wood products of all types; incentivizing growth of big trees on private corporate lands that currently lack them; making financial assistance available to private corporate owners for reducing fire hazard and recovery following wildfire; developing policies and programs that support the use of prescribed fire on private corporate and state lands; and strengthening social networks for addressing wildfire.

Keywords: multi-ownership landscape, US Forest Service, private corporate forestry, state forestry, wildfire hazard

Bio: Susan Charnley is an anthropologist and works as a research social scientist with the US Forest Service, Pacific Northwest Research Station. Her research investigates how best to achieve the dual goals of environmental conservation and rural community well-being in the western USA and Africa.

She conducts research in four broad areas: (1) socioeconomic assessment and monitoring of forest management and policy; (2) understanding the social context for environmental management; (3) natural resource use and management practices of ranchers/pastoralists and forest owners/users; and (4) how to promote conservation and sustainable livelihoods in rural, natural-resource based communities.

S8.4. A Typology of Community Wildfire Exposure from US National Forests
Presenter: Cody Evers, PhD Student, Portland State University
Additional Authors: Ager, Alan; PhD; Research Forester; USFS Rocky Mountain Research Station
Nielsen-Pincus, Max; PhD; Assistant Professor; Portland State University
Paliologos Palaiologou; PhD; Research Fellow; USFS International Visitor Program
Ken Bunzel; Kingbird Software

Community wildfire exposure varies along multiple geographic continuums and results in a diversity of different contexts within which wildfire risk is managed. Typologies are a means for matching mitigation and intervention programs to particular groups of exposure factors. In the case of community wildfire exposure, typologies describe discrete strategies for building community resilience to wildfire based on common social and biophysical drivers of community risk. Existing community wildfire risk typologies are few and omit key factors that determine the scale and mechanisms of wildfire exposure and opportunities to improve community resilience. In this presentation, we address this gap by describing a new typology that considers an array of biophysical factors describing fire behavior, fuels, and the source of large fires in the surrounding wildlands. The typology is based on a spatial framework that links the source of wildfire exposure to communities and the affected area, thereby defining a specific spatial container to minimize scale mismatches. We examined wildfire exposure for 5000 communities in the western US and identified five common archetypes and associated risk mitigation strategies based on their biophysical composition. The archetypes exhibited strong spatial clustering in different regions of the western US and the diversity in archetypes at the state scale was related to diversity in vegetation types and associated fuels. The results can be used to help guide public investments in communities to improve fire resilience on public lands surrounding communities that transmit fire into them.

Keywords: risk exposure; typology; wildfire simulations; western US national forests

Bio: Cody Evers is a doctoral student and NSF IGERT research fellow at Portland State University in the Department of Environmental Science and Management. He has been involved in wildfire research for nearly a decade through projects funded by the NSF, USDA, and JFSP. His dissertation uses social-ecological network modeling to evaluate scale-matching between the social and ecological aspects of wildfire risk governance.

S8.5. Network Governance of the Chernobyl Exclusion Zone: When Fire and Radiation Mix (Phase 1)
Presenter: Derric Jacobs, Research Associate, Portland State University
Additional Authors: Nielsen-Pincus, Max, Assistant Professor, Portland State University
Ager, Alen, Research Forester, U.S. Forest Service

On April 26th 1986 one of the worst nuclear power plant disasters in history took place in Chernobyl, Ukraine. To date, the governments of Ukraine, Belarus and Russia manage their respected forested regions around the Chernobyl power plant location as places with high risk to radiation exposure. In the Ukraine, the Chernobyl Exclusion Zone (CEZ), a roughly 2,600 km2 area, is managed to reduce

radiation exposure risks. Since the accident, forests in the CEZ have mostly been left to grow, allowing radioactive elements to be bound up in the soil and vegetation. As a result, the frequency and severity of wildfires in in the CEZ have become a focus of Ukrainian and international concerns over the last decade due to the potential to the spread radiation through smoke locally as well as into the atmosphere and across the globe. A joint taskforce sponsored by the Regional Eastern European Fire Monitoring Center, The U.S. Forest Service, and leading natural resource and wildfire institutions within Ukrainian's national bureaucracies were tasked with understanding the current wildfire-radiation risks in the CEZ, the current opportunities to better manage the risks, and the paths for improvement in preventing wildfires and responding to events to reduce radiation exposure and transmission. To contribute to the growing understanding of wildfire risk from the CEZ, we conducted a network governance survey of wildfire managers operating in the CEZ. Network analysis was conducted by surveying 39 key managerial informants across 14 organizations and agencies operating to manage wildfire risks for the CEZ. Respondents were asked to identify who they work with in six domains of CEZ fire risk management: (1) fire prevention, (2) pre-fire preparation, (3) incident management and response, (4) radiation safety, (5) research and monitoring, and (6) funding. The survey identified many additional organizations and agencies operating in CEZ wildfire risk management. The analysis highlights the structure of network governance operating in the CEZ and a more complex array of organizations and actors than initially suspected. Quadratic Assignment Procedures followed by regression analysis using UCINET show network correlations between actors operating in each of the action domains. Further quantitative analysis shows that structural positions affect perceptions of network effectiveness at managing wildfire risk. The analysis was presented to agency directors in Kiev, Ukraine in June 2017, stimulating a growing interest in focusing on the network governance of CEZ.

Keywords: Network Governance, Chernobyl Exclusion Zone, Wildfire and Radiation Risks

Bio: Derric is post-doctoral research associate working with Dr. Max Nielsen-Pincus at Portland State University. He received a Masters of Public Policy and a Ph.D. in Environmental Sciences at Oregon State University. Derric's academic training and specialization is working in the theoretical / and methodological fields of social capital and social network analysis. His research interests focus on climate adaptation and the complex socio-ecological dimensions of wildfire risks in the western U.S. Specifically, Derric focuses on networked governance, the structure and character of networked stakeholder relationships, which may be a fundamental key to addressing and co-managing wildfire risks.

S8.6. Anticipating interactions between forest management and wildfire as private forestland owners adapt to climate change

Presenter: Jeffrey Kline, Research Forester, USDA Forest Service, Pacific Northwest Research Station
Additional Authors: Hashida, Yukiko; Postdoctoral Associate; Yale Univsersity
Lewis, David J.; Professor; Oregon State University

On private forestlands, climate change will influence wildfire via two pathways: (1) Changes in temperatures and precipitation will induce direct changes in wildfire likelihood and severity; and (2) Changes in management by forestland owners seeking to adapt to climate change will result in shifts in species composition and harvest timing and intensity, which act as additional indirect influences on wildfire. We examined private forestland owners' management behavior in the context of climate change and wildfire, to anticipate how forestland owners in California, Oregon, and Washington (USA) are likely to adapt to climate change and how their adaptation could influence wildfire in the region. Drawing on fine-scaled panel data describing forest conditions, climate, wildfire, and private forest management, we estimated empirical models characterizing forestland owners harvest and replanting decisions in response to climate and wildfire variables. We used our empirical models to simulate forestland owners' future harvest and replanting decisions, and the likelihood and severity of future wildfires, as private forestland owners shift their management in response to changing climate. Our results suggest that climate change will induce moderate shifts away from Douglas fir in favor of Ponderosa pine and hardwoods, and associated increases in wildfire, particularly in the western Cascades.

Keywords: Nonindustrial private landowners, adaptation, fuel management, climate change

Bio: Jeff Kline is a research forester with the USDA Forest Service's Pacific Northwest Research Station in Corvallis, Oregon. He has worked with forestry and land use issues for over 30 years with nonprofit, state, and federal agencies and organizations. His current research examines the effects of population growth and land use change on forests and their management, as well as related changes in how the public uses and values forests.

S8.7. Building Community Capacity for Cross-Boundary Fire Risk Management
Presenter: Daniel Williams, Research Social Scientist, USFS - Rocky Mountain Reserach Station
Additional Authors: Maureen Essen, Social Science Analyst, Forest Service, Rocky Mountain Research Station

Reducing wildland fire risk to lives, property, and landscapes is among the most intractable and expensive problems facing the U. S. Forest Service and consequently represents an urgent and high priority research topic within Forest Service R&D. The Forest Service invests over $300 million annually in fuel reduction projects, but lacks sufficient knowledge of how to effectively engage community partners in the collective management of those risks. A key problem is that wildfire processes operate at landscape scales in which threats, risks, and benefits and costs are transmitted (and thus shared) across a complex geographic network of co-dependent stakeholders and land ownerships and thus requires an "all hands – all lands" approach. This presentation introduces a new research management partnership within USFS between Fire and Aviation Management and the Rocky Mountain Research Station aimed at investigating ways to improve wildfire risk management through cross-boundary collaboration among co-dependent stakeholders. The project targets selected communities in the Western US for hazardous fuels investments where there biophysical models have identified particularly high fire risk transmission from Forest Service lands to private homes and property. The aim of these case studies is to test and evaluate locally driven approaches to cross-boundary engagement that result in reduced risk. Taking a systems approach case studies are designed to document the biophysical and social characteristics of communities and the surrounding landscape that enhance community stakeholder capacity for cross-boundary wildfire risk management across four levels of scale: (1) household characteristics, attitudes and parcel risk assessments; (2) describe alternative social community types and their different pathways for building cross-boundary capacity; (3) map the regional network of stakeholders across the larger landscape; and (4) describe the formal and informal governance structures and processes that support and undermine adaptive governance of wildfire risk. These efforts will be documented and reported to understand the differences both across communities and through time to strengthen our understanding how best to work with communities to advance fuels management and other restoration actions, and how risk sharing between communities and the Forest Service evolves over time based on experience of these efforts.

Bio: Daniel R. Williams is a Research Social Scientist with the USDA Forest Service, Rocky Mountain Research Station in Fort Collins, Colorado. He has worked for RMRS for 19 years and previously served on the faculty at University of Illinois, Virginia Tech and the University of Utah. He received his Ph.D. in Forestry from the University of Minnesota. Dan's research on wildland fire focuses on the adaptive capacity of communities in the WUI, the human dimensions of landscape change, and the adaptive governance of complex social-ecological systems.

S8.8. Assessing influences on social vulnerability to wildfire using surveys, spatial data and wildfire simulations

Presenter: Catrin Edgeley, PhD Candidate, University of Idaho
Additional Authors: Paveglio, Travis, Assistant Professor, University of Idaho
Stasiewicz, Amanda, PhD student, University of Idaho

A growing body of research focuses on identifying patterns among human populations most at risk from hazards such as wildfire and the factors that help explain performance of mitigations that can help reduce that risk. Emerging policy surrounding wildfire management emphasizes the need to better understand such social vulnerability—or human populations' potential exposure to and sensitivity from wildfire-related impacts, including their ability to reduce negative impacts from the hazard. Studies of social vulnerability to wildfire often pair secondary demographic data with a variety of vegetation and wildfire simulation models to map potential risk. However, many of the assumptions made by those researchers about the demographic, spatial or perceptual factors that influence social vulnerability to wildfire have not been fully evaluated or tested against objective measures of potential wildfire risk. The research presented here utilizes self-reported surveys, GIS data, and wildfire simulations to test the relationships between select perceptual, demographic, and property characteristics of property owners against empirically simulated metrics for potential wildfire related damages or exposure. We also evaluate how those characteristics relate to property owners' performance of mitigations or support for fire management. Our results suggest that parcel characteristics provide the most significant explanation of variability in wildfire exposure, sensitivity and overall wildfire risk, while the positive relationship between income or property values and components of social vulnerability stands in contrast to typical assumptions from existing literature. Respondents' views about agency or government management helped explain a significant amount of variance in wildfire sensitivity, while the importance of wildfire risk in selecting a residence was an important influence on mitigation action. We use these and other results from our effort to discuss updated considerations for determining social vulnerability to wildfire and articulate alternative means to collect such information.

Keywords: social vulnerability, wildfire, risk, simulation, survey, demographics

Bio: Catrin Edgeley is a Ph.D. Candidate in the Department of Natural Resources and Society at the University of Idaho. Her doctoral research focuses on community adaptation to wildfire across the West. This includes post-fire recovery in rural communities, intended evacuation behaviors, and community support for wildfire management actions.

S8.9. Obstacles to improving wildfire risk governance in Greece

Presenter: Palaiologos Palaiologou, Geographer, USDA Forest Service International Visitor Program: Oregon State University
Additional Authors: Kalabokidis, Kostas, Professor, University of the Aegean, Department of Geography, Greece.
Ager, A. Alan, Research Forester, USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, USA
Nielsen-Pincus, Max, Assistant Professor, Portland State University, Department of Environmental Sciences and Management, USA.
Bailey John, Professor, Oregon State University, Department of Forest Engineering, Resources and Management, USA
Xanthopoulos, Gavriil, Researcher, Hellenic Agricultural Foundation 'Demeter', Greece

Adapting to the escalating large-scale wildfire occurrence and their effects in Greece is a difficult risk governance problem. Existing policies governing fuel management and fire have seen only minor adjustments during the last half century. Rarely do new scientific advancements gained acceptance from policy makers, whose decisions are usually dictated by public reactions or fear for unprecedented political/legal consequences. Few studies have explained the current trends and beliefs of Greek society on wildfire issues, including fire prevention and management, suppression efforts and effects. This research aims at highlighting the views of different social groups (i.e. citizens, forestry and fire suppression agency professionals, and researchers/academia) to inform policy makers and propose necessary changes to risk governance. We used an on-line questionnaire to query civil protection agencies and research organizations, and received 125 responses, a quarter of which came from the engaged stakeholders through social networks. Results emphasize the importance of different categories of wildfire effects, to understand what is considered negative or unacceptable, indifferent, or positive. Results are expected to guide post-fire management agencies on mitigating the aftermath of wildfire events that have had the most social impact. For fire prevention, we examined the range of public acceptance and views on fire use and fuel management activities that are applied elsewhere in the world, but that are limited or not allowed in Greece. Lastly, we examined the beliefs of ignition causes and responsibility, in addition to how different policies might reduce wildfire-related problems. Building off a transboundary risk analysis conducted for a northern Greek region, we explore inefficiencies in the current wildfire management scheme and provide policy recommendations and methods to eliminate them. Survey results will help identify feasible proposed policy changes, while helping public agencies that administer wildfire prevention programs promote and apply more effective procedures.

Keywords: Greece, Fire management, Risk governance, Society perceptions, Fire effects.

Bio: Palaiologos Palaiologou is a Geographer with a Ph.D. in Wildfire Effects and Behaviour, from the University of the Aegean, Department of Geography, Greece. His research interests include wildfire effects and coupled human and natural systems for wildfire risk governance. He has been involved in a number of EU-funded research projects on forest fires, dealing with integration of new technologies into wildfire suppression. Since 2016, he lives in the USA, working as a visiting scholar for the International Visitor Program of the US Forest Service, invited by Dr. Alan Ager, in collaboration with Portland State University and Oregon State University.

S8.10. Prioritising WUI fuel treatments using statistical models of past fire ignition and spread
Presenter: Price Owen, Senior Busfhire Risk Modeller, Centre for Environmental Risk Management of Bushfire, University of Wollongong
Additional Authors:

Objective prioritisation of fuel treatments is possible through quantitative understanding of the components of wildfire risk (the location of assets, the distribution of fuels, the distribution of ignitions and patterns of spread of fires under different weather conditions). Fire spread simulators have been applied to this problem, but they have some disadvantages, most notably that they potentially under-predict fire spread in real-world wildfire conditions because they were developed in prescribed burning conditions and/or take little account of the spotting process.
In this talk, we present a method based on a published statistical model of the spread of 700 fires in WUI situations around the city of Sydney, which predicted whether a fire will spread from its ignition point to a randomly selected WUI 'receiver' as a function of distance, direction, weather, drought factor, time since last fire and forest cover. This model can applied to any spatial set of assets and treatment blocks to measure wildfire risk and the benefits of treatment via a five-step process:
1) Apply the model to a sample of lines radiating from each asset, which calculates the probability of a fire reaching the asset should a fire start at the end of each line.
2) Multiply each line probability by the probability of ignition at the start point (a raster derived by kernel density or statistical modelling) to get the probability of a fire starting and reaching. The mean among sample lines is used to compare risk to assets.
3) Calculate the sum of risk for all sample lines from all assets that pass through each treatment block. This is used to map and compare risk posed by the fuels in each treatment block.
4) Recalculate 3 with time since fire reduced to zero for the proportion of each line passing through the treatment block.
5) The difference between 3 and 4 is the achievable risk reduction and is used to prioritise treatments.
This method has been implemented as a freely available r package, that requires three raster layers (time since fire, forest cover and ignition density/likelihood) and two feature layers (assets and treatment blocks). We show results for two study areas. The processing time on a PC for a study area with 6000 assets and 900 treatment blocks was about 1 hour.

Keywords: Wildfire Risk, Wildfire Likelihood, Wildfire Spread, Fuel Treatment

Bio: Owen started his research career in wildlife conservation in the savannas of northern Australia where fire influences all aspects of ecology. He now works at the University of Wollongong where he focuses on learning about fire behaviour and consequence from historical data on wildfires. This includes analysis of the drivers of fire spread, area, severity, house loss, smoke production and spotting. He has written or contributed to over 80 journal papers and 40 reports.

S8.11. Participatory modeling of stakeholder-developed landscape strategies for fire and fuels management
Presenter: Andrew Merschel, PhD Student, Research Ecologist, College of Forestry, Oregon State University
Additional Authors: White Eric, USFS
Tom Spies, USFS
Emily-Jane Davis, OSU
Kreg Lindberg, OSU Cascades

John Bailey, OSU
Keith Olsen, OSU

Federal agencies, state government, and forest collaborative groups are under great pressure to increase the pace and scale of restoration in fire-adapted landscapes on Oregon's eastside. Agreed upon restoration strategies typically employ a mix of timber harvest, mechanical treatments, and prescribed and natural fire applied at landscape scales, sometimes across ownerships. Because of landscape complexity in forest conditions, history, human development, and social values for landscape outputs, there are often divergent views on the appropriate intensity, location, timing, and extent of restoration activities. Science and science tools are often called on to provide information on the likely outcomes from alternative treatment strategies. We used a landscape model to simulate the effect of the interacting processes of succession, fire, and restoration and management treatments on landscape conditions and fire behavior under alternative management strategies. We report on landscape outcomes for 4 strategies developed by mangers and collaborative stakeholders that represent distinct values. We also describe the potential of using a participatory landscape model as a decision and discussion support tool for collaborative landscape management.

Spatial optimization of fuel treatments and prescribed fire were more effective at limiting the extent of severe fire during extreme weather than simply increasing treatment area. However, differences in the total amount of severe fire over 50 years were not as large as many participants expected. Strategies also had important unintended consequences: 1) Treating areas adjacent to late seral forests to protect them from fire resulted in decreased recruitment of habitat for late seral species, and 2) increased wildland fire use reduced severe fire area in subsequent extreme fire events, but increased the cumulative amount of severe fire across the landscape. Changes in forest structure and ecosystem services (e.g. wildlife habitat, forest products, carbon) were generally nominal among restoration strategies. This demonstrated that landscapes are slow to change, and helped participants develop realistic expectations for landscape restoration. Participants were encouraged that their diverse values were robust under several management scenarios.

Keywords: Fire Modeling, Landscape Restoration, Coupled Human Natural Systems, Socioecological fire management, Participitory Simulation Modeling

Bio: Andrew Merschel is a fire ecologist who works with management agencies and forest collaboratives to develop a shared understanding of historical fire regimes and opportunities for forest restoration. Andrew's study areas include ponderosa pine and mixed-conifer forest in the eastern Cascades, lodgepole pine forests on the central Oregon Pumice Plateau, and Douglas-fir forests on the west slope of the Cascades in southern Oregon. Andrew enjoys sanding in his spare time.

S8.12. Sharing the road: managers and scientists transforming fire management

Presenter: Craig Bienz, Director Sycan Marsh, The Nature Conservancy
Additional Authors: Parsons, Russ, Research Ecologists, Fire Sciences Lab, USDA Forest Service
Grulke, Nancy, Director WWETAC, USDA Forest Service
Sauerbrey, Katie, Sycan Marsh Preserve Steward, The Nature Conservancy
Rosendaul, Kalaena, Contractor

The Nature Conservancy and the U.S. Forest Service have long range goals to reintroduce fire into U.S. ecosystems at ecologically-relevant spatial and temporal scales. Building on decades of collaborative work, they developed a Master Participating Agreement (2017) to increase overall fire management capacity, through training and education. In October 2017, the goals of this partnership were exemplified when TNC hosted a collaborative training, education, research, and restoration-related event for two-weeks at Sycan Marsh Preserve in Oregon. Through interagency/ inter-organizational participation in the shared learning and training experience the group applied fire on over 1,000 acres, across administrative boundaries, in grasslands and forested communities. In the context of a prescribed burn, eighty people from fifteen organizations worked together to accomplish both operational goals and carry out multidisciplinary fire research investigations incorporating multiscale thermal imagery, drones, fixed wing aircraft, weather data, ground measurements and sophisticated modeling. Building trust, developing relationships, and transparent communication between managers and scientists was the genesis of adaptive management / translational ecology wherein: scientifically informed management decisions during planning and implementation of Rx fire allows for better decision making (case and point improved modeling efforts throughout the years), scientists better understand the dynamics of fire management on the ground which informs their work and end products for the fire community, and exponential increase in landscape scale ecologically relevant restoration. This presentation will summarize some of the critical components that can lead to successful and long-lasting collaborations between managers and scientists, and the role that such partnerships play in the long-term success of fire adapted restoration.

Keywords: Fire ecology, collaboration, adaptive management, translational ecology

Bio: Craig has worked to develop resilient ecosystems to sustain native species in frequent-fire forests. Fire and hydrologic regimes, forest structure and species composition are areas of interest. He has extensive experience in multi-party, cross jurisdictional agreements to facilitate landscapes scale restoration projects. His recent work has been to evaluate the effectiveness of forest and fire management treatments in dry pine forest.

S9.1. What Are These Things We Call Fire Refugia?
Presenter: Meg Krawchuk, Assistant Professor, Oregon State University
Additional Authors:

Fire refugia, sometimes referred to as fire islands, shadows, skips, refuges, residuals, or fire remnants, are an important element of the burn mosaic. There is growing interest in fire refugia, particularly their form and function within fire events and fire regimes. As interest grows, so does confusion over what exactly is meant by the term fire refugia. Here, as an introduction to the special session on fire refugia, we present different ways that refugia have been characterized and quantified. Our goal is to help guide interpretation and facilitate open discussion of refugia ideas. We propose four major dichotomies, as a taxonomy of sorts, to delineate a framework for orienting different perspectives of fire refugia: i) locations that are unburned versus burned at low severity; ii) characterized as species-specific versus landscape attributes; iii) predictable versus stochastic formation; and iv) landscape elements that are ephemeral versus persistent over time. The relative persistence of refugia also contributes to ongoing debate and ambiguity in the literature regarding the distinction of refugia from refuges, and we suggest this is less a dichotomy but rather a clarification in language. In the real world, fire refugia express themselves along gradients rather than these book-end dichotomies, and our aim is to illustrate the important variability that exists in how we identify and describe these phenomena. Very generally, we propose fire refugia can be considered as areas relatively more resistant to burning than the surrounding matrix, and that these locations confer resilience to landscapes. This partnership of resistance and resilience plays an important role for land management and conservation, particularly in the context of global environmental change. The challenge, scientifically, is to collect the evidence to support this proposition, and that is the focus of this special session “Fire refugia: identification, formation, function, and management”.

Keywords: fire, refugia, conservation, conceptual, global change

Bio: Dr. Meg Krawchuk is an Assistant Professor at the Department of Forest Ecosystems and Society at Oregon State University. Dr. Krawchuk leads the Landscape Fire and Conservation Science Research Group, with research and teaching focused on landscape and fire ecology, pyrogeography, conservation science. Research includes: predictability, form, and function of fire refugia within burn mosaics of western North American forest ecosystem; ecological implications of overlapping short-interval disturbances such as insect outbreaks, forest harvest, and wildfire; spatially varying constraints over modern and historical patterns of burning at landscape and regional scales; effects of invasive species on fire regimes dry forest ecosystems.

S9.2. Mapping and Characterizing the Distribution of Forest Wildfire Refugia Across Burn Severity Mosaics

Presenter: Ryan Walker, , Western State Colorado University
Additional Authors:

Post-fire mosaics can include large regions of high severity fire effects interspersed with surviving forest remnants, known as forest wildfire refugia. Refugia support surviving legacies critical to subsequent recovery of the forest ecosystem, yet little is known about their abundance and distribution in burn interiors. Readily-accessible 30-m satellite imagery and MTBS burn severity products are commonly employed to characterize post-fire landscapes; however, coarse image resolution and assumptions inherent in burn severity thresholding may not accurately represent ecologically important residual forest patches. Our objectives were to develop high-resolution maps of post-fire landscapes using 1-m NAIP imagery, to use those maps to understand the abundance and distribution of fire refugia across burn mosaics, and to develop thresholds that can be applied to post-fire satellite imagery products to optimize the detection of refugia. We mapped ten burns that occurred in interior dry mixed conifer forest across Colorado, New Mexico, Arizona, and Oregon. Map accuracy was assessed using imagery-based and ground truth methods, returning mean overall classification accuracies of 94% (Kappa=0.87) and 95% (Kappa=0.88) respectively. Refugia patch sizes were highly variable but collectively accounted for nearly half of most burn interiors. Burns contained an average mean density of 0.25 patches ha-1. Distance to potential seed source, inferred by refugia patch edges, was positively related to burn severity across non-forested regions. An average of 5.2% of areas classified as high burn severity per MTBS differenced normalized burn ration (dNBR) thresholds were composed of surviving forest. Post-fire NBR and relativized dNBR (RdNBR) were the strongest predictors of refugia, and optimal thresholds of these spectral indices (NBR=0; RdNBR=440) produced a binary classification accuracy of 77% (Kappa=0.53) when validated against 1-m resolution maps. Our findings highlight the abundance of fire refugia even within severely burned landscapes, and reveal the limitations of using MTBS-based burn severity thresholds to infer tree survival and potential natural reforestation from these seed sources. Methods that optimize the

detection of surviving forest can inform efficient post-fire management interventions and adaptive planning in wildfire-prone systems.

Keywords: refugia, burn severity, post-fire mosaics, remote sensing

Bio: Ryan is a recent graduate of the Masters in Environmental Management program at Western State Colorado University, where he collaborated with an inter-institutional research group investigating the ecological structure and function of forest wildfire refugia. He currently applies his interests in geospatial analysis and remote sensing to his position as a GIS Specialist with an independent environmental consulting firm in southern Colorado.

S9.3. Abundance and pattern of forested refugia within burn perimeters
Presenter: Luke Collins, Research Fellow, Department of Ecology, Environment & Evolution, La Trobe University; The Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning
Additional Authors:

Wildfire refuge is essential for the persistence of many fire sensitive species across forested landscapes globally. However, there has been little quantitative assessment of factors that determine the distribution of fire refuge across space and time. Identification of the relative influence of 'fixed' (i.e. landscape) and 'transient' (e.g. climatic) factors on refuge will be of particular importance in order to understand likely changes in the distribution of wildfire refuge under future climates. The primary factor limiting our understanding of fire refuge dynamics has been the inability to reliably map refuge over broad landscapes at a resolution that is meaningful to plants and animals. This research (i) investigates the utility of Random Forests (RF) to map fire severity at moderate resolution (30 m) across forested ecosystems of south eastern Australia using Landsat imagery and (ii) examines the relative effect of landscape and climatic factors on the location of refuge across several large wildfires over the past 30 years. Sixteen large (>2500 ha) wildfires were used to investigate the potential application of RF for fire severity classification. Training data (n = 10 855 points) was generated using high resolution post-fire aerial photography, with five severity classes being recognised: unburnt, canopy unburnt, canopy partially scorched, canopy scorched and canopy consumed. RF was found to improve classification accuracy of fire severity across all five severity classes by 12% - 21% relative to widely used classification approaches using the differenced Normalised Burn Ratio (ΔNBR). The RF approach was particularly effective at reducing misclassification between unburnt refuges and areas with an unburnt canopy and burnt understorey. Analysis of wildfire refuge patterns revealed that fire weather and drought severity were the primary drivers of refuge location. The likelihood of refuge occurrence decreased with increasing drought intensity and was more likely to occur under moderate fire weather conditions than under extreme conditions. Topographic roughness was the most influential landscape factor, with more rugged landscapes having a higher likelihood of refuge occurrence. However, the effect of topography decreased with increasing drought severity. Results show that increased severity of fire weather and drought predicted under future climate scenarios is likely to lead to a contraction of wildfire refuge across forests of southern Australia. Protection of areas likely to provide fixed fire refuge will be an important step towards maintaining the ecological integrity of forests under future climate change.

Keywords: fire severity mapping, fire refuge, remote sensing

Bio: Dr Luke Collins is a postdoctoral Research Fellow at La Trobe University and the Arthur Rylah Institute for Environmental Research. His research primarily focuses on (i) the effect of climate change on fire regimes and (ii) the response of plant and animal communities to changes in fire regimes.

S9.4. Fire Refugia in Forests of Mexico: What do we Know?

Presenter: Larissa Yocom, Assistant Professor, Utah State University Department of Wildland Resources
Additional Authors: Azpeleta Tarancón, Alicia, PhD student, Northern Arizona University
Cerano Paredes, Julián, Investigator, CENID-RASPA INIFAP
Cortés Montaño, Citlali, Sr. Biodiversity and Forestry Program Coordinator, KfW - German Development Bank, Mexico Office
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Stephens, Scott, Professor, University of California Berkeley

Forests in Mexico range from tropical rainforests to high-elevation mixed-conifer, and fire regimes are equally diverse. Places that are less likely to burn, or where organisms can survive a fire, are no doubt important in all forest types for post-fire succession and ecological function. To date, there is little published literature on fire refugia in Mexico. However, there are many opportunities for research across the country. We will present examples from our experience, illustrating the diversity of fire refugia that may be considered. Examples will come from the Sierra San Pedro Mártir in Baja California, the Linares area of northeastern Mexico, pine forests of Chihuahua and Durango including La Michilía, and steep mountainsides in Michoacán. We will also present ideas for moving the field forward in Mexico and beyond.

Keywords: fire refugia, Mexico, forests

Bio: Larissa is an Assistant Professor at Utah State University in the Department of Wildland Resources.

S9.5. Influence of Topography and Fire Weather on Late-successional Forest Fire Refugia in the US Pacific Northwest

Presenter: Garrett Meigs, Research Associate, Oregon State University
Additional Authors: Krawchuk, Meg, Assistant Professor, Oregon State University

Across western North America, increasing fire activity presents a challenge to land managers seeking to protect and restore late-successional and old-growth (LSOG) forests. Fire refugia – locations that remain unburned or burn less severely than surrounding areas – influence forest regeneration and wildlife recolonization, and their occurrence appears to be more likely under specific topoedaphic and weather conditions. Here, we investigate how the predictability of LSOG fire refugia varies with topography and fire weather. We focus on recent fires in forests managed under the Northwest Forest Plan, which maintains a network of LSOG forest reserves to sustain and restore habitat for the northern spotted owl *(Strix occidentalis caurina)* and other vulnerable species. Specifically, within large forest fires that burned between 2004 and 2015 in the West Cascades of Washington and Oregon (n = 44), we use annualized imputation maps to identify locations that supported LSOG forest composition and structure prior to burning. We classify refugia as those LSOG locations exhibiting minimal change in the RdNBR severity index (30-m Landsat pixels). This refugia class corresponds to estimated tree basal area

mortality of 0-10% based on pre- and post-fire field observations across the region. We define the remaining burned LSOG locations as non-refugia (estimated basal area mortality: >10-100%). We then employ boosted regression tree modeling to quantify the relationship between refugia predictability and a suite of topography and fire weather indices. Consistent with recent studies, our analyses indicate that LSOG forest fire refugia exhibit highest predictability under relatively moderate and benign terrain conditions. Multiple fine- and intermediate-scale topographic metrics explain the variability of refugia occurrence, but their relative importance depends on fire weather. Our findings aim to inform ongoing conservation planning initiatives and bioregional assessments by determining locations most likely to persist as fire refugia, particularly in LSOG forest environments critical to the survival of threatened and endangered species. Maps developed from this study could enable forest and fire managers to prioritize locations and conditions where it is appropriate to either suppress or allow wildfires to burn.

Keywords: biological legacies, burn severity, disturbance, late-successional forests, Pacific Northwest, pyrogeography, refugia, wildfire

Bio: Garrett is a disturbance ecologist who studies how forests change across multiple scales in space and time. He investigates forest health and landscape dynamics using multiple methods, including field observations, remote sensing, GIS, and ecological modeling. Garrett's research currently focuses on the landscape patterns of fire effects, particularly the composition, structure, and function of fire refugia. He also grew up in a zoo.

S9.6. Drivers and outcomes of burn severity in the northwestern Canadian boreal forest

Presenter: Ellen Whitman, PhD Candidate, University of Alberta
Additional Authors: Parisien, Marc-André, Research Scientist, Canadian Forest Service
Thompson, Dan K., Research Scientist, Canadian Forest Service
Flannigan, Mike D., Professor, University of Alberta

The fire regime of the northwestern boreal forest is characterized by intense, stand-replacing (i.e., lethal) crown fires. Wildfires recur every 50-100 years and many boreal tree species display adaptions to high-intensity fire, such as serotinous cones or vegetative resprouting from rhizomes. Climate change is leading to increasingly severe fire weather, and larger and more frequent wildfires are expected. Despite adaptations to lethal fire, more intense and severe fires may overwhelm evolutionary adaptations to fire. In regions without substantial topographical variability, such as the boreal plain, fire refugia or areas characterized by lower-severity burning may be less predictable. To identify drivers and outcomes of burn severity in the northwestern Canadian boreal forest we sampled post-fire environments in six large (~14,000 to 700,000 ha) lightning-ignited wildfires in the Northwest Territories and Wood Buffalo National Park. We measured surface and overstory burn severity one year post-fire, as well as pre-fire stand structure and composition. We measured seedling density one and three years post-fire. Surface and overstory burn severity were significantly explained by topoedaphic context, pre-fire stand structure, and fire weather at the time of burning. Observed burn severity was substantially a product of fuel structure, different vegetation communities had characteristic levels of burn severity. Post-fire species compositions of seedlings were significantly different from pre-fire stand compositions. Although pre-fire forests, climate, and site moisture were primary drivers of post-fire seedling density and tree species dominance, burn severity and fire history were key secondary drivers of post-fire shifts in all tree species compositions. The dominant importance of pre-fire stand structure and topoedaphic context to burn severity and tree species dominance shifts suggests that boreal forests may be inherently resilient to

change; however, increasingly frequent and severe fires have the capacity to surpass such controls, as burn severity and fire alter post-fire assemblies of trees through secondary pathways.

Keywords: Burn severity, fire severity, fire history, regeneration, boreal forest, fire refugia

Bio: Ellen Whitman is a PhD Candidate at the University of Alberta and a visiting scientist with the Canadian Forest Service. Her research interests include burn severity and spatial patterns of wildfire, as well ecological impacts of boreal fires to trees and understory plants. She is passionate about conducting research about forest distrubances in the extensive Canadian north and subartic.

S9.7. Distribution of Persistent Forest Fire Refugia Patches in the Alberta Rocky Mountains
Presenter: Marie-Pierre Rogeau, Landscape fire ecologist, Wildland Disturbance Consulting
Additional Authors: Rogeau, Marie-Pierre, Landscape Fire Ecologist, Wildland Disturbance Consulting
Barber, Quinn, Fire Science Analyst, Canadian Forest Service
Parisien, Marc-André, Senior Fire Scientist, Canadian Service

Persistent fire refugia are forest patches distributed within the forested landscape mosaic and have avoided burning for decades and centuries. We are currently observing the increasing disappearance of persistent refugia under extreme burning conditions, notably during the last decade. This trend prompted us to examine the role topography played in promoting persistent refugia patches within a contiguous landscape of 9119 km2 of the Canadian Rockies under historical pre-1950 forest fire regime conditions. We used a time-since-fire map derived from aerial photo interpretation and fire history field plots, to identify 557 fire refugia patches covering 21% of the forested landscape (4250 km2). From a set of 18 relevant topographic variables, our preliminary statistical analyses point to six dominant variables as good predictors of persistent fire refugia: elevation, aspect, proportion of non-fuel in a 5000 m-window, Topographic Position Index in a 2000 m-window, proportion of non-fuel in a 300 m-window, and distance from headwaters. The prediction map indicates that a significant portion of the subalpine zone offers a combination of topographic elements favorable to the formation of persistent fire refugia. It would appear that the favorable zone is approximately two to three times larger than the current area of fire refugia patches. Nearly 60% (332) of our data set contains patches smaller than 50 ha, which total 4093 ha when combined, and represent a small 3.5% of the total refugia area. We are pursuing further analyses to verify if smaller patch sizes are regulated by different topographic drivers. We hypothesize that patches smaller than 50 ha may not respond as strongly to topography as those larger than 50 ha and their occurrence may be more random in nature. Our initial conclusions suggest that although topography is an important driver of fire refugia, additional factors (presumably related to climate, vegetation, and human factors) affect the length of their persistence, which will require further investigation. The results of this study may help explain how climate-induced changes in fire regime favouring large, extreme severity fires may override even the most favorable topographic elements and thus increase the current vulnerability of refugia forests. They also point to the urgency for fire management practices to be implemented to limit the loss of old-growth forests and their important contributions to ecosystem resilience.

Keywords: refugia, subalpine, topography, old-growth

Bio: Dr. Rogeau has been working in the field of fire history and fire regime studies since 1991 out of Banff, Alberta, Canada. Marie-Pierre (M-P) received her PhD from the University of Alberta in 2016 and is an independent fire researcher consulting for different levels of government and the forest industry. She uses her skills to help integrate the knowledge of historical fire regimes in forest and fire management planning. M-P has a strong interest regarding the effect of topography on fire return intervals and fire spread patterns, and more recently the role fire refugia play in ecosystem resilience.

S9.8. Life-History Traits Mediate The Impact Of Climate Change And Enhanced Fire Regimes On Fire Refugia Of Endemic Tasmanian Conifers

Presenter: Andres Holz, Assistant Professor, Portland State University
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Recurrent landscape fires present a powerful selective force on plant regeneration strategies that form a continuum between vegetative resprouters and obligate seeders. In the latter case, reduction of the interval between fires, combined with factors that affect plant traits and regeneration dynamics can drive plant population to local extinction. Here we use Athrotaxis selaginoides, a relict fire-sensitive Gondwanan tree species that occurs in western Tasmania, as model system to investigate the putative impacts of climate change and variability and human management of fire. We integrate landscape ecology (island-wide scale), with field survey, and dendrochronological (stand-scale) and sedimentary records (watershed and landscape-scales) to garner a better understanding of the spatial patterns, timing and impact of landscape fire on the vegetation dynamics of Athrotaxis at multiple scales. Landscape modeling indicates that historic fires have been killed ca. one third of the range of Athrotaxis and currently surviving populations only exist within the most protected topographic fire refugia. Stand-scale tree-age and fire-scar reconstructions suggest that populations of this species have survive and favored from very infrequent landscape fires over the last 4-6 centuries, but that following European colonization fire severity has increased and resulted in population collapse of Athrotaxis and an associate shift in stand structure and composition that favor resprouter species over obligate seeders. Sedimentary charcoal and pollen concentrations from across the southern half of Athrotaxis range indicate that the postfire recovery time since the last fire has consistently lengthened over the last 10,000 yrs. Overall our findings suggest that both the resistance to fires and the postfire recovery of populations of A. selaginoides have both gradually declined throughout the Holocene and more rapidly after Europeans altered fire regimes, a trend that is common among other Gondwanan conifers in temperate rainforests elsewhere in the southern Hemisphere.

Keywords: Australia, Gondwana, Resilience, Regeneration Failure

Bio: Andres Holz is a forest and fire ecologist working causes and consequences of altered fire regimes as mediated by climate change and variability and landuse change in temperate forests, including Patagonia, Tasmania, New Zealand and the PNW. His work engages a multi-scalar and interdisciplinary approach that uses an assortment of techniques, including dendrochronology, landscape ecology, remote sensing and geographic information systems, spatially-explicit modeling and geostatistics, field studies, and historical and documentary records.

S9.9. Flammability as an ecological driver
Presenter: Dylan Schwilk, Associate Professor, Texas Tech University
Additional Authors: Keeley, Jon, Research Scientist, U.S. Geological Survey
Pausas, Juli, Research Scientist, CIDE, Valencia, Spain

Small scale variation in fire behavior can have dramatic consequences for plant communities. Variation in topography produces differences in local fire return interval and fire behavior through direct effects on air temperature and fuel moisture, but differences in species composition can also control fine scale variation in fire regime. Topography, soil moisture, and soil nutrients can drive landscape flammability patterns through their effects on species composition. For example, local topographic depressions with higher soil moisture can enable the growth of less flammable plants (e.g. broad-leaved species that shade out flammable grasses). Variation in plant flammability has strong effects on fire, yet there has been little agreement on how flammability covaries with ecological strategy.

We argue that part of the problem lies in the concept of flammability, which should not be viewed as a single quantitative trait. Flammability is multi-dimensional with strong empirical support for at least two orthogonal axes of variation (total heat release and flame spread rate) and a potential third dimension (ignitability). These axes are controlled by different plant traits and have differing ecological impacts during fire. At the individual plant scale, these traits define different positions in the flammability space that represent alternative flammability strategies: the non-flammable, the fast-flammable, and the hot-flammable strategy. These strategies increase the survival or reproduction under recurrent fires, and thus, plants in fire-prone ecosystems benefit from acquiring one of them; they represent different (alternative) ways to live under recurrent fires. This framework based on different flammability strategies helps us to understand variability in flammability across scales, and provides a basis for further research.

Keywords: flammability, refugia, fire behavior, ecological strategies

Bio: Dylan Schwilk is fire ecologist interested in the evolution of fire-related plant ecological strategies.

S9.10. Fire refugia plant community composition and structure in Oregon's Blue Mountains
Presenter: Will Downing, , Oregon State University
Additional Authors: Krawchuk, Meg

Fire refugia are increasingly recognized as important components of the burned mosaic, but we lack an understanding of fire refugia plant community composition. This knowledge gap is particularly acute in the context of understory plant communities. Fire refugia are unburned or low-severity burned areas within fire perimeters that may promote ecosystem resilience and post-fire recovery. Although concerns exist that interior mixed-conifer forests are particularly vulnerable to the effects of increasing fire activity and climate warming, little is known about fire refugia community composition in these fire-prone landscapes. Our objective was to compare understory plant community composition in stand replacement patches, low-severity burned refugia, and unburned refugia. We quantified the abundance of 293 vascular plant species 12 – 17 years post-fire in plots located in both fire refugia and stand-replacement patches. Fire refugia were identified as areas where live tree canopy persisted following fire. We used multivariate community analyses to determine how communities varied along environmental gradients, and to test for differences in community composition between stand-replacement patches, low-severity fire refugia, and unburned fire refugia.

Differences in understory community composition between fire refugia and stand-replacement patches were statically significant according to multi-response permutation procedures, but subtle. Non-metric multi-dimensional scaling demonstrated low within-group homogeneity and overlap between plot-types. Understory plant community composition varied most strongly along environmental gradients rather than with fire severity (dNBR) or plot type. There was no evidence of a difference between plot types in species richness, diversity, or the proportion of plots containing invasive annual grasses. We identified 7 fire refugia indicator species, but the indicator value for species associated with fire refugia was lower on average than for species associated with stand replacement patches. We found no evidence of a difference in composition between unburned and low-severity burned fire refugia. Compositional similarities between fire refugia and stand replacement patches 12-17 years post-fire highlight the resilience of mixed conifer forests in the Blue Mountains to high-severity fire effects. Our results suggest that fire refugia in the Blue Mountains are important primarily as locations where relatively intact forest structure persists, rather than as "safe havens" for particular plant communities.

Keywords: Fire refugia, community analysis, resilience

Bio: Will Downing is an aspiring forest ecologist with a background in fire management. Prior to enrolling at Oregon State University as a MS student in 2016, Will spent a decade working as a Hotshot, rappeller, and smokejumper. He is particularly interested in management approaches that seek to improve forest resilience in the face of global change and in supporting cooperation between scientists and fire managers.

S9.11. The importance of fire refugia in the persistence and recolonization of a fire-sensitive conifer in northwest Patagonia

Presenter: Jennifer Landesmann, Postdoctoral research associate, Laboratorio Ecotono, INIBIOMA-CONICET, Universidad Nacional del Comahue
Additional Authors:

Fire is an intrinsic disturbance of plant community dynamics worldwide. However, the current alterations in the frequency, severity, and spatial extent of wildfires may threaten the persistence of plants, especially of certain post-fire colonizer trees that are sensitive to fire because they are obligate-seeders and lack fire-resistant traits. Accordingly, fire refugia may play a key role allowing their survival and the subsequent recolonization of burned areas, and as such, may be crucial for landscape resilience. However, the actual capacity of expansion and permanence within the burned area will also depend on competition with other plants and their life-history traits. In northern Patagonia, shrubland woody species rapidly resprout and dominate the site after fire, increasing the subsequent landscape flammability. In contrast, Austrocedrus chilensis is a post-fire colonizer conifer that despite of being fire-sensitive has been able to persist within the fire-affected Patagonian

landscapes. I recorded biophysical attributes of A. chilensis fire refugia and the surrounding matrix and cored A. chilensis trees to compare their growth patterns in and out of refugia. I also assessed the potential of A. chilensis fire refugia to act as seed sources by estimating dispersal distance and microsite attributes associated with the presence of recruits. Furthermore, I studied the interaction between already established A. chilensis trees and resprouting woody shrubs within the burned matrix, through the analysis of their radial growth patterns. I found that A. chilensis fire refugia are positioned in locally elevated topographical settings and are characterized by high rock and low vegetation cover. These environmental conditions may reduce fire severity allowing greater probability of survivorship. The estimated average dispersal distance of an A. chilensis seed from refugia was between 33 and 140 m. Large woody debris, litter, and the protection of shrubs were the factors associated with the presence of recruits. Regarding competition with resprouters, I found that A. chilensis trees' growth was suppressed by shrubs during ~15 years, potentially making the community to stay more flammable for longer time. Finally, A. chilensis trees growing within refugia showed higher growth rates during climatically favourable years but displayed severe reductions in growth during droughts. Thus, fire refugia immersed in a highly flammable landscape coupled with reduced growth during dry years may imply higher vulnerability under the expected increase in the severity of droughts and fires. This could reduce the capability of persistence within locations that in the past may have served as fire refugia.

Keywords: fire refugia, persistence, seed source, recovery, fire-sensitive

Bio: Jennifer studied Environmental Sciences in the University of Buenos Aires, Argentina, and then obtained a doctoral degree from the same University. For her doctoral degree she studied the post-fire successional dynamic of a fire-sensitive conifer and resprouting shrubs in northwest Patagonia. She focused on how fire refugia allow survival and post-fire recolonization, and how tree-shrub interactions change along time since fire. Currently, she has a postdoctoral position in Laboratorio Ecotono (INIBIOMA-National University of Comahue) to study how fire severity affects seed dispersal and establishment, as well as the successional trajectories of plant communities (their structure and flammability).

S9.12. Wildfire impacts on neo-tropical bird communities and habitat in the sky islands of Southern Arizona

Presenter: Jose Iniguez, Research Ecologist, US Forest Service, Rocky Mountain Research Station
Additional Authors: Jamie S. Sanderlin
William M. Block
Joseph L. Ganey
Samuel Cushman

The vegetation and avifauna within the Sky Islands of southeastern Arizona includes species found nowhere else in the U.S. We initiated a study on birds across montane forest and woodland types in the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleño Mountains (Coronado National Forest) from 1991 to 1995. Since then, the region has been drastically changed by drought and wildfire, likely associated with climate change. These circumstances provided an opportunity to quantify the impact and increase our understanding of these disturbances on both avian communities and their habitats. Our objective was to better understand the impacts of fire severity and time since fire on forest structure and ultimately avian communities. In 2014, we resampled birds and vegetation at 28 transects (n = 328 count stations) where we sampled bird communities during the 1990s. The impact of fire on vegetation was assessed by comparing pre and post fire tree densities and basal area across different vegetation types. The impact of fire on bird communities were assessed using multi-species, multi-season occupancy models in a Bayesian hierarchical framework to estimate species richness and community dynamics, while accounting for imperfect detection. We used time since fire and fire severity to assess temporal and spatial variation in fire effects. In regards to the vegetation, low severity wildfires resulted in minimal changes to the forest structure, while moderate severity wildfire reduced both tree densities and basal area to desired levels as defined by historical conditions. High severity wildfire resulted in complete tree mortality, although this was followed by quick re-sprouting in some vegetation types. We observed both positive and negative responses to fire by individual bird species, which resulted in changes in bird communities. By re-sampling vegetation and birds following wildfire, our study can provide guidance with post-fire restoration, and assist with conserving avian community structure. Overall the refugia created by low and moderate severity wildfires and the addition of new high severity habitat following recent wildfires appears has resulted in greater diversity of forest structures, which has led to increases in species richness across these mountains.

Keywords: avian communities, fire severity, arizona, sky islands

Bio: Jose is currently a Research Ecologist with the Rocky Mountain Research Station in the Wildlife and Terrestrial Ecosystems Program, in Flagstaff Arizona. His current projects include several studies related to the impacts of recent wildfires on Southwest forests. His work has focused in southwest region United States particularly in the Gila and Sky Islands regions. Jose is interested in linking stand and landscape level processes related to fire and fire history. He is also the Scientist-in-Charge for the Long Valley Experimental Forest.

S9.13. Fire refugia promote forest resilience

Presenter: Jonathan Coop, Associate Professor, Western State Colorado University
Additional Authors: Haire, Sandra, Research Landscape Ecologist, Haire Laboratory for Landscape Ecology
DeLory, Tim, Western State Colorado University
Krawchuk, Meg, Assistant Professor, Oregon State University
Miller, Carol, Research Ecologist, Aldo Leopold Wilderness Research Institute
Walker, Ryan, Western State Colorado University
Downing, Will, Oregon State University

Vulnerability of some forest types to increasing wildfire activity compels efforts to understand and enhance the ecological resilience of these systems. Fire refugia, places disturbed less frequently or severely by wildfire than the surrounding landscape, may play a critical role in sustaining and recovering forest biota and ecological functions in fire-prone landscapes. We examined the role of refugia in the regeneration of obligate-seeding tree species within 12 large burns that occurred between 2000 and 2005 in ponderosa pine and dry mixed conifer forests across the western US. Refugia (patches of surviving trees within burn perimeters) were mapped with 1-m NAIP imagery; 686 field sample plots of tree and tree seedling density were sampled along gradients of burn severity and refugia density neighborhoods. We determined the neighborhood metrics that best predicted forest recovery using generalized linear mixed effects models. These relationships then served as the foundation for a landscape simulation model to examine how variation in refugia neighborhoods could influence patterns of forest recovery.

Refugia supported a diversity of tree species and size classes. Tree regeneration was sparse within refugia, was greatest proximal to refugia (within 10 m), and declined abruptly with increasing distance. A combination of Euclidean distance to nearest seed source and a square-distance-weighted measure of refugia density most strongly predicted the probability of tree seedling establishment for ponderosa pine and other obligate seeding conifer species. Spatially-explicit simulation model outputs point towards optimal sizes, densities, and spacing of refugia for ponderosa pine regeneration and natural post-fire forest recovery.

Our findings highlight one way that fire refugia may contribute to forest resilience and suggest that their formation and maintenance should be a management consideration. Resilience is derived from system components with enhanced resistance to disturbance (surviving trees within refugia) that promote recovery (via regeneration) where disturbance was more severe elsewhere. Model outputs may allow managers to optimize fuel treatment placement or fire suppression tactics to promote the landscape patterns that most effectively contribute to post-fire forest recovery, and/or identify locations where natural recovery is unlikely over relevant time frames.

Keywords: refugia, post-fire regenereration, resilience, simulation model

Bio: Dr. Jonathan Coop is a ecologist whose focus is the forests of the Rocky Mountain region. Themes include tree regeneration, plant community patterns and dynamics, effects of fire, and management strategies for a no-analog future. He is an Associate Professor at the School of Environment and Sustainability at Western State Colorado University.

S9.14. Developing a ranking system for unburned areas within fire perimeters in the Pacific Northwest for the conservation of fire refugia

Presenter: Arjan Meddens, Assistant Research Professor, University of Idaho
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Hudak, Andrew, Research Forester, US Forest Service

A warming climate, fire exclusion, and land cover changes are altering historical fire regimes and are facilitating increased wildfire activity in the northwestern US. One important and understudied aspect of wildfires is the unburned area within fire perimeters. These areas that do not burn within fire perimeters can act as fire refugia, providing (1) protection from fire effects, (2) seed sources, (3) post-fire habitat on the landscape, and (4) landscape heterogeneity and biodiversity. With increasing fire activity, there is speculation that fire intensity and combustion completeness are also increasing, possibly leading to a reduction in unburned islands across the landscape. We developed a spatially explicit database for 2,298 fires across the inland northwestern USA, delineating unburned areas within the fire perimeters from 1984 to 2014. We used ~1,600 Landsat scenes with two scenes before and two scenes after the fires to capture the unburned areas of the fire. We report on the following research goals using this database: (1) assessing spatial and temporal patterns of the unburned proportion of wildfires across the northwestern US from 1984-2014, (2) ranking the unburned islands according to natural resource manager-perceived conservation value, and (3) identifying fire refugia for the greater sage grouse.

We found that unburned area proportion exhibited no change over the three decades, suggesting that recent trends in area burned and overall severity have not affected fire refugia. There were ecoregional differences in mean unburned proportion, patch area, and patch density, suggesting influences of vegetation and topography on the formation of unburned area. Subsequently, the unburned islands database was used to delineate fire refugia by ranking important unburned areas using expert opinion from natural resource managers. Fire refugia that are isolated and include critical habitat were identified to be most important. Finally, we investigated sage grouse population dynamics following wildfires in southeastern Oregon using our database. We found that sage grouse population recovery at lek sites within unburned islands was faster compared to population recovery at lek sites in the surrounding burned landscape. Our established unburned island database facilitates better informed natural resource management and is important for identifying fire refugia characteristics, flora and fauna population recovery studies, and assessing contributions of refugia to ecosystem resilience across the northwestern USA.

Keywords: Fire refugia, remote sensing, vegetation recovery

Bio: Dr. Meddens is an Assistant Research Professor in the Department of Natural Resources and Society at the University of Idaho. His scientific goals are to further the understanding of ecological processes related to terrestrial ecosystems at local to global scales under global change. His research focuses on forest ecology, remote sensing, carbon cycling, and forest disturbances and he uses satellite and other geospatial data for assessing global change.

S9.15. Are Essential Fire Refugia Black or Green? The Real Megafire Story

Presenter: Rick Hutto, Professor, University of Montana
Additional Authors:

Any management concerns surrounding green-tree fire refuges pale in comparison with concerns surrounding the blackened fire refuges that sit within a sea of green conifer forests throughout the West. This is because blackened fire refuges harbor unique, early-successional plant and animal species that occur under no other forest conditions. The presence of species that are nearly restricted to severely burned forest patches is a clear reflection of a long evolutionary history that each species has had in an environment consisting of blackened, standing dead trees.

Given these eco-evolutionary facts, and given our legal and moral obligation to manage forests in a manner that should never compromise the ecological integrity of native biological diversity in disturbance-dependent forest systems, we must question the merit of several management activities that currently dominate land management in our western conifer forests: (1) fire suppression—aggressive efforts to suppress fires outside the WUI are misguided. The sizes and severities of fires across most of the forested West are burning well within the historical range of variation, and fires outside the WUI bear little risk to the public or to developed areas, as fire-lab research has repeatedly shown; (2) forest "restoration" efforts—efforts to restore open-forest conditions through timber harvesting so that fires burn less severely are not ecologically sound for most western conifer forestlands. Instead, the presence of severe-fire-dependent plant and animal species confirm that most mixed-conifer forests (which account for ~90% of all western conifer forest types) fall well within a mixed- to high-severity, not a low-severity, fire regime; (3) salvage logging and tree planting—attempts to speed the "recovery" of green-tree forests through proposals to expedite salvage logging and tree planting following severe fire is perhaps the most ecologically unsound management activity currently undertaken on our western forestlands. There are plenty of less ecologically sensitive places we can go to harvest timber while providing community buffers at the same time.

If the public is to gain a better appreciation of the naturalness and necessity of severely burned forest refuges across the western landscape, more ecologically informed education messages must accompany the current "megafire" messages that are now sweeping across the West.

Keywords: fire refugia, fire severity, fire suppression, forest restoration, salvage logging, ecosystem integrity

Bio: Dr. Richard L. Hutto is Professor Emeritus in the Division of Biological Sciences at the University of Montana (http://cas.umt.edu/dbs/labs/hutto/). He has published numerous papers on the ecology of birds in relation to forest fire. Hutto established the USFS Northern Region Landbird Monitoring program in 1990, and the Avian Science Center on the University of Montana campus in 2004 to promote the kind of informed decision making that follows from directly from listening to what western birds tell us about the ecological effects of human land-use practices. Hutto maintains a Facebook page (https://www.facebook.com/FireEcologyLab) devoted to exposing the ecological importance of severe fire.

S9.16. The fate of fire refugia in future, warmer climates: Modeling spatial patterns and thresholds of disturbance-resistant areas in the Jemez Mountains, New Mexico USA

Presenter: Rachel Loehman, Research Ecologist, USGS
Additional Authors: Haire, Sandra, Research Landscape Ecologist

The spatial patterns of large fires produce a diversity of habitats, and include places less affected by fire. These fire refugia foster survival of a wide array of species and communities, surviving legacies that repopulate surrounding areas and play a key role in ecosystem recovery. The presence and persistence of refugia are influenced by the complex interaction of multiple factors: stable landscape features that influence microclimate, reduce flammability or create topographic or hydrologic barriers to fire spread, stochastic weather factors, long-term climate, and legacies from past fires. In addition, anthropogenic climatic change and wildfire and land management activities have potential to alter the spatial patterns and characteristics of refugia, thus altering long-term, post-fire ecosystem dynamics. We used the mechanistic, spatial fire-climate-vegetation simulation model FireBGCv2 to examine climate and management impacts on refugia in the Jemez Mountains of northern New Mexico. Fire regimes here have been the focus of intensive research, due to the unique perspectives gained from the long history of interactions between climate, fire and human activity on this landscape. Moreover, rapid and ongoing changes in the landscape ecology of the region have followed recent fires with large high severity components. Simulation modeling of refugial dynamics allows us to quantify shifts in community composition and spatial extent of refugia over long time frames, understand the influence of natural processes and human activities, and compare outcomes under varying future climates and management strategies. We used spatial attributes generated across 100 simulation years to develop species-specific definitions of fire refugia that reflect expected response to fire at different return intervals and severities, and identified links between ecological stability and underlying environmental (physical and bioclimatic) characteristics. In a null model (no climate change or active management) refugia that occurred in wetter, cooler environments varied through time in species composition, but exhibited consistently high basal area and low tree mortality. Ponderosa pine (Pinus ponderosa) refugia occurred in a broad range of environments, including places with lower mean seasonal and annual precipitation and more moderate mean annual temperature. Warmer, drier projected future climate altered the spatio-temporal dynamics of refugia, both as a direct effect and moderated through changing fire regimes. Recovery of systems was dependent both on the biophysical environment and post-fire regeneration. Results suggest that refugia may persist under future climates, but both their form and function are expected to change over time.

Keywords: refugia, southwest, Jemez, climate, spatial modeling

Bio: Rachel Loehman is a Research Ecologist with the USGS. Her work focuses on disturbance ecology, interactions of climate, wildland fire, and ecosystems, and fire effects.

S10.1. Linked and compound disturbance interactions between multiple fires in conifer forests of the western US

Presenter: Brian Harvey, Assistant Professor, University of Washington
Additional Authors: Bisbing, Sarah, Assistant Professor, University of Nevada - Reno
Enright, Neal, Professor, Murdoch University (AUS)
Fontaine, Joe, Assistant Professor, Murdoch University (AUS)
Turner, Monica G., Professor, University of Wisconsin

Steadily increasing forest fire activity in western North America over the last several decades has led to many fires overlapping with recently burned areas (i.e., "reburns"), and many questions remain about how these events may affect forest resilience (the ability to tolerate a disturbance without shifting to a non-forest state). Multiple fire events may interact as linked disturbances, wherein one fire affects the likelihood, size, or severity of a subsequent fire. In addition, two fires in short succession may erode mechanisms of resilience via compound disturbance effects; that is, the ecological response to two fires is qualitatively different than the sum of the responses to single fires. In this talk, findings are synthesized from recent research, and insights are shared from new projects on reburns in several study areas in the western US (Northern Rocky Mountains, Coastal California, and the interior Pacific Northwest), focusing on the following questions: 1) What patterns emerge across systems in how reburns are linked disturbances with respect to occurrence, size, and severity?; and 2) What conditions generally lead to reburns producing compound effects on forest resilience? For each question, key unknowns and research frontiers are highlighted.
For question 1, broad-scale remote sensing work suggests that reburns in the US Northern Rockies and interior Pacific Northwest show strong negative links (i.e., feedbacks) with past fires, as reburns are generally less likely to occur, smaller, and less severe than the fires that preceded them. However, these negative feedbacks are short-lived, and in many cases they can become positive feedbacks after 10-15 years from the first fire. Key frontiers which are currently being explored in broad-scale remote sensing of reburns are: 1) testing the accuracy for widely used remote sensing indices (e.g., dNBR, RdNBR, RBR) in reburns, as these indices are typically validated on burned forests of large/old structure; and 2) understanding how landscape patterns of burn severity (i.e., the spatial arrangement of unburned, low-, moderate- and high-severity patches) in overlapping fires interact to affect forest heterogeneity following multiple fires. For question 2, existing work on reburns demonstrates that a key constraint on forest resilience following reburns is the lack of propagule availability at the time of the second fire (often termed "immaturity risk"). Ongoing field research using the coastal California closed cone conifers as a model system is examining constraints on cone production and seed availability between fire events across multiple spatial scales.

Keywords: reburns, disturbance interactions, forest resillience, tree regeneration

Bio: Brian J. Harvey is an assistant professor in the School of Environmental and Forest Sciences at the University of Washington. His research focuses on understanding the nature of forest disturbances (e.g., fires and insect outbreaks) – and how forest structure and function is shaped by disturbances, interactions among disturbances, and climate. Dr. Harvey's work emphasizes field studies that are integrated with large spatial datasets and analyses, drawing on insights from landscape ecology and community ecology. Over the last 10 years, he has conducted research on the disturbance ecology of forests in coastal California, the Rocky Mountains, and the interior Pacific Northwest.

S10.2. Fire-fire interactions and multi-scale controls on fire severity in historical mixed-severity fire regimes of the northern U.S./southern Canadian Rockies

Presenter: Cameron Naficy, Post doctoral scientist, University of British Columbia
Additional Authors: Thomas T. Veblen, Professor, University of Colorado at Boulder
Lori D. Daniels, Professor, University of British Columbia
Paul F. Hessburg, Landscape Ecologist, Pacific Northwest Research Station

In light of projected climate-driven increases in fire activity, quantitative knowledge of the feedbacks and biophysical controls on fire occurrence and severity is key to understanding future fire regimes and landscape conditions. In recent decades, quantification of the trends and spatial patterns of fire severity have become a central focus of fire ecology research. Despite the robust spatio-temporal information available for modern fires, a number of factors have complicated ecological interpretations of modern severity patterns. First, modern fire records are relatively short, offering few opportunities to study fire-fire interactions and recovery trajectories over sufficient time scales. Second, the legacy of fire exclusion and altered forest vegetation conditions, which likely influences the patterns and relationships derived from modern fires, cannot be controlled for. Third, it is often unclear how to interpret observed fire severity patterns in the context of ecosystem resilience.

Historical landscapes offer a rich data source for study of fire feedbacks and controls over long periods and under active fire regimes. Historical fire regime research may therefore represent one of our best opportunities to understand future fire regimes. However, a narrow focus on fire frequency in many historical studies and methodological limitations to reconstruction of the spatial ecology of historical fire severity have impeded comprehensive analyses of feedbacks mechanisms and controls in historical landscapes. We combined robust estimates of fire severity and frequency from a large dendroecological network, geospatial vegetation structure data derived from historical aerial photography, and statistical modeling to reconstruct spatio-temporal fire regime attributes for mixed-severity fire regime (MSFR) forests in the northern U.S. and southern Canadian Rockies. We use these data to examine the feedbacks and biophysical controls on fire severity at multiple spatial (patches, fire events, watersheds) and temporal (individual events, time-integrated fire regime) scales.

We present a framework that clarifies the implicit temporal and spatial scales associated with different definitions of MSFRs and provides an overview of expected scale-dependent controls on fire severity. Specifically, we examine 1) severity of individual fire events at the scale of individual patches, 2) relative proportion of burn area in different severity classes for entire fire events, 3) the time-integrated fire regime at the scale of individual patches and 4) the percent area and median patch size of time-integrated fire severity classes within watersheds. Climate, topography, and fire feedbacks were important across all scales, but the strength of individual models and the relative importance of specific variables were scale-dependent.

Keywords: fire severity, mixed-severity fire regime, Rockies, mixed-conifer, resilience

Bio: Cameron Naficy is a landscape ecologist that uses remote sensing, dendrochronology, and field data to study the response of temperate forest systems across scales (e.g. tree level physiology to large landscapes) to disturbances (especially fire and insect outbreaks), climate change, and human influences. He earned a MSc from the Division of Biological Sciences at the University of Montana and his PhD from the University of Colorado, Boulder. He is currently a post doctoral scientist at the University of British Columbia.

S10.3. Compromised resilience of northern boreal forests following large wildfires

Presenter: Marc Parisien, Research scientist, Canadian Forest Service
Additional Authors: Whitman, Ellen, graduate student, University of Alberta
Thompson, Dan, research scientist, Canadian Forest Service
Price, David, research scientist, Canadian Forest Service
Stralberg, Diana, research affiliate, University of Alberta
Flannigan, Mike, professor, University of Alberta

Over the last half-century, the western region of Canada's northern boreal zone has undergone a rapid increase in mean temperature, which has driven increases in regional drought occurrence. Although the forested ecosystems in this area have co-evolved with large and intense disturbances, namely wildfires, climatic change may be transforming natural disturbance regimes to the point of compromising the abilities of biological communities to recover to their pre-disturbance states. More frequent and severe droughts are causing biome-wide tree mortality and reduced productivity. Accelerated permafrost thaw is fundamentally changing the hydrology of some landscapes, leading to increased mortality on waterlogged sites. Formerly rare—or even novel—occurrences of insect and pathogen outbreaks are becoming commonplace in some areas, further contributing to tree mortality and accumulation of dead wood. By virtue of their changes to vegetation composition and structure, these phenomena will interact with the dominant disturbance agent, wildfire, which is itself being altered by a changing climate. The unprecedented nature of these interactions will almost certainly lead to ecological surprises. Large and intense wildfires may have a restorative effect in some cases (e.g., by reducing pathogens), but they may also accelerate the collapse of some forest communities. We have identified several sites with failed or reduced post-fire tree recovery, which were previously forest-covered for centuries (or millennia). We hypothesize these sites are on new successional trajectories that will lead to non-forest vegetation types. Such changes appear to reflect climate-driven vegetation shifts, as suggested by bioclimatic models, which project a loss of tree cover, (particularly coniferous species) to the benefit of deciduous shrubs and grassland species. The changing climate has a multi-pronged effect on northern wildfire regimes by: (1) creating more and different fuels through non-wildfire mortality; (2) increasing the frequency of conditions conducive to fire ignition and spread; and (3) driving changes in the structure of post-fire vegetation, which will in turn affect how wildfires burn. Although, at present, the potential effect of wildfires as triggers of change in northern forests is acknowledged, it is poorly understood. Vegetation changes where, for example, upland forests would become shrubland or grassland complexes—i.e., a 'steppe' ecosystem, which has not existed since the early Holocene in this area—have the potential to cause profound changes in ecological and biogeochemical processes at the biome level.

Keywords: wildfire, boreal, climate change, vegetation, disturbance

Bio: Marc is a research scientist in the fire research group of the Canadian Forest Service, where he has worked since 2000. He holds a BSc from McGill University, a MSc from l'Université du Québec, and a PhD from the University of California, Berkeley. His work focuses on understanding large-scale patterns of wildfires in North America.

S10.4. Change in vegetation patterns over a large forested landscape based on historical and contemporary aerial photography

Presenter: Jamie Lydersen, Associate Specialist, UC Berkeley
Additional Authors: Collins, Brandon, Research Scientist, UC Berkeley

Changes to vegetation structure and composition in forests adapted to frequent fire have been well documented. However, little is known about changes to vegetation patch sizes, and detailed information linking vegetation type to specific locations and growing conditions on the landscape is lacking. We used historical and recent aerial imagery to characterize historical vegetation patterns and assess contemporary change from those patterns. We compared an orthorectified mosaic of air photos from 1941 to aerial imagery from 2005 covering approximately 100,000 ha in the northern Sierra Nevada. Both sets of imagery were classified into four relative forest cover classes using random forests analysis. Topographic associations of dense forest cover on the historical and contemporary landscapes were compared using a generalized linear mixed model. The amount of dense forest cover increased from 30% to 43% from 1941 to 2005, replacing moderate forest cover as the most dominant class. Historically, dense forest cover was rare on southwesterly aspects, but in the contemporary forest it was common across a broad range of aspects. Concurrent with the increase in extent, the area weighted mean patch size of dense forest cover increased ten-fold, indicating greater continuity of dense forest cover and more homogenous vegetation patterns across the contemporary landscape. These changes, along with regional increases in severe fire weather and surface fuel loads, likely contributed to a loss of resilience on the landscape. Several uncharacteristically large and severe fires occurred within our study area after 2005, burning nearly one third of the analysis area. Based on remotely sensed estimates of fire severity half of that recently burned area was stand replacing. Our study suggests that decreasing the size of dense forest patches, particularly by reducing tree cover on south facing aspects, could restore historical vegetation patterns and thereby improve forest resilience to wildfire and insect outbreaks.

Keywords:

Bio: Jamie Lydersen is an associate specialist in the department of environmental science, policy and management at the University of California, Berkeley and a contractor for the Pacific Southwest Research Station, USDA Forest Service. Jamie received a Master of Science in Ecology from the University of California, Davis in 2012. Her research focuses on fire ecology and forest restoration, with an emphasis on scientific questions that can be applied to forest management.

S10.5. Persistent fire-induced vegetation state switches in southwestern ponderosa pine forests

Presenter: Chris Guiterman, Research Associate, Laboratory of Tree-Ring Research, University of Arizona
Additional Authors:

Across the southwestern US, the late-19th century disruption of frequent low-severity fire regimes has created a worrisome legacy that now includes overly dense, dry ponderosa pine-dominated forests. In recent years, this forest architecture has spawned an uncharacteristic surge in high-

severity fire activity, leaving some areas with large conifer-depleted patches. One consequence is a rapid transition of these patches to resprouting shrub species, such as Gambel oak. The long-term successional trajectory of shrub-dominated areas is uncertain, but many fear extensive fragmentation of conifer forests in the Southwest. We recently evaluated patterns of fire and succession in large, pre-1900 shrubfields in the Jemez Mountains, New Mexico. These oak-dominated shrubfields (76-348 ha) historically burned concurrently with adjoining conifer forests and under the same fire-climate relationships. Their age structures related to the last widespread fire ca. 1899, showing that they can persist both in the presence and absence of fire. Indeed, the shapes and sizes of shrubfields did not change since 1935 aerial photographs were taken. Additionally, we found that the largest heavily shrub-dominated high-severity patch in the Jemez Mountains following the 2011 Las Conchas Fire is over 30 times the size of the largest shrubfield we identified. These findings underscore the extensive impact that past management activities (e.g., fire suppression) and climate change are having on many southwestern ponderosa pine ecosystems, including the persistent type-conversion of pine-oak forests in northern New Mexico.

Keywords: Shrubfields, high-severity fire, dendrochronology, alternative stable states

Bio: Chris Guiterman is a forest and fire ecologist, with a Masters in Forestry from the University of Maine and a doctorate in Natural Resource Studies from the University of Arizona. His research interests include fire history, dendroecology, human-environmental interactions, and the vulnerabilities of forests to climate change and altered disturbance regimes. His current research is collaboration with Navajo Nation foresters to reconstruct recruitment and disturbance dynamics in old-growth ponderosa pine forests.

S10.6. Climatic controls of post-fire conifer regeneration in low-elevation forests of the western U.S.

Presenter: Kimberley Davis, University of Montana
Additional Authors: Higuera, Philip, Associate Professor, Department of Ecosystem and Conservation Sciences, University of Montana
Dobrowski, Solomon, Associate Professor, Department of Forest Management, University of Montana
Zachary Holden, Ecologist, USFS Region 1
Sean Parks, Research Scientist, Aldo Leopold Research Institute

Fires, combined with climate change, have the potential to catalyze vegetation shifts, particularly in low elevation forests. Annual climate, fire properties, and biotic communities interact to determine patterns of post-fire tree regeneration. Therefore understanding the relative importance of these drivers and their specific relationships to tree regeneration is critical in predicting future vegetation trajectories. We characterized post-fire recruitment-climate relationships for two dominant conifer species. We destructively sampled and precisely aged 2820 seedlings and saplings of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) that recruited following 32 fires occurring between 1992 and 2007. Samples were collected across four large regions of the western U.S.: the Southwest, Colorado Front Range, Northern Rockies, and Northern California. We found post-fire recruitment was more episodic with increasing aridity and shrub cover. Annual recruitment probability declined sharply as vapor pressure deficit and maximum surface temperature increased and soil moisture decreased past threshold values. Climate has increasingly limited recruitment opportunities over the past 35 years and most of our *Pinus ponderosa* study sites no longer experience climate conditions suitable for regeneration. However, distance to seed source was

equally or more important than annual climate variability. The effects of larger and more severe fires on seed availability will compound reductions in recruitment probability due to warmer and drier conditions, potentially leading to vegetation change following fire in low elevation forests. Reductions in fire severity, and thus distance to seed source, have the potential to significantly increase recruitment probability, possibly offsetting some of the changes expected due to climate change.

Keywords: post-fire regeneration, conifer regeneration, climate

Bio: Kimberley Davis is a postdoctoral research associate in the PaleoEcology and Fire Ecology Lab at the University of Montana. She is currently working on understanding how annual climate affects post-fire conifer regeneration across the western U.S. Past work has focused on the feedbacks between invasive plants and fire.

S10.7. Historical Fire Disturance Regimes and Implications for Forest Restoration
Presenter: James Johnston, Faculty Research Associate, Oregon State University
Additional Authors: John Bailey, College of Forestry, Oregon State University

Treatments to restore resiliency to¬ conifer forests of western North America are often designed to synchronize structural and compositional patterns to historical wildfire processes. Most researchers emphasize the importance of frequent low-severity fire in maintaining relatively open pine-dominated forests and invoke "mixed-severity" or stand-replacing fire regimes to account for the more complex structure and composition observed on more productive mixed conifer sites.
This study describes the range of fire frequency and severity reconstructed from tree ring evidence across a wide variety of forest types ranging from dry ponderosa pine to moist mixed conifer stands in eastern Oregon. We also briefly discuss new research in western hemlock/Douglas-fir forests west of the Cascades. Although standard succession and disturbance models assume that frequent fire excluded fire intolerant late seral species, we found relatively frequent (<18 year MFRI) fire in forests that were historically dominated by fire intolerant species. Current theory suggests that frequent fire in dry pine sites created compositionally and structurally stable uneven aged stands, while higher fuel loading in more productive moist mixed conifer stands resulted in coherent regeneration pulses following periodic mortality events. However, we found evidence of significant disequilibrium in forest structure on dry pine sites, while most moist mixed conifer sites appeared compositionally and structurally stable over time. These results suggest the need to develop new conceptual frameworks that better link data about historical fire occurrence to landscape context, edaphic

Keywords: Dendroecology, fire regimes, mixed-conifer, mixed-severity fire, ponderosa pine

Bio: James Johnston is a Faculty Research Associate at OSU College of Forestry. His research interests include fire ecology, dendroecology, restoration forestry, environmental law and policy, and collaborative governance.

S10.8. Long-Term Understory Vegetation Response to Prescribed Burning in Pinyon-Juniper Woodlands
Presenter: Alexandra Urza, PhD Candidate, University of Nevada-Reno
Additional Authors: Weisberg, Peter, Professor, University of Nevada-Reno
Chambers, Jeanne, Research Ecologist, Rocky Mountain Research Station (Reno, NV)
Board, David, Ecologist/Data Analyst, Rocky Mountain Research Station (Reno, NV)

Flake, Sam, PhD Student, North Carolina State University

Where pinyon-juniper woodlands and sagebrush steppe overlap, prescribed fire and other tree-reduction measures are often used to maintain shrub- and grass-dominated habitats and conserve sagebrush obligate species. Post-fire management objectives typically prioritize the recovery of perennial species and resistance to invasion by exotic annual grasses. In this study, we examined post-fire responses of the understory plant community at the woodland–shrubland interface, using repeat vegetation surveys spanning 15 years from a network of prescribed fire treatments in the Shoshone Mountains, Nevada. Sites were arranged along two major environmental gradients: elevation and pre-fire tree cover. We characterized post-fire understory trajectories using both taxonomic (species-level) and functional (functional group-level) classifications. Fourteen years after burning, understory composition at all burned sites was on a trajectory towards comparable unburned communities. However, the drier (low- to mid-elevation) burned sites had become heavily invaded by cheatgrass. These site types are less resilient to burning and less resistant to invasion, and the observed fire-initiated invasion greatly enhanced the potential for cheatgrass dominance following future fires. Recovery was especially poor in sites with high pre-fire tree cover, where cheatgrass dominated the understory by the end of our study. To reduce the risk of invasion, the use of prescribed fire should be avoided in the drier portions of the landscape, and only more resilient higher-elevation sites with sufficient perennial herbaceous species to promote recovery should be considered for prescribed fire treatments. When fire cannot be avoided in low-resilience site types, our results indicate that seeding native perennial grasses and shrubs after burning speeds recovery and reduces the risk of cheatgrass invasion. Our results highlight the need for long-term studies to evaluate plant community responses to prescribed fire, as a shorter (3-4 year) post-fire monitoring period would not have captured some of the important treatment differences including the dramatic increase in cheatgrass dominance that was amplified on sites with high levels of tree cover prior to burning.

Keywords: pinyon-juniper, cheatgrass, sagebrush, resilience, resistance, community assembly

Bio: Alexandra Urza is a PhD Candidate in Ecology, Evolution, and Conservation Biology at the University of Nevada-Reno. Her research focuses on plant community responses to disturbance and climate in the western US.

S10.9. Fire across North America, a continuum process across three contrasting countries
Presenter: Diego R. Pérez-Salicrup, Investigador Titular, Universidad Nacional Autónoma de México/University of British Columbia
Additional Authors: Martínez-Torres, H. Leonardo, Ph.D. candidate, Insituto de Investigaciones en Ecosistemas y Sutentabilidad, Universidad Nacional Autónoma de México
Garduño, E. Project Researcher. Insituto de Investigaciones en Ecosistemas y Sutentabilidad, Universidad Nacional Autónoma de México
Jardel Peláez, E. Professor, Centro Universitario de la Costa Sur, Universidad de Guadalajara
Alvarado, E. Professor. School of Environmental and Forest Sciences, University of Washington

Fire affects important ecosystems across the three largest countries in North America, many times affecting the same ecosystem across National boundaries differently. In one extreme of this continuum, Canada can be characterized by extensive vegetation types with low human density, where fires are generated and allowed to continue following natural processes. In the other extreme, Mexico harbors the highest plant diversity, but with a much lower continuity of vegetation types, and high human density across the country. The United States offers and intermediate position, but fires in the Western part of the country are largely affected by the suppression policy of the XX century. Fires across the borders of the three countries differ as a consequence of past management legacies, but in some cases experience similar patterns suggesting departures from natural regimes. The three countries also differ notoriously in the size of academic and government institutions dedicated to fire, and in the collaboration between academic research and users and managers of fire. Therefore, strategies to respond to the challenges we face in the Anthropocene differ across the three countries. Because Mexico has the highest diversity species and ecosystems, the highest population density in forested and rural areas, but the lowest number of publications on social or ecological aspects of fire management, we propose that participatory approaches that involve local population can provide useful information to create more resilient socio-ecosystems. We present results from research participatory approaches, one at local and one at national scale, and provide information on how these efforts helped identify areas of higher fire risk, fire danger, and areas with the higher conservation importance.

Keywords: Diversity, Fire Management, Participatory Research, Socio-Ecosystems

Bio: Diego Pérez-Salicrup completed his degree in Biology at the Universidad Nacional Autónoma de México, and then his MSc and PhD at the University of Missouri-St. Louis. He was a postdoctoral fellow at the Harvard Forest of Harvard University.

Since 2000 he works at the National Autonomous University of México, where he heads the laboratory of Ecology of Forest Management in the Institute for Ecosystem Research and Sustainability. His publications show a broad range of research interests with a particular focus on forest management, ecological restoration, and lately, fire ecology.

S10.10. 2017 Wildfires in British Columbia: Urgent Need to Adapt Management to Improve Forest Resilience
Presenter: Lori Daniels, Professor, University of British Columbia
Additional Authors: Gray, Robert W., Fire Ecologist, R.W. Gray Consulting Ltd.
Burton, Philip J., Professor, Ecosystem Science & Management Program, University of Northern British Columbia

In many dry forests in British Columbia, Canada, historical fire regimes included frequent, mixed-severity fires. Fire exclusion and suppression have altered these regimes, as indicated by long fire-free intervals, increases in forest density, and numerous persistent subcanopy trees forming ladder fuels. These stand structures contribute to homogeneous landscapes susceptible to high-severity fire. Climate change exacerbates this situation through drought, increased tree mortality, and longer and dryer fire seasons. These forests and the communities surrounded by them are not resilient to wildfire.

The status quo approach of addressing wildfire threat in British Columbia is not working. In 2017, wildfires overwhelmed suppression capabilities, burned 1.2 million hectares, and cost $750 million. From 2006-2015, the province spent $1.82 billion on fire suppression, but only $183 million on pro-active, preventative wildfire management. Research in other jurisdictions has shown that the cost of reducing wildfire extent and severity through pro-active fuel management is lower than the cost of fighting extensive wildfires. A holistic, landscape view of this problem and transformative changes to wildfire and forest management are urgently needed to achieve forest and community resilience to wildfires.

We propose a four-part approach to improve forest and community resilience in British Columbia:

1. Initial Attack and Emergency Fuel Reduction Treatments. Improvements to short-term wildfire response requires significant increases in human resources for all facets of wildfire management: wildfire suppression, managed wildfire, prescribed fire, and fuels mitigation.

2. Integrate Wildland-Urban Interface Zoning and Pro-Active Landscape Planning. In fire-prone areas, long-term maintenance of low fire hazard in forests and rangelands surrounding rural communities needs to be the primary land management objective. Existing policies that run counter to community resilience must be amended, if not abolished.

3. Forest Restoration and Adaptive Forest Management. Science-based fire management and First Nations traditional ecological knowledge need to be combined in landscape-level strategies to counter unintended consequences of the past and achieve long-term forest resilience and sustainable management.

4. Research to Inform Adaptive Wildfire Management. Given climate change, we are entering a new era in land management and risk reduction planning. Effective transformation of wildfire management must incorporate new knowledge on fire regimes and ecosystem function and be evidence-based to overcome current limitations.

The 2017 wildfire season revealed tremendous vulnerability of our forests and communities, and short-comings of past mitigation efforts. Our recommendations aim to transform policies and practices to improve ecological and social resilience to wildfire.

Keywords: forest and community resilience, adaptive management, policy and practices, transformative change

Bio: Lori Daniels is a Professor of Forest Ecology in the Forest and Conservation Sciences Department at UBC-Vancouver, where she directs the Tree-Ring Lab at UBC. Her research applies tree-ring analyses to investigate disturbance regimes and the impacts of climate and humans on forest dynamics. With her graduate students, Lori's on-going research invetigates fire regimes, forest dynamics, forest and community resilience to climate change in western Canada. To contribute to effective wildfire science and management, she serves on British Columbia's Prescribed Fire and Fire Smart Councils and is member of the Canadian Wildfire Strategy Implementation Team.

S10.11. Reintroduction of Fire as a Natural Process in Banff National Park - Implications for Wildlife Habitat Management and Forest Resilience

Presenter: Jane Park, Fire and Vegetation Specialist, Parks Canada - Banff National Park
Additional Authors:

Evidence has shown a long history of mixed severity fire in the Canadian Rocky Mountains stemming from indigenous land use practices and lightning fire. However, as with many North American ecosystems, a legacy of fire exclusion has been a decrease in habitat diversity, biodiversity, and an increase in forest insects and disease and wildfire. Parks Canada fire managers are using landscape level, often stand replacing, prescribed fire to improve wildlife habitat for species such as grizzly bears, bighorn sheep, elk and wolves, while also mitigating the potential impacts of large wildfires on infrastructure and communities. Rather than defaulting to full suppression, large wildfires are selectively managed to maintain this important natural process on the landscape. Multiple iterations of prescribed fire have been used over a period of 30 years to convert large tracts of dense, closed forest to montane grasslands to improve ungulate, grizzly bear and wolf habitat; and large-scale meadow burning is facilitating the reintroduction of bison, a keystone species, to Banff National Park.

Through prescribed fire, managed wildfire and landscape fuel management, Parks Canada is creating a more resilient forest landscape. Resiliency to large forest insect and disease outbreaks, and catastrophic wildfires is increasingly important as climate change results in longer, more severe fire seasons. This presentation will focus on the reintroduction of fire onto the landscape and identify future challenges and opportunities.

Keywords: prescribed fire, managed wildfire, wildlife habitat, forest resilience, fuel management

Bio: Jane Park is the fire and vegetation ecologist for Banff Field Unit in Banff National Park. Jane has been involved with active fire restoration with Parks Canada for the past 15 years. She obtained her M.Sc. from the University of Calgary in Forest Ecology. Her interests include prescribed fire for ecosystem management in protected areas, ecological effects of fire on various ecosystem components. Parks Canada's fire program has been a leader in the implementation of prescribed fire in Canada for the past 30 years.

S10.12. Toward a resilient wildfire management organization: current efforts and future needs

Presenter: David Calkin, Research Forester, USFS, RMRS
Additional Authors: Thompson, Matthew, Research Forester, USFS, RMRS
Dunn, Christopher, Post-doctoral research fellow, Oregon State University

The concept of resilience has undergone a considerable transformation over just the last few decades. Initial concepts of resilience now termed 'engineering resilience' emphasized the ability of a system to rebound as quickly as possible from disturbance, minimize disturbance or maintain constancy and stability. More recent definitions have focused on the capacity to continually change while remaining within critical thresholds, through transformation and adaptation. The US Cohesive Wildfire Management Strategy established three primary goals: resilient landscapes, fire adapted communities, and safe and effective response. Within the wildfire science literature concepts of ecological resilience have largely framed our understanding of how stressors such as fire exclusion and climate change threaten the health and resiliency of our landscapes. Increasingly there is recognition of the need to incorporate social systems into the debate on how to promote a broader social ecological resilience of fire adapted landscapes through community planning and increased application of wildfire in fire dependent ecosystems. However, concepts of organizational resilience as applied to the wildfire management community have been largely absent from the debate. In this presentation we will suggest that the wildfire management community to date broadly meets the definition of engineering resilience in that the current approach has persisted through increasing stressors, is broadly resistant to change, and in the face of increasing demand and complexity has focused most intently on increasing the scale and scope of existing organizational approaches and strategies. We then will discuss how efforts to achieve organizational resilience through assessment of the threat, acceptance of new conditions, and amendment of strategy are needed and emerging to facilitate improved system resilience.

Keywords: Organizational Resilience

Bio: Dave is the team lead of the Fire Management Science group (https://www.fs.fed.us/rmrs/groups/wildfire-risk-management-team) of the National Fire Decision Support Center working to improve risk based fire management decision making through improved science development, application, and delivery. Dave's research incorporates economics with risk and decision sciences to explore ways to evaluate and improve the efficiency and effectiveness of wildfire management programs.

S10.13. Risk-based spatial fire planning from concept to execution: a case study of the Tonto National Forest

Presenter: Christopher O'Connor, Forest Ecologist, US Forest Service Rocky Mountain Research Station
Additional Authors: Haas, Jessica, Ecologist, USFS Rocky Mountain Research Station
Thompson, Matthew, Research Forester, USFS Rocky Mountain Research Station
Calkin, Dave, Research Forester, USFS Rocky Mountain Research Station

Effectively managing forest resources for the future requires balancing the need for safely maintaining or restoring fire as an ecosystem process where appropriate while protecting human assets and fire-sensitive systems where necessary. Aligning these goals with operational challenges requires a better understanding of where and under what conditions fire management actions are most likely to succeed or fail. In a pilot study on the Tonto National Forest of Arizona, we developed a model for predicting potential future fire control locations (PCLs) from conditions that stopped fires in the past. The model produces a probability surface that highlights potential control opportunities and challenges across a landscape based on landscape features, potential fire behavior, and operational effort. Working closely with line officers, fire staff, and resource specialists, we applied the PCL atlas to the regional wildfire risk assessment map to create a series of Potential wildfire Operational Delineations (PODs) with pre-identified strategic response actions classified by fire hazard and bounded by operationally relevant control features. The resulting map product was used by the Forest during the 2017 fire season to manage fires in accordance with risk-based principles.

Keywords: social-ecological systems, risk-based fire management, fire operations, fire in ecosystems

Bio: Dr. Kit O'Connor is an ecologist with the Wildfire Risk Management Group at the US Forest Service Rocky Mountain Research Station. His current work is focused on developing spatially explicit risk-based tools that support integrating operational fire response with sustainable landscape planning, fire responder safety, and efficient resource use. His research background in disturbance ecology draws from forest ecology, fire science, entomology, dendrochronology, ecological risk assessment and spatial analysis and modeling. He holds a BS from Penn State University, an MS from the University of Quebec at Montreal, and a PhD from the University of Arizona.

S10.14. The value in resilience: integrating normative and objective dimensions of resilience in fire-prone landscapes

Presenter: Philip Higuera, Associate Professor, University of Montana, Department of Ecosystem and Conservation Sciences
Additional Authors: Metcalf, Alexander, Research Assistant Professor, University of Montana
Metcalf, Elizabeth, Associate Professor, University of Montana
McWethy, David, Assistant Professor, Montana State University
Miller, Carol, Research Ecologist, Aldo Leopold Wilderness Research Institute
Buma, Brian, Assistant Professor, University of Alaska-Southeast
Ratajczak, Zak, Postdoctoral Scientist, University of Wisconsin

Resilience is becoming an increasingly common goal for science-based natural resource management, particularly in the context of changing climate and disturbance regimes. For example, the 2014 National Cohesive Wildland Fire Management Strategy focuses on fire-resilient landscapes and fire-resilient human communities. This and other recent applications of resilience implicitly refer to both value-free ecological properties, as in ecosystem resilience to wildfires, and value-laden social properties, as in the desire to foster fire-adapted communities. Integrating these two perspectives is a complex and often unrecognized challenge for applying resilience concepts to managing social-ecological systems. In fire-prone landscapes, this requires an understanding of both social and ecological perspectives of wildfires and fire management.

Through a two-day workshop that included ecologists and social scientists, we developed a framework to help expose and separate the components of resilience, and clarify how varying definitions may be integrated and applied to understand social-ecological systems. Here, we describe this framework and apply it to examples in fire-prone landscapes. The framework differentiates between the inherent properties of a system that maintain system structure, function, or states (e.g., following a wildfire) from human perceptions of which system structures, functions, or states are desirable. In doing so, the framework distinguishes between the value-free and value-laden dimensions of resilience, and it reveals four scenarios of ecosystem states, objectively assessed (i.e., probability of change after a wildfires) and subjectively evaluated (i.e., the acceptability of the change by the human community). We highlight that ecological resilience and the social desirability align in only two of the four scenarios, which has important implications for developing management goals. Our framework helps clarify existing theory, provides links among literature in multiple disciplines, and facilitates the use of the resilience concept in future research and land management applications. While our examples are specific to fire-prone landscape in the western U.S., this approach serves as a model that could be applied to other disturbance-prone systems.

Keywords: resilience, social-ecological systems, wildfire, management, values

Bio: Philip Higuera is an associate professor of fire ecology at the University of Montana, where we directs the PaleoEcology and Fire Ecology Lab. Research in the lab focuses on understanding the causes and ecological consequences of wildfires and fire regimes, over time scales spanning years to millennia.

S10.15. Social resilience to wildfire: Perspectives from fire-affected communities

Presenter: Elizabeth Metcalf, Associate Professor, University of Montana
Additional Authors: Metcalf, Alexander, Assistant Research Professor, University of Montana
Higuera, Philip, Associate Professor, University of Montana
Miller, Carol, Research Ecologist, USFS Rocky Mountain Research Station
McWethy, David, Assistant Research Professor, Montana State University
Phillippe, Chelsea, Research Assistant, University of Montana
Rafferty, Rebekah, Research Assistant, University of Montana

Recent wildfire seasons have been dramatic, with implications for both social and ecological systems (SES). The concept of resilience – 'bouncing back' after disturbance - has been used as a catalyst to encourage human communities to adapt and transform to wildfire impacts. Social resilience has been prominent in the natural hazard literature with some emphasis on wildlife resilience (e.g. fire preparedness). We sought an expanded definition of resilience which better integrated social and ecological characteristics. To do so, we conducted in-depth interviews in two fire-affected landscapes: Methow Valley, WA, and Bitterroot Valley, MT. Each landscape had experienced a number of large wildfires and residents were acutely aware of wildfire impacts. We specifically wanted to understand how community members' experiences and perspectives on wildfire might expand notions of resilience in ways not previously considered or emphasized. By directly engaging communities on these questions we hoped to clarify what constitutes a resilient community and identify acceptable responses that help build and maintain community integrity.

Our sample of key informants were selected to broadly represent local interest groups. We used state and local directories to identify interviewees (e.g. local officials and leaders). After an initial sample was selected, we used a chain referral procedure until we were reasonably certain we assembled a comprehensive set of community perspectives. Interviews were guided by a semi-structured instrument to: (1) query past fire impacts; (2) assess 'ideal' community responses to wildfire; and (3) evaluate acceptability of potential management actions. Interviews were recorded, transcribed, and coded using NVivo 11 and content analyzed inductively into thematic categories. Relationships among categories were identified and themes compared within and across cases.

Several themes emerged from the data; a subset included: community character (e.g. rural self-sufficiency, demographic heterogeneity) and community cohesion (e.g., ability for community to come together) were identified as qualities that promoted resilience. Another theme was inter-agency cooperation during a fire event, with strong cooperation leading to resilience. Complimenting this theme were communication networks and transparency of information. Respondents indicated that strong formal and informal communication networks enhanced their ability to respond during and after a fire event. Lastly, landscape features influenced adaptability and vulnerability including topography, vegetation, weather conditions, and dispersal of

structures/homes. Results suggest that social resilience is defined by both social and ecological characteristics, emphasizing the need for SES perspectives.

Keywords: Resilience, Social ecological systems, human communities

Bio: Dr. Libby Metcalf is an Associate Professor of Recreation & Natural Resource Management in the W.A. Franke College of Forestry and Conservation at the University of Montana. In 2011, Dr. Metcalf received a dual Ph.D. at the Pennsylvania State University in Recreation, Parks, and Tourism Management and the Human Dimensions of Natural Resources and the Environment. Her research interests generally center around recreation management issues, wildlife related issues, and understanding complex social-ecological systems. Dr. Metcalf's theoretical approach is based in social-psychology and often includes the examination of attitudes, values, and beliefs.

S10.16. Planning for resilience in federal forest management: Analysis of the current state of practice

Presenter: Jesse Abrams, Research Associate, Institute for a Sustainable Environment, University of Oregon
Additional Authors: Evans, Alexander, Executive Director, Forest Stewards Guild
Fernandez-Gimenez, Maria, Associate Professor, Department of Forest and Rangeland Stewardship, Colorado State University
Schultz, Courtney, Associate Professor, Department of Forest and Rangeland Stewardship, Colorado State University
Timberlake, Thomas, Doctoral student, Department of Forest and Rangeland Stewardship, Colorado State University

The U.S. Forest Service has undergone substantial transformations in its management paradigm in recent decades, including shifting from maximizing the output of discrete products while suppressing disturbance processes to a more integrated approach that recognizes the role of disturbances and attempts to integrate them with the continued production of valued goods and services. Policy directives such as the 2008 Strategic Framework for Responding to Climate Change and the FY2015-2020 Strategic Plan have centered the concept of resilience in the agency's continued strategic and managerial evolution. Given the complexity of the concept of resilience, and its potentially transformative implications for the management of federal forestlands and effects on related social and ecological systems, there is a need to better understand how resilience is being operationalized in Forest Service planning and management. In this presentation, we provide preliminary results from an analysis of Environmental Impact Statements that engage with the resilience concept along with a case study of the recent forest plan revision on the Kaibab National Forest. We analyze these to provide a picture of the past and future trajectories of "resilience thinking" and resilience-oriented management on federal lands and raise questions regarding potential institutional barriers to greater adoption of a resilience perspective in national forest management.

Keywords: Resilience; Planning; Forest Planning; Environmental Impact Statements

Bio: Jesse Abrams is a Research Associate with the Institute for a Sustainable Environment at the University of Oregon, where he conducts policy-relevant social science research on topics related to natural resource management and rural community development. Recent efforts include research on Rangeland Fire Protection Associations in Oregon and Idaho and an analysis of community wildfire protection planning in the West.

S10.17. Recognizing Resilience of Indigenous communities in Canada to Wildland Fire

Presenter: Amy Christianson, Research Scientist, Canadian Forest Service (NRCan)
Additional Authors: Eustache, Jeff, Forest Fuel Management Lead, First Nations Emergency Services Society
Andrews, Darrick, Forest Fuel Management Liaison, First Nations Emergency Services Society
Caverley, Natasha, President, Turtle Island Consulting Services Inc
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Whitefish Lake First Nation 459

Indigenous peoples in Canada have a culture of fire, with extensive knowledge about fire behaviour and effects. Research led by Indigenous researchers and communities, incorporating Indigenous knowledge, on all aspects of fire management can help to increase the resilience of Indigenous communities to wildland fire. Indigenous communities in Canada are frequently at high risk from wildfire because they are often situated in isolated, remote locations in areas prone to fire with complex cultural, social, and economic landscapes. We will summarize several research projects, led by Indigenous researchers in partnership with Indigenous communities in Canada, that recognize how incorporating Indigenous knowledge into fire management increases resilience including: (1) the First Nations Wildfire Evacuation partnership with seven First Nations, (2) Revitalizing traditional burning with Xwisten and Shackan Indian Band, (3) Lessons from Indigenous firefighters in Alberta, and (4) Learning from Indigenous Children in Fort McMurray.

Keywords: Indigenous fire management, Indigenous knowledge, traditional knowledge

Bio: Amy Christianson is a Fire Research Scientist at the Canadian Forest Service. She obtained her PhD from the University of Alberta in 2011 where she examined Indigenous perceptions of fire management and joined the CFS fire research team shortly after. Amy's research predominantly involves working with Indigenous communities in Canada to improve wildfire management.

S10.18. Cross-Boundary Wildfire Governance

Presenter: Laurie Yung, Professor of Natural Resource Social Science, University of Montana
Additional Authors: Wyborn, Carina, Research Associate, University of Montana

By definition, addressing wildfire risk requires working across jurisdictional and institutional boundaries. Aspirations for cross-boundary governance are often stated in the literature and in policy, however cooperation at the landscape or fireshed scale remains a challenge. This presentation will explore what kinds of institutional structures and organizational cultures, and informal and formal mechanisms might enable effective more cross-boundary efforts to address risk at the landscape scale. In the case of wildfire, systems of governance not only need to work across diverse institutions, from federal agencies to individual private landowners, they also need to work at relevant spatial and temporal scales, and across scales. We will look at the relevance of governance systems that are increasingly discussed in the fire context, such as co-management, as well as governance work that is relevant but rarely applied to fire, including risk governance, knowledge governance and anticipatory governance. From this review, we will identify different governance options and strategies that could be adopted by diverse actors associated with wildfire

governance to effectively share wildfire risk and build capacity to work across jurisdictional and institutional boundaries.

Keywords: governance, cross-boundary

Bio: Laurie Yung is a Professor of Natural Resource Social Science in the W.A. Franke College of Forestry and Conservation at the University of Montana. Her work focuses on the social aspects of conservation and natural resource management, with an emphasis on agricultural communities and public lands in the Northern Rockies, and in particular the ways in which private landowners, rural communities, and land management institutions navigate change. She often examines the intersections between ecological change, natural resource management, rural livelihoods, and governance innovations. Yung's current research focuses specifically on climate adaptation, wildland fire, and the food, energy, and water nexus.

S11.1. Improved Simulation of Probabilistic Wildfire Risk Components for the Conterminous United States: 2018 FSim Product Updates

Presenter: Karen Short, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: Vogler, Kevin C., Spatial Wildfire Analyst, Pyrologix LLC
Scott, Joe H., Principal Consultant, Pyrologix LLC
Finney, Mark A., Research Forester, USDA Forest Service, Rocky Mountain Research Station
Grenfell, Isaac C., Mathematician, USDA Forest Service, Rocky Mountain Research Station

National-scale assessment of wildfire risk offers a consistent means of understanding and comparing threats to valued resources and predicting and prioritizing investments in management activities that mitigate those risks. We used a simulation system to estimate the probabilistic components of wildfire risk for 128 distinct regions of contemporary wildfire activity (pyromes) across the conterminous US (CONUS). The system, called FSim, consists of modules for weather generation, and for modeling of large-fire occurrence, growth, and suppression. FSim is designed to simulate the occurrence and growth of fires under tens of thousands of hypothetical contemporary fire seasons in order to estimate burn probabilities and conditional flame lengths at multiple spatial scales, given current landscape conditions and fire management policies. These outputs have been generated for the CONUS for several years to support a number of planning and risk assessment efforts. In 2016, national maps of burn probability (BP) and conditional fire intensity levels (FIL) were made publicly available from the US Forest Service Research Data Archive: https://www.fs.usda.gov/rds/archive/Product/RDS-2016-0034/. Since the 2016 product release, additional changes have been made to the system and to the input and reference data that have improved our ability to characterize outcomes of spatially explicit ignitions under conditions conducive to large fire development across the CONUS. Here we describe those improvements and spotlight the large-fire perimeter 'event set' output of FSim, which in conjunction with the maps of BP and FIL, rounds out the current suite of national FSim products.

Keywords: wildfire simulation, burn probability, fire intensity level, event set, hazard, risk assessment

Bio: Karen Short is a Research Ecologist with the USDA Forest Service, Rocky Mountain Research Station, Human Dimensions program. She received her BSc in Wildlife and Fisheries Science from the University of Arizona and her PhD in Organismal Biology and Ecology from the University of Montana. Her work has included fire-effects research in southwestern ponderosa pine forests; development and maintenance of spatial datasets on vegetation, fuels, and fire-occurrence for several national applications; and mapping of wildfire hazard for risk assessment and other applications. One product of this work is a spatial database of wildfires in the US, now spanning 1992-2015: http://www.earth-syst-sci-data.net/6/1/2014/essd-6-1-2014.html.

S11.2. Deterministic generation of flame-length probabilities for use in risk assessments

Presenter: Joe Scott, Principal Consultant, Pyrologix LLC
Additional Authors: Julie Gilbertson-Day

Wildfire risk assessments rely on flame-length probabilities—the conditional probabilities that fire intensity will be within various flame-length classes. The factors affecting flame-length probability include the elements of the fire behavior triangle—fuel, weather and topography—plus a fourth factor, relative spread direction (the orientation of the flaming front relative to the heading direction).
Current methods for determining flame-length probabilities include: 1) a single deterministic simulation of flame length at the head of the fire for one weather type (wind speed, wind direction, fuel moisture content), which results in a single flame-length value for a pixel; 2) multiple deterministic simulations of flame length at the head of the fire (for several weather types), which are then integrated (by a weighted mean) into a single flame-length value for the pixel; and 3) stochastic simulation of fire growth and flame length across a few to several dozen weather types. Rather than producing a single fire intensity value for a pixel, stochastic simulation produces flame-length probabilities for a range of flame-length classes.
The single-simulation approach can be run at a fine pixel size (30 m) but fails to account for the wide variety of weather types under which a pixel can burn, and non-heading spread directions. The multiple-simulation approach accounts for some variability in weather types, but still focuses on the head of the fire. Current methods of weighting the weather types (weighting by temporal relative frequency) does not account for any potential differences in area-burned among the weather types. The stochastic simulation approach addresses several of the shortcomings of the other approaches by inherently weighting the weather types and spread directions by their actual influence on the landscape, but they cannot be accomplished across a large landscape at 30-m resolution, and they generally result in a small sample size from which to determine the distribution of flame lengths.
In this presentation we describe a deterministic process, called FLEP-Gen, that addresses shortcomings of the current methods. It improves upon the multiple-simulation approach by 1) incorporating fire intensity in non-heading spread directions, and 2) weighting the weather types by their relative area burned rather than just their temporal relative frequencies. We present the mathematical basis for the process—based on the geometry of an ellipse—as well as spatial and non-spatial examples of its application to various fire management problems.

Keywords: fire intensity, flame length, effects analysis, wildfire risk

Bio: Mr. Scott has more than 25 years' experience in wildland fire science research, development and application. He has led projects related to surface and canopy fuel characteristics, wildfire behavior modeling, crown fire hazard assessment, and risk assessment. Mr. Scott's current work focuses on the application of Monte Carlo wildfire simulations to wildfire risk assessment and for private enterprises and local, state and federal government agencies. Joe earned a B.S. in Forestry and Resource Management from U.C. Berkeley and an M.S. in Forestry from the University of Montana. He is a Certified Forester™ as recognized by the Society of American Foresters.

S11.3. Calculating Fire Season Length with Weather and Fire Activity Metrics

Presenter: Karin Riley, Research Ecologist, US Forest Service, Rocky Mountain Research Station
Additional Authors: Freeborn, Patrick, PhD, Research Physical Scientist, US Forest Service--Rocky Mountain Research Station
Short, Karen, PhD, Research Ecologist, US Forest Service--Rocky Mountain Research Station
Jolly, Matt, PhD, Research Ecologist, US Forest Service--Rocky Mountain Research Station
Brown, Tim, PhD, Research Professor, Desert Research Institute, Reno, NV
Calkin, Dave, PhD, Research Forester, US Forest Service--Rocky Mountain Research Station
Nauslar, Nick, PhD, Research Scientist, Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, NOAA/NWS/NCEP Storm Prediction Center Prediction Center

Commonly used approaches to calculating fire season length indicate fire seasons are growing longer. Some of these approaches incorporate elements of fire management, as they rely on the reported discovery date of the year's first and last large fires as well as the reported control dates of the last large fires. Alternative approaches to calculating fire season length incorporate fire weather metrics (based on fire danger indices) and fire activity observations (based on documentary or satellite records). We classify these approaches as three distinct methods for calculating fire season length: 1) fire management season, 2) fire weather season, and 3) fire activity season. We derived three variants of the fire season length based on fire management reports, fire weather metrics, and fire activity observations, and compared these with three independent measures of burned area in forested lands across the western United States. While the length of the fire activity and fire weather seasons are fairly strongly correlated with each other and burned area totals, the length of the fire management season is more weakly correlated with the other measures. This result suggests that fire management season length may not be strongly associated with increases in fire season duration due to climate change, and may be affected by changes in fire policy, including mop-up standards and use of managed fires, as well as fire reporting, due to lack of consistent reporting standards over time.

Keywords: fire season; fire weather; fire management; fire activity

Bio: Dr. Karin Riley is a Research Ecologist with the Rocky Mountain Research Station of the US Forest Service stationed in Missoula, Montana. Karin also serves as the Vice President of the Association for Fire Ecology. Karin's current work concerns calculating fire season length, creating a tree-level model of the western US, and examining tradeoffs in alternative fire suppression policies.

S11.4. Modeling Synchronous Large-Fire Activity Across the Conterminous United States

Presenter: Karen Short, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: Finney, Mark A., Research Forester, USDA Forest Service, Rocky Mountain Research Station
Grenfell, Isaac C., Mathematician, USDA Forest Service, Rocky Mountain Research Station
Scott, Joe H., Principal Consultant, Pyrologix LLC

The co-occurrence of large wildfires across regions of the US can have substantial socio-ecological impacts, often exacerbated by competition for limited firefighting resources. Historical large-fire synchrony can be examined using documentary fire records and remotely sensed data, but due to the relative rarity of large wildfires and to changes in fuels and climate over past decades, empirical data provide limited information about the full potential for large-fire synchrony across regions under contemporary environmental conditions. Here, we describe a geospatial modeling system

used to simulate the occurrence and growth of fires under tens of thousands of hypothetical contemporary fire seasons, given current landscape conditions and fire management policies. The system, called FSim, consists of modules for weather generation, and for modeling of large-fire occurrence, growth, and suppression. The fire seasons used in the weather module are based on a national gridded weather dataset from the North American Land Data Assimilation System (NLDAS), which is a contemporary surface weather data assimilation system. The NLDAS data are analyzed to produce daily spatial-temporal realizations of a fire danger index (ERC) that retain the spatial covariance structure and temporal auto-correlation of the weather inputs. This approach maintains synchrony across weather scenarios used among independently simulated units. We present results from simulations for 128 units covering the conterminous US. We discuss our findings within the framework of national wildfire risk assessment, which offers a consistent means of understanding and comparing threats to valued resources and predicting and prioritizing investments in management activities that mitigate those risks.

Keywords: large wildfires, synchrony, fire modeling, simulation, hazard, risk

Bio: Karen Short is a Research Ecologist with the USDA Forest Service, Rocky Mountain Research Station, Human Dimensions program. She received her BSc in Wildlife and Fisheries Science from the University of Arizona and her PhD in Organismal Biology and Ecology from the University of Montana. Her work has included fire-effects research in southwestern ponderosa pine forests; development and maintenance of spatial datasets on vegetation, fuels, and fire-occurrence for several national applications; and mapping of wildfire hazard for risk assessment and other applications. One product of this work is a spatial database of wildfires in the US, now spanning 1992-2015: http://www.earth-syst-sci-data.net/6/1/2014/essd-6-1-2014.html.

S11.5. Modeling Long-Term Effects of Fuel Reduction on Fire Severity on the Deschutes National Forest

Presenter: Rachel Houtman, Faculty Research Assistant, Oregon State University
Additional Authors: Ager, Alan, Research Analyst, USDA Forest Service
Seli, Rob, Cedar Creek Consulting LLC
Day, Michelle, Faculty Research Assistant, Oregon State University

We re-engineered the Parallel Processing Extension to the Forest Vegetation Simulator and incorporated the Large Fire Model (FSIM) to create a forest landscape simulation model (LSIM) in order to study landscape change in response to wildfire, fuel management, and climate change. The model was optimized for simulating large landscapes (e.g. national forests) with stand-specific management prescriptions using the standard set of FVS keywords. We converted three variants (Central Oregon, Blue Mountains, Northern Idaho) and are in the process of completing case studies at the 1.5 – 2.5 million acre scale in all three regions. In each study area we are analyzing 6 to 12 management scenarios in which spatial treatment priorities and intensities are varied and landscape responses are measured over 50-year simulations. Response variables include burned area and severity; wildfire impacts on the wildland urban interface; and a cost-benefit analysis of fuel treatments in terms of suppression costs. In this talk we will present findings from the simulations from the central Oregon study area.

Keywords: forest vegetation simulator, forest fuels treatments; forest landscape modeling; forest restoration; wildfire simulation.

Bio: Rachel Houtman has worked as Faculty Research Assistant at Oregon State University College of Forestry since completing her master's degree in Forest Resources at OSU in 2011. Her research focuses on using wildfire and vegetation modeling to explore landscape-level wildfire risk analysis, as well as expected long-term impacts of current policies and land management activities.

S11.6. Results and application of the National Risk Assessment
Presenter: Greg Dillon, Spatial Fire Analyst, USDA Forest Service, Rocky Mountain Research Station
Additional Authors:

Spatial wildfire risk assessments that account for both the probability and consequences of wildfire events are becoming an important element of strategic fire and fuels planning. Using a standardized framework, these assessments can be scaled from local communities up to the continental scale. Inputs, spatial resolution, and methodology considerations change with different assessment scales, as do the types of questions that can be addressed with the results. The Forest Service's Fire Modeling Institute recently completed analysis for a national-scale risk assessment for all National Forest System (NFS) lands in the conterminous U.S. In this presentation, I will present results from that analysis including summary of conditional and expected Net Value Change metrics by individual National Forests and NFS Regions. I will also discuss intended applications of the results, including a "wildfire risk index" that the Forest Service plans to use to monitor performance toward the agency's broad objective of mitigating wildfire risk.

Keywords: wildfire risk, national forests

Bio: Greg Dillon is a Spatial Fire Analyst with the Fire Modeling Institute, part of the USDA Forest Service Rocky Mountain Research Station's Fire Sciences Lab in Missoula, Montana. His work generally involves geospatial and statistical analyses of large spatial datasets related to fire and fuels management. He is currently involved in spatial wildfire risk assessments at national, forest, and community scales. Greg's previous work includes potential vegetation mapping for the LANDFIRE project and analysis of satellite-derived burn severity data. He has an MA in Geography from The University of Wyoming, and a BS in Geography from James Madison University.

S11.7. Assessing Wildfire Risk in Real Time on the 2017 Frye Fire
Presenter: LaWen Hollingsworth, Fire Behavior Specialist, US Forest Service, Rocky Mountain Research Station
Additional Authors: Panunto, Matthew, Ecologist, Rocky Mountain Research Station

The Frye Fire started June 7, 2017 in the Pinaleño Mountains of southeast Arizona. The Pinaleños are host to a long list of important resources and assets including Mount Graham International Observatory, recreation residences, church camps, Forest Service infrastructure, spiritual significance to tribes, and eleven endemic fish and wildlife species that are only found on Mount Graham. As is often the case with any wildfire, the resources and assets identified by the Coronado National Forest and stakeholders created a blurry picture of how to manage the fire as there were often multiple resources and assets present in any particular area. Which resource or asset is of the highest importance? In addition, if it is likely that the fire will burn into an area that has important resources and assets, how do you provide substantive information to guide the desired fire effects?

This assessment was stimulated by the need to make sense of the numerous resources and assets within the planning area of the Frye Fire to enable quality dialog between the Coronado NF and the

incident management team and guide the management of the fire to best meet the desires of the local unit and stakeholders. The risk assessment completed for the Frye Fire had numerous objectives: 1) identify and prioritize the resources and assets within the planning area , 2) calculate the net value change to inform incident strategy, and 3) better connect strategy and tactics. A mix of strategies were used including suppression, confine, point/zone protection, and monitor.

Highly valued resources and assets (HVRAs) in the fire's planning area were identified, split into three groups, and then prioritized. The response function to fire for each individual HVRA was identified as positive, neutral, or negative by flame length class by local staff. The conditional net value change (cNVC) was calculated using predicted flame lengths from FlamMap and the expected net value change (eNVC) was then calculated based on cNVC and fire spread probability from FSPro. cNVC and eNVC were categorized into classes: strongly negative, mildly negative, and positive. We were then able to discern the probable effects to an area if it were to burn and isolate which HVRA was driving that response. This assessment allowed us to verify the incident strategies, develop tactics, prioritize actions on the ground, and better link the strategy and tactics by providing pertinent information to ground resources.

Keywords: wildfire risk assessment, fire management, HVRAs

Bio: LaWen Hollingsworth is a Fire Behavior Specialist for the Fire Modeling Institute at the Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. She is currently focused on improving science applications and delivery in NWCG fire courses and guides, developing delivery methods to improve foundational fire behavior knowledge in the field, applying science in project planning, and incorporating the concepts of wildfire risk assessment in incident management. Most of her federal career has been spent in the field working as a fire ecologist, firefighter, and conducting long-term vegetation monitoring in upland and riparian systems.

S11.8. Use of FSPro and a Quantitative Wildfire Risk Assessment (QWRA) to create Exceedance Probability Curves to Aid Incident Prioritization

Presenter: Rick Stratton, Fire Analyst, Planning & Budget, WO Fire & Aviation Management
Additional Authors:

Wildfires can cause significant negative impacts to private property, infrastructure, recreation, and natural resources, including water, timber, and wildlife habitat. However, there can be ecological benefits to fire, particularly in areas where assets are absent. Every year individual units, area commands, and regional multi area commands are challenged with the task of prioritizing resources to protect highly valued resources and assets (HVRAs) and still balancing the benefit of fire. The prioritization process varies among different units and geographic areas, but analyses are generally a-spatial, not quantitative, and frequently do not account for predicted fire behavior or growth. Exceedance probability (EP) curves are one way to graphically depict the benefit and/or loss to HVRAs by a given fire and comparisons among fires can be made. A mean expected net value change (eNVC) by HVRA was obtained from the Pacific Northwest all-lands QWRA. The probability of fire growth was estimated from 7, 10, or 14-day Fire Spread Probability (FSPro) runs. The product is a series of curves displaying a net expected loss or benefit by fire for the given timeframe. This graph can provide decision makers with a quantitative metric of potential loss or benefit to help aid in the difficult task of prioritization of resources among large fires.

Bio: Rick Stratton is a fire analyst for the Washington Office, Planning and Budget. His wildland fire interests include geospatial fire modeling, long-term assessment, fuel treatment design and effectiveness, risk assessment, resource allocation, and wildland-urban interface home ignitability assessments and destruction investigations.

Rick has a B.S. in conservation biology and an M.S. in forestry. Prior to his current position, Rick was at the USFS Regional Office/BLM State Office in Portland, OR (2010-2017) and a consultant at the Fire Sciences Lab in Missoula, MT for Systems for Environmental Management (SEM) (2000-2010). While going to college, he worked eight seasons with the USFS and NPS in various biological and fire suppression and monitoring capacities.

S11.9. Wildfire hazard assessment for community land use planning: a case study in Chelan County, WA

Presenter: Eva Karau, Spatial Analyst, USDA Forest Service Rocky Mountain Research Station
Additional Authors: Noonan-Wright, Erin, Fire Application Specialist, Rocky Mountain Research Station, Wildland Fire Management Research and Development Group
Haas, Jessica, Ecologist, Rocky Mountain Research Station, Human Dimensions Group
Dillon, Greg, Spatial Fire Analyst, Rocky Mountain Research Station Fire Modeling Institute

Federal wildland fire agencies are increasingly reaching across jurisdictional boundaries to their state, county, and local partners to better manage the unwanted effects of wildland fire, guided, in part, by the National Cohesive Wildfire Strategy. This collaborative and inclusive fire management strategy includes efforts to promote fire adapted communities through land-use planning. We report on the collaborative process between federal research and management with county and local representatives in Chelan County, WA, to map wildfire hazard as the basis for identifying areas where existing and proposed development may require regulation that safeguards life and property. Coupling new methodologies with emerging tools used for wildfire risk analysis (Large Fire Simulator - FSim, FlamMap 5), we developed a set of maps to support recommendations for improved land-use planning in Chelan County, including: two scales of wildfire hazard maps ("landscape" and "local"), locally-refined wildland urban interface (WUI) zones, and an index describing the level of effort required to mitigate wildfire hazard. We integrated wildfire likelihood and intensity information from 120-m cell size fire behavior modeling outputs from FSim, originally produced by Pyrologix LLC for a wildfire risk assessment for OR and WA to characterize "landscape" wildfire hazard, or the hazard due to large fires. We also used the FlamMap5 burn probability generator to model wildfire likelihood and intensity at a finer scale (60-m cell size), incorporating input from local subject matter experts to map "local" wildfire hazard under "problem fire" conditions. WUI zones were mapped following slightly modified Federal Register definitions, and using county address point data as the basis for the structures per area metric. We characterized the relative effort required to modify landscape characteristics in a way that could reduce wildfire hazard, using combinations of vegetation life form, slope and potential for crown fire activity. Together, maps of wildfire hazard, WUI and mitigation difficulty link to recommendations for planning documents that delineate conditions across the community landscape that may warrant enhanced mitigation measures like fire-resistant building materials or defensible space. In this presentation, we highlight innovative methods to summarize large and problem fire burn probability outputs to quantify wildland fire hazard important for federal, state, and local community interests. We emphasize the importance of an iterative and collaborative process of modifying methods according to local input, and we discuss

potential opportunities and limitations of extending the application of wildfire hazard maps across varying scales and desired uses.

Keywords: wildfire hazard, land-use planning

Bio: Eva Karau is a spatial analyst with the Fire Modeling Institute at the USDA Forest Service Rocky Mountain Research Station, Missoula Fire Sciences Laboratory.

S11.10. Wildfire Risk to Homes in Western Montana

Presenter: April Brough, Spatial Wildfire Analyst, Pyrologix
Additional Authors: Scott, Joe H., Principal Consultant, Pyrologix
Gilbertson-Day, Julie, Senior Spatial Wildfire Analyst, Pyrologix
Vogler, Kevin C., Spatial Wildfire Analyst, Pyrologix

In this presentation we examine wildfire threat to homes in western Montana. We compare fire simulation outputs and structure locations, emphasizing the fire effects, fire exposure, potential loss, and exposure-source for homes. We used the Montana Structures/Addresses Framework dataset to represent residential structure locations, and used subsets of the results from the Northern Region Risk Assessment (NoRRA) for fire behavior modeling.

We incorporated two types of exposure for homes: direct and indirect. Direct-exposure structures may be directly exposed to ignition from a wildfire. Indirect-exposure structures may be ignited secondarily, such as through spotting or house-to-house spread. In our analysis, we evaluate both types of exposure to assess overall threat to homes.

Our findings are presented spatially, using maps to illustrate the patterns of fire effects, fire exposure, and potential loss across the landscape. In our assessment of exposure-source, we divided the assessment area into zones based on the distance from any structure and then evaluated simulated ignitions within those zones. We review those results using both maps and tables. The results suggest that although the wildfire simulations include the infrequent but very large fires that account for the majority of area burned annually, the locations with the greatest potential to expose homes are not the remote backcountry but are the areas immediately near the homes. This suggests that fuel management activities designed to protect homes should be located very near the homes.

Keywords:

Bio: April Brough has over twelve years of experience as a GIS programmer/analyst, and five years of experience in wildfire research, development, and application. Ms. Brough uses GIS techniques to conduct spatial analyses related to human, social, cultural, economic, and ecological environments, with a recent focus on wildland fire risk assessments and national forest plan revisions. She has GIS experience with datasets at the national, regional, and local level and has been involved in GIS communities at local and state levels.

S11.11. Wildfire threat to surface drinking water in western Montana

Presenter: Julie Gilbertson-Day, Spatial Wildfire Analyst, Pyrologix LLC
Additional Authors: Scott, Joe, Principal Consultant, Pyrologix LLC
Jensen, Amy, Regional Hydrologist, Forest Service Northern Region
Archer, Vince, Soil Scientist, Forest Service Northern Region

Broad-scale wildfire risk assessments have frequently relied on a national dataset providing watershed-level summaries of surface drinking water importance, namely the USDA Forest Service Forests to Faucets. The Forest to Faucets dataset includes many of the components needed to identify areas important to surface drinking water, including: population served, water supply, and distance to intake(s). These data are mapped with a consistent approach and available for any extent within the continental U.S. Each watershed is given a surface drinking water importance score based on the above factors and this value has historically been used in wildfire risk assessments to determine the relative importance of some areas of the landscape over others to surface drinking water. The limitation of this approach, however, is that watershed importance from Forests to Faucets is assigned to the entire 12-digit Hydrologic Unit and implies equal importance of every location within the watershed boundary.

In a wildfire risk assessment completed for the USDA Forest Service Northern Region, we wished to highlight the area nearest the surface drinking water intakes and allocate a higher share of per-unit-area importance to these areas over those located in the remote reaches of the watershed. Using the Public Water Supply intakes and watershed polygons delineated using a 10-m digital elevation model, we calculated importance as a function of population served and distance to intake. We performed this calculation in a raster-GIS environment, by calculating the Euclidean distance from the intake point for every pixel within a watershed boundary. We then used the product of inverse Euclidean distance and population served to allocate the importance spatially within the watershed, resulting in pixels containing the intake point receiving an importance value equivalent to the population served and all other pixels receiving a proportion of that value, commensurate with location. The watershed delineations for various populations can overlap such that portions of one watershed may drain to one or more intakes across the landscape. Therefore, our importance results are cumulative across all watersheds, reflecting each pixel's contribution to population served.

The spatial importance results were then overlaid with erosion potential data and an associated response function to describe the general response at that location to wildfire of different intensities. We integrated those results with wildfire hazard results from the FSim large fire simulator to calculate wildfire risk to watersheds across the Region. Using these results, we identify and compare wildfire risk to communities' surface drinking water across western Montana.

Keywords: Wildfire risk, watershed risk, surface drinking water

Bio: Julie Gilbertson-Day is a Senior Spatial Wildfire Analyst with Pyrologix LLC. She has ten years of experience in wildfire research and application with emphasis on integrating resource and asset data with wildfire hazard information in wildfire risk assessments. Ms. Gilbertson-Day has experience with spatial data analysis, fire behavior modeling, and developing data processing tools for broad-scale projects. Her past research includes data and scale issues related to wildfire modeling and wildfire risk assessments, downscaling wildfire risk assessments, and analysis of historical fire occurrence and suppression expenditure data. Julie earned a B.S. in Wildlife Biology and a M.S. in Geography/GIS from the University of Montana.

S11.12. Success rate of alternative criteria for the prioritization of fuel management in the Deschutes National Forest

Presenter: Ana Margarida Gracio de Barros, Research associate, Oregon State University
Additional Authors: Ager, Alan, Research Forester, USDA Forest Service, Rocky Mountain Research Station
Day, Michelle, Faculty Research Assistant, Oregon State University
Paleologou, Paleologos, Researcher, USDA Forest Service J-1 International Visitor Program

Wildfire occurs in juxtaposition with ecological and human systems, which are, by nature, uncertain. Risk assessment couples exposure to wildfire with values at risk to predict expected losses and inform risk management decisions. In real landscapes, managers often rely on multiple and sometimes conflicting criteria to allocate fuel treatments, including non-risk metrics such as potential timber revenue or ecological departure to identify priority areas to treat. The potential benefits of fuel treatments can be quantified in terms of fire-treatment interactions, i.e., how often treatments are intersected by subsequent fires. Different criteria for treatment allocation can lead to potentially different areas to treat and thus different success rates based on the pattern of fire occurrence and vegetation growth after treatment.

In this work, we compare success odds of different alternative risk (e.g., burn probability, flame length, fire transmission) and non-risk metrics (e.g., ecological departure, timber revenue) used to prioritize fuel management. We ask: given the spatial and temporal uncertainty in wildfire ignition, wildfire spread, and fire-vegetation feedbacks, what are the odds of given criteria successfully predicting future area burned on a dynamic landscape? Moreover, how do these success odds change over time? Working at the level of planning areas for the Deschutes National Forest in central OR, US we identified the planning areas that constitute a priority for treatment according to each criterion. We then used Envision to model the effects of wildfire and vegetation succession in annual area burned in the planning areas, over the course of 50 years. For each criterion, we calculated the success odds, of each criteria selecting planning areas with 1,2,… 100% of the total burned area within a 5-year period after treatment allocation. We also quantified how the odds changed over the course of 50 years and compared all considered metrics with random allocation of treatments. Overall, burn probability, and wildfire transmission metrics outranked alternative non-risk metrics. Success odds were small for moderate thresholds of area burned (>40%), suggesting that ambitious management goals are unlikely to be achieved. Prioritizing fuel management based on economic or ecological criteria performed similarly to random allocation of treatments. Our results quantify the potential outcome of the different priority metrics and provide insight into their relative performance through time, thus contributing information to support forest management decisions and frame management and public expectations regarding the performance of fuel treatments programs aimed at reducing area burned in fire-adapted forests.

Keywords: spatiotemporal fire modeling; fuel treatment prioritization; Deschutes National Forest; Envision;

Bio: Ana earned her master's and doctorate degree in Forest Engineering and Natural Resources at the University of Lisbon Portugal. After graduating, Ana worked in the private industrial forest sector, focusing on wildfire risk assessment and wildfire management of eucalypt plantations in Portugal. Since 2014 Ana has been a postdoctoral scholar researching wildfire and landscape ecology in the College of Forestry at Oregon State University. Specifically, she uses landscape spatiotemporal modeling of wildfire, succession and forest management to understand wildfire and forest dynamics in coupled natural-human systems in Central Oregon. Ana's current research interests include using disturbance ecology of future western US forests and the ecology and sociology of landscape restoration.

S11.13. Optimizing large-fire response based on risk and responder exposure
Presenter: Yu Wei, Associate Professor, Colorado State University
Additional Authors: Matt Thompson
Joe Scott

In this presentation we build on recently developed decision support tools that optimize large fire containment and point protection strategies. The basic building blocks of the optimization model are: (1) pre-identified potential control locations (PCLs) such as roads, ridge tops, and streams; (2) their aggregation into management units called potential wildland fire operation delineations (PODs); and (3) fire behavior modeling and corresponding net value change (NVC) measures. The model is able to cluster multiple PODs together to form a container that is referred to as the response POD, or rPOD. Suppression effort can be directed towards construction of fire line along the boundary of the selected rPOD to contain the fire, as well as to point zone protection of assets such as communities and infrastructure within the rPOD. The total amount of expected suppression effort associated with a given rPOD represents overall fire responder exposure, which we balance against expected NVC, aiming to find solutions that simultaneously minimize exposure and net loss. Relative to earlier work, major advancements here include: (1) the incorporation of probabilistic fire spread results from the Fire Spread Probability (FSPro) modeling system; and (2) the incorporation of probabilistic flame length results from the Flame Length Probability Generator (FLEP-GEN) modeling system. We use the 2017 Lolo National Forest Sliderock fire as a test case to study how to determine a large fire containment strategy to minimize expected fire risk and fire responder exposure together.

Keywords: large fire, containment, point protection, probability, fire responder exposure, optimization

Bio: Yu Wei is currently an associate professor at Colorado State University. He earned a PhD and a MS degree from University of Minnesota. His research emphasis is developing operations research models to support wildland fire management decisions.

S11.14. Concepts and tools to simplify complicated risk management problems)
Presenter: Matthew Thompson, Research Forester, Rocky Mountain Research Station
Additional Authors:

The basic premise of this presentation comes directly from the 2018 Red Book: pre-season preparedness work is critical to success when a fire starts. The wildland fire management community's growing emphasis on pre-season assessment and planning reflects its maturing proficiency with risk management principles and practices. By prospectively assessing various fire scenarios and their associated risks, opportunities, and contingencies, fire managers can simplify the response decisions they may face in the future. In the ideal, doing so provides fire managers with a sound understanding of the range of available management opportunities and the corresponding range of possible fire consequences. To that end, recently developed decision support tools focus on the pre-identification of potential fire control locations, their spatial aggregation into meaningful management units, and their integration with spatial risk assessments. We will briefly review these new tools, and then review some key lessons learned from past assessments and workshops.

Bio: Research Forester, Human Dimensions Program, Rocky Mountain Research Station, USDA Forest Service

S11.15. Fire Risk at California Utilities
Presenter: Mason Withers, Quantitative Risk and Control Manager, San Diego Gas and Electric
Additional Authors: Randy Lyle, Fire Program Manager, San Diego Gas and Electric

Risk Management is a powerful framework that is used increasingly more across business and government organizations. It can be used to quantify and communicate risks as well as allow studies to determine the effectiveness of risk reducing programs. This presentation will give an introduction to how these tools can be used for fire risk. The introduction will walk through various terminology and methods including "risk bowties", expected values, effectiveness of mitigations, etc. Examples will be catered to topics of wildfire risk and should give food for thought on how the fire fighting industry can utilize aspects of Risk Management. Many examples will be taken directly from San Diego Gas & Electric's efforts to improve its position after the catastrophic fires that occurred in 2007.

Keywords: Risk Management, Quantitative, Probabilistic

Bio: Mason Withers is currently the Quantitative Risk and Controls Manager for San Diego Gas & Electric and SoCalGas. He has been with SDG&E and SoCalGas for nearly 12 years, mainly in Electric Reliability and Enterprise Risk Management. He has a degree in Mathematics from the University of California at San Diego, and an MBA from San Diego State University. Mason has been involved in Fire Risk issues since 2007. That involvement has been centered around trying to find cost-effective ways to reduce fire risk within the regulated environment of a public utility. While managing the Electric Reliability group, SDG&E was given the "Best Reliability in the Nation" award by PA Consulting. Mason is currently on a team of individuals who are shaping how the California Public Utilities Commission views risks.

S11.16. An assessment of wildfire risk from utility-related ignitions in California
Presenter: David Sapsis, Fire Scientist, CAL FIRE
Additional Authors: Soctt, Joe, H. , Principal Consultant, Pyrologix
Saah, David, PhD Managing Principal, Spatial Informatics Group

California wildfire history has a well-documented incidence of large and damaging fires from utility-related ignitions (e.g., Laguna 1970, Calabasas 1996, Witch/Guijito 2007). In support of a regulatory rulemaking by the California Public Utility Commission, we constructed a fire risk model to map areas of California with elevated likelihood of large damaging fires associated with potential ignitions from overhead utility equipment. The model has three discrete indices characterizing hazard: 1) conditional ignition probability; 2) initial fire spread related to initial attack escape; and 3) a large fire event set. Impacts were assessed by overlaying the hazard sub-model with a map surface of human housing infrastructure compiled using LANDSCAN data. We used a WRF model 10 year, 2-km reconstruction of fire weather and a threshold extraction process using the Fosberg Fire Weather Index to provide climate and weather inputs for the first two hazard components. We then utilized a large fire event set that was sourced from regional conditional large fire probability analysis using the FSIM modeling package. Results developed at the orignal 2 km resolution were then ordinated into a cumulative frequency distribution, then spatially smoothed using a 3 x 3 gridcell splining routine. The resultant surface was then used to refine and validate a final map classified into two tiers for enhanced fire-safety regulations, targeted at implementation in the fall of 2018. Evaluations against large fires from late 2017 showed excellent correspondence, and the data surface will continue to be systematically improved with potential uses in other extreme fire/risk applications.

Keywords: utilities, risk assessment, mapping, fire mitigation

Bio: Dave has been working in wildland fire for over 30 years. He currently served as the senior fire scientist at CAL FIRE's Fire and Resource Assessment Program, where he leads work on hazard and risk mapping, forest policy to improve forest health and carbon stability, and wildland-urban interface issues. He holds a B.S in Forestry from UC Berkeley, and an M.S. in fire ecology from Oregon State.

S11.17. Wildfire Risk Mitigation at San Diego Gas and Electric

Presenter: Brian D'Agostino, Meteorology Program Manager, San Diego Gas and Electric
Additional Authors: Randy Lyle, Fire Program Manger, San Diego Gas & Electric
Mason Withers, Quantitative Risk and Controls Manager, San Diego Gas & Electric

The occurrence of large and devastating wildfire continues to be on the increase across the state of California. As a result, San Diego Gas & Electric (SDG&E) has developed comprehensive and innovative programs to mitigate this risk. This session will examine SDG&E's fire mitigation plan, focusing on how a targeted mix of analytics, electric system hardening, and the largest utility owned weather network in the country is used to strategically mitigate wildfire risk and gather data to operate the electric infrastructure safely and reliably.

Keywords: Utilities, Powerlines, Santa Ana Winds

Bio: Brian D'Agostino is the Meteorology Program Manager in Emergency Management for San Diego Gas & Electric (SDG&E). As program manager, D'Agostino provides operations support for the delivery of safe and reliable energy. D'Agostino oversaw the design and construction of SDG&E's weather network, one of the United States most sophisticated and extensive weather networks. D'Agostino joined SDG&E in 2009 and has established many relationships within the scientific community of Southern California. D'Agostino currently serves as an advisor and former chair of the American Meteorological Society's National Energy Committee and works closely within the meteorological community coordinating research projects specializing in fire science, solar forecasting, climate adaptation and emergency management. D'Agostino is a graduate of Plymouth State University with a bachelor's of science degree in meteorology.

S12.1. The promise and challenges of CFD physics-based wildland fire behavior modeling

Presenter: William (Ruddy) Mell, Combustion Engineer, USFS Pacific Wildland Fire Sciences Laboratory
Additional Authors:

The methods of computational fluid dynamics (CFD) have been applied to model a wide range of flow driven phenomena. Over approximately the last twenty years, CFD methods have been used as the framework for physics-based simulations of fire (both structural and wildland) behavior. In the most comprehensive approaches for wildland fire, sub-models that explicitly account for the processes of heat transfer (convective and radiative), the thermal degradation of vegetation, and gas-phase combustion are coupled within a CFD framework. The overarching promise of this approach is that, by explicitly modeling the coupled processes, a better understanding and prediction of the fire behavior of interest (including smoke plume rise) will result. This is especially the case for fire behavior that is not quasi-steady. There are significant challenges to arriving at a CFD physics-based fire behavior model that has a well-characterized prediction performance. These challenges include conducting experiments suitable for assessing model performance across and range of scales and fire behaviors. These experiments need to measure the right quantities in the right way to be of use for model testing and development. Field measurement require an interdisciplinary approach that uses the methods of geospatial science and technology and results in spatially integrated and temporally synchronized datasets. In addition, not all sub-models for the processes involved have reached the same level of maturity. Advancement of the sub-models and the overall fire behavior model requires an integrated and productive collaboration between modelers and experimentalists.

Bio: William (Ruddy) Mell's primary focus is on the advancement of fire behavior and smoke models for application to problems in wildland and wildland-urban interface fires.

S12.2. Using process-based coupled fire/atmosphere models to gain better understanding of wildfire dynamics

Presenter: Rodman Linn, Senior Scientist, Los Alamos National Laboratory
Additional Authors: Winterkamp, Judy, Scientist, Los Alamos National Laboratory
Jonko, Alex, Post Doc, Los Alamos National Laboratory
Sieg, Carolyn, Research Scientist, USDA Forest Service
Parsons, Russell, Research Scientist, USDA Forest Service
Goodrick, Scott, Research Scientist, USDA Forest Service
Holmes, Marlin, Graduate Research Assistance, Los Alamos National Laboratory

Experiments and observations have demonstrated the fact that the two-way feedbacks between fires and atmosphere play critical roles in determining how fires spread or if they spread. Advancements in computing and numerical modeling have generated new opportunities for the use of models that couple process-based wildfire models to atmospheric hydrodynamics models. These process-based coupled fire/atmosphere models, which simulate critical processes such as heat transfer, buoyancy-induced flows and vegetation aerodynamic drag, are not practical for operational faster-than-real-time fire prediction due to their computational and data requirements. However, these process-based coupled fire-atmosphere models make it possible to represent many of the fire-atmosphere feedbacks and thus have the potential to complement experiments, add perspective to observations, bridge between idealized-fire scenarios and more complex and realistic landscape fire scenarios, allow for sensitivity analysis that is impractical through observations and pose new hypothesis that can be tested experimentally. Specific examples of the use of FIRETEC in this fashion include: 1) investigation of the 3D fire/atmosphere interaction that dictates multi-scale fireline dynamics; 2) fundamentals of slope/fire interaction; 3) the influence of vegetation heterogeneity and variability in wind fields on predictability of fire spread; 4) the interaction between ecosystem disturbances such as insect attacks and potential fire behavior. Additionally, coupled wildfire/atmosphere modeling opens new possibilities for understanding the sometime counterintuitive impacts of fuel management and exploring the implications of various prescribed fire tactics. Results from these studies highlight critical roles coupled fire/atmosphere interaction, which is directly affected by the fire geometry, structure of the vegetation and topography. Certainly, there need to be continued efforts to validate the results from these numerical

investigations, but, even so, they suggest relationships, interactions and phenomenology that should be considered in the context of the interpretation of observations, design of fire behavior experiments, development of new operational models and even risk management.

Keywords: wildfire behavior modeling

Bio: Dr. Rodman Linn is a Senior Scientist at Los Alamos National Laboratory (LANL). A background in theoretical turbulence modeling provided the foundations for Dr. Linn's research in the area of forest fire modeling beginning in 1995. He was the principle investigator/developer for a physic's-based wildfire model utilizing computational fluid dynamics techniques, FIRETEC. Dr. Linn is the project leader for the wildfire research at LANL and continues his wildfire research work with a focus on coupled fire/atmosphere behavior.

S12.3. Improvement of sub-modeling in physical fire spread models
Presenter: Albert Simeoni, Professor, Worcester Polytechnic Institute
Additional Authors: Hadden, Rory, Senior Lecturer, University of Edinburgh
Morvan, Dominique, Professor, University of Aix-Marseille
Mell, William, Research Combustion Engineer, US Forest Service

This paper will present the approach of improving fire spread CFD models as a tool to better capture and understand the physics that drive fire behavior in wildland fires. The CFD modeling approach will be presented. Then, the different types of sub-models used to close the CFD model will be presented with some of their assumptions and limitations.

The improvement of CFD models will then be illustrated through previous research on the representation of gas phase combustion, drag forces in vegetation, convective transfer, and thermal degradation of the vegetative fuel. Sub-models will be presented with the challenge of testing and validating the model with experiments and the challenge of capturing enough of the physics to enhance the model capacity without making it unmanageable.

These studies will be used as an example of developing a generic approach based on a combination of experiments at laboratory and field scales and their simulation. Other ongoing studies and perspectives will also be presented with the identification of research bottlenecks and needs.

Keywords: Fire behavior, Fire-spread modeling, CFD modeling, sub-models

Bio: Professor Albert Simeoni is the Department Head of Fire Protection Engineering at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts. He is an internationally recognized leader in wildland fire and fire science with over 120 journal papers, conference papers, and book chapters. He has more than 20 years of experience developing experimental, analytical, and numerical techniques to better understand fire dynamics and to predict fire and wildland fire behavior. Before joining WPI, he held academic leadership positions in fire research in the UK and in France. He has also experience as a consultant in fire science in the US and has spent over 10 years volunteering and working as a firefighter in France.

S12.4. How 10 years of physical assumptions led to the development of the Balbi model, from laboratory scale to field scale

Presenter: Jacques-Henri Balbi, Emeritus Professor, University of Corsica
Additional Authors: Chatelon, François-Joseph, Associate Professor, UMR-CNRS 6134, University of Corsica
Rossi, Jean-Louis, Associate Professor, UMR-CNRS 6134, University of Corsica
Marcelli, Thierry, Associate Professor, UMR-CNRS 6134, University of Corsica

This work deals with the construction of a fire behavior model that can be easily used by people involved in firefighting or in environmental planning. The model has to provide the main physical characteristics of the fire front (rate of spread, tilt angle, height, length, temperature etc.)
As this model has to be a universal one, it can be applied to any surface fire configuration without any change in the model. This first condition automatically leads to a physical model instead of an empirical model. In order to be integrated into helpful mobile applications, computational time has to be much lower than real time. So, a complete 3D model with partial differential equations is avoided. The physical model has to take into account physical laws describing the major part of the phenomena but in a simplified manner.
The first attempt of this simplified physical model (in 2007) neglected convective effects. Only radiation from the base and from the flame were taken into account. The model consisted in two main algebraic equations where rate of spread and flame tilt angle depend on wind velocity, terrain slope angle and fuel bed characteristics. But some fire front characteristics are defined thanks to empirical laws. For instance, flame height is determined with the empirical McCafrey law.
This radiative model has been successfully confronted to many laboratory fires and some fires at the field scale.
The next step concerned model improvements (2010). Indeed, substituting empirical laws for physical laws and taking into account more physical phenomena were the new major goals.
Firstly, a physics-oriented flame length submodel was developed in order to change the McCafrey law. Secondly, physical assumptions on the fresh air stream coming from the unburnt fuel bed led to a better understanding of the backfire.
More recently, from the basis of the former radiative model, a convective-radiative model was developed. Convection was described as a contact flame inside the vegetal stratum. Convective effects were quantified by computing the pyrolysis gases flow which crossed the unburnt fuel bed. The aim was to give a physical modelling of the fingers of fires observed by Rothermel and Anderson. This model (without any model parameter) was confronted to more than 400 laboratory fires. An NMSE under a 7% level was obtained. It is currently confronted to many fires at the field scale, which requires to take into account dead and living materials.

Keywords: Physical Model - Radiation - Convection -

Bio: Jacques-Henri Balbi is an emeritus Professor in applied physics at the University of Corsica. He has been the President of the University of Corsica twice. He created the research fire team at the University and has been the head of the UMR-CNRS 6134 laboratory. He is now retired but has not given up research on wildland fires. He created the surface fire propagation model used at the University of Corsica.

S12.5. Direct measurements of energy transport in naturally burning fires
Presenter: B.W. Butler, Research Mechanical Engineer, Forest Service, Rocky Mountain Research Station
Additional Authors:

Direct measurements of energy incident on a small sensor located down stream of flames burning over beds of pine needles for a range of wind speeds reaching 27 m/s are presented. When the data are time averaged over 3 seconds radiant heating exceeds convective heating by approximately 2 times over the entire wind speed range studied. Both modes of heating increase monotonically with increased wind speed as well as with fire spread rate; however, radiant heating is shows the strongest correlation with wind and rate of spread.

S12.6. Laboratory experiments in fires spreading with wind and slope
Presenter: Mark Finney, Research Forester, USFS, Missoula Fire Sciences Laboratory
Additional Authors: Forthofer, Jason Mechanical Engineer, USFS Missoula Fire Sciences Laboratory
Torben Grumstrup Research Mechanical Engineer, USFS Missoula Fire Sciences Laboratory

Wildfire spread strongly depends upon non-steady convective heat transfer by flame bursts that originate as buoyant instabilities in the flame zone. Previous studies with wind driven fires have shown these bursts have characteristic frequencies and forward travel distances which scale with flame size (0.1-2.5 m) and wind speed (0.1 – 2.2 m s-1). New experiments were conducted on fires spreading upslope through laser-cut cardboard fuel beds at various angles on a tilting platform without wind. Data from slope-driven fires show flame intermittency and forward burst distances exhibit similar scaling using flame length and depth of the actively burning region. Static pressure measurements are also revealing of flame dynamics as well as a possible role in flame attachment on steep slopes.

Keywords: Flame, instability

Bio: Mark A. Finney has been a Research Forester with the US Forest Service, Missoula Fire Sciences Laboratory since 1993. He leads a research team on wildfire behavior, fire modeling, wildfire risk analysis, and ignition by firearms and explosives. A major part of his work is to understand the physics of wildfire spread using laboratory and field-scale experiments. He holds a Ph.D. in wildland fire science from Univ. California at Berkeley (1991), an M.S. in Fire Ecology from University of Washington (1986), and a B.S. in Forestry from Colorado State University (1984).

S12.7. Observing kinematic structures of large wildfire plumes from ground and airborne platforms
Presenter: Craig Clements, , San Jose State University
Additional Authors: Lareau, Neil, San Jose State University
Kingsmill, David, University of Colorado
Rodriguez, Bruno, SJSU

The Rapid Deployments to Wildfires Experiment (RaDFIRE) was a meteorological field campaign dedicated to observing fire-atmosphere interactions during large active wildfires. Using a rapidly deployable scanning Doppler lidar, airborne Doppler radar, and a suite of other instruments, the field campaign sampled 21 wildfires from 2013-2016 in the Western US. Access to wildfires was accomplished via team members training as wildland firefighters and through integration with wildland fire management agencies. Fire-atmosphere interactions examined in this talk include (1) vigorous vertical-axis vorticity in wildfire convective plumes, (2) penetrative convective processes and associated multi-layered smoke detrainment, (3) convective plume entrainment processes, (4) newly discovered smoke-induced density currents, and (5) pyrocumulus and pyrocumulonimbus initiation, including aircraft in-situ observations of a developing pyrocumulus. Collectively, these RaDFIRE observations highlight the range of phenomena associated with fire-atmosphere interactions, especially plume dynamics, and will provide a valuable data set for the wildfire and smoke-injection modeling communities.

Keywords: smoke, plume dynamics, lidar, radar, pyrocumulus

Bio: Associate Professor of Meteorology, San Jose State University.

S12.8. Wind effects upon the behavior of wildfires: unsteady and 3D effects
Presenter: Dominique MORVAN, Professor, Aix-Marseille University
Additional Authors: MORVAN Dominique

Three factors are mainly identified to affect the behavior of wildland fires: weather conditions (wind, air temperature, relative humidity), topography (slope) and fuel (structure, composition, moisture content, fuel load). This presentation is dedicated to study the effect of the wind speed upon the behavior of wildland fires. Both 2D and 3D numerical simulations (obtained using a detailed physical model) are presented and compared to experimental data [1, 2]. The study was restricted to surface fires propagating on a flat terrain. The evolution of the rate of spread versus the wind speed is analyzed in order to understand the variability of the power law function (mainly the exponent) observed experimentally. Theoretical interpretations have also been proposed, in introducing dimensional analysis and similitude parameters (such as the ratio rate of spread / wind speed and the Byram's convective number) to understand the behavior of the fire front. The effects resulting from the regime of propagation (plume dominated or wind driven), associated to the main mechanisms of heat transfer (by radiation and convection) have also been studied. A part of the presentation was dedicated to the unsteady character of the fire behavior in correlation to the hydrodynamics instabilities (shear instability and thermo-convective instability) governing the behavior of the flame. The impact of the 3D organization of the flame front (structured in peaks and troughs) upon the fire dynamics has been also considered [4].
Reference
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Keywords: Fire behavior, wind effect, rate of spread

Bio: Dominique MORVAN has obtained a PhD in Mathematics and Fluid Mechanics in 1985 at the Aix-Marseille University 2. He is a specialist in Fluid Mechanics, in Biomechanics, in Heat and Mass Transfer, in Combustion, in Computational Fluid Mechanics. Dominique MORVAN has worked 15 years as a searcher in the National Center of Scientifi Rerearch (CNRS) in laboratories located Compiègne and in Marseille. Then he joints Aix-Marseille University as a professor of fluid mechanics, since 2015 he heads the department of mechanical engineering.
He is the author of more than 60 publications in international scientific journals and he has presented more than 200 communications in international conferences.
Since 1998, he develops researches in wildfire modeling and fire safety engineering.

S12.9. Modeling of stationary wind-driven flames to understand wildland fire behavior

Presenter: Michael Gollner, Associate Professor, Department of Fire Protection Engineering, University of Maryland, College Park
Additional Authors: Trouve, Arnaud, Professor, Department of Fire Protection Engineering, University of Maryland, College Park
Verma, Salman, Graduate Student, Department of Fire Protection Engineering, University of Maryland, College Park
Ren, Xingyu, Graduate Student, Department of Fire Protection Engineering, University of Maryland, College Park
Tang, Wei, Graduate Student, Department of Fire Protection Engineering, University of Maryland, College Park

Renewed effort is currently being made towards understanding the mechanisms by which wildland fires spread, especially the means by which heat is transferred from the flame to unignited fuel ahead. While it has proven difficult to study spread phenomena in large-scale fires, a series of stationary, laboratory-scale, gaseous-fueled, flame experiments has been performed to determine the underlying physics. This presentation will describe the series of experiments performed at the University of Maryland (UMD) and the companion numerical simulations designed to examine the mechanisms by which wind-driven flames attach to, or lift from solid surfaces and transfer heat in the downwind direction. These experiments examine non-spreading, gaseous-fueled, buoyancy-driven, turbulent flames under an imposed wind velocity and on flat terrain; scaling arguments suggest that these flames share similar features with larger-scale wildland fires; in addition, they are more readily accessible for detailed measurements and analysis. Experiments have produced detailed measurements of flame structure and heating during liftoff and attachment leading to correlations that can be used at larger scale.

The computational component of the UMD wildland fire research program is focused on performing detailed flame-scale simulations that provide fundamental information on the structure of wildland fire flames. Numerical simulations have been performed to analyze the transition from an attached flame to a lifted flame using wall-resolved large eddy simulations (LES). Simulations are performed

with an LES solver developed by FM Global and called FireFOAM. The LES simulations provide detailed information on the flame structure and in particular on the relative weight of convective and radiative heat transfer. For wind-driven flames on flat terrain, the simulated transition between the attached flame regime and the lifted flame regime is interpreted through an analysis of the different contributions to flow kinetic energy in the horizontal and vertical directions thereby allowing a quantification of the competing effects of the external momentum of the horizontal cross-flow and the internal momentum of the vertical buoyant motions produced by the combustion heat release and the resulting unstable thermal stratification. A new criterion is proposed to measure the relative strength of external/cross-flow-driven versus internal/buoyancy-driven motions. This criterion is also currently evaluated in simulations of flames on sloped terrain.

Keywords: fire behavior, stationary burner, flame attachment

Bio: Michael Gollner is an Associate Professor in the Department of Fire Protection Engineering at the University of Maryland, College Park. He is broadly interested in fire science, using a background in combustion and fluid mechanics to understand fire spread, fire whirls, ignition of homes in the wildland-urban interface, and emissions from fires. He serves on the Board of Directors of the IAWF and is a principal member of the NFPA Technical Committee on Wildland and Rural Fire Protection. He holds a Ph.D. in Mechanical Engineering from the University of California, San Diego.

S12.10. Extreme Fire Behaviour in Complex Topography

Presenter: Domingos Viegas, Professor, ADAI, University of Coimbra
Additional Authors: Raposo, Jorge, PhD, ADAI - Univ. of Coimbra
Abouali, Abdelrahman, ADAI - Univ. of Coimbra
Rodrigues, André, MSc, ADAI - Univ. of Coimbra
Almeida, Miguel,PhD, ADAI - Univ. of Coimbra

Fires spreading in areas of complex topography or with strong wind generate convective flows that modify their behaviour dynamically, producing some forms of extreme fire behaviour that can become very dangerous and hard to control. Examples of such behaviour are the eruptive spread of fires in canyons, the lateral growth of fires on ridges or canyons and the junction of approaching fire fronts. The spread of fire between two ridges under wind conditions may also generate an extreme fire development condition that has the potential of catching operational personnel by surprise.
The fires of 17.th June of 2017 in Portugal had several manifestations of extreme fire behaviour that put in evidence the important role of the interaction between atmospheric flows and the fire. This interaction associated to the junction of two major fire fronts on complex topography produced a widespread development of the fire that ultimately caused the death of 66 persons.
In this paper, a survey of the research that is being carried out by the authors on the topics mentioned above, based on laboratory scale experiments and the analysis of real fires and accidents is presented. The paper is mainly descriptive of phenomena that is uncommon and poorly studied that require a more detailed analysis and an attempt to model it.

Keywords: Extreme Behaviour; Topography; Junction fires

Bio: Domingos Viegas is a Full Professor at the Department of Mechanical Engineering of the University of Coimbra, in Portugal.
He is the Director of Association for the Development of Industrial Aerodynamics (ADAI) and of its Centre for Forest Fire Research (CEIF).

He created a Forest Fire Research Laboratory equipped with original test rigs to perform research on fire behaviour.
He authored more than seventy articles in peer reviewed journals and was a Lecturer at several International Conferences.
He organized seven International Conferences on Forest Fire Research, Seminars and training courses on forest fires.

S12.11. Contrasting Internal and External Vulnerabilities of Buildings to Fire
Presenter: Jose Torero, , University of Maryland
Additional Authors:

Construction materials used in interiors of buildings tend to be different than those used in the exterior of buildings. The functionality requirements of materials such as external cladding is generally very different to that of interior linings. Furthermore, when it comes to fire safety, materials used internally tend to be selected among those who will sustain slow fire growth so that untenable conditions are only reached after evacuation is guaranteed. Flammability criteria and testing methodologies that enable flammability requirements to be verified are therefore based on those premises. Tests vary in nature, with some providing fundamental parameters or material properties that can serve as inputs for predictive tools and others reproducing scenario conditions that enable classifications and rankings. When it comes to external fires, burning conditions are very different. Fundamental flammability tests still apply but scenario based tests do not necessary deliver relevant information. The objectives are also different, egress or time are not variables of relevance but magnitude of damage is probably a more relevant variable. This paper reviews research in flammability as well as in scenario definition and contrasts internal and external fires to establish what tools can be used for either scenario.

Keywords: Flammability fire behavior fire modeling

Bio: Professor José L. Torero holds the John L. Bryan Chair and is the Director of the Center for Disaster Resilience at the Clark School of Engineering, University of Maryland. He works in the field of Fire Safety Engineering where he specializes in the behaviour of fire in complex environments such as forests, tall buildings, novel architectures, tunnels, aircraft and spacecraft. He holds a BSc for the Pontificia Universidad Católica del Perú (1989), and an MSc (1991) and PhD (1992) from the University of California, Berkeley.

S12.13. How reduced plume entrainment in large fires effects the burning rate
Presenter: Sara McAllister, Research Mechanical Engineer, USDA Forest Service - RMRS Missoula Fire Science Lab
Additional Authors:

Large outdoor fires often exhibit unexpected behavior, particularly compared with much smaller fires. Large fires are often characterized by very tall plumes that likely entrain relatively little, and may act in a similar fashion to a chimney. To explore the possible changes in the steady burning rate due to this chimney effect, experiments were conducted with wood cribs burned with a chimney of variable height. Seventeen crib designs were tested with chimney heights ranging from 0 to 3.7 m. Eleven of the crib designs had burning rates that monotonically increased with chimney height with increases as high as 190%. The increase in flow through the fuel bed due to the chimney not only increases the equivalence ratio of the gas phase (particularly important for ventilation-limited cribs),

but also increases the char oxidation rate. Six of the crib designs, however, had burning rates that first increased then decreased with chimney height. The common factors with these cribs are lower non-dimensional heat release rates ($Q^* < 2.5$), which tipped the balance between heat generated and lost. The maximum normalized burning rate can be well correlated to the ratio of the fuel surface area to the crib porosity.

Keywords: burning rate, fire behavior

Bio: Sara received her PhD in Mechanical Engineering from UC Berkeley in 2008. Since then she has worked for the Forest Service at the Missoula Fire Sciences Lab where she studies the fundamentals of wildland fire behavior. In particular, her research has focused on ignition, live fuel flammability, and the burning rate of wildland fuel beds.

S12.14. Flow Dynamics of Plume Attachment in Fires on Slopes

Presenter: Torben P. Grumstrup, Research Engineer, Missoula Fire Sciences Laboratory, U. S. Forest Service
Additional Authors:

Fires propagating up a slope can exhibit spread rates up to 20 times that on flat ground. Such behavior has resulted in many firefighter entrapments, injuries, and fatalities worldwide. Apart from the obvious safety implications, understanding fire behavior on slopes is also important for improving suppression strategies, predicting fire effects, and advancing fire modeling. Higher spread rates on slopes are enabled by plume attachment, where flames and hot combustion gasses momentarily flow along the surface uphill of the actively burning zone before rising into the air. This flow enhances the rate and extent of heating of unburned fuel uphill from the fire, resulting in faster spread rates. Understanding the dynamics of plume attachment is key to understanding heating of unburned fuel and, therefore, fire behavior on slopes. Plume attachment was explored in the laboratory with a meter-scale tilt table with a fixed propane-fired burner fitted flush to the surface. The shadowgraph optical technique was used to visualize attachment behavior as the table was set to various slope angles. An array of fine gauge thermocouples showed the extent of attachment by measuring gas temperature just uphill from the burner. Observed plume attachment behavior was very similar to that observed by other workers conducting similar experiments. Plume attachment is generally attributed to leaning of the fire plume by imbalance in entrainment between the uphill and downhill side (in the absence of wind). The plume lean concept will be revisited and expanded upon by drawing from theoretical works on convection from outside the fire research community. Shadowgraph imagery and video will be used to illustrate the dynamics of attached plume flow and show how the interplay of buoyancy and entrainment cause it to occur.

Keywords: fire spread; slope; plume attachment; buoyancy; entrainment; convection

Bio: Torben is a research engineer working on fire behavior on slopes, and instrumentation of fires in the field and in the laboratory. His educational background is rooted in the physics and chemistry of combustion and emissions formation. In his younger years, Torben was a firefighter on various USFS engine and helitack crews in the Rocky Mountain West.

S12.15. Modeling the role of fuel moisture on ignition in thin fuels
Presenter: Shankar Mahalingam, Dean and Professor, The University of Alabama in Huntsville
Additional Authors: Shotorban, Babak, Associate professor, The University of Alabama in Huntsville

The relative and changing roles of radiation and convective heat transfer mechanisms on an evolving fire continues to be of interest in current research on wildland fires. The focus of our work is on modeling the initial process of drying and pyrolysis leading to ignition of thin, live fuels such as leaves subject to controlled radiation and/or convective heating. The computational framework that we utilized is a coupled FDS-Gpyro3D model originally developed by Lautenberger (2014). We improved this model to account for subgrid net volume reduction of the condensed phase due to moisture evaporation and pyrolysis (Shotorban et al., 2018). The initial pyrolysis model developed by Yashwanth et al. (2016) used only cellulose for the dry mass, while Shotorban et al. (2018) used an advanced mechanism including cellulose, hemicellulose, and lignin. A thin, leaf-like fuel element with dimensions 40 mm x 40 mm (in the horizontal) x 2 mm (in the vertical) subject to heating from a vertically oriented radiant panel at a temperature of 1500 K, similar to the experimental configuration of Pickett et al. (2010), was studied. The temperature response and thermal degradation rate was higher at a 5% fuel moisture content (FMC) in comparison to 40 and 80% FMC. For the first time, non-uniform evaporation from the solid phase prior to ignition was observed. Shotorban et al. (2018) performed a comprehensive validation of the kinetic scheme by comparison against experimental and computational TGA results. Then the ignition and burning behavior of fuel elements with dimensions 23.7 mm x 23.7 mm (in horizontal) x 0.51 mm subject to convective heating over a flat flame burner similar to the experimental study involving ignition of Manzanita leaves by Pickett et al. (2010), was examined. The temporal evolution of dimensionless fuel mass compared well with the published experimental data. The computed ignition times were within the range reported in the experimental work. The nonuniform evolution of moisture and pyrolysis was again observed and is attributed to near field fluid flow behavior. Our current efforts are focused on improving moisture evaporation through an equilibrium model.

Keywords: live fuels moisture pyrolysis ignition modeling

Bio: Dr. Shankar Mahalingam is Dean of the College of Engineering and Professor in the Department of Mechanical and Aerospace Engineering at The University of Alabama in Huntsville. He received his B.Tech., graduating with distinction, from the Indian Institute of Technology, Madras, MS from the State University of New York at Stony Brook, and PhD from Stanford University, all in Mechanical Engineering. His research expertise include direct and large eddy simulations of turbulent combustion, forest fire modeling, flame spread experiments, and computational fluid dynamics applied to turbulent combustion. He has authored or coauthored150 scientific papers that include 70 plus peer-reviewed papers (journals and refereed proceedings) and nearly 80 full conference papers. Dr. Mahalingam is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), Fellow of the American Society of Mechanical Engineers (ASME), and Fellow of the American Association for the Advancement of Science (AAAS).

S12.16. A review of current knowledge of woodland firefighter safety zones
Presenter: Jean-Louis Rossi, Associate Professor, UMR 6134 - SPE - University of Corsica
Additional Authors: Marcelli, Thierry, Associate Professor, UMR-CNRS SPE 6134 University of Corsica
Chatelon, François Joseph, Associate Professor, UMR-CNRS SPE 6134 University of Corsica

In the last few years the increasing influence of global warming on the environment has produced periods of drought, which in turn have led to wildfires with devastating consequences. So, wildland fires represent a growing threat on human activities particularly due to the spreading of the Wildland-Urban Interface. The fire has two main impacts: it can damage structures and affect people. Particularly, firefighters wearing protective equipment have to remain at a close distance from the fire front to fight against it and not too close in order to keep safe. Thus, there is a pressing need to produce an accurate evaluation of the distance between the fire and men required to prevent injury during operational phases. Actually, safety zones are always defined to have some space between the fire and the men.
For many of the regulations and standards used throughout the world the criteria for human exposure are specified only by heat flux magnitude. Commonly, in operational conditions, a rule-of-thumb is applied to determine this safety zone. So, several works have established empirical correlations between fireline intensity and time average flame length. They were estimated using statistical fitting procedures. The use of these relationships needs a solid understanding of the limitations of these models and this precludes an empirical approach to evaluate safety zones in fuel types, which are structurally very different. This is a strong argument for physical approaches developed in other studies.
Physical models are based on mathematical analysis of the fundamental physical and chemical processes. So, mathematical expressions are generated from the laws that govern combustion, fluid mechanics and heat transfer. Due to the complexity of fire mechanisms, models have been carried out with different degrees of simplification from simplified approaches to software packages implementing computational fluid dynamics of reacting flow.
In this work, a review of current knowledge of wildland firefighter safety zones is proposed.

Keywords: Physical models - safety zones - ASD - Acceptable Safety Distance - Wildland Urban Interface

Bio: Jean-Louis Rossi is an assistant professor (HDR) at the University of Corsica, France, where he got is PhD (1996). Prior to entering the field of wildland fire he worked in the areas of modeling underwater sound scattering phenomena. His three main areas of research interests are: 1) Development of a physical simplified surface fire spread model. 2) Development of models of radiant heat from shrub. 3) Development of safety distance models to address firefighter safety zones. The motivation of his current work is to develop better tools for operational institutions.

S12.17. Experimental investigation of ignition and thermal degradation of natural fuels and structural materials under static and dynamic conditions

Presenter: Alexander Filkov, Research Fellow, The University of Melbourne
Additional Authors: Nguyen, Kate, Research Fellow, the University of Melbourne
Kuznetsov, Valery, Principal Research Fellow, Tomsk State University
Fateev,Vladimir, Research Fellow, Tomsk State University
Agafontsev, Mikhail, PhD student, Tomsk State University

Autoignition of wood and thermal degradation of cladding materials under static, decreasing and increasing radiative heat fluxes were studied. Two different custom experimental setups were used. The first experimental setup was built on the base of the optical furnace "Uran-1". The intensity of the heat flux was changed during the experiment by moving the test sample along the vertical optical axis of the setup. Pine wood was used as the test samples. It was found that when the radiative heat flux is dynamic (increasing or decreasing), the averaged ignition time of samples is 2-3 times less than that for

the static heat flux. The temperature gradient on the sample surface is generally higher in a dynamic mode than in the static one, therefore the surface temperature reaches a critical value faster than in the static mode. As a result, for the same heat flux, the ignition time in the dynamic mode should be smaller than in the static mode. The second experimental setup was a custom-made Radiative Heat Flux Apparatus, which consists of radiative panel with infrared short wave quartz lamps and linear stage. The radiative panel is installed on the linear stage, which allows the panel to move forward and backwards simulating variable heat flux. The thermal degradation of two types of aluminium composite panel (ACP) cladding, subjected to both static and dynamic heat fluxes was investigated. Sixteen thermocouples were used to measure temperature distribution along the sample. Analysis of temperatures shows that convective cooling has greater effect on exposed surface temperature than conductive heat transfer, except of section with direct heating. It was found that the degradation of ACP samples for an increasing heating regime started at a heat flux lower than that for static regime. Moreover, the total energy reaching the surface of the sample by that time for increasing regime was lower (6542 kJ/m2) than for static (7600 kJ/m2). Analysis of both experiments shows that the dynamic radiative heat flux initiates similar processes at lower energies compare to the static heat flux for considered samples.

Keywords: natural fuels and structural materials, ignition, thermal degradation, static and dynamic heat flux

Bio: Dr. Alex Filkov received his PhD in Ecology (Physical and Mathematical Sciences) in 2005 from Tomsk State University, Russia. After completing his PhD he worked as Associate Professor at the same university. His research interests encompass wildfire behaviour and risks, WUI and extreme fires. During previous decade he conducted laboratory experiments on fuel ignition and fire spread, participated in the development of a deterministic and probabilistic system for the prediction of forest and peat fire hazard, as well as in the simulation of fuel drying and kinetics.

S13.1. The Importance of Time and Space when Monitoring Effectiveness of Forest Restoration Treatments

Presenter: David Peterson, Research Forester, USDA Forest Service
Additional Authors: Rossman, Allison, Graduate Research Assistant, University of Washington
Bakker, Jonathan, Associate Professor, University of Washington
Halpern, Charles, Research Professor, University of Washington

Mechanical thinning and prescribed burning are commonly used in dry forest restoration to reduce fuel loads, alter potential wildfire behavior, and restore ecological structure and function of dry mixed-conifer forests of western North America. These treatments – especially thinning followed by prescribed burning – have been shown to be effective for reducing surface and canopy fuels and modifying forest structure. There is also increasing evidence that restoration treatments are effective for reducing fire severity during wildfires, though fire weather and time since treatment are also important factors regulating fire behavior and effects. Questions remain, however, about treatment longevity with respect to fuels and fire behavior, and about long-term effects on ecological functions and biodiversity. We present results

To address questions about the long-term effects of thinning and prescribed burning on understory biodiversity, we surveyed understory vegetation cover and species richness two and ten years after treatment on a large-scale forest restoration experiment in dry coniferous forests of north-central Washington. We asked if understory vegetation responses to treatment varied among life form groups (e.g., herbs and shrubs); if long-term (10 year) responses were consistent with short-term (2 year) responses; and if assessments of vegetation responses to thinning and prescribed burning treatments are influenced by the spatial scale of observation.

Responses to thinning and burning varied between lifeforms and with spatial scale. Shrub species richness was unaffected by thinning, irrespective of scale, but increased with burning at small and intermediate scales. Herb species richness increased with both thinning and burning at all spatial scales. Treatments did not promote establishment of new shrub species, but burning promoted the expansion of shrub populations present prior to disturbance. On the other hand, treatment did promote establishment of numerous new herbaceous species, presumably in response to altered resource availability. At smaller spatial scales, increases in herbaceous richness likely reflect establishment of widely dispersed, disturbance-adapted species and localized spread of residual species. Our research shows that not only do ecological responses to thinning and burning vary with spatial scale and lifeform, but analyses at multiple scales can reveal the patterns and mechanisms of response to disturbance.

Keywords: prescribed fire, mechanical thinning, plant diversity, scale

Bio: Dave W. Peterson is a Research Forester with the U.S.D.A. Forest Service, Pacific Northwest Research Station, located in Wenatchee, Washington. Dave's research focuses primarily on restoration and management of dry coniferous forests, including forest ecosystem responses to wildfires, the effects of post-fire management practices, and vegetation responses to fuel management treatments. He also maintains ongoing research interests in oak savanna ecology and dendroecology.

S13.2. Succession in Columbia Basin sagebrush steppe following wildfire: insights from long-term vegetation monitoring

Presenter: Claire Wainwright, Research Associate, University of Washington
Additional Authors: Bakker, Jonathan, Associate Professor, University of Washington
Davies, G. Matthew, Assistant Professor, The Ohio State University

Long-term monitoring of vegetation communities following wildfires is an integral part of land management in fire-prone ecosystems. Vegetation monitoring programs spanning multiple wildfires over several decades are rare, but can provide valuable insight into short and long-term successional patterns post-fire.

We explored compositional change over three decades in sagebrush-steppe communities in the Columbia Basin in central Washington State (western United States). Sagebrush-steppe provides valuable resources for rangeland agriculture and biodiversity conservation, but invasion by exotic annual grasses (particularly cheatgrass) has drastically shortened fire return intervals. As a result, sagebrush-steppe landscapes are composed of communities varying in successional phase and resilience to fire, highlighting the need to synthesize results of long-term monitoring across a variety of conditions.

We used data collected from 1996-2017 on permanent monitoring plots in the Fitzner-Eberhardt Arid Lands Ecology Reserve (Hanford Reach National Monument, USFWS). Communities varied in initial species composition and extent of cheatgrass invasion, and also spanned large edaphic and elevational gradients. Three large fires occurred during the monitoring period in 2000, 2007, and 2016. We related vegetation responses to fire history and restoration actions over the monitoring period using data collected in 1996, 2002, 2009, and 2017. We used a variety of statistical techniques to identify compositional changes over time and how these changes depended on fire frequency, abiotic conditions, and restoration.

We found that sensitivity to multiple wildfires was contingent upon initial species composition and environmental conditions. Low elevation communities (initially Big sagebrush-cheatgrass associations) experienced the most change over time. Following the first two wildfires and associated restoration, low elevation communities were dominated by native forbs (especially longleaf phlox) and bunchgrasses. However, these communities have proven to be transient, and have transitioned to shrubless exotic annual grasslands. Big sagebrush reseeding and replanting efforts have had some success, but this has been localized and patchy. By contrast, higher elevation communities (native bunchgrass and resprouting shrub associations) were more resistant to change, despite having burned three times (as opposed to twice) and received limited restoration.

Our results highlight the benefits of long-term post-fire monitoring across a range of ecological and management conditions. Importantly, long-term monitoring can help distinguish when altered vegetation compositions represent temporary phases versus sustained changes in state. In addition, long-term monitoring across a range of conditions can help clarify determinants of vegetation change (e.g. restoration, climate, disturbance), which can be used to inform future management priorities.

Keywords: plant community ecology, species composition, succession, monitoring, restoration

Bio: Claire Wainwright is a plant community ecologist in the School of Environmental and Forest Sciences at UW, Seattle. Her research interests include invasion ecology, ecological restoration, and temporal plant community dynamics. She is especially fond of semi-arid ecosystems and has worked in the deserts of southern California, Western Australia, and the Pacific Northwest.

S13.3. Lessons from long-term stand dynamics of old-growth longleaf pine communities in the mountains of north Alabama, USA

Presenter: J. Morgan Varner, Research Scientist, Pacific Wildland Fire Sciences Lab
Additional Authors: Darcy Hammond, University of Idaho
John S. Kush, Auburn University School of Forestry & Wildlife Sciences
Joseph Fan

Fire-prone forests, woodlands, and savannas are dynamic, yet most research focuses on static snapshots of structure and composition. Long-term data allows for testing of hypotheses of establishment, ingrowth, growth, and mortality of trees in space and time. These data can be used to better understand how these communities persist with frequent fire regimes and how management can better emulate natural forest dynamics. We briefly review several on-going long-term research in fire-prone longleaf pine (Pinus palustris) communities across the US. As an example of the values of long-term research, we present results from a study initiated in 1998, where we stem-mapped, measured, and aged two ca. 2 ha old-growth stands of longleaf pine (Pinus palustris) in the mountains of north Alabama. The two stands burned frequently over the 15 year period. Over this span, we remeasured all longleaf pine for growth and mortality as well as mapped and measured ingrowth. At the outset, the stands were uneven-aged (all age classes from 20 to over 150 years old) comprised of patches of even-aged cohorts and isolated individuals. Subsequent remeasurements identified individual and patch-level tree mortality that corresponded to fires. Over the 15 year period, we detected density-dependent mortality in small (10 cm diameter class) longleaf pines but not in larger trees. Individual even-aged cohorts suffered the greatest mortality, essentially undergoing rapid self-thinning or patch breakup that transpired over the decade plus of stand development. Basal area and overstory tree density fluctuated following fires. Snapshot approaches that fail to follow the fate of trees and how fire drives stand development would be unable to detect the stand dynamics critical to understanding ecological processes.

Bio: Morgan Varner is a Research Scientist and Team Leader at the Pacific Wildland Fire Sciences Lab in Seattle, WA where he is engaged in research on linking fuels and fire behavior to better understand fire effects.

S13.4. Impacts of six different complex fire regimes in a longleaf pine ecosystem: Results over twenty-five years

Presenter: Sharon Hermann, Assistant Professor, Auburn University
Additional Authors: Kush, John, Research Fellow, Auburn University School of Forestry and Wildlife Sciences

In the United States, prior to European settlement, vast areas of the country were associated with frequent fire regimes. However, many long-term studies established to document fire effects often target ecosystems with extended fire return intervals and the associated research usually documents succession over time. Studies on frequent fire return intervals usually span a few years to a decade. A common assumption is that this is sufficient time to evaluate effects of burning in different seasons and/or under different fire frequencies although this is beginning to be questioned. This is due in part to growing awareness that in some frequent-fire ecosystems, many (perhaps most) dominant plant species (not just trees) are long-lived. Recently-developed models support the idea that large areas of the US once burned multiple times a decade and, in some areas, more frequently than every 2 years (on average). This provides an additional reason to improve understanding of effects of frequent fires.

Current research is based in a native ecosystem dominated by longleaf pine (Pinus palustris), often described as a fire-dependent species. Longleaf pine forests and woodlands once dominated over 37 million ha in the southern US and it is now well-accepted that these ecosystems were maintained by frequent fire. However some important questions remain. How frequent must fire be to be frequent enough? How important is season of burn?

The study evaluates data based on complex treatments in seven different sampling years spanning 25 years. Treatments are six different complex fire regimes: fire every two, three, or five years in either winter or late spring plus a no burn treatment in each of three blocks. The study site is Escambia Experimental Forest (USDA Forest Service) in south-central Alabama. Assessments have been made every 3-5 years and data collected on longleaf pine trees plus all hardwood stems > 2.5cm at breast height.

Results through Year 25 revealed little difference among treatments for longleaf pine survivorship or growth. However, over time, there have been significantly different shifts in number and size of hardwood stems, depending on treatment. It is not surprising that the data shows more frequent growing season fires are the most beneficial for managing longleaf pine ecosystems. However even longer time periods may be needed because earlier in the study no-burn and winter, 5-year intervals appeared to have positive management results but in later years this trend appears to be part of a continuum of fire effects.

Keywords: fire effects, complex fire regime, frequency, season, longleaf pine, Souteastern USA

Bio: Sharon M. Hermann is an Assistant Professor (Department of Biological Sciences, Auburn University). She has a BA in zoology and an MA in botany (both from University of Iowa); her PhD is in Biology/Ecology (University of Illinois at Chicago). For many years, prior to moving to Auburn, Sharon was the Plant and Fire Ecologist at Tall Timbers Research Station. Most of her research interests are based in community ecology or topics of conservation concern and include influence of habitat structure on species composition, ecological restoration, and especially fire regimes and effects. Sharon assists with maintaining long-term fire research projects.

S13.5. Fuel loads and simulated fire behavior in 24-year old, post-fire lodgepole pine forests

Presenter: Kellen Nelson, Postdoctoral Fellow, Desert Research Institute
Additional Authors: Turner, Monica, Professor, Department of Zoology, University of Wisconsin
Romme, William, Professor-emeritus, Natural Resource Ecology Laboratory, Colorado State University
Tinker, Daniel, Associate Professor, Department of Botany, University of Wyoming

Vast areas of forest have burned in recent decades raising concern about the risk of short-interval re-burning. Post-fire succession generates the fuel for future fires, but little is known about how fuel loads and fire behavior vary shortly after burning. We sampled fuels and simulated fire behavior in 24-year-old lodgepole pine (Pinus contorta var. latifolia) stands that regenerated after the 1988 Yellowstone Fires to address the following questions: (1) How do fuel characteristics and simulated fire behavior vary among young, lodgepole pine stands? (2) To what extent do stand and environmental conditions drive fuel characteristics across the landscape? (3) What are the relative contributions of fuel characteristics, moisture, and wind on fire behavior in these stands? Operational fire models were parameterized with empirical fuel characteristics, 50–99% fuel moisture conditions, and 1–60 km hr-1 open winds. Results indicate that fuel characteristics varied tremendously across the post-1988 Yellowstone landscape and were sufficient to support fire in all stands. Total surface-fuel loads were similar or greater than those reported in mature lodgepole pine stands; however, 88% of fuel was in the 1000-hr fuel class, and litter, 1-hr, and 10-hr surface fuel loads were lower than values reported for mature lodgepole pine forests. Pre-fire successional stage was the best predictor of 100-hr and 1000-hr fuel and strongly influenced the size and proportion of sound and rotten logs, where post-fire stand structure was the best predictor of litter, 1-hr, and 10-hr fuels. Available canopy fuel loads and canopy bulk density met or exceeded loads observed in mature lodgepole pine forests and exhibited a strong positive relationship with post-fire tree density. Sensitivity analysis of simulated fire behavior indicated the greatest contributors to output variance were stand structure mediated wind attenuation, shrub fuel loads, and 1000-h fuel moisture for fireline intensity; crown base height for crown fire initiation; and crown bulk density and 1-h fuel moisture for crown fire spread. Simulation results predicted some type of crown fire (e.g. passive, conditional or active types) in over 90% of stands at 50th percentile moisture conditions at wind speeds >3 km hr-1. We conclude that dense canopy characteristics heighten crown fire potential in young, post-fire lodgepole pine forests even under less than extreme wind and moisture conditions. Fire rotations in Yellowstone National Park are predicted to shorten to a few decades and this prediction cannot be ruled out by a lack of fuels to carry repeated fires.

Keywords:

Bio: Kellen Nelson is a postdoctoral fellow studying forest disturbance ecology at the Desert Research Institute. His research focuses on how disturbance processes interaction with vegetation and the environment. Current investigations include the successional dynamics of fuel loads, fuel moisture, and fire behavior in post-fire forests, the effects of prescribed fire on fuels and plant communities in upper montane Sierra Nevada forests, and the development of aerial survey, sensing, and sampling methods using small unmanned aircraft systems (sUAS).

S13.6. Initial prescribed fire treatment reduces mixed-conifer forest resilience

Presenter: Malcolm North, Research Scientist, USFS PSW Research Station
Additional Authors: Goodwin, Marissa, Research Technician, University of New Mexico
Hurteau, Matthew, Associate Professor, University of New Mexico
Zald, Harold, Assistant Professor, California State University at Humboldt

Twenty years ago at the Teakettle Experimental Forest in the Sierra Nevada, we began a full factorial experiment combining different levels of mechanical thinning and prescribed fire to examine ecosystem response in what was old-growth mixed conifer forest with more than 130 years of fire exclusion. Initially (1-4 years after treatments were applied), prescribed burn plots showed increases in diversity, nutrient availability, and decomposition rates as more soil moisture, the limiting resource, became available. Thinning alone also increased water availability, but increases in surface fuel loads suppressed the understory community, stalled some soil processes, and reduced regeneration, particularly of pines. However after six years, shrub cover, particularly of whitethorn ceanothus, increased to more than 85% of the cover. The shrub height, vigor and total cover were directly related to fire intensity that was proportional to the amount of activity fuels generated by the different levels of thinning. In addition, most snags fell within 8-10 years of the burn, substantially increasing large (>1000 hr) fuel loads. The recent (2012-2015) California drought has significantly decreased radial growth in trees that did not die, suggesting they may be less resilient to stressors including additional fire. While it is evident that low-severity fire restoration is needed in this ecosystem, plots that included the initial prescribed fire treatment now have much lower diversity, heavy fuel loads, and reduced tree vigor. In spite of these concerns, in October of 2017, 16 years after the initial burn, prescribed fire was re-applied to all of the burn plots within the mean historic fire return interval. Fire effects on vegetation and fuels appear to be highly variable with some loss of large, old growth trees. We will continue following Teakettle's ecosystem response, but caution that ecological restoration is far from complete after initial thinning and burning treatments. In fact, needed additional treatments are perhaps more challenging, with few current guidelines to help managers decide the timing, fuel moisture or weather conditions that may help restore more resilient ecosystems.

Keywords: Fuels treatment, mechanical thinning, shrub response

Bio: Malcolm North is a research scientist with the US Forest Service PSW Research Center and an Affiliate Professor in the Department of Plant Sciences at U.C. Davis. He has researched the ecological effects of restoration and fuels treatments on western conifer ecosystems.

S13.7. Retaining Fire Resilience: Twenty Years of Forest Development Following Wildfire in Old Growth Ponderosa Pine Forest

Presenter: Alan Taylor, Professor Geography and Ecology, Department of Geography, Penn State University
Additional Authors: Pawlikowski, Natalie, Research Assistant, Department of Geography, The Pennsylvania State University
Knapp, Eric, Research Ecologist, USDA Forest Service, Pacific Southwest Research Station
Coppelleta, Michelle, Ecologist, USDA Forest Service Region 5

Historically, forest structure and species composition in ponderosa pine forests was maintained by frequent, low to moderate intensity, wildfire. However, fire suppression policy and land-use practices following Euro-American settlement have altered forest conditions and contributed to reduced resilience to wildfire in these forests. Growing recognition of how structural attributes influence fire resilience there is an interest in restoring structural heterogeneity to both stands and landscape scales. Here, we use permanent plot data to quantify how forest structure – density, composition, and spatial patterns – has changed over 20 years in a forest restored by wildfire in the Southern Cascades. We also modeled potential fire behavior to determine if current stand conditions would be resilient to wildfire. Data show that forest structure is starting to homogenize – disturbance-tolerant species – namely, California black oak – are being lost, gaps are being infilled by small trees, and small diameter pines (5-15cm dbh) dominate ~1/3 of the site. Yet, potential fire behavior suggests that the majority of overstory (trees >30cm dbh) would be resilient to wildfire. Overall, this research broadens our understanding of the potential to use wildfire to restore fire resilience, and how long resilient stand conditions can persist.

Keywords: fire effects, succession, forest structure, gaps, permanent plots, potential fire behavior, diversity, resilience

Bio: Alan H. Taylor, is Professor of Geography and Ecology at The Pennsylvania State University. Alan's research is focused on the effects and interactions of fuels, terrain, climate, and people on fire disturbance and vegetation dynamics at various time scales. His fire related research includes work in the Pacific Northwest, California, and the American Southwest, and he has also worked extensively in highland bamboo forests in southwestern China in giant panda habitat. He has served as Associate Director of the Earth and Environmental Systems Institute, Co-Director of the Giant Panda Project, and Associate Editor of the Canadian Journal of Forest Research.

S13.8. Combined Effects of Fuel Treatments and Beetle Outbreak on Forest Fuel and Fire Hazard Development in Ponderosa Pine

Presenter: Justin Crotteau, Postdoctoral Research Associate, University of Montana and Rocky Mountain Research Station
Additional Authors: Keyes, Christopher, PhD, Research Professor of Silviculture, University of Montana
Hood, Sharon, PhD, Research Ecologist, Rocky Mountain Research Station
Affleck, David, PhD, Professor of Biometrics, University of Montana
Sala, Anna, PhD, Professor, University of Montana

Fuel reduction treatments have been widely implemented across the Western U.S. in recent decades for fire protection and restoration purposes. Although research has demonstrated that combined thinning and burning effectively reduces crown fire hazard in the few years immediately following treatment, very little research has identified the mid-term effectiveness of thinning and burning treatments. Furthermore, it is also unclear how post-treatment disturbances in treated areas, such as

widespread bark beetle outbreak, affect fuel treatment effectiveness. We used an experiment to test the differences in fuel loads and crown fire hazard between fuel reduction treatments (no-action Control, Burn-only, Thin-only, Thin+Burn) that were affected by mountain pine beetle outbreak approximately five years after implementation. Stands were measured in 2002 (immediately following fuel treatment) and 2016 (14 years after treatments and at least 4 years following beetle outbreak). We found that beetle-altered thinned treatments (Thin-only and Thin+Burn) had overall less fuel and lower crown fire hazard than corresponding unthinned treatments. The post-beetle effects of burning (Burn-only and Thin+Burn) were initially milder than those of thinning, but burning still reduced crown fire hazard over unburned stands 14 years after treatment. Additionally, we used mediation analysis to determine the relative impacts of silviculture and beetle outbreak on treatment differences for those metrics. Beetle kill inflated differences between Controls and thinned units for surface fuel loads and probability of torching, but diminished differences between these treatments for canopy fuel loads, bulk density, and crowning index. Despite a muting effect that beetle outbreak and time had on some fuel and crown fire hazard metrics, our study suggests that the effects of silvicultural treatment on mitigating crown fire hazard persist even after stand-transforming insect outbreaks, especially when thinning and burning are combined.

Keywords: Fire and Fire Surrogate Study; fuel dynamics; treatment longevity; mediation analysis; disturbance interaction; Dendroctonus ponderosae

Bio: Justin is a recent graduate of the University of Montana where he studied the effects of crown fire hazard mitigation treatments on forest development.

S13.9. Stand-Density Reduction Treatments Alter Tree-Level Climate–Growth Relationships and Vulnerability to Drought in Low-Elevation Ponderosa Pine Forests of the Northern Rockies

Presenter: Alan Tepley, Postdoctoral Fellow, University of Montana
Additional Authors: Hood, Sharon, Research Ecologist, Forest Service Rocky Mountain Research Station, Fire, Fuel, and Smoke Science Program
Sala, Anna, Professor, University of Montana, Division of Biological Sciences

As the climate warms, drought stress is increasing in western forest landscapes. In many ponderosa pine forests, increasing stand density due to fire exclusion could exacerbate the effects of intensifying climatic drivers of drought. Management efforts in recent decades have been directed toward reducing the risk of high-severity fire by restoring historical stand structures in many of these forests. However, these fuel treatments can have wide- and long-ranging effects in addition to altering fire behavior. In particular, the mechanisms and degree to which fuel and restoration treatments affect tree vulnerability to drought remain poorly understood.

Here we conduct a dendro-ecological evaluation of the changes in climate–growth relationships and drought vulnerability of ponderosa pine trees during a 23-year interval following restoration treatments relative to the pre-treatment period. The study was conducted at the Lick Creek Demonstration/Research Forest of the Bitterroot National Forest in west-central Montana, where a long-term photo series documents vegetation change since the early 20th century. Two fully replicated experiments were initiated in 1992: a shelterwood experiment that removed 62% of the trees and 56% of the basal area, and a commercial thinning experiment that reduced tree density and basal area both by 34%. Portions of each experiment were prescribed burned in 1993 and 1994. In

2016, we collected increment cores from 386 ponderosa pine trees distributed among the burned and unburned treatments and unthinned control plots within each experiment.

The thinning was followed by a pronounced growth increase that persisted to the present in all treatments. Climate–growth relationships were altered in consistent ways following both silvicultural treatments. The reduction in canopy cover in treated stands likely altered snowpack accumulation and snowmelt dynamics, as suggested by the stronger growth response to late winter/early spring precipitation in treated than control stands. This enhanced growth response in treated stands was partially counteracted by a reduced response to late-summer precipitation. Following treatments, the relationship between late-summer precipitation and tree growth shifted from positive to negative in all treated stands, but it remained positive in the controls. This result may indicate that grasses, which markedly increased in cover following treatments, now outcompete trees for the moisture produced in late-summer rain events. Relative to growth in preceding years, the altered climate–growth relationships following treatments led to slight decreases in the growth reduction during dry years and larger growth increases in wet years than found in control plots.

Keywords: drought, ponderosa pine, shelterwood, thinning, dendro-ecology

Bio: Alan Tepley is a postdoc in the College of Forestry and Conservation and the Division of Biological Sciences at the University of Montana. He is a forest disturbance ecologist with research focused on the responses and ecological feedbacks to altered disturbance regimes in the context of on-going global change. Much of his work focuses on fire, and he has led field studies characterizing historical fire regimes and contemporary responses to altered fire regimes in the Pacific Northwest, the southern Rocky Mountains, the Klamath Mountains, and New Zealand. He is also evaluating how forest restoration treatments affect tree-level vulnerability to drought.

S13.10. Ecological Responses to Prescribed Fire Regimes in Ponderosa Pine Forests: Lessons Learned From a Long-Term Study

Presenter: Becky Kerns, Research Ecologist, Pacific Northwest Research Station, US Forest Service
Additional Authors: Douglas Westlind, Forest Technician, PNW US Forest Service
Michelle A. Day, Senior Faculty Research Assistant, Oregon State University

Despite uncertainties regarding appropriate prescribed fire treatments, manipulative testing of prescribed fire regimes remains limited, especially in the western US. The unique long-term permanent plot Season and Interval of Burn study (SIB) was developed in the southern Blue Mountain Ecoregion in 1997. The main objectives of the study are to examine the impact of burn season (fall, spring, control) at two intervals (very frequent 5 year, frequent 15 year) and to determine multiple ecosystem responses, including 1) ponderosa pine growth and mortality, and insects and disease interactions; 2) fuel loads; 3) understory vegetation abundance and composition; 4) conifer regeneration; and 5) soil C, N, K, pH, and fungal composition. A secondary objective is to examine the interaction of seasonal very frequent reburning and cattle grazing on understory vegetation response.

Results suggest that the treatments tested in this study resulted in some anticipated forest structural changes often associated with prescribed fire use. Frequent fall burning increased tree growth for surviving trees, and reduced finer fuels and conifer regeneration. But frequent fall and spring burning had little or subtle and ephemeral impacts on other response variables, including the understory plant community, although some typical "increaser" species responded to fall burning, including the invasive exotic species cheatgrass. None of our fire treatments increased understory productivity or diversity, and species composition was not strongly altered; however, cattle grazing exclusion resulted in increased understory cover, regardless of burn treatment. Spring burning generally produced fewer significant changes overall as compared to fall burning, particularly after the first burns. Very frequent reburning effectively reduced conifer regeneration, yet also resulted in increased 1000 hr fuels and cheatgrass cover, and decreased cover for some native plant functional groups. Very frequent spring burning decreased soil carbon and nitrogen content as compared with very frequent fall burning, but very frequent fall burning mildly increased soil pH. We found that prescribed fire is meeting only a few management objectives associated with the restoration of these forests in the interior west. These results may be due to common fire prescriptions for operational burning. That is, returning fire to these landscapes may require more historically relevant seasonal ranges for burning, and rethinking effective prescriptions for meeting restoration objectives. However, exotic plant invasion remains a significant management challenge with any prescribed fire use. Where restoration objectives are focused on enhancing native plant abundance, cattle grazing exclusion may provide effective outcomes.

Keywords: prescribed fire, fire regimes, reburning, burn season, burn frequency, ponderosa pine, Oregon, Blue Mountain Ecoregion

Bio: Dr. Kerns is a Research Ecologist with the Pacific Northwest Research Station in Corvallis, OR. She holds a Ph.D. in Forest Science from Northern Arizona University, where she first started working in southwestern ponderosa pine forests. Kerns has conducted research the past 20 years to develop knowledge and understanding about how disturbances and their interactions affect the structure and function of plant communities, and how this information can be used to develop management and adaptation practices to achieve land management goals and promote ecological resilience to disturbances.

S13.11. Twenty-five years of ecological restoration research at the G. A. Pearson Natural Area, Fort Valley Experimental Forest, Arizona

Presenter: Andrew Sánchez Meador, Assistant Professor, School of Forestry, Northern Arizona University
Additional Authors: Moore, Margaret.M, Professor, School of Forestry, Northern Arizona University
Fulé, Peter Z., Professor, School of Forestry, Northern Arizona University
Huffman, David W., Director of Research and Development, Ecological Restoration Institute, Northern Arizona University
Laughlin, Daniel C., Associate Professor, Department of Botany, University of Wyoming
Strahan, Robert T., Adjunct Faculty, Department of Biology and Environment Science and Policy, Southern Oregon University
Normandin, Donald P., Lab Coordinator Sr., Ecological Restoration Institute, Northern Arizona University

Restoration of ponderosa pine (Pinus ponderosa)-bunchgrass forests in Arizona relies on tree thinning and prescribed fire to reestablish structure and function and encourage more resilient ecosystems. In this study, we investigate differences in stand- and individual-tree growth and mortality, herbaceous production and richness, fuel loads, and fine-scale tree spatial patterns among two restoration treatments (thin from below; thin from below plus prescribed burning) and an untreated control. This long-term (1992-2017) study is located on a decommissioned portion of the G.A. Pearson Natural Area of the Fort Valley Experimental Forest, Coconino National Forest, near

Flagstaff, Arizona. We used tree census data to quantify stand-level demographic trends (i.e., regeneration, ingrowth and mortality) and dendrochronological analysis to examine climate-treatment tree growth interactions. We used linear mixed effects models to examine herbaceous understory biomass and species richness among restoration treatments. A combination of stem-mapping, remote sensing and spatial analyses were used to explore changes in fine-scale tree spatial patterns. In general, restoration treatments reduced basal area by approximately half, retained presettlement trees, and removed most small trees. Preliminary long-term results indicate that net stand basal area growth was about 10% per decade following treatment and was slightly higher in the thin-only treatment. Net basal area loss in the control was approximately 15% per decade. Individual tree growth patterns showed large decreases (as much as 7-times) in annual basal area increment (BAI) due to four exceptional droughts that occurred during the 25-year study, and higher resilience to drought was observed in both restoration treatments as compared to the control. Herbaceous biomass responded positively to both restoration treatments. Prior to treatment remnant grass openings had significantly higher herbaceous biomass (~8 times higher) than all other treatments (<100 kg ha-1). Species richness increased and became similar to remnant openings in the thinning plus burning treatments, and treatment, time, and treatment-by-time interaction effects explained 45% of the variation in species richness. Surface fuel loads differed among treatments and heterogeneity in tree spatial patterns increased following restoration treatments. Results of this study provide implications for landscape-scale ponderosa pine restoration projects throughout the western United States.

Keywords: ecological restoration, thinning, prescribed fire, ponderosa pine, long-term experiment

Bio: Andrew is an Assistant Professor of Forest Biometrics and Quantitative Ecology in the School of Forestry at Northern Arizona University and is the current Chair of the Society of American Foresters' Forest Science and Technology Board. Andrew's research focuses on solving problems at the interface between federal land management, applied statistics and quantitative forest ecology. His current work focuses on quantifying how natural and anthropogenic disturbances influence forested ecosystems and the application of statistical, computer science, and remote sensing techniques to characterize forest structure, composition and ecosystem dynamics.

S14.1. Wildfire Exposure to Buildings: Vulnerabilities and Mitigation Strategies

Presenter: Stephen Quarles, Chief Scientist for Wildfire and Durability, Insurance Institute for Business & Home Safety
Additional Authors: Zhou, Aixi, Associate Professor, University of North Carolina at Charlotte

Post-fire assessments have shown that wind-blown firebrands are the most important cause of building ignitions. Firebrands that land on or adjacent to exterior materials can result in direct ignition. Firebrands can also enter a building through an open window or vents, igniting materials inside. Firebrands landing in combustible mulch, a woodpile, or vegetative debris on a roof or gutter can also cause ignition, resulting in building exposure to radiant heat or flame contact. Because of the importance of wind-blown firebrands in building ignitions, research at the Insurance Institute for Business & Home Safety (IBHS) Research Center has focused on the built environment. IBHS simulates firebrand exposure on buildings and building components.

The IBHS Research Center's large test chamber can hold full-scale one- or two-story buildings. The large test chamber includes a wind tunnel powered by a 105-fan array that can simulate the flow characteristics of the atmospheric boundary layer at speeds greater than 100 miles per hour (71.5

m/s). For wildfire laboratory experiments, a fluctuating wind-speed record is used, typically with gusts in excess of 50 miles per hour (22 m/s). The wind tunnel incorporates a turntable, with a diameter of 55 feet (16.8 m) that can rotate 360 degrees, to evaluate the impact of wind direction on the potential for firebrand deposition and building ignition. Wind-blown firebrand experiments use a custom-made apparatus to generate firebrands.

This presentation will summarize some of our research and findings, focusing on the vulnerability of vents, decking and fencing to firebrands, and our research on coatings, conducted in collaborating with the University of North Carolina at Charlotte.

Keywords: Built environment, mitigation strategies

Bio: Steve joined the IBHS Research Center team in 2011. His research focus is on wildfire exposures to and mitigation strategies for the built environment. Prior to joining IBHS, he worked for the University of California as a cooperative extension advisor. During 2007 and 2008, Steve worked part-time for the California Office of the State Fire Marshal, providing support for an education program related to the then new building code affecting construction in wildfire prone areas in the state.

S14.2. Characterization of Firebrands from Common Structural and Wildland Vegetative Fuels
Presenter: Aixi Zhou, Associate Professor, University of North Carolina at Charlotte
Additional Authors: Stephen L. Quarles, Ph.D., Chief Scientist for Wildfire and Durability, Insurance Institute for Business & Home Safety.

Spotting ignition caused by airborne burning firebrands (also called embers) is a fundamental mechanism for fire spread in large fires in the wildland, wildland urban interface (WUI) communities and urban areas. Spotting by firebrands, or the firebrand phenomenon, can be understood in three major sequential processes: firebrand production, firebrand transport and firebrand ignition of recipient fuel. Firebrand production is the first step and the basis for understanding the subsequent transport and ignition processes.
This presentation will discuss recent efforts to investigate firebrand production from burning wildland and structural (construction materials) fuels in the wildland and WUI, with a focus on the characterization of produced firebrands. The structural fuels evaluated included oriented stranded board, plywood, and solid wood products used for siding and sheathing applications. Roof covering materials included non-fire retardant and fire-retardant treated cedar shakes and a recycled rubber product. Wall and roof assemblies were framed with lumber from the spruce-pine-firs species group. Wildland vegetative fuels included shrubs (chaparral and palmetto), trees (southern yellow pine and cypress) and grass (little bluestem grass). The specimens were prepared and tested in a wind tunnel facility at three nominal wind-speed levels. Experimental design, firebrand production tests and firebrand collection and characterization procedures will be presented. Representative results related to the characterization of the generated firebrands will be discussed. The firebrand characteristic parameters include the number and the rate of firebrand production, the characteristic size (e.g., mass and projected area and their statistical distributions) and shape of firebrands, travel distance of firebrands under a range of wind speeds, and surface temperature and heat flux of representative firebrands.

Keywords: firebrand, ember, production

Bio: Dr. Aixi Zhou is an Associate Professor in Fire Safety Engineering Technology at the University of North Carolina at Charlotte. His current research focuses on the response of materials and structures under fire and other extreme conditions. Dr. Zhou has been the PI or co-PI on more than 20 funded projects at UNC Charlotte since 2007, and has over 90 technical publications in his expertise areas. Dr. Zhou is currently leading a multi-year multi-institutional Joint Fire Science Program project on fire ember production from wildland and structural fuels. Dr. Zhou teaches courses in fire safety and mechanical engineering areas at UNC Charlotte. He is a registered Professional Engineer in the state of North Carolina.

S14.3. Physical and Chemical Processes Controlling Ember Production in Wildland Fires

Presenter: David Blunck, Assistant Professor, Oregon State University
Additional Authors: Hudson, Tyler

A significant mechanism for the spread of wildland fires are spot fires caused by lofted embers (i.e., firebrands). Much of the research regarding spot fires has focused on the transport of lofted embers and the subsequent ignition of biomass after landing. Studies which have sought to identify processes controlling the generation of embers have typically focused on evaluating particular parameters (e.g., role of fuel density), yet the importance of these parameters relative to others is not clear. The objective of this study is to identify the relative importance that the species composition, branch size, velocity, temperature, moisture content and bark have on controlling ember generation characteristics. A suite of laboratory and outdoor studies have been conducted to help address the objective, and allow controlling parameters to be identified at multiple lengths. Laboratory studies comprised of burning dowels in a heated wind tunnel and measuring the time required for an ember to generate (as a metric of ember generation). The aspects which were varied included crossflow temperature, cross-flow velocity, moisture content of the dowel, species, and dowel diameter. A factorial analysis showed that the diameter has the largest influence on the time to ember generation compared to the other parameters. The second most important parameter was the composition of the dowel. A second laboratory study evaluated the ember generation rate for natural samples (i.e., sticks collected from a Douglas-fir trees). Natural samples generated embers approximately 55% slower than dowels. This sensitivity is attributed to the layer of bark on natural samples. Outdoor studies of trees were conducted in an effort to evaluate the applicability of the trends observed from the laboratory studies to conditions more realistic of the field. Douglas-fir, western juniper, and ponderosa pine trees with an average height of 3.7 m were torched in a bed of straw. An array of fire resistant fabric panels were used to collect embers. Scorch marks on the fabric provided an indication of ember size and temperature. The average ember sizes for each species (based on scorch marks) were 12, 37, and 12 mm2, respectively. This indicates that the species type can influence the size of embers generated, as expected. The flux of embers collected on the sheets were 6.2, 30.7, and 32.7 embers/m^2 for Douglas-fir, western juniper and ponderosa pine trees, respectively. This sensitivity in ember flux is attributed primarily to differences in tree morphology.

Keywords: Ember, Wildland Fire, Generation

Bio: Dr. David Blunck is an expert in combustion processes. Prior to joining Oregon State University (2013) he was the lead investigator in fundamental combustor research at Air Force Research Laboratory. Dr. Blunck is the recipient of a Young Investigator Award from ONR, was nominated for a PECASE Award from the Propulsion Directorate at AFRL (2012), and was named Outstanding Graduate Student at the School of Mechanical Engineering at Purdue University (2010). Dr. Blunck has 72 peer-reviewed and conference publications.

S14.4. Breakage and Transport of Firebrands from Wildland Fuels
Presenter: Ali Tohidi, , One Concern, Inc
Additional Authors: Caton, Sara, Jensen Hughes
Gollner, Michael, University of Maryland, College Park

During wildfires, firebrands form when they break off of burning vegetation or structures. Many are then lofted into the fire plume where they are transported long distances, igniting new "spot" fires as they land. To date, very few studies have been conducted on the breakage mechanism of thermally degraded vegetative elements. Knowledge of these mechanisms is needed to feed mathematical models of firebrand transport from traditional wildfires as well as those that spread into communities. First, a framework to understand the behavior of thermally-degraded wooden elements under simultaneous external loading is presented. A set of experiments were designed such that cylindrical wooden dowels of different species are exposed to different heating conditions similar to wildland fires, in order to model the breakage mechanisms of these elements in the absence of wind. The thermally degraded elements are subjected to a three-point bending test to obtain the mechanical response of the materials after combustion. Assuming Hookean Orthotropic behavior for combusted dowels, dimensional analysis of the results reveals that the ultimate strength of the dowels is controlled by the recoverable elastic strain during loading, found to occur under two distinct regimes. These results are not only important for better understanding of the breakage mechanisms but also are advantageous for developing a failure theory of thermally degrading wooden elements under simultaneous wind loading conditions.

Keywords: firebrands, wildland-urban interface, ember

Bio: Ali Tohidi is a scientist at One Concern Inc., a benevolent AI company that combines human insight, science, and Deep Learning to minimize the impact of disasters and their socio-economic stresses on humanity. Previously, Ali was a postdoctoral scholar at the University of Maryland, College Park. He received his M.Sc. from Sharif University of Technology, Tehran, Iran focusing on wind-induced gravity currents in aquatic canopy zones. He then moved to Clemson University, where he received his Ph.D. in Applied Fluid Dynamics, working on wildfire spread mechanisms, firebrands' thermo-mechanical and aerodynamic properties, and fire plume dynamics. His corresponding research thrusts are AI, Fluid/Fire Dynamics, and HPSC.

S14.5. Influence of Thermal Degradation in Dispersion and Deposition of Firebrands in a Turbulent Boundary Layer
Presenter: Chandana Anand, PhD candidate, The University of Alabama in Huntsville
Additional Authors: Anand, Chandana, Graduate Student, The University of Alabama in Huntsville
Mahalingam, Shankar, Professor, The University of Alabama in Huntsville

The dispersion, diffusion and deposition of cylindrical firebrands carried by wind in a turbulent boundary layer were studied. Their motion was influenced by the forces of drag, lift and gravity. Furthermore, the firebrands underwent thermal degradation leading to pyrolysis and char formation, while exchanging convection and radiation heat with the ambient air. First, the model was validated against the experiments of Muraszew et al. (1993), based on which, simulations were performed with firebrands subjected to uniform air flow with velocities of 6.7 and 4.5 m/s. The cylindrical firebrands had a length of 12.7 cm and radius ranging from 1.3 to 2.5 cm. Consistent with the experiments, four different species of wood were considered in the simulations. The simulated

residual fractional mass was found to compare reasonably well with the experimental data. Next, firebrands with a specified initial temperature and different initial densities of 230 and 570 kg/m3 were released at different elevations. The firebrands were tracked in the Lagrangian frame while their mass loss rate and temperature were calculated. Large eddy simulation was used for the boundary layer flow. A rigorous statistical analysis was carried out to quantify the impact of the turbulent velocity fluctuations on firebrands by calculating the turbulent dispersion and diffusion of the carried firebrands and the distribution of the firebrands deposited on the ground.

Keywords: firebrands, turbulence, dispersion, deposition, boundary layer

Bio: Chandana Anand is a PhD candidate at the Department of Mechanical and Aerospace Engineering at The University of Alabama in Huntsville. She received an M.S. degree in Mechanical Engineering from UAH in 2014 and a B.S. degree in Aeronautical Engineering from Visvesvaraya Technological University, India, in 2012. For her dissertation research, she is investigating the role of firebrands in the spread of wildland and WUI fires by physics based modeling.

S14.7. Structure Vulnerability to Firebrands from Fences and Mulch

Presenter: Kathryn Butler, Physicist, National Institute of Standards and Technology (NIST)
Additional Authors: Johnsson, Erik, Mechanical Engineer, NIST

Fences and mulch contribute to the spread of WUI fires. They act as both ignition targets and as sources that may themselves ignite nearby objects through direct flame contact and firebrand generation. The linear nature of fences gives them the capability of spreading fire over long distances.

This talk will present the findings from outdoor experiments that investigated the spread of fire through firebrand spotting along fences and mulch beds near a structure in a wind field. In these experiments, a fence section, with or without a mulch bed beneath, was arranged perpendicular to the wall of a small structure, at a distance between 0 m and 1.8 m from the wall. Beyond the fence was a large fan that generated a wind field of 6 m/s to 14 m/s. Along the length of the small structure at its foot was a mulch bed 0.5 m in width. A propane burner was used to ignite the fence at its base at the windward end farthest from the structure. The time for the first firebrand to ignite a spot fire in the mulch was observed, as well as the time for the fire to reach the wall. Data were also collected on the flame spread rate over fence and mulch bed. A variety of fence and mulch types and materials were tested.

Fence type, proximity to the structure, wind speed, and type of ground cover beneath the fence all affect firebrand spotting. Firebrand spotting is random in nature, but some trends are apparent from the data. In most cases with fences combined with mulch beds, spotting occurs within the first seven minutes after ignition. Spotting tends to be delayed for the slowest (6 m/s) wind speed. Compared to the cases with the mulch bed only, the addition of a fence tends to decrease the time to spotting. A bed of pine straw mulch tends to burn quickly and intensely but gives off small firebrands that do not generally result in spot fires. In cases with fences only, in the absence of mulch, spotting occurs much more slowly and in some cases did not occur at all.

Future experiments will include effects of coatings and aging on the generation and spotting of firebrands from fences.

Keywords: Firebrands; WUI fires; fences; mulch; exposure

Bio: Dr. Kathryn Butler is a physicist in the Wildland-Urban Interface Fire Group in the Fire Research Division of the National Institute of Standards and Technology. She is currently working on understanding vulnerabilities in WUI fires. Her work at NIST over the last 24 years includes studying bubbling and flow behaviors of materials in fire, using video evidence to determine the structural damage after impact for the World Trade Center disaster, and collecting and analyzing opinions of people with mobility impairments on fire evacuation. Dr. Butler holds a Ph.D. in Applied Physics from Harvard University.

S14.8. Short-range firebrand hazard assessment – firebrand flux, travel distance and heat flux from accumulations

Presenter: Rory Hadden, Lecturer, School of Engineering, University of Edinburgh, Edinburgh, Scotland, UK
Additional Authors: Thomas, Jan Christian, PhD, School of Engineering, University of Edinburgh, Edinburgh, Scotland, UK
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The physical phenomena that cause ignition of combustible substrates, whether solid of porous, due to firebrand accumulations is still not fully understood. This includes understanding the combustion behavior of individual particles, the bulk behavior of particle accumulations, and the heat and mass transfer between particles, accumulations and substrates. These mechanisms are being studied in bench scale experimentations around the world in order to understand the firebrand hazard from wildfires at the wildland-urban interface. In this work, a quantifiable firebrand accumulation is deposited on inert insulation board equipped with in-depth thermocouples. The temperature data is subsequently used in inverse-modelling to estimate the heat flux from the accumulation. In this manner, it is possible to better understand ignition potential through the systematic variation of parameters, within realistic bounds determined through field-scale investigations.
A current obstacle to proper assessment of the firebrand hazard is the lack of knowledge about firebrand characteristics, travel distance, and quantity of particles landing at a target a distance away from the fire front, i.e. firebrand flux. Particle characterization and quantification of firebrand flux is essential for bench-/intermediate scale type experimentation, as described below. Without this knowledge, bench scale heat transfer experimentation is incomplete, since surrogate particles and accumulations used are unsupported estimations. In this work, a data collection methodology is presented that provides information on firebrand characteristics, travel distances and firebrand flux. This is achieved by conducting a number of field-scale experiments. Wildfire behavior is quantified in terms of fireline intensity and spread rate. Firebrands are collected downwind in collection areas. Results prove intuition correct – firebrand flux and travel distance increases with fireline intensity, and a first quantification of this relationship is provided in this study. Data produced in the field experiments can now be used to inform bench-/intermediate scale experimentation as well as validation exercises for numerical models.

Keywords: embers, firebrand shower, wildfire behavior, forest fire, WUI, inverse modelling, ignition

Bio: Dr Rory Hadden is the Rushbrook Senior Lecturer in Fire Investigation at the University of Edinburgh. His research interests centre around the understanding the process of thermal decomposition of solid fuels, advancing material flammability characterisation and understanding fire spread in large outdoor fires. His work has specific application to wildfires, the built environment, process safety and materials development. He holds grants from Department of Defence, the National Institute for Standards and Technology, Arup, BRE, and the Defence Science and Technology Laboratory (UK).

S14.9. Experimental investigation of the ignition potential of single firebrands and their accumulation

Presenter: Alexander Filkov, Research Fellow, The University of Melbourne
Additional Authors: Kasymov, Denis, Associate Professor, Tomsk State University
Hadden, Rory, Senior Lecturer, University of Edinburgh
Simeoni, Albert, Professor, Worcester Polytechnic Institute
Skowronski, Nicholas, Research Forester, USDA Forest Service
Prohanov, Sergey, Research Assistant, Tomsk State University

This paper presents the results of laboratory experiments on firebrand generation and their ignition potential. The series of laboratory experiments have been conducted to study ignition potential, time and conditions for ignition of fuel bed (pine needles) caused by a single firebrand and a group of glowing firebrands. An experimental setup was constructed for generation of firebrands and their impact on the fuel bed. In all experiments, square pine bark samples (*P. sylvestris*) with sides 15 ± 2, 20 ± 2, 30 ± 2 mm and a thickness of H = 4–5 mm, and pine twigs with a diameter Δ = 2–4, 4–6, 6–8 mm and a length L = 10 ± 1, 20 ± 2, 40 ± 2, 60 ± 2 mm were used as the simulators of firebrands. The density of the fuel bed was 60, 80 and 105 kg m–3. The glowing firebrands dropped on the fuel bed were blown with the heated air flowing at the rate and the temperature of 1 m s–1 and 40°C, 1.5 m s–1 and 50°C, 2 m s–1 and 60°C, 2.5 m s–1 and 90°C, 3 m s–1 and 110°C. It was found that irrespective of the bark sample sizes and experimental conditions, the ignition of the fuel bed by a single firebrand did not happen. Conversely, single pine twig, under certain conditions, ignited fuel beds of any density (from 60 to 105 kg m–3) and for wind velocities equal to or above 2 m s–1. An increase of the firebrand length and diameter led to the decrease of the ignition time. With increase of the fuel bed density opposite situation was observed, and the ignition time increased. The experiments with firebrand accumulation have shown that the increase in wind velocity leads to the increase in potential of fuel bed ignition, i.e. wind plays a role of catalyst in the ignition process, bringing oxygen to firebrands. However, if the wind velocity is insufficient for ignition, only low intensity smouldering occurs. The results have also shown that the increase in fuel bed density leads to the decrease in the potential of fuel bed ignition. Under the same conditions, the potential of ignition of fuel bed by twigs was found to be higher compared to bark, due to the difference in their thermal properties.

Keywords: firebrands, generation, accumulation, ignition

Bio: Dr. Alexander Filkov received his PhD in Ecology (Physical and Mathematical Sciences) in 2005 from Tomsk State University, Russia. After completing his PhD he worked as Associate Professor at the same university. His research interests encompass wildfire behaviour and risks, WUI and extreme fires. During previous decade he conducted laboratory experiments on fuel ignition and fire spread, participated in the development of a deterministic and probabilistic system for the prediction of forest and peat fire hazard, as well as in the simulation of fuel drying and kinetics.

S14.10. Firebrand Ignition of Attic Insulation and an Ornamental Grass

Presenter: Savannah Wessies, The University of Texas at Austin
Additional Authors: Ezekoye, Ofodike A, PhD., PE
Marr, Kevin C., PhD, PE
Chang, Michael K

It is well known that wildland firebrands ignite homes in a myriad of ways, including through penetration into attic spaces and by igniting materials in close proximity to the home, like ornamental plants and other landscaping elements. The effects of firebrand characteristics on the susceptibility of attic insulation materials and an ornamental grass to ignite were studied in order to provide insight into how different insulation materials and landscaping choices affect a structure's performance in the wildland urban interface. Several common insulation materials were tested: polyurethane foam, expanded polystyrene (EPS), extruded polystyrene (XPS), flame-retarded and non-flame-retarded denim, and flame-retarded and non-flame-retarded loosefill cellulose. Additionally, an ornamental grass, little bluestem, was tested. A new experimental setup was developed in an order to quantify the effects of firebrand heating, air flow, and firebrand surface area on different ignition scenarios. Two different firebrand configurations were used: one large, whole firebrand (50mm long, 9.5mm-diameter) and five small, fragmented firebrands (10mm long, 9.5mm-diameter). Compared to the whole firebrands, the fragmented firebrand piles more reliably ignited the various materials. The synthetic insulation materials experienced flash flaming, with no sustained ignition. In the case of XPS and EPS, after flash flaming, the firebrands would melt through the material and eventually extinguish. For the cellulosic insulation materials, sustained flaming ignition would occur given adequate airflow. For the materials with sustained ignition, the ignition signature was explored through temperature measurements of the fuel bed and the firebrands. Additionally traditional lab scale flammability experiments were conducted using cone calorimetry and thermogravimetric analysis (TGA). The time to ignition, peak heat release rates, and other derived data from cone calorimetry are presented for the various insulation materials and ornamental grasses. Contrary to the firebrand ignition tests, for the cone calorimetry tests, ignition was observed in all insulation materials given a high enough heat flux. For TGA, the mass loss derivatives of each material were compared to the other materials. Additionally, an onset of degradation temperature, which is presented in this study, could be determined from the TGA tests. There was relatively little correlation between the firebrand ignition tests and the traditional laboratory scale experiments. A simple model has been developed to better correlate the firebrand tests to the cone calorimetry and TGA tests. In general, the overall complexity of firebrand ignition processes requires additional data processing to better connect the tests across scales to results of standard test methods.

Keywords: Wildland-fire firebrand, thermal insulation, Ignition, Smoldering, Flaming

Bio: Savannah Wessies graduated from LeTourneau University with a B. S. in Mechanical Engineering in 2016. She is currently pursuing a PhD in Mechanical Engineering at The University of Texas at Austin. Her research focuses on the problem of fire spread at wildland-urban interface through material flammability characterization and associated modelling.

S14.11. Temperature Measurement and Ignition Potential of Firebrands

Presenter: James Urban, Postdoctoral Researcher, University of California
Additional Authors: Fernandez-Pello, Carlos, Professor, University of California - Berkeley
Vicariotto, Michela, Graduate Student Researcher, University of California - Irvine
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Liu, Naian, Graduate Student Researcher, State Key Laboratory of Fire Science, University of Science and Technology

Ember spotting is an important mechanism by which wildland and Wildland-Urban Interface (WUI) fires can rapidly spread. Key parameters of interest include the temperature of embers, as well as their ability to ignite fuels. Results presented show the surface temperatures of glowing embers measured using Color Ratio Pyrometry with a DSLR camera and the ability of glowing embers to ignite a smolder in coastal redwood sawdust fuel beds at various fuel moisture content levels and ember sizes. The embers were cylindrical with a unity aspect ratio ranging in diameter from 3 -16 m. The temperature measurements show the glowing temperatures of various size embers exposed to different strength wind speeds (1-4 m/s). The results show that the increased glowing combustion temperature with wind speed and reynolds number, 750oC at 1 m/s to 950oC at 4 m/s. The results were compared to simultaneous measurement with an Infrared camera. The results show that accumulation of ash on the ember surface makes obtaining an accurate temperature measurement with an Infrared camera difficult, because the Infrared camera is more sensitive to the emissivity of the surface. From the ignition experiments, we were able to determine an ignition boundary based on FMC and ember diameter. As expected, the results show that larger embers are capable of igniting sawdust with a higher FMC. We then found that, for the conditions tested, 3.17mm was the smallest ember size which would ignite have a 50% chance to ignite the fuel with a FMC <1%. Results indicate that as the ember size is increased FMC ignition threshold decreases because the inner, unreacted portion of the ember cools the glowing combustion reaction on the surface.

Keywords: WUI fires, Ember spotting, Diagnostics

Bio: James Urban is a Postdoctoral Researcher at the University of California, Berkeley where he studies fundamental fire, combustion, and thermal science phenomena. His research has focused on the ignition of natural fuels by hot metal particle and embers and most recently the burning of individual fuel elements.

S14.12. Heating and Ignition from Firebrand Piles

Presenter: Michael Gollner, Associate Professor, Department of Fire Protection Engineering, University of Maryland, College Park
Additional Authors: Hamed Salehizadeh, Graduate Student, Department of Fire Protection Engineering, University of Maryland, College Park
Raquel Hakes, Graduate Student, Department of Fire Protection Engineering, University of Maryland, College Park

Smoldering firebrands (embers) are a major cause of ignition and eventual structural damage during wildfires at the wildland-urban interface (WUI). These small pieces of burning wood can loft several kilometers ahead of the main flame front and ignite spot fires in vegetation or directly ignite structural elements, such as decks. Small-scale experiments, designed to give a better understanding of the ignition process, were conducted using laboratory-fabricated cylindrical wooden smoldering

firebrands. The influences of firebrand diameter, firebrand pile mass, and wind on heating from firebrand piles were explored. It was found that firebrand diameter had little effect on heating, pile mass had a moderate effect, and wind had a large effect on measured heat flux. Peak heat fluxes showed distinct differences between heat fluxes produced by firebrand piles and by individual firebrands, which have been studied exclusively in the past. Above a critical mass, piles did not produce higher heat fluxes; however, larger piles heated fuels for an increasingly longer duration and over a larger area. Ignition tests under wind were also performed on common WUI materials, e.g. plywood, oriented strand board (OSB) and a wood-plastic composite. These tests were compared to temperature and heat flux measurements over an inert sample, allowing for comparison of the thermal conditions present just prior to ignition. Implications of these results as they relate to protection of homes in the WUI will also be discussed.

Keywords: Wildland-urban interface, WUI, firebrands, ignition

Bio: Michael Gollner is an Associate Professor in the Department of Fire Protection Engineering at the University of Maryland, College Park. He is broadly interested in fire science, using a background in combustion and fluid mechanics to understand fire spread, fire whirls, ignition of homes in the wildland-urban interface, and emissions from fires. He serves on the Board of Directors of the IAWF and is a principal member of the NFPA Technical Committee on Wildland and Rural Fire Protection. He holds a Ph.D. in Mechanical Engineering from the University of California, San Diego.

S15.1. Factors facilitating and frustrating collaborative adaptive management in forest landscape restoration

Presenter: Tony Cheng, Director and Professor, Colorado Forest Restoration Institute, Colorado State University
Additional Authors: Greg Aplet, Senior Science Director, The Wilderness Society
Amy Waltz, Science Delivery Director, Ecological Restoration Institute, Northern Arizona University

The Collaborative Forest Landscape Restoration Program (CFLRP) has created the conditions in which collaborative adaptive management (CAM) approaches in forest restoration can be tested. In theory, CAM engages stakeholders to collectively: define forest landscape restoration goals, assumptions, uncertainties, and options; develop and implement a science-based monitoring strategy to assess restoration effects; deliberate the effects of actions on goals, assumptions, and uncertainties; and recommend changes in goals, assumptions, and actions based on the "best available science". In reality, since people are involved, things get messy, fast. My presentation addresses two questions: 1) In what ways do multi-stakeholder group dynamics interact with federal agency institutional and organizational processes?; and 2) To what extent do these interactions facilitate or frustrate collaborative adaptive management on federal landscapes? Drawing on experiences and perspectives of colleagues involved with the Colorado Front Range CFLRP, the Four Forest Restoration Initiative, and the Uncompahgre Plateau CFLRP, I discuss social group dynamics and institutional/organizational factors affecting CAM across these cases. A key take-away is that in order for CAM to realize its potential for integrating science into forest restoration decision-making, CAM participants need to be intentional and reflexive about social group dynamics and institutional/organizational processes.

Keywords: forest restoration, collaboration, adaptive management

Bio: Tony Cheng is Director of the Colorado Forest Restoration Institute and Professor in the Department of Forest & Rangeland Stewardship at Colorado State University. His primary research interest is in forest governance, policy and administration, with a focus on multi-stakeholder collaborative approaches to promote resilient social-ecological systems linked to forest landscapes. Tony has a PhD in Forestry (Oregon State University), a MS in Forestry (University of Minnesota), and a BA in Political Science (Whitman College).

S15.2. Co-Managing Risk or Parallel Play? Examining Connectivity Across Wildfire Risk Mitigation and Fire Response in the Intermountain West

Presenter: Emily Jane Davis, Assistant Professor and Extension Specialist, Oregon State University
Additional Authors: Huber-Stearns, Heidi, Faculty Research Associate, University of Oregon
Cheng, Antony, Professor, Colorado State University
McAvoy, Darren, Extension Assistant Professor, Utah State University
Caggiano, Michael, Research Associate, Colorado State University

Landscapes with similar wildfire threats ("firesheds") contain multiple entities undertaking a variety of pre-wildfire mitigation and fire response actions across scales from neighborhoods to watersheds. Despite laws, policies, and agreements calling for cohesive strategies, these entities often do not work closely for efficient and effective risk management. They face inconsistent policies and budgets, organizational structures and processes, and conceptions of values at risk. Collectively, these challenges discourage joint accountability and action, and contribute to rising fire suppression costs. Our research question is: What factors can overcome organizational disconnects to foster co-management of firesheds? We will use comparative case studies of six firesheds in varied socio-ecological settings to analyze how boundary-spanning attributes enable co-management across spatial scales and between mitigation and fire response. We present initial results from case study development, preliminary spatial analysis, and literature synthesis.

Keywords: Co-management, risk, organizational

Bio: Emily Jane's research and extension position at OSU focuses on collaborative natural resource management and social science.

S15.3. Risk Co-Management on Interjurisdictional Lands

Presenter: Toddi Steelman, Professor, University of Saskatchewan
Additional Authors: Nowell, Branda, Professor, North Carolina State University
Velez, Anne-Lise, Research Associate, Virginia Tech University

Ineffective risk co-management manifests in conflict and problematic communication and coordination among the variety of stakeholders during an incident, hindering the effectiveness in incident response. The adoption of collaborative risk management has been offered as a path forward to deal with the ongoing challenges associated with wildfire management, however, realizing its promise is difficult. Our presentation focuses on the models and practices that facilitate or impede risk management dialogue and the socio-psychological mechanisms through which these models operate, leading to greater insight into the theories, practices, and mechanisms associated with more effective co-management of risk. Drawing from a national sample from the 2017 fire season and interviews with key informants across different jurisdictional levels (local, state, federal), we document substantive differences in risk perception among key stakeholders, including their relative levels of intensity in risk perception and how they prioritize different risks.

Keywords: risk co-management, interjurisdictional lands, communication, coordination, governance

Bio: Dr. Toddi Steelman is a Professor at the School of Environment and Sustainability, University of Saskatchewan, Saskatoon, Canada. She has a 15+ year history working on the human dimensions of wildfire research and has conducted research on community aspects of wildfire management in Canada and the United States. Her research agenda has focused on understanding community responses to wildfire and how communities and agencies interact for more effective wildfire management. Steelman is also Co-director, with Dr. Branda Nowell, of the Fire Chasers project at North Carolina State University (www.firechasers.ncsu.edu), which focuses on advancing the science of adaptive capacity toward more disaster resilient communities.

S15.5. Policy Barriers to Increasing Prescribed Fire Accomplishments on Federal Lands: A Diversity of Challenges and Approaches Across the West

Presenter: Courtney Schultz, Associate Professor, Colorado State University
Additional Authors: Huber-Stearns, Heidi, Research Assistant Professor, University of Oregon
McCaffrey, Sarah, Reserach Social Scientist, US Forest Service Rocky Mountain Research Station
Ricco, Gwendolyn, Research Associate, Colorado State University

Prescribed fire is an essential management tool for restoring and maintaining fire-dependent ecosystems; however, land managers are unable to apply prescribed fire at the necessary levels. Past surveys have identified a range of policies and regulations that managers say limit their ability to conduct prescribed fire. We are conducting a project investigating barriers to prescribed fire across the West for the BLM and the US Forest Service. Our goals are to identify the origin and range of interpretation of perceived policy barriers (i.e. whether these reside in law, agency guidance, culture, or individual discretion) and characterize the opportunities and mechanisms that are available to overcome barriers at various scales. The first phase of our project involved a legal analysis and interviews across the 11 Western states with BLM and Forest Service fire and fuels managers and state-level air quality regulators. We report on the diversity of regulatory approaches, policy barriers, and strategies for overcoming challenges across the West, based on our legal review and interviews. While air quality regulation limits managers' ability to conduct prescribed fire, it is only one of many issues that managers say affect their programs; other significant challenges include capacity limitations, a lack of incentives to increase accomplishments, and individual risk aversion. We will discuss the importance of governance and communication strategies for overcoming the challenge of integrating air quality and land management concerns and discuss other suggestions from interviewees that would afford managers greater opportunities to get more prescribed fire on the ground.

Keywords: prescribed fire, smoke, air quality, policy

Bio: Courtney Schultz is associate professor of forest and natural resource policy at Colorado State University in the Department of Forest and Rangeland Stewardship. She directs the CSU Public Lands Policy Group, and her current research focuses on the design of governance institutions to support fire management, collaborative forest restoration, and climate change adaptation.

S15.6. The National Cohesive Wildland Fire Strategy and Fire Adapted Communities

Presenter: Sarah McCaffrey, Research Forester, Rocky Mountain Research Station, USDA Forest Service

Additional Authors: Wall, Tamara, Deputy Director, Western Regional Climate Center Program, Desert Research Institute
Goldstein, Bruce, Associate Professor, University of Colorado Boulder

The 2009 FLAME Act highlighted the importance of human adaptation and resilience to wildfire in its requirement that Fire Adapted Communities be one of the three strategy areas the National Cohesive Wildland Fire Strategy should address. This presentation will examine how various stakeholders are interpreting notions of how to foster human adaptation to wildfire via insights from two research projects examining different angles of community fire adaptation. The first part will discuss findings from a survey of how practitioners (federal to local) in the Western US feel the Cohesive Strategy has or has not enhanced their fire management efforts, with specific discussion on findings related to fire adapted communities and landscape resilience. The second will explore local interpretations of what it means to be a Fire Adapted Community based on findings from interviews of stakeholders in 8 communities across the United States actively working toward being a FAC.

Keywords: Cohesive Strategy, Fire Adapted Communities

Bio: Sarah McCaffrey, Ph.D. is a Research Forester for the USDA Forest Service, Rocky Mountain Research Station. Her research focuses on the social aspects of fire management. This work has included projects examining wildfire risk perception, social acceptability of prescribed fire and thinning, incentives for creation and maintenance of defensible space. More recent work has examined social issues that occur during and after fires including evacuation decision making and agency-community interaction during fires, including work in Australia and Portugal. She received her PhD in Wildland Resource Science in 2002 from the University of California at Berkeley.

S15.7. The Future of Fire Management in Alaska: Adapting Approaches in Light of Current and Predicted Effects due to Climate Change

Presenter: Tait Rutherford, MSc Student, epartment of Forest and Rangeland Stewardship at Colorado State University
Additional Authors: Schultz, Courtney, Associate Professor, Colorado State University

Climate change is causing an increase in wildland fire activity in the boreal and tundra ecosystems of Alaska, threatening the capacity of federal and state fire management agencies to meet management goals. Our research involved an iterative process of fire and vegetation modeling, science delivery, and direct communication with fire managers to explore how fire management agencies will respond to the pressures of climate change. We evaluated how fire regimes will change under current management approaches using projections created in the Alaska Frame-Based Ecosystem Code (ALFRESCO) model. Through interviews with fire managers and stakeholders, we then sought perceptions of current and projected challenges, particularly regarding climate change, and possible needed changes to adapt to those challenges. We modified the ALFRESCO model using possible changes to management approaches that we developed based on our interviews and used these updated projections in a second round of communication with managers to understand possible future strategies and needs. We discuss our findings, focusing on the aspects of the fire management system that both support and impede managers' ability to adapt to changing conditions. While we found that budgeting and staffing challenges are especially salient issues for the agencies, managers also emphasize the importance of adapting fire management by increasing and better prioritizing the use of suppression tactics and fuels management strategies to mitigate risk to communities and valued sites. This will require continued utilization of the unique interagency

strategies in place in Alaska but also may necessitate some fundamental changes in management priorities, policy, and approaches.

Keywords: Alaska, adaptive governance, fire policy

Bio: Tait Rutherford is a master's degree candidate in the Department of Forest and Rangeland Stewardship at Colorado State University studying forest policy and management. He graduated with a bachelor's degree in political science from Columbia University in 2016 and recently was hired as a Pathways intern by the US Forest Service, where he will to convert to full-time work in August of 2018.

S16.1. The Fire and Smoke Model Evaluation Experiment Western Wildfire Campaign

Presenter: Roger Ottmar, Research Forester, US Forest Service, Pacific Northwest Research Station
Additional Authors: Hudak, Andrew, Research Forester, US Forest Service
Prichard, Susan, Research Scientist, University of Washington
French, Nancy, Senior Scientist, Michigan Tech Research Institute
Brown, Timothy, Research Climatological Director, Desert Research Institute
Larkin, Narasimhan, Research Physical Climatologist, US Forest Service

The Fire And Smoke Model Evaluation Experiment (FASMEE) Western Wildfires Campaign, partially supported by the Joint Fire Science Program, will provide source characterization for a large coordinated field effort that will opportunistically sample 8-12 large, active wildfire plumes during July-August, 2018 and 2019. Project partners include the National Science Foundation Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption and Nitrogen (WE-CAN) and the joint National Oceanic and Atmospheric Administration and National Aeronautics and Space Administration FIREX-AQ program. This combined field effort will provide a better understanding of the impact of western North American wildfire smoke on the atmosphere. The FASMEE Western Wildfires Campaign portion of the project will compile existing field and remotely sensed datasets that will be used to assist with selection and characterizing the source of the wildfire events sampled for smoke by WE-CAN and FIREX-AQ.

Keywords: smoke, fuel, fuel consumption, plume, wildfire source characterization.

Bio: Roger Ottmar is a Research Forester with the Fire and Environmental Research Applications Team, Pacific Northwest Research Station at the Pacific Wildland Fire Sciences Laboratory located in Seattle, Washington. During his career he has been involved with fuel, fire, and smoke related research. He led the Prescribed Fire Combustion Atmospheric Dynamics Research Experiment (RxCADRE) and currently leads the Fire and Smoke Model Evaluation Experiment (FASMEE).

S16.2 Overview of the upcoming Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption and Nitrogen (WE-CAN) study

Presenter: Emily Fischer, Assistant Professor, Colorado State University
Additional Authors: Collett Jr., Jeffrey, Professor, Colorado State University, Department of Atmospheric Science
Sullivan, Amy, Research Scientist II, Colorado State University, Department of Atmospheric Science
DeMott, Paul, Senior Research Scientist, Colorado State University, Department of Atmospheric Science
van den Heever, Susan, Monfort Professor, Colorado State University, Department of Atmospheric Science
Schumacher, Russ, Associate Professor, Colorado State University, Department of Atmospheric Science
Murphy, Shane, Assistant Professor, University of Wyoming, Department of Atmospheric Science

Western wildfire smoke impacts air quality, nutrient cycles, weather and climate. The WE-CAN project will deploy the NCAR/NSF C-130 research aircraft in summer 2018 (22 July – 2 September) to sample wildfire smoke during its first day of atmospheric evolution. The flight plans and aircraft payload are designed to answer three linked sets of scientific questions related to fixed nitrogen, absorbing aerosols, cloud activation and chemistry in wildfire plumes. The project also has a strong educational focus; five different universities are involved in the project and we will develop of a graduate aircraft observations class. We will provide an overview of the scientific questions motivating this work, our current forecasting and logistics plans, and opportunities for collaboration. More details on the project timeline and payload can be found here: https://www.eol.ucar.edu/field_projects/we-can

Keywords: measurement campaign

Bio: Dr. Fischer is an atmospheric scientist who works on a variety of applied atmospheric chemistry problems, including the impact of smoke on air quality and health. Her research group uses a variety of tools including in situ observations, chemical transport models and new satellite products to investigate the sources of air pollutants and their dispersion to downwind regions of the atmosphere. She also leads research on the barriers to underrepresented groups in STEM.

S16.3. Fire Influence on Regional Environments and Air Quality (FIREX-AQ)

Presenter: James Crawford, , NASA Langley Research Center
Additional Authors: Warneke, Carsten, NOAA ESRL Chemical Sciences Division
Dibb, Jack, University of New Hampshire
Schwarz, Joshua, NOAA ESRL Chemical Sciences Division
Ryerson, Thomas, NOAA ESRL Chemical Sciences Division
Lefer, Barry, NASA Headquarters
Fahey, David, NOAA ESRL Chemical Sciences Division

Fire Influence on Regional Environments and Air Quality (FIREX-AQ) is a focused field study jointly sponsored by NOAA and NASA to broadly sample North American fires to improve understanding of their emissions and atmospheric impacts. An updated plan for the field intensive scheduled for August-September 2019 will be presented. The consolidation of instrumentation onto NASA's DC-8 platform will enable the most comprehensive characterization of trace gas and particulate emissions from fires in the ambient atmosphere ever conducted. The range of the aircraft will also enable fires

to be sampled across the continental United States in response to opportunities as fires occur and their impacts are felt at downwind locations. An important priority will be to conduct near-field sampling of western wildfires to understand the rapidly changing chemical environment as primary emissions are converted to secondary products. Additionally, widespread sampling of small fires (agricultural and prescribed) will be pursued to build statistics on the relationships between fuels and fire intensity with emissions and plume rise. Working closely with the Joint Fire Science Program, FIREX-AQ intends to make a strong connection between the atmospheric emissions sampled and the conditions on the ground in terms of fuel conditions and fire behavior. FIREX-AQ is expected to contribute to improving our understanding of issues facing satellite detection of fire activity, scaling of emissions, and representation of the chemistry and transport of fire emissions in models.

Bio: James H. Crawford currently serves and the Senior Scientist for Atmospheric Composition at NASA Langley Research Center. He has over 25 years of experience in the design and execution of airborne field studies to understand atmospheric chemical cycles and atmospheric response to human impacts as it relates to air quality and climate. A large part of his work focuses on the development of improved understanding of atmospheric change through development of an integrated observing system combining multi-perspective observations from satellites, aircraft, and surface networks with models to provide better information for decision makers.

S16.4. Coordinated Activities of Fire Influence on Regional and Global Environments and Air Quality (FIREX-AQ)

Presenter: Carsten Warneke, , NOAA/CU Boulder
Additional Authors: Roberts, James, Research Chemist, NOAA
Joshua Schwarz, Research Chemist, NOAA
Steven Brown, Research Chemist, NOAA
Thomas Ryerson, Program Lead, NOAA
Ru-Shan Gao, Program Lead, NOAA
Daniel Murphy, Program Lead, NOAA

NOAA's FIREX campaign is a five-year effort to study North American Wildfires. NOAA and NASA's large aircraft efforts have recently been consolidated onto NASA's DC-8 platform into FIREX-AQ (Fire Influence on Regional and Global Environments and Air Quality) to broadly sample North American fires to improve understanding of their emissions and atmospheric impacts. FIREX-AQ will be conducted during wildfire season in the summer of 2019 and coordinated with other agencies bringing various assets to the field. In this presentation we describe all the coordinated activities related to FIREX-AQ that have taken place already or are planned to be coordinated with the DC-8 deployment.

To meet the FIREX-AQ science goals that are difficult to perform with the large DC-8 aircraft, the NOAA CSD will potentially deploy the NOAA Twin Otter to Boise, ID. The Twin Otter could focus on the variability of the emissions measuring close to the fire for extended time periods, the fast evolution of smoke in the first few hours after emission, and could coordinate with the DC-8 that will be flying further downwind to study the chemical evolution on day to multi-day timescales. In addition, the Twin Otter could study the evolution of fire plumes at night.

Aerodyne will deploy their Mobile Laboratory to provide medium-scale surveys of fire impacts and exposure at night. In coordination with the mobile laboratory NOAA CSD, the University of Colorado, and BlackSwift Technologies will deploy an instrumented UAV as part of the NightFOX campaign to characterize smoke, fires, and fire radiative power at extremely high spatial resolution and at night.

Rapidly deployable ground and mobile sites will likely be established to include local scale chemical and physical measurements for near-source ground observations extending the aircraft domain and instrument suite, especially at night.
In preparation for FIREX-AQ, in 2016 emissions and aging of laboratory fires were studied during the NOAA FIREX Fire Lab Experiment in Missoula, Montana. A very comprehensive set of emission factors for various fire conditions, such as high and low temperature combustion, were measured and are available for trace gases and aerosol from fuels typical in the Western and Southeastern US. The Fire Lab Experiment also provided a better understanding of the mechanisms of trace gas emissions for different fire conditions.
FIREX-AQ will collaborate with (1) the Western wildfire Experiment for Cloud chemistry, Aerosol absorption and Nitrogen (WE-CAN), and (2) the Joint Fire Science Program's Fire Western Wildfire Campaign.

Keywords: FIREX-AQ field campaign

Bio: Dr. Carsten Warneke works at the NOAA Chemical Sciences Division and at CIRES CU Boulder as an atmospheric chemist. He is leading a research group with focus on studying volatile organic compounds in the atmosphere. He is currently one of the principal investigators of the NOAA/NASA FIREX-AQ field campaign to study wildfires in the US.

S16.5. FIREX-AQ: Fueled from below: Linking Fire, Fuels and Weather to Atmospheric Chemistry
Presenter: Amber Soja, Assoicate Research Scientist, Associate Program Manager, NASA LaRC / NIA
Additional Authors: Hudak, Andrew, Senior Reasearch Scientist, Rocky Mountain Research Station, Forest Service
McCarty, Jessica L., Assistant Professor, Department of Geography, Miami University
Hiers, Kevin, Wildland Fire Scientist, Tall Timbers Research Station and Land Conservancy

Wildland fire is largely under the control of weather and climate, and extreme fires are increasing, compelling us to improve understanding of the connections between fuels, fire, weather, atmospheric chemistry and smoke transport, which are critical to understanding impacts on air quality, atmospheric chemistry and climate.

As a member of the FIREX-AQ team, we endeavor to use this forum to connect with air quality, modeling, and fire communities to communicate our responsibilities, to facilitate the FIREX-AQ campaign, and to solicit community support, as the community deems advantageous and viable.

Our goals and responsibilities fall into two major categories: preparing the best-available fuels database in advance of the campaigns at a scale that is relevant to Near-Real-Time modelers; and provide active-fire campaign intelligence. During the first year, we intend to provide the best information available during the WE-CAN campaign, both to support that team and as a test case to prepare for FIREX-AQ.

Specifically, we have committed to providing support to guide flight planning that includes: (1) generating historic information on wildland, cropland, grassland and prescription fires in preparation for the field campaigns; (2) prepare pre-campaign intelligence on locations where cropland, prescribed and wildland fires are expected; (3) provide satellite and ground-based near-real-time observations and interpretation of fire activity and smoke extent; (4) provide fire weather as an indicator of active-fire continuance; (5) provide the location of areas with the best characterized fuels; (6) provide intelligence on actioned and experimental fires (2-week roving window); (7) provide the locations and timing of planned prescription and/or cropland fires; and (8) prepare daily reports for flight planning and summary synopsis reports of the fires sampled during the campaign.

We believe the base information provided by this project will provide the background information necessary to characterize difference in the variability in emissions of gases, aerosols and aerosol precursors as they relate to specific fires (size class, surface, intermittent, crown) in unique ecosystems and fuel types under a variety of fire-weather conditions. The fire and fuel data produced by our team is anticipated to be relevant to the composition and injection height of plumes, air quality and chemistry, chemical evolution of gases and aerosols, and the impact of biomass burning on climate-relevant properties.

Keywords: Fire science, fuels, smoke, air quality, Remote sensing, satellite

Bio: Bio: Dr. Soja is a resident in the Climate Science and Chemistry and Dynamics Branches of Atmospheric Sciences at NASA Langley Research Center. She has been working in the fire community for decades, and she has expertise in fire science, fire program management, and transitioning scientific data to stakeholder organizations. Her scientific focus has been on using satellite, Geographic Information Systems and modeled data as tools to explore the dynamic relationships that exist between fire regimes, fire weather, the biosphere, atmosphere and climate systems.

S17.1. Identifying the energy demands of the job and developing effective tactical nutrition for performance and recovery

Presenter: Brent Ruby, Director, Montana Center for Work Physiology and Exercise Metabolism Department of Health and Human Performance The University of Montana McGill Hall Missoula, MT
Additional Authors:

There are prior examples within the USFS and Internationally that have attempted to document the metabolic demands of arduous wildland fire suppression. These have included the collection of expired gas/breath samples for analyses during simulated fireline tasks. However, we have documented the total energy demands of the job across a wide range of wildfire incidents using the gold standard method established for humans in field settings. Considering these data, wildland fire suppression results in average daily energy expenditures approximating 5,000 kcals/24 hours (hotshots) while on assignment and is dependent on terrain, suppression tactics, and fire behavior. Considering these results as a foundation of overall energy demands, we have continued to work with crews to establish best practices relating to tactical nutrition strategies to optimize work output, safety and recovery. These studies and the implications of this work will be discussed. Moreover, these data provide empirical evidence that suggest necessary and specific revisions to the National catering contract policies for feeding fire crews in camp, on the fire lines and during extended deployment (remote spike/coyote camps). Operational specific examples of feeding strategies while on the fire line as well as post shift recovery suggestions will be discussed in detail.

Bio: Brent Ruby received his Ph.D. in exercise science from the University of New Mexico in 1994. Dr. Ruby serves as the Director of the Montana Center for Work Physiology and Exercise Metabolism (Montana WPEM) and is a fellow of the American College of Sports Medicine (ACSM). Dr. Ruby's research interests include nutritional strategies during ultra-endurance work/competition, muscle metabolism during and after exercise, the use of stable isotope tracers for measures of water turnover and energy expenditure, and issues surrounding heat stress during arduous work. Dr. Ruby has been studying wildland firefighter physiology since stepping onto the fireline in 1997.

S17.2. Energy Costs of Load Carriage and the Assessment of Seasonal Readiness
Presenter: Matthew Bundle, Associate Professor, University of Montana
Additional Authors:

Field measures of biological energy use during wildland fire suppression indicate that the greatest physical demands of the job typically involve load carriage during ingress and egress from the fireline. The level of exertion required by fire crews during these efforts is further influenced by the terrain, rate of travel and the load carried. Accordingly, wildland firefighters must pass the arduous pack test -- a 3 mile (4.83 km) hike completed in less than 45 min while wearing a 45lb (20.45 kg) pack -- to demonstrate the level of aerobic fitness that is critical for job performance. Delivery of individual feedback to guide the physical training of candidates during the off-season is hampered by several factors; first, successful completion of the pack test is widely considered the minimum level needed for a crew member, second, the pass/fail assessment allows candidates to self-select a sub-maximal and unknown exercise intensity and finally, the influence of body mass, stature, sex, and personal fitness level interact to preclude reliable inference from published results when hiking with heavy loads at speeds approaching the limit of human walking. We therefore measured the energy use and heart rate response of a large group of subjects completing the arduous pack test and several subsequent laboratory bouts of loaded walking. We will discuss the implications of these results to the different anthropomorphic characteristics present among wildland firefighters and the new understanding of the fitness requirements and physiology of load carriage permitted from this data.

Keywords: bioenergetics, load carriage, fitness, job readiness, physical training

Bio: Matt Bundle is an Associate Professor in the Department of Health and Human Performance and the Director of the Biomechanics Laboratory at the University of Montana. His area of research expertise is the physiology and mechanical performance of the body's nervous and muscular systems during an array of human powered movements. His work on human gait and muscle performance has been published in scientific journals, presented at international meetings, and highlighted by print and broadcast media from around the world.

S17.3. Hydration is not your only option in the avoidance of heat related injuries
Presenter: Charles Dumke, Professor, Graduate Program Coordinator, University of Montana, Health and Human Performance
Additional Authors:

Wildland firefighters (WLFF) are at risk for heat related injuries. Because of this, hydration is a focus for mitigating risks while working in hot environments while wearing personal protective equipment (PPE). Although not inappropriate, other factors contribute to elevations in core and skin temperature that put the WLFF at risk. Research at the University of Montana has focused on this very risk. This presentation will provide a summary of some of that work and the strategies available to mitigate the accumulation of heat. Previous research has addressed factors such as acclimation, fitness, PPE, work to rest ratios, work intensity, individual characteristics, and drink constituents. Administrative policies dictate some of the decisions affecting the accumulation of metabolic heat (type and use of helmets, shrouds, etc…); however, crew bosses and individuals themselves are also

in control of factors contributing to heat related injuries. This talk will focus on practical applications for the attenuation of the accumulation of heat in the WLFF.

Keywords:

Bio: Chuck Dumke, PhD, FACSM has been a professor for 18 years, first at Appalachian State in NC, and since 2008 at the University of Montana. His areas of interest span across energy expenditure, fuel utilization, sport nutrition, environmental physiology, and adaptations to exercise. He has published more than 100 peer-reviewed articles on these topics. Dumke is a fellow of the ACSM and serves on several national and regional committees. He is not a firefighter, but in his free time he enjoys competing in triathlons, biking, running, taking on building projects with little know-how, and coaching his son in ball sports.

S17.4. The Safety Zone: Injury Prevention Strategies for the WLFF
Presenter: Valerie Moody, Professor, HHP, Program Director Athletic Training, University of Montana
Additional Authors:

Wildland firefighters (WLFF) face extremely dynamic work environments posing an increased risk for injury. Working in remote environments with steep terrain, uneven ground, variable temperatures, and elevations ranging from sea level to high altitude is not uncommon. Environmental factors coupled with long arduous hours and the physical demands of the job cultivate injury risk in these tactical athletes. WLFFs are often deployed to a fire for days to weeks at a time. Therefore, it is critical to optimize performance and safety by minimizing injury risk. It is critical to examine and better understand types of injuries that WLFFs sustain while on the line. Keeping these individuals healthy and safe is vital not only to the success of wildland fire suppression, but also to fire management services and to the communities they serve. The purpose of this investigation was to determine what types of injuries WLFFs sustain, determine if these injuries were perceived as preventable, and conduct an analysis on environmental factors to guide future recommendations for injury surveillance and injury prevention programs. This session will discuss the types of injuries sustained as well as specific recommendations for development and implementation of injury prevention strategies.

Keywords: Injury prevention; firefighter safety

Bio: Valerie is currently in her 12th year at the University of Montana where she serves as Program Director of the Athletic Training Program. She is the Vice President of External Affairs for the NATA Foundation, President of the Montana Athletic Trainers' Association and is a CAATE Review team Coordinator. She serves on several committees at the local, regional and national level and is active in researching youth sports safety as well as injury prevention strategies in wildland firefighters. She enjoys spending time with her husband and two children playing ice hockey and flyfishing.

S17.5. Challenges of Developing a Physical Training Program for WLFFs: Lesson Learned
Presenter: Annie Sondag, Professor, University of Montana
Additional Authors: Pena, Jose - Graduate Research Assistant, Health and Human Performance, University of Montana

A group of researchers at the University of Montana were tasked with creating a performance training program to improve work capacity and prevent injuries among wildland firefighters (WLFF)

in the United States. The program was metaphorically named "The Black" in reference to a recently burned, and thus blackened, area of land used by WLFFs as a safety zone. The Black performance program aimed to become an ongoing "safety zone" through its development of evidence-based, job-specific physical training routines, educational materials and physical fitness screenings, among other features. Participants in The Black consisted of a group of experienced WLFFs who attended a "Train the Trainer" seminar conducted over three days in Bakersfield, CA. Seminar attendees were asked to recruit the first-year pilot cohort, consisting of their crew mates. The pilot cohort was invited to participate in an evaluation conducted for the purpose of improving and refining the program. Evaluators used a mixed-methods research approach, gathering both interview and digital survey data. Analysis of data revealed that The Black was considered to be a reliable and valuable source of information, and users perceived the scientific expertise of the developers, as well as the specificity of the program for WLFFs, as positive. Despite the encouraging feedback, the program was not widely disseminated and consistent use of the program was not sustained. Although the program was tailored specifically for WLFFs, the heterogeneity of this population may require further diversification of content in an effort to address the varied needs of specific crew types and individual resources, adjusting to their seasonal cycles. Lessons learned from this attempt to create a standardized performance training program will be shared. Additionally, program developers' will discuss plans for remodeling the program to better meet the WLFF's needs.

Keywords: wildland firefighter, training program, program development, evaluation

Bio: Annie Sondag is a professor specializing in Community Health and Prevention Sciences within the Department of Health and Human Performance. She completed her Doctorate in Community Health at Southern Illinois University. Her teaching includes a focus on health behavior theory and program development and evaluation. She works closely with the Montana Department of Public Health and Human Services conducting health related needs assessments and program evaluations. Her work with the U.S. Forest Service includes an assessment of the barriers and motivators to physical training among wildland firefighters, and an evaluation of a standardized performance training program for wildland firefighters.

S17.6. Podcasts, social media, websites and their role in knowledge dissemination

Presenter: Charles Palmer, Professor, University of Montana

Additional Authors:

Wildand firefighting is an extremely challenging occupation, and taxes the mind and body in a myriad of ways, be it physical, nutritional, or psychological. Research has helped to answer many questions in terms of understanding how best to prepare individuals for the rigors they will face on the fireline. However, much of that knowledge never makes it to the end user, the wildland firefighter. Reading peer reviewed journals and attending scientific conferences are not high on the "to do" lists of most firefighters. This simple fact raises an important question: how best can we get useful, empirically-based information in to the hands of firefighters so they can potentially be safer and more effective at what they do? Researchers at the University of Montana are employing a multitude of different strategies to breakdown this divide through the usage of podcasts, website resources, and social media avenues, and with very positive results. The process for doing so will be articulated during this session.

Keywords: wildland firefighters, podcasts, websites, social media

Bio: Charlie worked for nearly twenty years as a wildland firefighter, in a variety of different capacities and with three different federal agencies. He spent ten years of his fire career with the Missoula Smokejumpers, based in Missoula, Montana.

Dr. Palmer joined the University of Montana's Department of Health and Human Performance in August of 2006, where he continues to teach and conduct research, primarily focusing upon human factors in wildland firefighting. Dr. Palmer is the author of Fired Up!: The Optimal Performance Guide for Wildland Firefighters, and Montana's Waldron Creek Fire: the 1931 Tragedy and the Forgotten Five.

S18.1. A Real Barn Burner: The Effectiveness of Home Protection During Wildfire

Presenter: Jude Bayham, Assistant Professor, Department of Agricultural and Resource Economics, Colorado State University
Additional Authors: Yoder, Jonathan, Professor, School of Economic Sciences, Washington State University

Federal expenditures on wildfire suppression have risen dramatically over the past several decades and regularly exceed $2 billion per year. Previous research suggests that the emphasis on structure protection is one of several factors contributing to increasing suppression expenditures. However, the effectiveness or efficiency of structure protection is not well-understood. The objective of this paper is to quantify the marginal effectiveness of suppression resource effort assigned to protect homes.
We use detailed panel data on large wildfires in the Western US from 2001-2010 to estimate an econometric model of home damage in response to suppression resource effort. The wildfire data come from Incident Status Summary (ICS-209) reports filed almost daily during an active suppression effort. These data contain information on wildfire behavior, suppression resources assigned to the fire, environmental conditions, and counts of structures threatened, damaged, and destroyed. Suppression resources include ground crews, aircraft, dozers, and engines. We supplement this data with daily weather data from NOAA National Climate Data Center, median home value data from the US Census, and a spatially explicit data on housing density. We hypothesize that suppression resources assigned to protect homes will mitigate damage to threatened homes.
We develop a two-part econometric model to estimate damage to homes as a function of suppression resources. Part one consists of a probit regression used to estimate whether suppression resources reduce the probability that homes become threatened conditional on no existing threatened homes. Part two of the model also uses a probit regression to estimate whether suppression resources reduce the probability that homes are damaged conditional on being threatened.
Preliminary results suggest that ground crews and engines, suppression resources generally assigned to structure protection, have little influence on the probability that homes become threatened by a fire. However, ground crews and engines reduce the probability of damage to homes when homes are threatened. We also find that wind speed increases the likelihood of threatened homes as well as damage to homes. In contrast, precipitation reduces the likelihood of threat and damage to homes.

Keywords: Values at Risk, Home Protection, Suppression Resource Allocation

Bio: Jude Bayham is an Assistant Professor in the Department of Agriculture and Resource Economics at Colorado State University. Jude's work has focused on understanding the factors that drive and constrain suppression resource allocation decisions particularly around the wildland-urban interface.

S18.2. Initial Attack Effectiveness of Large Air Tankers: An Econometric Approach
Presenter: Hari Katuwal, , Tarleton State University
Additional Authors: Michael Hand
Matthew Thompson
Crystal Stonesifer
David Calkin

Large air tankers (LATs), that drop retardant to assist ground crews in suppressing fires, account for a significant share of the suppression expenditures. A better understanding of effectiveness of suppression resources employed for Initial Attack (IA) such as LAT is essential for effective IA and cost efficient wildfire management. However, there has been limited empirical study of the effectiveness of LATs for containing ignitions during initial attack. This paper seeks to improve the understanding of the conditions under which LATs are effective at containing ignitions. In this paper we use econometric methods to analyze past wildfire data to estimate the marginal effectiveness of LATs for suppressing ignitions before they become large fires.
The goal of the empirical model is to identify the average treatment effect of LAT drops on the likelihood that an ignition becomes a large fire. However, LATs are not likely randomly assigned to new ignitions. Traditional regression models could be inadequate in such circumstances. To address this endogeneity issue we explore an instrumental variables approach and a matching-on-observables estimator to identify the effect of LAT assignment to contain fires while they are still small (<300 acres) by controlling for the growth potential and other fire and weather related variables. These methods allow us to compare outcomes for ignitions that did not receive an LAT drop to ignitions that otherwise look identical but did receive LAT drops. Results provide weak evidence that LAT drops improve the likelihood of containing ignitions at initial attack under certain conditions. Ignitions where the growth potential is moderate show that LAT assignments are positively associated with the likelihood of initial attack success. However, effect sizes are small and imprecisely measured.

Bio: Hari Katuwal is an Instructor of Economics at the Tarleton State University, and he currently teaches a variety of undergraduate and graduate courses in the areas of Macroeconomics, Microeconomics, Econometrics and Environmental Economics. Hari received his PhD in Economics from the University of New Mexico. He is an applied microeconomist, and his areas of specialization lie at the intersection of Econometrics and applied Microeconomics with a specific focus on Natural Resource and Environmental Economics. He uses surveys and data, applies economic theory and estimates econometric models to make policy recommendations. His current research focuses on suppression effectiveness, efficiency, and wildfire risk management.

S18.3. Fire on the frontier: Understanding Alaskan homeowner preferences for wildfire risk mitigation

Presenter: Joseph Little, Professor of Economics, University of Alaska Fairbanks
Additional Authors: Molina, Allen, PhD Candidate, Naturals Resources and Sustainability Program, University of Alaska Fairbanks

The amount of wildfire risk mitigation that happens on private land is a key indicator for a community's overall wildfire vulnerability. In this analysis, we attempt to identify homeowner preferences for different types of wildfire mitigating activities and risk reductions in two different Alaskan boroughs. Utilities were calculated from a choice experiment delivered via online survey and were used to calculate Willingness to Pay (WTP) for the choice variables. The results of the survey indicated a strong preference for thinned fuel treatments (versus clear cutting and no treatment). These results should initially be seen though an Alaskan lens, as avoiding permafrost thaw may be a primary explanation for this strong preference. An overall appreciation for the amenity values of vegetation may also explain this preference. Results also showed a preference for neighbor's risk reduction, while also showing a larger preference for a homeowner's own risk reduction

Keywords: Fuel Treatments, Risk Mitigation, Choice Experiment

Bio: Little is a Professor of Economics at the University of Alaska Fairbanks (UAF). His research interests center on topics in environmental and natural resource economics. He currently serves as the director of the MS in Resource and Applied Economics Program at UAF.
Allen Molina is a PhD candidate at the University of Alaska Fairbanks, studying homeowner preferences for wildfire risk mitigation. He is also employed by the Oregon Department of Fish and Wildlife, as an Economist. Originally completing a Physics degree in San Francisco California, Allen made the jump to Economics, as well as the frigid winters of Alaska, to complete his MS in Resource Economics. He along with his wife, adorable 1.5 year old daughter, Malamute and Newfoundland couldn't be happier to have finally settled down in beautiful Salem, OR.

S18.4. Efficient wildfire suppression in Mediterranean ecosystems: A stochastic frontier analysis

Presenter: Michael Hand, Research Economist, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: Rodriquez y Silva, Francisco, Professor, Department of Forest Engineering, University of Cordoba (Spain)
Katuwal, Hari, Instructor, Accounting, Finance and Economics, Tarleton State Universtiy

In Spain, hundreds of fire ignitions threaten communities and highly valued resources annually. Spanish firefighting organizations respond quickly to these fires using a variety of suppression resources at their disposal, including brigades of firefighters, engines, dozers, helicopters, and fixed-wing aircraft. It is important to efficiently deploy and manage limited firefighting resources to achieve fire management objectives, often with a small window of time to control potentially damaging fires. Yet to date little empirical information is available to guide managers of Spanish wildfires on how productive inputs (i.e. suppression resources) can be combined to efficiently control fires. Research on production models and efficiency of wildfire suppression has primarily focused on large wildfires in the western United States.

In this paper we use an econometric approach to estimate suppression production and efficiency functions for wildfire incidents in Andalusia, Spain. Using detailed data of suppression resource

assignments, geospatial information, and fire incident outcomes from a sample of 168 incidents, we conduct a stochastic frontier analysis (SFA) to determine production relationships between suppression inputs (brigades, engines, dozers, helicopters, fixed-wing aircraft) and factors that affect the efficiency of suppression operations (terrain, weather, fire behavior). We estimate SFA models for two dependent variables: length of fire perimeter controlled per hour, and surface are controlled relative to modeled fire growth without suppression. The empirical estimates of the production function indicate the average marginal contribution of each suppression resource to production of the dependent variable (either smaller perimeters or greater relative reduction in burned area) and the relative rates of substitution among suppression resources. The efficiency function estimates the marginal effect on production of factors outside of a manager's control.

The estimates from the SFA model can indicate how suppression resources affect the ability to control a fire incident given characteristics of the fire environment. This information is particularly useful for managers in planning the scale of suppression efforts and the mix of suppression resources that will be most effective at controlling an ignition. In addition to aiding decision support for managers, future research could pair the SFA model with spatial models of landscape-level fire effects already in use in Spain. This would allow managers to assess tradeoffs in fire suppression efforts to determine if additional suppression resources (or a different mix of resources) would yield net benefits in terms of avoided damage or resource loss.

Keywords: suppression effectiveness, production function, suppression efficiency, Spain

Bio: Michael Hand is a research economist with experience in applied research on wildfire suppression expenditures and effectiveness, perceptions and responses to risk, the value of ecosystem services, and behavioral economics. He received his PhD in Economics from the University of New Mexico in 2007, and now works and lives in Washington, DC.

S18.5. The role of previous fires in the management and expenditures of subsequent wildfires

Presenter: Erin Belval, Forest Operations Research Associate, Department of Forest & Rangeland Stewardship, Colorado State University
Additional Authors: Hand, Michael, Research Economist, USDA Forest Service
Thompson, Matthew P, Research Forester, USDA Forest Service
O'Connor, Christopher, Ecologist, USDA Forest Service

Growing federal wildfire suppression expenditures over time have motivated research to examine how specific factors influence suppression costs. Previous work suggests that past fires might influence suppression expenditures, however the specific mechanisms through which these past fires influence subsequent fire expenditures remain poorly understood. We build upon a previously developed spatial-temporal model of wildland fire expenditures by adding two new sets of data: 1) the area of overlap between each fire and previous fires' footprints (preburned area) and 2) the length of the fire perimeter that aligns with the perimeter of previous wildfires (perimeter overlap). Including these new data in the model allows us to examine how managers leverage features of the fire environment when deploying suppression resources and how these decisions affect cost. We test how the preburned area and perimeter overlap variables affect costs as well as how these variables interact with each other fire environment factors (e.g., perimeter overlap interacting with distance to a city). We then discuss management responses to previous fires that might be responsible for the results we observe.

Keywords: Suppression costs

Bio: Erin Belval is a researcher at Colorado State University. She holds doctorate in forestry and a masters of engineering from Colorado State University and a bachelors in physics from Reed College. She applies operation research methods to fire management problems to examine the effectiveness and efficiency of current management practices. Her recent work focuses on quantifying how resources are used and shared across the United States throughout the fire season.

S18.6. Examining the Spatial Alignment of Large Airtanker Use and Potential Fire Control Locations

Presenter: Crystal Stonesifer, Ecologist, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: O'Connor, Christopher, Ecologist, USDA Forest Service, RMRS
Calkin, Dave, Research Forester, USDA Forest Service, RMRS
Rieck, Jon, Biological Scientist, USDA Forest Service, RMRS

Faced with rising suppression costs, the USDA Forest Service is actively working toward addressing the need for increased efficiency and effectiveness throughout all areas of fire management. Large airtankers are key suppression assets. However, while these aircraft represent a relatively small number of resources (approximately 20 federally owned and contracted airtankers in 2017), they account for a disproportionate amount of wildfire cost and exposure. Understanding where and under what conditions these resources are used is an important objective for achieving Agency-scale improvements in efficiency.

The effectiveness of individual fire suppression resources is greatly dependent on landscape features, fire weather, and other spatial factors defining the fire environment. Water and retardant delivery aircraft are no exception. An informed response to fire activity in a given area that integrates local knowledge, geospatial landscape data, and fire modeling techniques can be used to assess suppression action effectiveness. Knowing in advance where, and under what conditions suppression actions are likely to succeed or fail has potential to significantly reduce aviation resource exposure and to improve the effectiveness and efficiency of these limited and relatively costly assets. Here we present a retrospective large fire case study where we examine the spatial alignment of large airtanker drop lines with potential control location data to illustrate the possible utility of these products in a real-time decision-making environment, where management activities are focused on minimizing exposure and committing responders only to those operations where they can be successful.

Keywords: airtanker, suppression effectiveness, potential control locations

Bio: Crystal Stonesifer is an Ecologist with the USDA Forest Service, Rocky Mountain Research Station in Missoula, MT. She graduated from the University of Montana with an MS in Resource Conservation and has been with the station for 7 years. Her primary areas of research interest and expertise center around fire management, including related data systems, aviation use, decision-support, and risk management.

S19.1. Assessing water contamination risk following vegetation fire: challenges, opportunities and a framework for progress

Presenter: Stefan Doerr, Professor, Swansea University, UK
Additional Authors: Nunes, Joao; University of Lisbon, Portugal
Sheridan, Gary; The University of Melbourne, Australia
Neris, Jonay; Swansea University, UK
Santin, Cristina; Swansea University, UK
Emelko, Monica; University of Waterloo, Canada
Silins, Uldis; University of Alberta, Canada

Fires represent one of the most hydrologically significant landscape disturbances, and affect ~4% of the global vegetated land surface each year. Ca 60% of water for the world's largest cities is supplied from fire-prone or fire-managed ecosystems such as forests, grasslands and peatlands. These cities are therefore exposed to the risk of significant water quality declines following severe wildfires as several examples in recent years have shown. This risk is projected to increase due to not only rising fire weather severity and lengthening fire seasons, but also regional trends in afforestation, land abandonment and suppression of small fires.

Landscape fires can lead to enhanced runoff and erosion, which, combined with the creation of a highly mobile ash layer, can transfer sediment, nutrients, and contaminants such as polycyclic aromatic hydrocarbons and heavy metals to streams and reservoirs. When fires follow prolonged droughts, these impacts may be enhanced by low reservoir water storage leading to reduced contaminant dilution. Our understanding of these processes to date is based predominantly on point and hillslope-scale studies. These report an enormous variability in both the drivers of post-fire contaminations, such as the type of pollutants or the mobilisation and transport processes; and on the quality issues of concern for end-users and water managers. This has resulted in a limited knowledge base, with regionally diverse case studies and few unifying points. It has therefore remained difficult to reliably assess post-fire contamination risks in fire-prone catchments, and to propose effective mitigation strategies.

Here we present a framework aimed to address regional and universal knowledge gaps in post-fire water contamination risk assessment in a coherent manner via three steps (i) identifying contaminants and water assets of concern, (ii) understanding the dominant processes that govern contaminant mobilisation; and (iii) mapping the dominant pathways that link contaminants to areas of concern. We also highlight current limitations in each step, as well as recent advances that could help in addressing the most critical water quality risks not only after, but also before the occurrence of significant fire events.

Keywords: water quality, ash, pollution, risk assessment, catchment management

Bio: Prof. Stefan Doerr holds a Diplom in Geography with Botany and Geology from Universität Tübingen. His PhD examined the effects of forest fires on soil hydrological processes. He is Professor of Physical Geography at Swansea University (UK) and Editor-in-Chief for the International Journal of Wildland Fire. He focuses on wildfire impacts, carbon dynamics, soil hydrology, water repellency and geomorphology. He has investigated the environmental impacts of wildfires in Europe, Australia (including the catastrophic 'Black Saturday' fires of 2009), and North America, with a focus on the relationships between fire severity, emissions, carbon dynamics, post-fire hydrology and water contamination risk.

S19.2. Prioritizing fuel treatments to reduce wildfire risk to municipal watersheds

Presenter: Benjamin Gannon, Research Associate, Colorado Forest Restoration Institute at Colorado State University
Additional Authors: Wei, Yu, Associate Professor, Department of Forest and Rangeland Stewardship at Colorado State University
Kampf, Stephanie, Associate Professor, Department of Ecosystem Science and Sustainability at Colorado State University
MacDonald, Lee, Professor Emeritus, Department of Ecosystem Science and Sustainability at Colorado State University
Jones, Kelly, Assistant Professor, Department of Human Dimensions of Natural Resources at Colorado State University
Wolk, Brett, Assistant Director, Colorado Forest Restoration Institute at Colorado State University
Cheng, Antony, Director, Colorado Forest Restoration Institute at Colorado State University

Wildfire increases the potential for erosion and sediment transport in forested watersheds to the detriment of downstream communities adapted to clean and regular water supplies. Water providers are investing in fuel reduction treatments to mitigate risk of wildfire impacts to their source water systems; however, questions remain about the effectiveness of fuel treatment strategies and the scale of investment required to meaningfully reduce risk of wildfire impacts to water supplies. We used the Big Thompson and Cache la Poudre Watersheds in northern Colorado (4,800 km^2), which contain three large municipal water systems and a major transbasin diversion, as a test case for prioritizing fuel treatments for watershed protection. A linked model approach was used to estimate risk reduction to downstream water infrastructure for multiple fuel reduction activities (e.g. mechanical thinning, prescribed fire, or both) by coupling burn probability, fire behavior, erosion, and sediment transport models with stakeholder-defined sediment impact costs. We then combined risk reduction estimates with modeled fuel treatment costs and feasibilities to parameterize a linear optimization model to maximize risk reduction to water infrastructure for a set of catchment and treatment type decisions. We found high variability in the cost-effectiveness of risk reduction due to existing fuel conditions, treatment type, erosion potential, proximity to infrastructure, and fire likelihood. Optimal treatment strategies target primarily densely-forested, steep slopes along higher order channels that contribute to multiple downstream values. Although prioritization can improve the efficiency of fuel treatment investments, our risk reduction and treatment cost estimates suggest there is not a positive financial return on investment for fuel treatments in these watersheds when considering only sediment impact costs to water systems, primarily due to low expected fuel treatment-wildfire encounter rates and high fuel treatment costs. For some water infrastructure, fuel treatment feasibility also considerably limits the risk that can be addressed with fuel treatment. Tools like this can be applied in other forested watersheds to spatially describe risk, streamline planning, and demonstrate potential outcomes of fuel treatment investments to protect source water supplies.

Keywords: risk assessment, fuel treatment planning, watershed protection

Bio: Ben is a Research Associate with the Colorado Forest Restoration Institute at Colorado State University. He works on management-driven questions in fire ecology, forest restoration, and watershed science.

S19.3. Forests to Faucets in National Forest risk assessments: a national perspective
Presenter: Greg Dillon, Spatial Fire Analyst, USDA Forest Service, Rocky Mountain Research Station
Additional Authors: Thompson, Matthew, Research Forester, USDA Forest Service, Rocky Mountain Research Station

Spatial wildfire risk assessments that account for both the probability and consequences of wildfire events are becoming an important element of strategic fire and fuels planning. Integral to that process is the identification of highly valued resources and assets (HVRAs) on the landscape that could potentially be impacted by wildfire. Within the National Forest System (NFS) in the U.S., land managers consistently identify the supply of surface drinking water to nearby populations as one of these HVRAs to include in risk assessments. We recently completed analysis for a national-scale risk assessment for all NFS in the conterminous U.S., using the Forests to Faucets dataset as the basis for the surface drinking water HVRA layer. In this presentation, we will discuss considerations around the spatial representation of, estimates of post-fire effects on, and variation in prioritization of surface drinking water importance in our assessment.

Keywords: wildfire risk, national forests, surface drinking water

Bio: Greg Dillon is a Spatial Fire Analyst with the Fire Modeling Institute, part of the USDA Forest Service Rocky Mountain Research Station's Fire Sciences Lab in Missoula, Montana. His work generally involves geospatial and statistical analyses of large spatial datasets related to fire and fuels management. He is currently involved in spatial wildfire risk assessments at national, forest, and community scales. Greg's previous work includes potential vegetation mapping for the LANDFIRE project and analysis of satellite-derived burn severity data. He has an MA in Geography from The University of Wyoming, and a BS in Geography from James Madison University.

S19.4. Stream channel stability at Fishtrap Creek after the 2003 McLure Fire, British Columbia, Canada
Presenter: Tim Giles, Research Geomorphologist, Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Additional Authors: Owens, Phil PhD. FRBC Endowed Research Chair in Landscape Ecology, UNBC

Wildfire is increasingly becoming the dominant natural disturbance in the dry southern interior of British Columbia. In addition to having a major impact on vegetation, wildfires may have extreme impacts on the vulnerability of soils to erosion and the consequent delivery of sediment from hillslopes to adjacent rivers. Increased sediment transport in rivers will have detrimental effects on water quality where high sedimentation rates can cause long-lasting ecological damage. Wildfire events, therefore, have important implications for natural resource management and ecosystem recovery in forested systems. There is considerable interest in the response of forested catchments to wildfires, and how things may change in the near future due to climate change.
The 2003 McLure Fire burned 26,420 hectares, including most of Fishtrap Creek watershed, which fortuitously had an established Water Survey of Canada stream gauge. The B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development along with the University of Northern British Columbia and the University of British Columbia began a long term study of the physical water quality, sediment genesis, groundwater, channel and bank stability and bedload movement in 2004. Water quality sampling, sediment genesis study and channel stability is ongoing through 2018. The riparian zone has yet to regenerate with larger trees and the channels continue to migrate across the floodplain.

Keywords: Wildfire, stream channels, channel stability, water quality, sediment genesis

Bio: Tim Giles is a Research Geomorphologist with the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Thompson Okanagan Region in Kamloops, British Columbia. He is currently studying the relationship between stream channels and hillslope processes throughout the various biogeoclimatic and physiographic regions of south central British Columbia. Permanent reach sites have been established, surveyed and photographed with detailed, low-level techniques to form a visual compendium of stream types and conditions.

S19.5. Muted streamflow response to increased net precipitation in wildfire-affected headwater catchments

Presenter: Chris Williams, , University of Alberta
Additional Authors: Silins, Uldis, Professor - Forest Hydrology, University of Alberta
Anderson, Axel, Water Program Lead, fRI Research, Hinton, Alberta

Wildfire can lead to widespread loss of forest canopy, which can affect the amount of precipitation reaching the forest floor and the subsequent routing of water to streams. Despite the potential for significant post-wildfire increases in net precipitation (PN), especially in dense sub-alpine coniferous forests, very few studies have attempted to quantify PN increases. Additionally, while post-wildfire runoff has been widely studied in regions of the United States, Australia and others, little information exists on post-wildfire runoff in the Canadian Rocky Mountains.

This study focuses on the first 10 post-fire years following the Lost Creek wildfire in southwestern Alberta, and combines information from the forest stand to watershed scale (3 burned, 2 reference catchments; 3.7 to 10.4 km2) to quantify changes in PN and runoff magnitude and timing. Traditional approaches from the rainfall interception literature were used to quantify throughfall and stemflow (=PN) during the summers of 2006-08 in burned and reference mixed subalpine fir stands. Snow accumulation was also measured in burned and reference stands annually (2005-14) near the date of peak snow water equivalent (SWE). Using hourly data from a dense network of precipitation and hydrometric gauging stations, runoff magnitude and timing were compared at three time scales: event-based summer stormflows, weekly total runoff, and monthly total runoff. At the event scale, baseflow separation was performed on hourly runoff data and stormflow (quickflow) magnitude was calculated as a function of total event rainfall. Rainfall intensity (I30), derived from 10-minute data, was also used as a predictor of storm/peak flow magnitudes. Additionally, basin lag and time-to-peak were calculated for each event. Weekly and monthly total runoff was also calculated to acquire a combined measure of runoff magnitude and timing.

Significantly higher PN was measured in the burned forest stand when compared with the reference, with 39% (126 mm) additional annual inputs of rain to the forest floor and approximately 60% (133 mm) more SWE each winter. However, this seemingly large hydrologic forcing does not appear to have translated into large impacts on runoff. Preliminary analyses show some evidence of earlier snowmelt runoff in burned watersheds, but no significant differences in stormflow magnitude or timing between burned and reference watersheds were detected.

Keywords: wildfire, net precipitation, runoff, magnitude, timing, mountains, coniferous forest

Bio: Chris Williams is currently a PhD student at the University of Alberta studying post-wildfire precipitation-runoff dynamics in Rocky Mountain headwater catchments. He has worked for the Southern Rockies Watershed Project (PI: Dr. Uldis Silins) since 2006 supervising field and lab work.

S19.6. Hydrologic Recovery After High Severity Wildfire

Presenter: Joe Wagenbrenner, Research Hydrologist, USDA Forest Service, Pacific Southwest Research Station
Additional Authors: Robichaud, Pete, USDA Forest Service
MacDonald, Lee, Colorado State University

Wildfires often significantly increase runoff and erosion rates, which can be detrimental to human safety as well as to forest and aquatic ecosystems. This is particularly true when high intensity or high magnitude precipitation occurs before the burned area has hydrologically recovered. Although many studies have documented short-term post-fire hydrologic responses, few studies have measured the effects of high severity fires on hydrologic processes for periods of more than two or three years. We collected or obtained precipitation and runoff data from a number of burned watersheds across the western US. While one location had a long pre-fire record, we generally had to rely on a comparison to reference conditions for the other watersheds. Hydrograph partitioning between pre and post-fire conditions clearly demonstrates the fire-induced shift in runoff mechanism to infiltration-excess overland flow. Hydrograph changes over time indicated a general decline in the frequency and magnitude of overland flow relative to subsurface flow, which we attribute to a shift in the threshold for overland flow initiation as the sites recovered. The data indicate that the reversion of runoff generation mechanism to subsurface storm flow usually occurs within about three years. However, with higher rainfall intensities overland flow could still occur five or more years after burning, particularly when revegetation was slow or burn severity was exceptionally high. This research helps clarify the changing risks over time with respect to increased overland flow, particularly flooding and soil erosion and the subsequent impacts of increased sediment delivery on water treatment, sedimentation, debris flow formation, and changes to stream morphology.

Keywords: post-fire, watershed, overland flow, flooding, recovery, resilience

Bio: Joe is a Research Hydrologist with the USDA Forest Service Pacific Southwest Research Station. He began research on the effects of fire and other disturbances on watershed properties and processes in 2000. Relevant work includes measuring the effects of fire on soil properties, runoff generation, erosion, and sediment delivery; testing the effectiveness of various post-fire runoff and erosion mitigation treatments; and assessing the impacts of post-fire salvage logging and post-salvage site preparation operations.

S19.7. Alternate Trajectories for Post-fire Watershed Recovery: Crystal Balling Nitrogen Production a Decade after Wildfire and Beyond

Presenter: Uldis Silins, , University of Alberta
Additional Authors: Emelko, Monica, Dr., Dept. of Civil & Environmental Engineering, University of Waterloo, Waterloo, ON, Canada.
Bladon, Kevin, Dr., Dept. of Forest Engineering, Resources & Management, Oregon State University, Corvalis, OR, U.S.A.
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While post-fire watershed recovery is often viewed through the lens of steady recovery of hydro-geomorphic processes back to pre-fire conditions, ecohydrological interactions between vegetation and stream biogeochemistry can add additional complexity to this notion. This is particularly true of ecosystem limiting nutrients such as nitrogen (N) where watershed exports reflect the balance between inputs and ecosystem uptake. A long-term study of post-disturbance N production more than a decade after severe wildfire in Alberta's Rocky Mountains provides important clues into ecohydrological drivers of potential decadal or successional trajectories of N export outside the basic notion of watershed recovery. Large initial increases in stream total N (TN) and nitrate (NO_3^-) 1-3 yr. after wildfire in both burned and burned /salvage logged watersheds declined strongly to levels similar to, and later well below that of unburned reference watersheds 4-6, 7-9, and 10-11 yr. after the fire. These changes closely corresponded with the early post-fire trajectory of initial establishment, early and latter juvenile growth of upper Montane and sub-alpine forest vegetation in both burned subsequently salvage logged watersheds. These results provide strong clues into likely trajectories of watershed N exports in the coming decades and beyond. Results of this study also provides insights into potential long-term implications of management in post-disturbance watershed resilience, and highlights ambiguity in the concept of stationary "control" or "reference" catchments, particularly for ecosystem limiting nutrients such as N.

Bio: Uldis is a forest hydrologist from the University of Alberta. His research focuses on trying to better understand hydrologic, geochemical, and ecological responses after both natural and managed forest disturbance.

S19.8. Impacts of the Fort McMurray Wildfire on the River Water Quality of Burned Catchments

Presenter: Craig Emmerton, Watershed Scientist, Government of Alberta (Environment & Parks)
Additional Authors: Cooke, Colin, Watershed Scientist, Government of Alberta
Kerr, Jason Watershed Scientist, Government of Alberta
Hustins, Sarah, Water Quality Technologist, Government of Alberta
Jackson, Brian, Water Quality Supervisor, Government of Alberta
Kruk, Mary, Data Technologist, Government of Alberta
Taube, Nadine, Data Technologist, Government of Alberta

The May 2016 Fort McMurray (Horse River) wildfire in northeastern Alberta, Canada was the most expensive insurable disaster in Canadian history. The wildfire caused the evacuation of nearly 90,000 people, destroyed over 2,000 structures and consumed almost 600,000 hectares of Boreal forest. The fire also disturbed operations within the Athabasca Oil Sands Region; one of the world's largest and most intensively-monitored industrial projects. The watersheds of the Athabasca River and several tributaries were burned near Fort McMurray, raising concerns about changes in the quality of river waters ultimately used for drinking, recreation and industry. During the growing season (2016) and snowmelt (2017) periods following the wildfire, we collected daily (ISCO) and weekly (grab) water samples from the Athabasca River and major tributaries for water quality analyses including physical chemistry, nutrients, recoverable metals and polyaromatic compounds (PACs). Concentrations and watershed yields of suspended sediments and closely correlated nutrients and metals were higher and more variable in the Athabasca River within the burned area relative to an upstream, unburned station. However, concentrations and variability of similar parameters collected from tributaries showed less consistent changes in space. Using post-fire data and historical concentration-discharge (C-Q) relationships for each river, we found only infrequent, episodic post-fire concentration increases of suspended sediments and selected ions, nutrients and metals relative to historical conditions. These episodes were short-lived and occurred during or shortly after

substantial local rainfalls or during the snowmelt period. Using post-fire PAC signatures in collected river water, ash and bitumen, we found only short-lived ash signals (i.e., 2-4 weeks) within river water draining burned watersheds, before returning to typical signatures dominated by natural bitumen. Considering the low-relief, wetland-dominated watersheds burned in this wildfire, our results suggest that water storage and landscapes resistant to hydrological connectivity limited fire-related impacts on sampled river water quality to only large snowmelt or precipitation events.

Keywords: wildfire; water quality; Boreal; river; polyaromatic compounds; nutrients; metals

Bio: Craig is a Watershed Scientist with the Alberta Government, specializing in catchment-scale responses of terrestrial and aquatic ecosystems to human and climate-related stressors. Craig earned his PhD from the University of Alberta where he studied the impacts of anthropogenic climate change on landscape carbon cycling within a large high-Arctic catchment. Afterwards, he took a post-doctoral fellowship with the IISD-Experimental Lakes Area, studying the impacts of wildfire and precipitation changes on nutrient budgets of a Boreal Shield catchment.

S19.9. The alteration of hydrological and biogeochemical behavior after wildfire, and relevance to water quality

Presenter: Sheila Murphy, Research Hydrologist, U.S. Geological Survey
Additional Authors: McCleskey, R. Blaine, Research Chemist, USGS
Martin, Deborah A., Scientist Emeritus, USGS
Writer, Jeffrey H., University of Colorado
Ebel, Brian A., Research Hydrologist, USGS

After wildfire, rain storms can deliver substantially elevated loads of sediment, organic carbon, nutrients, and metals to surface waters, leading to impairment of water supplies and drinking-water treatment processes. In order improve our understanding of the factors affecting post-fire water quality, we evaluated discharge and water quality of streams for five years after the 2010 Fourmile Canyon Fire, Colorado, USA, with a focus on high-frequency sampling during storm events. This five-year period included three extreme climate events—a drought (the lowest winter-spring precipitation in 30 years of record) and two extreme rainfall events (one with <0.1% annual exceedance probability [AEP]). This wide range of hydrologic conditions allowed us to evaluate how different disturbance events affect relations between stream discharge and constituent concentrations, which can be used to infer hydrologic flow paths. We found that during relatively common (20-50% AEP) thunderstorms in the first two years after wildfire, concentrations of constituents present in wildfire ash—such as calcium, alkalinity, and aromatic carbon—were significantly elevated in surface waters downstream of the burned area. In contrast, concentrations of constituents that are bedrock-derived and not present in ash (e.g., sodium and silica) decreased. This change in geochemical composition was related to the generation of overland flow during thunderstorms that mobilized highly erodible ash and exposed soil, and the concomitant bypass of subsurface flow paths. In contrast, extreme-rainfall events three and five years after the wildfire saturated the subsurface and activated both shallow and deep subsurface flow paths, which led to elevated concentrations of bedrock-derived solutes and nitrate but did not alter dissolved organic carbon/discharge relations. Drought conditions led to low stream discharge and decreased constituent concentrations during spring runoff, possibly due to decreased connectivity between water and source material. This work shows that wildfires and other extreme climate events can cause abrupt changes in the hydrological and biogeochemical behavior of streams and rivers. This work is a step toward an improved framework to characterize how disturbances affect hydrologic flowpaths, mobilization of sediment and solutes, and thus concentration/discharge relationships, which will be required for accurate water-quality prediction in landscapes subject to climate and land cover change.

Keywords: Wildfire; drought; flood; Colorado Front Range; extreme climate events; water quality; aquatic ecosystems; concentration/discharge relations; chemostasis; dissolved organic carbon

Bio: Sheila F. Murphy is a Research Hydrologist at the U.S. Geological Survey. Her research focuses on hydrology and water quality of watersheds and how they are affected by both natural factors and disturbance.

S19.10. Wildfires cause long-term shifts in stream nutrient dynamics

Presenter: Allison Rhea, PhD Student, Colorado State University, Department of Ecosystem Science and Sustainability
Additional Authors: Tim Covino, Assistant Professor, Colorado State University, Department of Ecosystem Science and Sustainability
Chuck Rhoades, US Forest Service, Rocky Mountain Research Station
Tim Fegel, US Forest Service, Rocky Mountain Research Station

Wildfires influence stream nutrient processing by fundamentally altering the physical structure and biological composition of upland landscapes, riparian corridors, and stream channels. While numerous post-fire studies have documented substantial short-term increases in stream nutrient concentrations (particularly reactive nitrogen, N), the long-term implications for watershed nutrient cycling remain unclear. For example, recent work indicates that nitrate concentrations can remain elevated for a decade or more following wildfire, yet the controls on these processes are unknown. This research utilizes empirical data from water quality monitoring, coupled tracer injections, and nutrient diffusing substrates to isolate the physical and biological mechanisms controlling nutrient processing across a burn severity gradient. Coupled nutrient tracer injections demonstrate substantial stream-groundwater exchange, but little biological nutrient uptake. Complementary nutrient diffusing substrate experiments highlight shifts in community composition and nutrient limitation that alter a stream's capacity for N uptake. By isolating the mechanisms that reduce the capacity of fire-affected streams to retain and transform elevated nutrient inputs, we can better predict dynamics in post-fire water quality recovery and help prioritize upland and riparian restoration.

Keywords: wildfire, biogeochemistry, nutrient cycling, nitrogen, carbon, phosphorous, hydrology, stream ecology

Bio: Allison Rhea is a PhD student studying watershed science at Colorado State University. Her research focuses on the long-term hydrologic and biogeochemical responses of watersheds to severe wildfire. She uses a variety of approaches that includes reach-scale biogeochemistry, catchment and hillslope hydrology, stream ecology, and remote sensing. She spends her free time climbing, skiing, and hiking throughout the Rockies.

S19.11. Using Watershed Scale Models to Predict Water Quality in Streams After Forest Fire
Presenter: Ashley Rust, Post Doctorate Researcher, Colorado School of Mines
Additional Authors: Hogue, Terri PhD, Civil and Environmental Engineering Department Chair, Colorado School of Mines

Wildfire size and frequency are increasing across the globe, creating short-term and long-term impacts on water quality. Surface water in forested watersheds provides water for municipal water supplies and aquatic ecosystems. After fire, runoff and erosion lead to elevated loading of nutrients, sediment, and metals in receiving streams for different extents of time. Our prior work using 159 wildfires across the western United States from 1984-2012 revealed significant increases in nutrient flux (different forms of nitrogen and phosphorus), major-ion flux, and metal concentrations are the most common changes in stream water quality within the first five years after fire. The current research follows up on this extensive survey of water quality response by developing tools to help quantify and predict nutrient loading. Currently, there are no published studies that attempt to model nutrient response after fire. Models that simulate hydrological response on the watershed scale are important tools in the field of hydrology. A hydrologic model, SWAT (Soil and Water Assessment Tool), is developed to quantify forest fire's impact on nutrient loading. SWAT has been widely used to model water quality impacts from land use change, including predicting sediment movement and nutrient loading. SWAT is applied to model dissolved and particulate nutrient loading after two fires: the 2002 Rodeo fire in Arizona and the 2013 West Fork Complex fire in Colorado. The SWAT model is applied to both watersheds and calibrated to current loading conditions. Improved water quality models will help facilitate management recommendations for water quality mitigation after fire and reduce nutrient loading to downstream water supplies. Prediction of fire impacts on water quality and aquatic ecosystems is critical as we experience more frequent and larger wildfires.

Keywords: water quality, watershed scale model

Bio: Ashley Rust is a post doctorate researcher for Dr. Terri Hogue at the Colorado School of Mines. Dr. Rust recently completed her PhD in hydrological sciences and engineering at the Colorado School of Mines. Dr. Rust also has a bachelors and master's degree in fish ecology from the University of Michigan. She is interested in how forest fires impact water quality in receiving streams and how the fish and aquatic insects are effected. She also teaches courses at both the School of Mines and Metropolitan State University of Denver. Dr. Rust loves to do field work and to be outside fishing.

S19.12. Eight Years Later: Long-term Effects of Severe Wildfire on Aquatic Ecology in Rocky Mountain Streams
Presenter: Amanda Martens, MSc Student, University of Alberta
Additional Authors: Silins, Uldis, Professor, University of Alberta
Proctor, Heather C., Professor, University of Alberta
Luchkow, Evan, Filmmaker/Entomologist
Williams, Christopher H.S., Hydrologist, University of Alberta
Wagner, Michael, Forest Hydrologist, Government of Alberta

Wildfire is an important natural disturbance on forested landscapes influencing both physical and biological processes. The 2003 Lost Creek wildfire was one of the most severe on Alberta's eastern slopes and provided a unique opportunity to assess the long term effects of wildfire on northern Rocky Mountain watersheds. The Southern Rockies Watershed Project (SRWP) was established to document the effects of the fire on hydrology, biogeochemistry and aquatic ecology. Eleven years of

continuous monitoring in reference (unburned), burned and burned & salvage logged watersheds has shown the effects of the wildfire on water quality and biogeochemistry to be persistent. Sediment production, nutrient (phosphorous and dissolved organic carbon) export and primary productivity have shown no signs of recovery over a decade post-wildfire.
Macroinvertebrates were sampled eight years after the wildfire to assess the long-term impacts on aquatic fauna. Invertebrates were identified to the finest practical taxonomic level and enumerated. Ordinations performed using non-metric multidimensional scaling (NMS) with Bray-Curtis dissimilarity matrices indicated distinct macroinvertebrate assemblages in reference, burned, and burned & salvage logged watersheds ($p < 0.01$). Burned watersheds had the greatest abundance of macroinvertebrates and were characterized by greater abundance of chironomids and caddisflies. Burned & salvage logged watersheds supported high numbers of riffle beetles and crane flies. Reference watersheds were characterized by more stonefly taxa and had the lowest abundance of macroinvertebrates. Stable isotope analysis of carbon and nitrogen was utilized to evaluate ecosystem energy dynamics and describe trophic relationships. Greater invertebrate productivity and enrichment in $\delta^{15}N$ in burned watersheds has been attributed to increased utilization of periphyton (instream) energy sources; however fewer studies have quantified the stable isotope signatures of the primary producers in disturbed catchments. Terrestrial and instream primary producers and macroinvertebrates in our wildfire affected catchments were all enriched in $\delta^{15}N$ by 0.71 to 2.02‰ ($p < 0.01$). The consistent enrichment in $\delta^{15}N$ across primary producers and consumers suggests that eight years post-fire the relative utilization of terrestrial and instream energy sources is not different between reference and burned watersheds but rather a reflection of a change in isotope ratios due to increased nitrogen uptake from an early succession forest.

Keywords: Wildfire, Aquatic Ecology, Macroinvertebrates, Stable Isotopes

Bio: Amanda completed her BSc in Ecology at the University of Alberta. She worked for 6 years on the Southern Rockies Watershed Project researching the effects on the Lost Creek wildfire on hydrology and aquatic ecology before starting her MSc. Her thesis work investigates the long term impacts of wildfire on aquatic macroinvertebrates and fish.

S19.13. Wildfire effects on soil hydraulic properties and organic matter in a southern Appalachian hardwood forest

Presenter: Kevin Bladon, Assistant Professor, Oregon State University
Additional Authors: Hatten, Jeff, Associate Professor, Oregon State University
SanClements, Mike, Senior Scientist, The National Ecological Observatory Network, University of Colorado
Strahm, Brian, Associate Professor, Virginia Tech University
Matosziuk, Lauren, Postdoctoral Scholar, Oregon State University
Egan, Jessie, M.Sc. Candidate, University of Colorado
Ruud, Danica, B.Sc. Honors, Oregon State University

The Chimney Tops 2 Fire burned 4,617 ha of the Great Smokey Mountain (GRSM) National Park, a National Ecological Observatory Network (NEON) site, in November 2016. Studying the effects of wildfire is always challenging due to the rapid post-fire changes to the environment and lack of robust controls. However, the location of the fire created a rare opportunity to assess and contrast pre- and post-fire soil and dissolved organic matter. We are currently examining both the solid and dissolved phases of thermally altered soil carbon to determine its fate in the environment. We are also attempting to quantify the effects of fire on the soil hydraulic properties, which would affect the

hillslope processes delivering water and carbon to the stream. Here, we will present preliminary data from a study examining the effects of fire on the movement of thermally altered dissolved carbon to deeper soil horizons (B and C horizons). We expect there to be an enrichment of thermally altered carbon at depth, which may be related to the constituents' molecular mass:charge, water flux through the soil profile, and time since fire. We will also present preliminary data examining the transport of DOC from the soil into the stream, using pre- and post-fire fDOM to examine how the flux of DOC has changed due to fire. We will tie these results to the soil with periodic measurements of DOC samples for detailed characterization of DOC quality (fluorescence, HPLC, GCMS, NMR, FTICR-MS). Using the soil solutions as our endmembers we will be able to determine the source of DOC and whether it is coming from a burned (solutions extracted post-fire collected cores and grab samples) or unburned (solutions extracted from pre-fire collected MSB cores). Additionally, we are investigating the effects of fire on soil hydraulic properties, which would influence the transport of both soil and carbon from soils to the stream. We will present preliminary data on soils water characteristics curves and hydraulic conductivity to provide key information about how fire may have affected soil water storage and permeability, thus influencing the movement of dissolved constituents. Overall, we intend for this information to facilitate a thorough examination of the effect of fire on the relative flux of DOC and thermally altered DOC from the watershed pre- and post-fire.

Keywords: soil hydraulic properties, carbon, soils

Bio: Kevin Bladon is an Assistant Professor of Forest Ecohydrology and Watershed Science in the Forest Engineering, Resources, and Management Department at Oregon State University. His research focuses on wildfire effects on water quantity, water quality, and aquatic ecology. He is also interested in transdisciplinary research, investigating the implications of forest disturbance on downstream drinking water treatability.

S19.14. Forest Fire Alters Dissolved Organic Matter Exports from Forested Watersheds: Impacts on Water Quality & Treatability

Presenter: Alex Chow, Associate Professor, Clemson University
Additional Authors: Uzun, Habibullah, Assistant Professor, Sakarya Üniversitesi, Turkey
Olivares, Christopher, Post-doctoral Scholar, University of California, Berkeley
Karanfil, Tanju, Professor, Clemson University
Majidzadeh, Hamed, Post-doctoral Scholar, Clemson University
Chen, Huan, Post-doctoral Scholar, Clemson University
Ersan, Mahmut Selim, Post-doctoral Scholar, Clemson University

Climate change could lead to more frequent and severe droughts. Hot temperatures and dry conditions increase the likelihood of wildfires. Prescribed fire, which is a fuel reduction technique, is an essential forest management practice to reduce the susceptibility of forests to wildfire. In either wildfire or controlled burn, forest fire rapidly modifies the chemical composition of the detritus layer on forest floors, converting lignin- and polysaccharide-rich and relatively degradable carbon and nitrogen pools to polycyclic aromatic- and charcoal-rich and recalcitrant black carbon and black nitrogen. Dissolved organic matter (DOM) exported from burned watersheds is likely to have different chemical characteristics and treatability compared to DOM exported from unburned watersheds. Notably, forested watersheds are critically important to supply clean drinking water to millions of people in the US, and DOM constitutes the main precursor of carcinogenic disinfection byproduct (DBP) such as trihalomethanes (THMs) and haloacetonitriles (HANs) typically formed

during water treatment. To investigate the impacts of wildfire and identify management strategies against it, our team has examined several wildland fires in California, Colorado, North and South Carolinas. These field investigations confirmed the negative impacts of wildfire on water quality and treatability, such as a lower coagulation removal efficiency and an increase of DOM reactivity in forming DBPs. Some of the impacts could even last over a decade. In contrast, managed watersheds with low intensity prescribed burns could have several benefits besides reducing the risk of wildfire, including a lower concentration of DBP precursor in source water and an increase of water export. Our research studies demonstrate prescribed burns could be effective watershed management strategies to reduce the risks of forest fires and to protect source water under the changing climate.

Keywords: Water Treatability

Bio: I received my bachelor degree in Chemistry from the University of California, Berkeley. I completed my graduate works at the University of California, Davis. I received a NIH granted post-doctoral career award "Professor of the Future". Currently I am an associated professor at Clemson University. I am particularly interested in climate change's related disasters including wildfire and hurricanes on NOM exports and processes in source waters. Currently I am the associate editor of the Soil Science Society of American Journal and Journal of Environmental Quality. I was also the 2015 outstanding associate editor in Journal of Environmental Quality.

S19.15. Linking Post-fire Watershed Responses to Drinking Water Quality Effects

Presenter: Amanda Hohner, Assistant Professor, Washington State University
Additional Authors: Rosario-Ortiz, Fernando, Associate Professor, University of Colorado-Boulder

Wildfires continue to threaten potable water supplies, often burning watershed areas surrounding and upstream of water intakes. Drinking water providers are increasingly concerned about post-fire effects on treatment processes and finished water quality. Recently, large municipalities (e.g., San Francisco, Portland, Denver) experienced wildfires near source waters, while small, single source water systems in fire-prone areas also face substantial risks, but may lack treatment flexibility, staff and operational resources, and watershed monitoring programs.

Our work aims to connect post-fire water quality directly to drinking water consequences, including the impacts on treatment process performance (e.g., design upgrades, chemical dosing) and finished water quality delivered to consumers. We will discuss the results of three projects conducted in collaboration with multiple water utilities: 1) a water intake below a burned watershed was monitored following a Colorado wildfire and compared to pre-fire data; 2) charred, riverbank sediment deposits were collected from the burned area and leached in the laboratory; and 3) surface soil and litter samples were heated in a furnace and leached. Particles (i.e., turbidity), nutrients, dissolved organic matter (DOM), drinking water treatability by conventional processes were evaluated.

The three studies showed consistent findings and revealed further insight into previous work. Following the fire, elevated particles and dissolved organic carbon (DOC) levels often challenged conventional treatment resulting in poor removal of DOC (10-20%) and degraded finished water quality, even when treatment conditions were optimized. In some instances EPA regulations were exceeded. Fire-affected sediments and debris mobilized to surface waters may leach DOM, creating treatment challenges, in addition to solids loading implications from erosion and runoff. Laboratory heating and leaching of soils and litter altered the DOM quality and adversely affected treatability.

The DOM was less amenable to removal by conventional treatment, serving to support findings observed in field-based studies. Water providers should consider expanding water storage capacity, exploring additional supplies, and constructing pre-sedimentation basins. Treatment operations will likely need to be adjusted to account for variable water quality including increased, or extreme, turbidity and elevated DOC to meet EPA Safe Drinking Water Act regulations, specifically following runoff events in fire-affected areas.

Keywords: Drinking water quality, treatment, watershed

Bio: Amanda Hohner is an Assistant Professor in the Department of Civil and Environmental Engineering at Washington State University. She completed her PhD in Environmental Engineering at the University of Colorado-Boulder. Her work focuses on watershed disturbances, such as wildfire, and the implications for drinking water quality. She often works in collaboration with water utilities and regulatory agencies concerned about the threat of wildfire to water supplies.

S19.16. Physicochemical Changes of Wildfire-Derived DOM & Precipitation Effects during First Year Recovery

Presenter: Alex Revchuk, Managing Engineer, Exponent Inc.
Additional Authors: Suffet, Mel (I.H.)

Wildfires directly affect surface water supplies by altering water quality which creates challenges to water treatment operations. In this study we evaluated physicochemical changes in dissolved organic matter (DOM) leachability characteristics before and after the first two rain events following a wildfire and established site-specific relationships between trihalomethanes formation potential (THMFP) and DOM size distributions, polarity, charge, and fluorescence characteristics throughout the first year of fire recovery. All analyses were conducted on leachates prepared from ash, charred leaves, and twigs collected from a fire-impacted site. The DOM size distributions were quantified by ultrafiltration (UF), molecular charge and polarity by polarity rapid assessment method (PRAM), and chemical functionality by excitation-emission matrix (EEM) fluorescence. The results show that wildfire altered size, charge, polarity, chemical functionality, and THMFP of the DOM, demonstrating a need for water treatment optimization. The post-wildfire precipitation events had substantial effects on abundance and physicochemical characteristics of the DOM, as well as its contributions to the THMFP: the wildfire caused a 50% increase in dissolved organic carbon (DOC) which corresponded to a 120% increase in THMFP. The year-long dataset highlights the importance of the first flush timing: precipitation occurring shortly after a wildfire will produce substantially more THMFP than rain occurring months after the fire. The wildfire also caused a shift in DOM size distribution from intermediate sizes (1-5 and 5-10K Da) before fire to larger sizes (>10K Da) after fire, and increased the hydrophobicity of the DOM. Fluorescence analyses revealed that wildfires decrease the humic-like fluorophores and that post-fire recovery is dominated primarily by increases in fulvic acids. Site-specific empirical relationships between THMFP and UV, DOC, fluorescence, polarity, and charge were developed. The development of wildfire site-specific UV-DOC, UV-THMFP, and DOC-THMFP empirical relationships may aid in quantification of impacts to surface water resources and inform water treatment operations.

Keywords: wildfire, impacts, water quality, water treatment, disinfection byproducts

Bio: Dr. Alex Revchuk is a professional registered engineer in California and Nevada, and a managing engineer at Exponent, Inc., a multi-disciplinary engineering and scientific consulting firm that focuses on failure analyses and investigations. Dr. Revchuk's expertise includes optimization of drinking water treatment processes, beverage manufacturing, failure root cause analysis, engineering cost estimation, and environmental forensics. He completed his PhD studies at UCLA, and the following work presents some of the results from those studies.

S19.17. Quantifying ash loads across burned watersheds using the Normalized Wildfire Ash Index- a remote sensing approach

Presenter: Cristina Santin, Senior Lecturer, Swansea University (UK)
Additional Authors: Chafer, Chris, Retired Researcher, Water New South Wales (Australia)
Doerr, Stefan H., Professor, Swansea University (UK)
Arellano, Stefano, PhD student, University of Santiago de Compostela (Spain)
Fernández, Cristina, Senior Researcher, CIF Lourizan (Spain)
Vega, Jose A., Emeritus Professor; CIF Lourizan (Spain)

The impacts of wildfire ash, the powdery residue from fuel burning, on post-fire ecosystems are can be substantial and very diverse. Ash is a source of nutrients and can enhance the recovery of vegetation. It can also contain substantial amounts of recalcitrant pyrogenic carbon and thus contribute to carbon sequestration. In its initial state, the ash layer on the ground can protect the bare soil, mitigating post-fire water erosion by runoff. However, when the adsorbent capability of this layer is exceeded, ash can be transported into the hydrological network and be a major contributor to water contamination. Ash can also contribute to post-fire mass movements such as debris flows.

The eco-hydro-geomorphic impacts of ash on post-fire ecosystems are therefore important, but remain poorly quantified. A fundamental step in that direction is the quantification of ash production and distribution at the landscape scale. Spatial modelling of ash loads will allow incorporating ash as a key parameter into post-fire risk models. In our recent work we developed a new spectral index, the normalised wildfire ash index (NWAI), using Landsat imagery to model the spatial distribution of ash loads in the post-fire landscape. It was developed based on a severe wildfire that burnt ~13,000 ha of dry eucalyptus forest in October 2013 near Sydney, Australia.

We have now tested this new spectral index for i) forested areas burnt by the Black Saturday fires near Melbourne (Australia) in February 2009; and ii) burnt Atlantic shrublands and forested lands affected by wildfires in 2013 in Galicia (NW Spain). For both cases we found that, although ecosystem and fire characteristics differed substantially from the 2013 Sydney wildfire, the NWAI index performs well. In this contribution we will present these results, and discuss the principles of the NWAI and its potential for water pollution risk forecasting.

Keywords: water quality, Landsat, modelling, fire severity, Australia, Spain

Bio: Cristina Santín is Senior Lecturer in the Biosciences Department at Swansea University. Her current research focuses on the effects of fire on carbon dynamics and, also, on fire impacts on soils, waters and social perceptions of fire. She currently holds a prestigious Sêr Cymru II COFUND fellowship which aims to advance our knowledge on the effects of prescribed fire in two fundamental ecosystem services: water supply and carbon storage.

S19.18. The 2016 Fort McMurray wildfire: Drinking water treatability challenges in an already-challenged watershed

Presenter: Monica Emelko, Professor, University of Waterloo
Additional Authors: Silins, Uldis, PhD, Professor, University of Alberta, Canada
Stone, Micheal, PhD, Professor, University of Waterloo, Canada
Cooke, Colin, PhD, Aquatic Ecosystem Scientist, Alberta Environment and Parks/University of Alberta, Canada
Emmerton, Craig, PhD, Post-doctoral Fellow, University of Alberta, Canada
Skwaruk, Jesse, MSc, Graduate Student, University of Waterloo, Canada
Kendel, Travis, Manager, Water TReatment, Regional Municipality of Wood Buffalo, Canada

The 2016 Horse River wildfire burned approximately 590,000 hectares, which constitutes ~6% of the Athabasca River Watershed in the Regional Municipality of Wood Buffalo, Alberta; including the city of Fort McMurray and several surrounding communities. It has been estimated that the costs of this wildfire will surpass $9 billion, making it the most expensive natural disaster in Canadian history. A spatial analysis of the watershed based on wet areas mapping, peatland distribution data, and the fire boundary polygon indicated that 254 burned sub-watersheds affecting the Athabasca River above Ft. McMurray would contribute post-fire runoff to the river. The vast majority of these are smaller ephemeral drainages along the immediate river break. The lower, downstream sections of five larger sub-watersheds were identified as those most likely to affect water quality and drinking water treatability at the Fort McMurray water treatment plant (WTP). Given the setting, extensive mixing of tributary-discharged sediment/carbon within the Athabasca River prior to arrival at the WTP intake was not expected—this was confirmed by aerial assessment. In this presentation, key changes in source water quality (i.e., turbidity, dissolved organic carbon [DOC], disinfection by-product formation potential, bioavailable phosphorus, etc.) resulting from the wildfire will be presented and the associated increases in drinking water treatment costs (i.e., chemical coagulant consumption, reservoir dredging, etc.) will be discussed. Notably, less than one year after the wildfire, changes in source water DOC resulted in increased chemical coagulant consumption equating to increased annual expenditures of at least 40% ($0.5 million). Additional costs (~$1 million) included reservoir dredging to mitigate water quality risks related to fine sediment-associated nutrient desorption and the associated risk of cyanobacterial bloom occurrence in the city's source water reservoirs. While experiences elsewhere in Alberta have demonstrated that such impacts may last for a decade or more in some regions, the longevity of these impacts in Fort McMurray remains unknown at present. This detailed investigation of drinking water treatment costs resulting from severe wildfire provides much-needed information for decision-making and optimization of investments in infrastructure and source water protection technologies, including those that are forest management-based.

Keywords: wildfire, Fort McMurray, treatability, drinking water, Canada, disinfection by-products, DBPs, DOC

Bio: Monica Emelko is a Professor of Civil and Environmental Engineering and the Director of the University of Waterloo's Water Science, Technology & Policy group. Her research focuses on drinking water supply and treatment. Monica has acted as a technical advisor to over two dozen utilities, the U.S. National Academies, and federal and provincial/state agencies in Canada, the United States, the UK, and Australia regarding water treatment and source protection policies and regulations. As of Fall 2017, she co-leads the "forWater Network," a Canada-wide and internationally-partnered research network focused on forest management-based approaches for drinking water source protection.

S19.19. Modelling ash contamination risk after wildfires: a new tool aimed at end-users

Presenter: Jonay Neris, Research Officer, Department of Geography, College of Science, Swansea University
Additional Authors: Elliot, William J, Research Civil Engineer, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (USA)
Doerr, Stefan H, Professor, Department of Geography, College of Science, Swansea University
Robichaud, Peter R, Research Engineer, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (USA)
Prats, Sergio, Post-doctoral researcher, Centre for Environmental and Maritime Studies (CESAM), Department of Environment and Planning, University of Aveiro (Portugal)
de Lima, João LMP, Professor, Marine and Environmental Sciences Centre (MARE), Department of Civil Engineering, Faculty of Science and Technology of the University of Coimbra
Keizer, Jacob J, Principal Researcher, Centre for Environmental and Maritime Studies (CESAM), Department of Environment and Planning, University of Aveiro (Portugal)

Every year wildfires and management burns affect ~4% of the global vegetated land surface. Fire affects forests, grasslands and peatlands, which together provide 60% of the water supply for the world's largest 100 cities. In addition to the potentially critical effects on vegetation and soil, fire can lead to severe impacts on water quality from highly mobile ash rich in undesirable chemical pollutants. Ash delivery has led to numerous drinking-water restrictions and substantial treatments costs in recent years (e.g. for Belfast, Canberra, Denver, Fort McMurray). The projected future further decline in fresh water availability and increase in fire risk in many regions around the world may promote the role of fire as a critical threat to fresh water availability at both local and global scales.

Current models used by scientists and land managers to evaluate hydrologic and erosion risk in the post-fire period lack capabilities to provide predictions of ash transport risk. To fill this knowledge and management gap, a prototype model to predict ash delivery risk is being developed. The prototype adds capabilities to anticipate ash transport to the widely-used Water Erosion Prediction Project (WEPP) by integrating the main processes that affect ash in the ecosystem: from its production to its transport by wind or water. The prototype calculates the initial ash load after a fire from Landsat imagery using the innovative Normalized Wildfire Ash Index (NWAI) whereas climate, runoff, and erosion outputs of WEPP are used as drivers to predict ash temporal availability and transport on the landscape. A preliminary validation using laboratory data is promising in this first attempt to predict ash transport and its delivery to the stream system. Using data from a flume experiment we have obtained ash transport thresholds and rates for two distinctive ash types representative of high and low burn severities.

Experimental data on ash properties and composition, and field data on ash delivery with runoff and erosion are still needed to evaluate potential contamination by ash and calibrate and validate the model for key vulnerable environments. Once calibrated and validated for specific scenarios, the model will support managers in anticipating water contamination risks from fire and implementing effective mitigation treatments to protect drinking water supplies and aquatic ecosystems.

Keywords: ash, pollution, fresh-water, risk reduction, WEPP

Bio: Dr Jonay Neris has focused his research career on the the hydrologic and erosional effects of wildfires. In 2015 he obtained a EU H2020 Marie-Sklodowska Curie fellowship (2015-2017) aimed at modelling and mitigating the hydrological and erosional response of fire-affected volcanic soils. He is currently co-investigator in a Natural Environment Research Council (NERC-UK) project (2018-2012) focused on modelling ash transport and contamination risk in fire-affected ecosystems. He has authored 14 papers in JCR journals and four book chapters, focused mainly on approaches to quantify, model, and mitigate fire impacts on soils and hydrology.

S19.20. Predicting Post-fire Hillslope Erosion and Small Watershed Response with an Online GIS Interface Using WEPP Technology

Presenter: Peter Robichaud, Research Engineer, USDA Forest Service Rocky Mountain Research Station
Additional Authors: Elliot, Willaim, Research Engineer, USDA Forest Service Rocky Mountain Research Station
Dobre, Mariana, Post-doc Fellow, University of Idaho
Lew, Roger, Research Assistant Professor, University of Idaho

In the aftermath of wildfires, the threat of erosion, flooding and debris flows continue to be on the forefront of concern for land managers and water purveyors through the US and around the world. The Water Erosion Prediction Project (WEPP) Post-fire Erosion Predictor (PEP) is an online GIS watershed interface tool intended to evaluate the risks of upland erosion, sediment delivery and flood flows from watersheds smaller than 5000 ha for US forests and rangelands. After a wildfire, managers develop a soil burn severity map from satellite imagery and ground surveys. The spatially explicit map showing the distribution of soil burn severity on the landscape is uploaded into the WEPP-PEP interface. The interface then seamlessly obtains local topography, soils and climate parameters from its own or national databases for the areal extent of the burn severity map. Minimal input is required by the user: selecting the dominant soil texture, noting whether the soils are water repellent, and entering the percent ground cover associated with each burn severity class. Numerous watershed erosion prediction calculations are automatically carried out until the entire burned area has been fully evaluated. After a watershed is modeled, results are displayed in both spatial and tabular data formats. A graphical display of hillslope erosion rates is color-coded for ease in visualizing high erosion hazard areas. Outputs are available for return interval comparisons sorted by precipitation, total runoff or peak flow at the outlet of the watershed. Additional outputs include data to run the Erosion Risk Management Tool (ERMiT) or Disturbed WEPP Batch programs for comparing hillslope erosion rates and various treatments at a larger scale. Users can also download all the GIS and WEPP files associated with the assessment and collate in a single GIS database. Watersheds can be evaluated prior to the wildfire as well. After release in early 2017, 40 wildfires were evaluated during the busy 2017 fire season with the WEPP-PEP interface by post-fire assessment teams.

Keywords: Post wildfire, WEPP-PEP, Modeling, Flooding

Bio: Pete Robichaud is a Research Engineer with the USDA Forest Service, Rocky Mountain Research Station in Moscow, Idaho. Pete studies and models soil erosion as affected by wildfires. His field research includes plot-scale infiltration, erodibility studies, paired watershed studies and large-scale remote sensing projects. He is an international leader in postfire hydrology effects and monitoring techniques. He leads various research teams, developed the popular web-based probabilistic Erosion

Risk Management Tool (ERMiT), and evaluate erosion mitigation treatments. Pete has published over 200 scientific articles, one book, holds two patents and still spends his summers chasing wildfires and playing in the dirt.

S19.21. Are Northern Latitudes Less Subject to Erosion, Landslides and High Sediment Yields after Wildfire?

Presenter: Peter Jordan, Geomorphologist, SNT Geotechnical Ltd.
Additional Authors:

In 2003, the southern interior of British Columbia experienced a devastating wildfire season, with the loss of hundreds of homes. Several debris flow and flood events followed the wildfires. After 2003, the BC Ministry of Forests has routinely conducted risk analyses of post-wildfire natural hazards, such as floods, landslides, and water quality impacts. This work is similar, although more limited in scope, to the BAER program in the western United States. Also, the province funded a research program on post-wildfire natural hazards in British Columbia.

Since 2003, about 40 debris flow and flood incidents have been documented in the region (Jordan, 2016). Several of these events have resulted in property damage and loss of life. However, it is notable that the majority of wildfires on which risk analyses have been conducted have not produced significant post-wildfire hydrologic or geomorphic events, or even increases in downstream sediment yield. Also notable is the rarity of reported events from the montane spruce and boreal forest zones of British Columbia's north.

In the western United States, Moody and Martin (2009) compiled post-fire sediment yield data and related it to various climate regions. Although their data do not show obvious correlations with latitude, it is notable that sediment yields and rainfall intensities were relatively low in the sub-Pacific (or intermontane) zone, which if one extends their zones north, would include the interior of British Columbia.

Possible explanations for apparently low post-fire sediment yields, and the low incidence of landslide and flood events, in more northern (or cooler) climate zones include:
- lower rainfall intensities in northern latitudes;
- dominance of snowmelt, as opposed to rainfall, in annual runoff and peak hydrologic events;
- a history of glaciation, which has resulted in low drainage density and U-shaped valleys;
- possibly lower erodibility of glacial, as opposed to residual, soils;
- thicker forest floors, and more rapid regeneration of post-fire ground cover in moister, snowmelt-dominated forest ecosystems.

Jordan, P. 2016. Post-wildfire debris flows in southern British Columbia, Canada. International Journal of Wildland Fire, 25, 322-336.
Moody, J.A. and Martin, D.A., 2009. Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States. International Journal of Wildland Fire 18, 96–115.

Keywords: post-wildfire processes, erosion, sediment yield, rainfall, landslides

Bio: Peter Jordan received his Ph.D. in debris flow processes from the University of BC in 1994. Since then, he worked as research geomorphologist with the BC Forest Service in Nelson, BC, studying landslides and post-fire geomorphic processes. He retired from the Forest Service in 2016.

S19.22. Long-term Suspended Sediment Yields in Wildfire Affected Mountain Streams in Southwestern Alberta, Canada

Presenter: Kalli Herlein, Field Hydrologist, University of Alberta
Additional Authors: Silins, Uldis, Forest Hydrologist, Dept. of Renewable Resources, University of Alberta
Williams, Chris, Research Hydrologist, Dept. of Renewable Resources, University of Alberta
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Wagner, Michael, Forest Hydrologist, Alberta Agriculture and Forestry, Forest Management Branch
Stone, Micheal, Fluvial Geomorphologist, Dept. of Geography and Environmental Management, University of Waterloo
Emelko, Monica, Water Resources Engineer, Dept. of Civil and Environmental Engineering, University of Waterloo

Wildfires can have a profound impact on sediment exports from forested mountain headwater streams. Changes to instream sediment concentrations can substantially alter delicate aquatic ecosystems and propagate downstream to affect drinking water quality. Most post-wildfire hydrology studies report increases in total suspended sediment (TSS) yields and turbidities in streams immediately after the disturbance with some responses being more dramatic than others. These studies usually report on sediment production for 1-5 year periods after wildfire; during which observed sediment yields often return to baseline reference conditions. Far fewer studies exist that report elevated sediment yields more than 5 years post-fire and even fewer have a sediment data record that is greater than 10 years in length.

This study is part of a long-term research project documenting the effects of the 2003 Lost Creek fire on water quality and quantity since 2004. The study region in the Rocky Mountains of southwestern Alberta, Canada has a geomorphological history dominated by the deposition of glacial moraine and the formation of fine-grained till blankets and veneers. Seven study watersheds were instrumented: three burned, two burned and subsequently salvage logged and two unburned reference watersheds. Depth-integrated grab samples and automated daily composite water samples from these seven study streams provide a TSS and turbidity data record for the years 2004 through 2014.

Our results show that despite 11 years of recovery time after the wildfire, the burned and the salvage logged watersheds continue to have elevated TSS yields and turbidities as compared to the unburned reference watersheds. Several well-documented driving factors can determine the magnitude and longevity of post-fire sediment yield responses to wildfire: severity and extent of the burn, changes to pre-existing soil characteristics, vegetation recovery, and hydroclimatic conditions. We propose that along with these drivers, there may be other dominant factors that govern watershed resilience to sediment production after wildfire disturbance.

Keywords: hydrology, sediment, erosion

Bio: Kalli has worked in forest hydrology for the last five years. Her work has primarily been with the Southern Rockies Watershed Project based in the Flathead range of the Rocky Mountains in southwestern Alberta, Canada. Her primary interests are how forest disturbances affect sediment transport and source water quality.

S19.23. Comparative effects of different post-fire forest management strategies on hillslope sediment yield

Presenter: Ryan Cole, Masters Student, Oregon State University
Additional Authors: Bladon, Kevin, Assistant Professor, Oregon State University
Wagenbrenner, Joe, Research Hydrologist, US Forest Service
Coe, Drew, Forest Practice Monitoring Program Coordinator/Hydrologist, California Department of Forestry and Fire Protection

High-severity wildfire can increase erosion on burned, forested hillslopes. Salvage logging is a post-fire forest management practice to extract economic value from burned landscapes, reduce fuel loading, and promote tree regrowth. Few studies assess the impact of post-fire salvage logging or alternative land management approaches on erosion in forested landscapes, especially in California. In September 2015, the Valley Fire burned approximately 31,366 ha of forested land and wildland-urban interface in the California's Northern Coast Range, including most of Boggs Mountain Demonstration State Forest. The primary objective of our study is to quantify rates of erosion and runoff at the plot scale (~75 m2) for different post-fire land management practices, including mechanical logging and subsoiling after logging. We measured sediment yields using sediment fences in four sets of replicated plots. We estimated ground cover in each plot using three randomly positioned 1-meter quadrats. We are also measuring precipitation amount and kinetic energy near each plot and surface runoff from a subsample of plots to understand hydrologic factors that influence erosion. Preliminary results indicate that burned, unlogged reference plots yielded the most sediment over the 2016-2017 wet season (34 Mg ha-1). Sediment yields of burned and logged plots (6.9 Mg ha-1) were substantially lower. Sediment yields from burned, logged, and subsoiled (17 Mg ha-1) fell between the two previous treatments. Burned and unlogged reference plots had the least ground cover (49%), while ground cover was higher and more similar between burned and logged (65%) and burned, logged and subsoiled (72%) plots. These initial results contrast with some previous studies in which the effect of post-fire salvage logging ranged from no measured impact to increased sediment yield related to salvage logging.

Keywords: erosion, post-fire, forest management, salvage-logging, sediment, soil

Bio: Ryan Cole is a Masters Student studying Water Resources at Oregon State University. He is interested in studying wildfire and its effect on forests and headwater streams. His research specifically involves the effects of post-fire forest management practices on soils and erosion on burned hillslopes.

S19.24. Scaling Post-fire Effects from Hillslopes to Watersheds: Processes, Problems, and Implications

Presenter: Lee MacDonald, Professor; Senior Research Scientist, Colorado State University
Additional Authors: Brogan, Dan, Ph.D. candidate, Colorado State University
Nelson, Peter, Professor, Colorado State University
Stephanie Kampf, Professor, Colorado State University
Wagenbrenner, Joe, Research Hydrologist, USDA Forest Service

Over the last two decades we have made considerable progress on understanding and predicting the effects of wildfires on runoff and erosion at the hillslope scale. One cannot, however, sum up the hillslope-scale effects to predict what happens downstream because of the scale-dependent changes in driving variables and controlling processes; yet resource managers need an understanding and

some predictive capability to assess post-fire risks and guide post-fire treatments. Our objectives are to: 1) show how scaling varies even at the hillslope to sub-watershed scales (<1 km2); 2) summarize the results of our four-year study on post-fire erosion and deposition at different spatial scales in two 15 km2 watersheds after the High Park Fire in Colorado; and 3) discuss the implications of this and other studies for predicting post-fire sediment deposition and delivery at the watershed scale for different site conditions and storm events.

At scales of up to about 1 km2 unit-area sediment yields typically decline with increasing area and especially with slope lengths, but the magnitude of these declines varies with soils, topography, vegetative recovery, and the dominant runoff and erosion processes. In our study watersheds lidar differencing and intensive field surveys showed a predominance of sediment deposition in the valley bottoms. In contrast, channel incision dominated during snowmelt due to the limited overland flow and surface erosion at the hillslope scale. Similar depositional trends have been observed at the watershed scale in other studies, but in our study an exceptional long-duration rainstorm reversed this depositional pattern as the sustained high flows removed nearly all of the post-fire sediment and extensively reworked and coarsened the valley bottom. Volume changes for 50-m channel segments over four different time periods were only weakly correlated with channel width, slope, confinement, maximum 30-minute rainfall intensity, and burn severity. Nevertheless, a process-based understanding, when combined with morphometric data, burn severity, and a specified rainstorm, can roughly estimate post-fire erosion, flooding, and deposition risks at scales of perhaps 20-50 km2. We hypothesize diminished risks at even larger scales based on the observed decreases in unit area peak flows and sediment delivery in unburned watersheds, but this has not been well documented for burned conditions. A more explicit assessment of changing effects over different spatial scales is needed to better evaluate risks to life and property, guide post-fire hillslope rehabilitation treatments, and assess risks to water quality.

Keywords: Erosion, Deposition, Scaling, Watersheds, Flooding

Bio: Dr. Lee MacDonald is professor emeritus of watershed science and senior research scientist at Colorado State University. He specializes in the effects of land use change on runoff and erosion, including fires, roads, timber harvest, spatial scaling, and cumulative watershed effects. He has advised more than 40 graduate students and co-authored approximately 75 peer-reviewed publications. He has intensively studied on wildfires for nearly two decades in both the U.S. and Europe, and has worked and traveled to more than 60 countries. More details and links to his publications and student theses can be found on his web site https://www2.nrel.colostate.edu/macdonald-lab/.

S20.1. Biomass Burning Observation Project (BBOP): Near Field Evolution of BB Emissions

Presenter: Arthur Sedlacek, Scientist, Brookhaven National Laboratory
Additional Authors: Lawrence I. Kleinman; Scientist, Brookhaven National Laboratory
Kouji Adachi; Scientist, Meteorological Research Institute, Japan
W. P. Arnott; professor, University of Nevada
Peter Buseck; professor, Arizona State University
Timothy B. Onasch; scientist, Aerodyne Research
Qi Zhang; professor, University of California/Davis

During the summer and fall of 2013, the Department of Energy's Atmospheric Radiation Measurement (ARM) program sponsored a coordinated field campaign that combined aircraft-based

measurements with mountain top observations to investigate the near-field (< 5 hrs) as well as regional evolution of biomass-burning (BB) aerosol particles. This field campaign, known as BBOP (Biomass Burning Observation Project), represents the first time that the near-field evolution of BB aerosol particles has been exclusively targeted with research aircraft. For the wildfire flights, a Lagrangian sampling protocol was employed in which flight transects orthogonal to the plume direction were conducted at selected distances downwind of the source. The plume age was calculated using prevailing wind speed/direction and the assumption of a constant emission source during the sampling period. In this way, plume samples of a specific age could be acquired.

I will present recent findings on the formation and evolution of tar balls, near field changes in aerosol chemical, microphysical, and optical properties, and on measurements from the Mt. Bachelor Observatory (MBO, ~ 2700k) in Central Oregon which provide complementary information on regional characteristics of wildfire plumes to the BBOP flight results.

Sedlacek III, A. J et al., (2018) Formation and evolution of Tar Balls from Northwestern US wildfires (ACP in review)
Adachi, A., et al., (2017) Thermal behavior of aerosol particles from biomass burning using transmission electron microscopy Aerosol Science and Technology DOI: 10.1080/02786826.2017.1373181
Liu, X., et al., (2017) Western U.S. wildfires: Emissions and air quality tradeoffs with prescribed burning JGR 122, 6108–6129, doi:10.1002/2016JD026315.
Zhou, S., et al., (2017) Regional Influence of Wildfires on Aerosol Chemistry in the Western US and Insights into Atmospheric Aging of Biomass Burning Organic Aerosol, Atmos. Chem. Phys., 17, 2477–2493, doi:10.5194/acp-17-2477-2017
Collier, S., et al., (2016) Aerosol Emissions from Western U.S. Wildfires and Correlation with Combustion Efficiency, Environmental Science & Technology 50, 8613–8622 DOI: 10.1021/acs.est.6b01617

Keywords: near-field evolution, BBOP, field campaign, biomass burning aerosols, tar balls, aerosol properties

Bio: Art is an atmospheric chemist in the Environmental and Climate Sciences Department at Brookhaven National Laboratory (BNL). Art's research interests are in elucidating and quantifying how atmospheric aging impacts the optical and microphysical properties of carbonaceous aerosols [black and brown carbon] through aircraft- and ground-based field campaigns as well as targeted laboratory studies. During the summer and fall 2013, Art co-led an aircraft-based field campaign to study the near-field evolution of biomass burning aerosols. The goal of this study, as with Art's other research activities, is to quantify the direct radiative forcing contribution of black and brown carbon aerosols.

S20.2. Identifying PM and O3 impacts in urban areas due to wildfires

Presenter: Crystal McClure, PhD Candidate, Department of Atmospheric Sciences, University of Washington
Additional Authors: Dr. Dan Jaffe, Professor and Chair Physical Sciences Division School of Science. Technology, Engineering and Math, University of Washington-Bothell

Over the last several decades wildfires in the western U.S. have increased and air quality standards have become tighter. This means it is more important than ever to understand the influence of wildfire smoke on urban air quality. While exceedances of both the particulate matter (PM) and ozone standards can occur due to smoke, it is much harder to identify and quantify the contributions to ozone compared to PM. While PM is nearly always presence in downwind fire plumes, it is also ubiquitous in urban areas from normal industrial sources. So separating out the effects of smoke PM from normal urban PM can be challenging at relatively low concentrations. At present we have a few tools to identify the presence of smoke in urban areas including in-situ PM measurements, models and satellite observations and these are generally fine for periods of strong smoke. But impacts on O3 in urban areas appears to be greatest during periods of light or moderate smoke (between 15-60 ug/m3). So this means we need to improve our tools to identify the presence of smoke in urban areas. Based on observations in a number of urban sites in the western, we have found that the CO-PM enhancement ratio is a useful marker of smoke, even at relatively low concentrations. In addition, I will discuss the use of other tracers, particularly acetonitrile, that can be used to indicate the presence of smoke in urban areas.

Keywords:

Bio: Crystal McClure is a PhD Candidate in the Department of Atmospheric Sciences at the University of Washington. She received her B.S. in Meteorology from Texas A&M University in 2011 and M.S. in Atmospheric Sciences from the University of Washington in 2014. She expects to complete her PhD dissertation in May 2018. Her general research topic is examining wildfire emissions and the effect these emissions have on urban and rural air quality in the western U.S.

S20.3. Space-Based Constraints on Smoke Aerosol Plume Injection Height, Source Strength, and Particle Type

Presenter: Ralph Kahn, Senior Research Scientist, NASA Goddard Space Flight Center
Additional Authors: Petrenko, Mariya, Post-doctoral fellow, NASA Goddard Space Flight Center
Val Martin, Maria, Lecturer, University of Sheffield UK
Limbacher, James, Programmer-Analyst, NASA Goddard Space Flight Center
Flower, Verity, Post-doctoral fellow, NASA Goddard Space Flight Center

Aerosol transport models initialize smoke sources with an injection height and a source strength. From space-based remote sensing, we are able to constrain both these quantities, especially when the source produces a distinct plume that can be imaged at multiple angles. Multi-spectral, multi-angle snapshots from low-Earth orbit can also provide qualitative information about particle microphysical properties, making it possible to map plume particle evolution on regional scales downwind of sources.

In case studies of wildfire plumes, we observe injection within as well as above the planetary boundary layer (PBL) is space-based stereo imagery; when used to initialize model simulations, the details of injection height can significantly affect the simulation of downwind dispersion. Model plume dispersion differences are greatest when injection height is initialized within vs. above the PBL. Depending on the wind-shear profile, dispersion forecasts can also be significantly different when initialization is at different elevations in the free troposphere, as might be expected.

Inverse modeling has been attempted to deduce smoke plume source strength from satellite aerosol optical depth (AOD) regional snapshots. One limitation of this approach is that the problem is highly underdetermined. Source location is among the few external constraints that can be applied to this problem, but is difficult to effect in the inverse-modeling framework. Using a

forward-modeling approach, we compare model simulations, initialized with different source-strength values and sampled at the time of satellite overpass, with regional AOD observations from space. This approach works best where the AOD contribution from the plume dominates background values, which occurs most commonly for boreal and tropical forest fires. When the background AOD is high, such as in polluted regions of northern India and eastern China, or when the fire plume is small or optically very thin, which is common in agricultural burning situations, the derived source-strength constraints from forward modeling are less certain.

Top-of-atmosphere radiance measurements from the NASA Earth Observing System's Multi-angle Imaging SpectroRadiometer (MISR) also contain qualitative information about particle size, shape, and light-absorption properties under favorable retrieval conditions. When mid-visible AOD exceeds about 0.15, about three-to-five bins in particle size, two-to-four bins in single-scattering albedo, and spherical vs. non-spherical shape can be derived. For well-formed volcanic plumes, we often observe downwind decreases in AOD, effective particle size, and non-spherical AOD fraction, consistent with expected preferential settling of larger, non-spherical ash particles relative to sulfates, water droplets, and background aerosol. We sometimes also observe increases in single-scattering albedo downwind, consistent with particle hydration and/or oxidation as the particles evolve. We have recently begun applying the same approach to wildfire plumes. This presentation will review our work in these areas to date, and will summarize what we might glean in ongoing work from the 18-year, global MISR and MODIS smoke plume data records.

Keywords: Satellite remote-sensing, smoke source strength, injection height, aerosol type

Bio: Ralph Kahn, a Senior Research Scientist at NASA's Goddard Space Flight Center, received his PhD in applied physics from Harvard University. Kahn is Aerosol Scientist for the NASA Earth Observing System's Multi-angle Imaging SpectroRadiometer. He focuses on using MISR's unique observations, combined with other data and numerical models, to learn about wildfire smoke, desert dust, volcano, and air pollution particles, and to apply the results to regional and global air quality and climate-change questions. His early work includes studies of the atmosphere and climate of Mars. Kahn has lectured on Global Change and atmospheric physics at UCLA and Caltech, is an Adjunct Professor at the University of Maryland, and is editor and founder of PUMAS, the on-line journal of science and math examples for pre-college education (http://pumas.nasa.gov).

S20.4. An Examination of Extreme Fire Behavior and its Impact on Smoke Plume Characteristics using Remote Sensing and Meteorological Data

Presenter: David Peterson, Meteorologist,
Additional Authors: Hyer, Edward, Naval Research Laboratory, Monterey, CA
Campbell, James, Naval Research Laboratory, Monterey, CA
Fromm, Michael, Naval Research Laboratory, Washington, DC

Extreme wildfires are known for periods of rapid fire spread and intense pyroconvection. The 2013 Rim Fire, which burned over 104,000 ha, was one of the most severe fire events in California's history, in terms of its rapid growth, intensity, overall size, and persistent smoke plume. At least two large pyrocumulonimbus (pyroCb) events were observed, allowing smoke particles to extend through the upper troposphere over a large portion of the Pacific Northwest. However, the most extreme fire spread was observed on days without pyroCb activity or significant regional convection. Traditional fire weather indices failed to distinguish between each type of fire behavior. A diverse archive of ground, airborne, and satellite data provides a unique opportunity to examine the

conditions required for both extreme spread events and pyroCb development. Results highlight the importance of upper-level and nocturnal meteorology during periods of rapid fire spread. Lidar data show that intense burning during these spread events can facilitate long-distance smoke transport, but fails to loft smoke to the altitude of a large pyroCb. Additional fire events across North America are incorporated to construct the first observationally based conceptual model for intense pyroCb development. Development occurs when a layer of increased moisture content and instability is advected over a dry, deep, and unstable mixed layer, typically along the leading edge of an approaching disturbance or under the influence of a monsoonal anticyclone. The current suite of automated forecasting applications predict only general trends in fire behavior, and specifically do not predict extreme fire spread events and injection of smoke to high altitudes. While these two needs are related, results show that they are not predicted by the same set of conditions and variables. The combination of meteorology from numerical forecast models and satellite observations exhibits great potential for improving regional forecasts of fire behavior and smoke production in automated systems, especially in remote areas where detailed observations are unavailable.

Bio: Dr. David Peterson is a meteorologist at the US Naval Research Laboratory in Monterey, CA. He has broad scientific interests in both meteorology and satellite remote sensing. He currently supports the US Navy's global aerosol modeling efforts, with a focus on extreme wildfires and smoke transport.

S20.5. Improving Nocturnal Fire Detection with the VIIRS Day-Night Band

Presenter: Jun Wang, Professor, University of Iowa
Additional Authors: Thomas Polivka
Edward Hyer
Charles Ichoku
Luke Ellison

Since 1999 when NASA launched Terra, the first satellite as part of its Earth Observation System (EOS), many new techniques and data products have been developed to measure fires from space, thereby providing much-needed information for air quality and climate research as well as fire management. Challenges, however, remain in areas to detect from the space those smaller and cooler fires, fires underneath the clouds, and fire phases (e.g., smoldering vs. flaming). Here, we will present a technique to address these challenges in various degrees by using Firelight Detection Algorithm (FILDA) that combines the visible light and infrared radiation to characterize the fires at night. Examples will be shown for various fire events, and evaluation will be made with ASTER data. A outlook of this algorithm for fire emission estimate will also be presented.

Keywords: VIIRS, nighttime fire

Bio: Jun Wang is a Professor in the University of Iowa (UI), with joint appointments in the Department of Chemical and Biochemical Engineering and the Iowa Informatics Initiative, and secondary affiliation with the Center for Global and Regional Environmental Studies and Department of Civil and Environmental Engineering. His research focuses on the integration of satellite remote sensing and chemistry transport model to study air quality, wildfires, aerosol-cloud interaction, and land-air interaction. Jun Wang has authored or co-authored 100+ citable works in the peer-reviewed literature, and has been a science team member of several NASA missions. More about his research team's work can be found at: http://arroma.uiowa.edu

S20.6. Hyperspectral and polarimetric fire emission characterization from the NASA ER-2 aircraft

Presenter: Olga Kalashnikova, , Jet Propulsion Laboratory, California Institute of Technology
Additional Authors: Le, Kuai, Research assosiate, UCLA
Hully, Glynn, Research scientist, JPL
Xu, Feng, Research scientist, JPL
Garay, Michael, JPL
Bates, Kelvin, Caltech
Cappa, Chris, University of California, Davis

Remote sensing from NASA's ER-2 high-altitude research aircraft can provide large-scale, high-resolution observations of fuel maps, fire intensity, plume rise, pollutants/smoke characteristics, and area burned. The Hyperspectral Thermal Emission Spectrometer (HyTES), recently integrated on the ER-2, produces a wide-swath thermal infrared (TIR) image with high spectral (256 bands from 7.5 to 12 μm) and spatial resolution (34 m from the altitude of the ER-2). The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) acquires multiangular observations over a ±67° along-track range in eight (355, 380, 445, 470, 555, 660, 865, 935 nm) radiometric and three (470, 660, and 865 nm) polarimetric bands with 10 m resolution from the ER-2. Using data from recent field campaigns including SEAC4RS and IMPACT-PM, we will demonstrate how hyperspectral and multi-angle, spectropolarimetric remote sensing imagery can be used to constrain gaseous emissions and particulate composition of smoke.
We evaluate the capabilities of HyTES to quantify surface and atmospheric temperature in the vicinity of the fire, and the amounts of ammonia (NH_3) and methane (CH_4) gaseous emissions downwind. We found that the amount of ammonia emitted by fires can be comparable to those emitted from local power plants. AirMSPI data were used to assess the relative contribution of organics, non-organic, and black carbon particles to the total airborne particle emissions, constrained by simultaneous, in situ, aerosol measurements from the Aerosol Mass Spectrometer (AMS), a Scanning Mobility Path Sizer (SMPS), and a Single Particle Soot Photometer (SP-2) flying in coordination on the CIRPAS Twin Otter aircraft. Because TIR spectrometers rely on the thermal emission and thermal contrast between the ground and the target gas, such measurements are less affected by particulate scattering from the smoke. This suggests the potential for joint analysis of the particulate and gaseous emissions within the same BB plume with the HyTES and AirMSPI instruments flying together on the ER-2 platform.

Keywords: HyTES, AirMSPI, ER-2

Bio: Olga Kalashnikova graduated from the University of Colorado, Boulder with a MS degree from Physics Department in 1997 and Ph.D. degree from the Department of Astrophysical, Planetary and Atmospheric Science (APAS) in 2002, and joined JPL in in the fall of 2002 as a National Research Council Postdoctoral Scholar. During her postdoctoral years she developed mineral dust optical models that later were incorporated into MISR operational aerosol retrievals. Presently Olga is a JPL scientist, and has over a decade of experience in the aerosol optical modeling and in studying aerosol properties. Dr. Kalashnikova's career has focused on the aerosol microphysical and optical properties, aerosol remote sensing science, and applications of aerosols and their various effects on the Earth's radiation balance. As a science team member of MAIA and MISR instrument teams, she is working on projects to convert aerosol remote sensing data into information to help public health policy makers and officials make better decisions on the potential impact of climate change on human diseases and health conditions. Recently Dr. Kalashnikova has expanded her research agenda into the area of polarimetry and the sensitivity of new polarimetric instruments to aerosols. She is an aerosol scientist actively participating in the algorithm development for the airborne Multiangle Spectro-Polarimetric Imager (AirMSPI) instrument.

S21.1. Post-fire Tree Mortality: Plant Hydraulic Responses to Heat Plume Exposure

Presenter: Alexandra Lodge, Postdoctoral Research Associate, Texas A&M University
Additional Authors: Dickinson, Matthew, Ecologist, U.S. Forest Service
Kavanagh, Kathleen, Professor & Department Head, Texas A&M University

Tree mortality following wild and prescribed fires is of considerable interest to researchers and managers. While some models exist that can predict post-fire mortality, process-based models that incorporate physiological mechanisms of mortality are still being developed and improved. One hypothesized mechanism of delayed mortality in trees is disruption of water transport in xylem due to atmospheric and xylem heating. For example, a fire's heat plume rapidly increases the vapor pressure deficit (VPD) in the tree canopy, quickly increasing the tension on water in the xylem, potentially leading to cavitation and eventual tree death. Cavitation in the roots could potentially be exacerbated by heating from smoldering of the duff layer. We conducted laboratory experiments examining the degree to which heating branches and roots increases their vulnerability to cavitation. We placed longleaf pine (Pinus palustris) branches and roots in a water bath at realistic exposure temperatures (~54°C) and applied pressure in a cavitation chamber to simulate a range of xylem tension levels (0-5MPa) and measured the subsequent percent loss of conductivity. Resulting vulnerability curves combined with outputs from a plume model were used to parameterize a hydraulic conductance model to assess if trees are likely to experience VPDs sufficient for xylem cavitation.

After comparing the resulting vulnerability curves of heated branches and roots to those pressurized at room temperature, we observed increased vulnerability to cavitation in the heated samples, especially at lower pressures. In branches, P50 (the pressure at which 50% of conductivity has been lost) decreased from -3.6MPa in unheated branches to -2.8MPa when the branches were pressurized while heated to 54°C, a decrease of 22%. Longleaf pine roots appeared to be even more vulnerable to cavitation under heated conditions, experiencing a decrease in P50 of 34% relative to unheated samples. Model results indicate canopy heating substantially increased the canopy area likely to experience conditions resulting in 50% loss of branch conductivity. The height at which branches would be expected to experience considerable cavitation extended 3 - 5 m higher into the canopy than would have been expected based on ambient temperature vulnerability curves. Wind plays an important role in dissipating heat during fires, and our models suggest that wind can help to limit the conditions leading to extreme decline in stem water potentials, thereby helping to protect mature trees. Continued advancement in understanding of the mechanisms leading to delayed mortality will improve models predicting tree mortality.

Keywords: tree mortality, cavitation, vulnerability curves, xylem, water transport

Bio: Alexandra (Sascha) is a postdoctoral research associate at Texas A&M University. She currently researches physiological mechanisms leading to post-fire tree mortality, with a focus on how heat impacts water transport. Her newest project is examining physiology of re-sprouting shrubs following low intensity and extreme prescribed fires. She also teaches an undergraduate Forest Ecology course. She earned her PhD from the University of Minnesota, where her researched focused on invasive plants in forests. Sascha enjoys volunteering as a Texas Master Naturalist and participating in other scientific outreach opportunities.

S21.2. The impact of season of burn on physiology, mortality and growth of sweetgum (Liquidambar styraciflua).

Presenter: Joseph O'Brien, Research Ecologist, USDA Forest Service Center for Forest Disturbance Science
Additional Authors: Ruswick, Stephen, graduate student, University of Georgia Warnell School of Forestry and Natural Resources
Aubrey, Doug, Asisstant Professor, University of Georgia Warnell School of Forestry and Natural Resources
Hiers, Kevin, Fire Scientist, Tall Timbers Research Station

Prescribed fire is a critical management tool in southeastern landscapes, particularly in long needled pine ecosystems in the Coastal Plain and Piedmont. Fire is used to maintain pine forest structure and control competing broadleaved vegetation. Most of the woody broadleaved competition survives repetitive fire by resprouting and there has been much manager interest in reducing stem density. High sweetgum (Liquidambar stryaciflua) density is seen by forest managers as particularly undesirable and difficult to reduce. Conventional wisdom among fire practitioners is that fires applied post bud break in the growing season have a greater impact on sweetgum than dormant season fires. The goal of this study was to compare the impact of fire damage that occurred during the dormant and growing season on sweetgum physiology, growth and survival. We tested the impact of experimental fires on 240 pot grown saplings. Experimental fires were applied in mid-February and mid-May 2017 using Piedmont loblolly pine (Pinus taeda) litter applied at 13.75 Mg ha-1 (6.1 tons acre-1). Both fire treatments resulted in 100% death of aboveground biomass, however, the dormant season treatment resulted in sapling mortality of 22% and the growing season lost 4% though average biomass did not differ when harvested in December 2017. Analysis of patterns of photosynthetic rates and non-structural carbohydrate concentrations are ongoing. Despite the loss of all aboveground biomass during the burns, both burned treatments appear to have higher total biomass at the end of the season than they did at the beginning because of the presence of a larger and more developed root system. Yet, the total biomass of burned treatments was almost half as much of the unburned saplings. To prevent midstory encroachment our results suggest that burning in ways that maximize aboveground mortality of sweetgum rather than applying fire in a particular season is critical due to small seasonal differences in biomass when compared to the absence of burning.

Keywords: season of burn, topkill, prescribed fire, sweetgum, fire damage, fire mortality

Bio: Dr. Joe O'Brien is a research scientist and the Fire Team Leader with the Center for Forest Disturbance Science of the USDA Forest Service Southern Research Station. He received his Bachelors degree from the State University of New York at Geneseo in 1986 and his Master's and Ph.D. from Florida International University in 1997 and 2001. His Master's thesis focused on the ecology and evolution of pine rockland endemic plants. His current research centers on the disturbance ecology of ecosystems, focusing on fire ecology, spatial interactions among wildland fuels, fire behavior and fire effects, as well as the impact of multiple disturbances on terrestrial ecosystems such as fire, hurricanes and sea level rise. He also has extensive experience in tropical ecology and has ongoing research in the Caribbean, Central America and Africa. His has worked in southeastern US and Neotropical fire dependent ecosystems for more than 25 years. He is an adjunct faculty member of the University of Georgia's Odum School of Ecology and the Warnell School of Forestry and Natural Resources.

S21.3. "Pyrohydraulic" Traits That Influence Post-Fire Tree Mortality Or Survival

Presenter: Adam West, Associate Professor, University of Cape Town
Additional Authors: Nel, Jacques, Mr, University of Cape Town
Atkins, Kayla, Ms, University of Cape Town
Midgley, Jeremy, Professor, University of Cape Town
Bond, William, Professor, University of Cape Town

Recent work has shown that hydraulic mechanisms play an important role in post-fire tree mortality. It has been suggested that a suite of 'pyrohydraulic' traits may help to explain why some tree species experience rapid post-fire mortality after low-intensity fires and others do not. We review current knowledge on these potential traits, and explore the role of hydraulic capacitance in conveying fire resistance, using the model system of Cape Proteaceace that vary in their ability to survive fire.

Keywords: pyrohydraulics, hydraulics, plant water relations, transpiration, cavitation, wood, ecophysiology

Bio: Adam West is an ecophysiologist in the Department of Biological Sciences at the University of Cape Town, South Africa, where he researches the intersection of plant water relations, climate and fire.

S21.4. Validating mortality predictions from the First Order Fire Effects Model (FOFEM) model with external data

Presenter: C. Alina Cansler, Research Forester, USDA Forest Service, RMRS-Fire Sciences Lab-Missoula
Additional Authors: Hood, Sharon, Research Scientist, USDA Forest Service, RMRS-Fire Sciences Lab-Missoula
Varner, J. Morgan, Research Scientist, USDA Forest Service, PNW-AirFire Research Team
Phillip J. van Mantgem, Research Scientist, USGS-Geological Survey, WERC-Redwood Field Station

Global wildland fires burn millions of forested hectares annually, affecting biodiversity, carbon storage, hydrologic processes, and ecosystem economic and social services largely through due to fire-induced tree mortality. However, the underlying mechanisms of fire-caused tree mortality remain poorly understood, limiting the ability to accurately predict mortality. Post-fire tree mortality has been traditionally modeled as a function of tree defenses (bark thickness) and fire injury (crown scorch, stem char). The same empirical models are all used to predict fire effects, from the fine-scale software tools for fire management planning, to process-based succession models, and global models of the terrestrial carbon cycle. We conducted a literature search of published data on fire injury and mortality and contacted all corresponding authors requesting collaboration and data sharing. In addition, we posted inquiries on numerous mailing lists about unpublished monitoring data. This effort resulted in 35 responses from state, federal, and university researchers. Our database currently includes data from 21 states collected in approximately 695 wild and prescribed fires of 139 tree species and >640,000 trees. We are using these data to formally validate existing fire-caused tree mortality models. We present initial results validating the FOFEM models for the 10 most numerous conifers in our data base: Pinus ponderosa (n≈ 48,500), Pseudotsuga menziesii (n≈19,000), Pinus contorta (n≈18,500), Abies concolor (n≈17,500), Abies lasiocarpa (n≈6,000),

Calocedrus decurrens (n≈6,000), Picea engelmannii (n≈5,500), Pinus strobiformis (n≈5446), Pinus lambertiana (n≈3,500), Pinus palustris (n≈2,000). Additionally, we will describe planned research testing whether additional climatic predictors—specifically pre- and post-fire climatic water deficit, precipitation, and vapor pressure deficit— can improve mortality predictions. Our results will be incorporated into widely used fire effects models, improving predictions and quantifying uncertainty. Lastly, we provide a roadmap for research needs in empirical and mechanistic modeling, and for true advances in understanding fire-induced tree death.

Keywords:

Bio: Alina is an AFE certified fire ecologist and a Research Forester with the USDA Forest Service who currently studies:

- uncertainty of models predicting post-fire tree mortality
- interactions between disturbance and climate change on alpine treeline ecotones
- fire spatial patterns and their relationship with climatic and biophysical controls

She received her PhD from University of Washington in 2015, and MS from the same institution in 2011. Prior to her graduate studies, she worked for the National Park Service Fire Effects program, leading crews monitoring the effects of prescribed fire on vegetation and fuels in the Colorado Plateau and Pacific Northwest

S21.5. Evaluating and refining the First Order Fire Effects Model for use in hardwood forests of the eastern US

Presenter: Mary Wachuta, Graduate student, University of Missouri
Additional Authors: Blood, Bridget, Graduate Student, Clemson University
Dey, Daniel, Research Forester, USDA Forest Service
Wang, Geoff, Professor, Clemson University

Recognition of the role of wildland fire in forested ecosystems of the eastern US has increased in recent decades, with greater interest in the use of prescribed fire and several recent high-profile wildfires. Prescribed fire is often used for specific regeneration objectives or for targeting certain ecosystem structures but may come at the cost of canopy tree mortality. To effectively plan wildland fire management, land managers in the eastern US require information on fire's effects on tree survival. The First Order Fire Effects Model (FOFEM) is an empirical model developed for western conifers to predict tree mortality following fire using bark thickness, which is derived from tree diameter, and crown scorch estimates. Although eastern hardwood species can be used with the model, prescribed burns in eastern hardwood forests often occur in the dormant season, which makes crown scorch irrelevant. We present preliminary results from a project designed to evaluate and refine FOFEM for use in eastern hardwood forests. Using a dataset compiled from experimental prescribed burn studies throughout the eastern US, we compared FOFEM mortality predictions following one fire to empirical results. There were no relationships between levels of predicted stand-level mortality and measured mortality ($p \geq 0.1704$) across a range of modeled fire intensities. At the stand level, FOFEM predicted approximately 50% mortality across all studies, with observed mortality around 10%, using modeled flame lengths of 0.5 m. Modeled probability of tree mortality varies by species and decreases with tree size based on species-specific, linear equations used to predict bark thickness from tree diameter. We develop new bark thickness equations for common eastern species, accounting for regional differences and non-linear relationships between bark

thickness and tree diameter when appropriate. Using data from the experimental studies, we calibrate FOFEM's logistic regression equation for tree mortality and develop new models with additional variables to improve model accuracy. Results from this work will provide a useful empirical model for fire management planning in eastern forests.

S21.6. Another look at analyzing post-fire tree mortality data

Presenter: J Morgan Varner, Research Scientist & Team Leader, USDA Forest Service Pacific Wildland Fire Sciences Lab
Additional Authors: Shearman, Timothy, Post-Doctoral Scientist, University of Washington
Cansler, C. Alina, Post-Doctoral Scientist, USDA Forest Service Rocky Mountain Research Station
Hood, Sharon M., Research Forester, USDA Forest Service Rocky Mountain Research Station

Understanding the causes of tree death following fire is a major area of research in fire-prone forests, woodlands, and savannas worldwide. Past research has relied overwhelmingly on regression analyses that predict tree mortality as a binary outcome of either living or dead. Beyond this coarse-grained and restrictive framework, this analytical approach has some major shortcomings that beg for advances. Here we review measurements of post-fire injury to the bole, crown, and roots, and then summarize how these multifaceted data are reduced in ANOVA and logistic regression analyses. Using a dataset of longleaf pines (Pinus palustris) burned in prescribed fires in northern Florida, USA, we compare standard ANOVA and logistic regression results with results generated by ordination techniques (PCA and NMS) and boosted regression trees, two alternative and complimentary analyses. Collectively, these analytical procedures tell a similar story, but there are added values to each alternative analysis. Ordination analyses retain a multitude of collinear variables that are often discarded in traditional logistic regression or are lost in model construction. Boosted regression trees are useful in that they do not assume any underlying data structure, can potentially identify complex interactions among terms, and do not over-fit the data. Lastly, we point to examples of analyses that focus on non-binary outcomes, using additional multiple outcomes (as in RandomForests) and continuous measures of tree growth, vigor, and defense as desirable alternatives to analyzing tree response to heating during wildland fires. These results have implications for a suite of studies focused on understanding the mechanisms of post-fire tree growth and mortality.

Keywords: crown scorch, duff consumption, ordination, prescribed fire, tree mortality

Bio: Morgan Varner is Research Scientist and Team Leader of the FERA Team at the Pacific Wildland Fire Sciences Lab in Seattle, WA. His research interests are post-fire tree mortality, fire-vegetation feedbacks, fire and disturbance interactions, and the natural history of fire-prone ecosystems.

S21.7. Short-term Stem Mortality of 10 Deciduous Broadleaved Species following Prescribed Burning in Upland Forests of the Southern US

Presenter: Tara Keyser, Research Forester, Southern Research Station
Additional Authors: McDaniel, Virginia, Forestry Technician, Southern Research Station
Klein, Robert, Fire Ecologist, National Park Service
Drees, Daniel, Fire Ecologist, National Park Service
Burton, Jesse, Refuge Biologist, US Fish and Wildlife Service
Forder, Melissa, Deputy Regional Fire Management Officer, National Park Service

In upland forests of the southern US, management is increasingly focused on the restoration and maintenance of resilient structures and species compositions, with prescribed burning being the

primary tool used to achieve these goals and objectives. In this study, we utilized an extensive dataset comprising 91 burn units and 210 plots across 13 National Park Service lands to examine the relationships between the probability of stem mortality (P(m)) 2 years after prescribed fire and stem size and direct fire effects for 10 common deciduous broadleaved species. Post-fire stem mortality ranged from 6.9% for Quercus alba to 58.9% for Sassafras albidum. The probability of stem mortality was positively associated with maximum bole char height (CHAR) and inversely related to diameter at breast height (DBH) for all 10 deciduous broadleaved species. Model goodness-of-fit varied, with the poorest fit generally associated with fire-tolerant species and best fit generally associated with fire sensitive species. The information presented contributes to our understanding of post-fire stem mortality and may contribute to the development of fire-related stem mortality models following prescribed burning for eastern tree species. Models should be validated with independent datasets across upland forests types to test for spatial relationships before widespread application.

Keywords: logistic regression, oak-hickory forests, mixed pine-hardwood forests, post-fire stem mortality

Bio: Dr. Tara Keyser is a Research Forest with the Southern Research Station in Asheville, NC. She enjoys figuring out and modeling how ecological systems work, especially in regards to fire and its effect on tree survival and regeneration, herbaceous plant diversity, and landscape restoration.

S21.8. Burning down the plot: Evaluating FVS-FFE predictions of tree mortality with post-fire assessment of inventory plots using local fire weather

Presenter: Jason Barker, Research Forester Post-doc, USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis
Additional Authors: Fried, Jeremy, Research Forest, USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis
Gray, Andrew, Research Ecologist, USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis
Monleon, Vicente, Research Math Statistician, USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis

Predictions of fire-caused tree mortality are typically based on observed relationships to bark thickness and degree of crown scorch. However, predictions of immediate and delayed mortality generated by models, such as FVS-FFE, can be inaccurate, possibly owing to a limited range of tree characteristics and fire weather observations underpinning the models and the omission of important factors that influence mortality (e.g., fire effects on soil and boles). Better modeling of fire-caused mortality would be useful in evaluating potential wildfire effects in forest planning.
Our objectives were to validate the accuracy of FVS-FFE mortality predictions, and suggest model refinements. We used data from 535 US Forest Inventory and Analysis (FIA) fire-affected plots in CA, OR and WA that were remeasured 1-2 years post-fire to assess effects on tree crowns, boles, and ground surface substrates. These plots span 105 fires occurring between 2003 and 2015 and modeled in five FVS variants (CA, NC, SO, WC, and WS) using local RAWS weather observations during a 12 hour date-time window during fire is likely to have burned. We devised three scenarios for aggregating RAWS hourly observations which might affect tree mortality: mean hourly RAWS wind speed (W), temperature (T) and fuel moisture (FM) observations in the window (SC1), maximum (Wmax, Tmax, FMmin: SC2), and minimum (Wmin, Tmin, FMax: SC3). SC3 had the best predictive performance (lowest root mean square error) for most FVS variants, closely followed by SC1. The extreme conditions represented in SC2 lead to predictions of over 90% mean mortality in all five

variants whereas the highest observed mean mortality in any variant was 58%, in SO. The over-estimated mortality in SC2 was driven in part by very high projected scorch heights, with the lowest mean scorch height at 60 meters. In contrast, the highest variant-wide mean estimated scorch height for observed trees was 7.8 meters and the highest mean FFE projected scorch height was 5.5 meters in SC3. Work is ongoing to evaluate model predictions of delayed mortality in fire-damaged trees and to incorporate fire-effects on boles and ground substrates in the prediction of tree mortality.

Keywords: FVS-FFE , Mortality , Fire Weather, FIA

Bio: Jason Barker is a post-doc Research Forester with the forest inventory (FIA) program at the PNW Research Station. His focus is on using forest inventory data to improve fire modelling to better assess fire hazards and management of wildfire-affected landscapes. Prior to coming to FIA, he researched the impact of variable retention harvesting (coastal BC) and the impact of wildfire (interior BC) on belowground ecosystems at the University of British Columbia. He plans on extending his current research into prescribed fires and participating in research to improve fire modelling.

S21.9. Pre-fire drought and competition mediate post-fire conifer mortality in western U.S. National Parks

Presenter: Phillip van Mantgem, Research Ecologist, U.S. Geological Survey, Western Ecological Research Center
Additional Authors: Falk, Donald A., Professor, University of Arizona, School of Natural Resources and the Environment
Williams, Emma C., University of Arizona, School of Natural Resources and the Environment
Das, Adrian, Ecologist, U.S. Geological Survey, Western Ecological Research Center
Stephenson, Nathan, Research Ecologist, U.S. Geological Survey, Western Ecological Research Center

Increasing incidence of high-severity fire is a growing concern in many forest types in the western U.S. Intense fire may cause extensive tree injuries and mortality, but environmental and biological stressors may also contribute to mortality. However, there is little evidence showing how the combined effects of two common stressors, drought and competition, influence post-fire mortality. Geographically broad observations of three common western coniferous trees subjected to prescribed fire showed the likelihood of post-fire mortality was related to intermediate-term (10 yr) average radial growth, which was presumably functioning as an index of tree health. Path analysis showed that competition and drought stress prior to fire can be described in terms of its effects on growth, indirectly affecting post-fire mortality. Our results suggest that the conditions that govern the relationship between growth and mortality in unburned stands may also apply to post-fire environments. Thus, biotic and abiotic changes that affect growth negatively (e.g., drought stress) or positively (e.g., growth releases following thinning treatments) prior to fire may influence expressed fire severity, independent of fire intensity (e.g., heat flux, residence time). These relationships suggest that tree mortality may increase under stressful climatic or stand conditions even if fire behavior is moderated.

Keywords: Bayesian analysis; dendrochronology; fire effects; path analysis; prescribed fire; tree health

Bio: Phil van Mantgem is a Research Ecologist with the US Geological Survey, stationed in Arcata, California. Dr. van Mantgem's research interests include forest dynamics, fire ecology and the management of forested ecosystems. He has been studying (and enjoying) forests in the western US since 1995.

S21.10. Mortality of the European beech (Fagus sylvatica L.) after forest fires of varying severity

Presenter: Janet Maringer, , Swiss Federal Institute for Forest, Snow and Landscape Research WSL
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The large forest fires that occurred in the Southern European Alps during the 2003 heat wave affected beech forests in particular. Beech trees are usually not prone to fire, but this could rapidly evolve in the light of global-change-type drought effects. This raises questions about the fire resilience of beech forests and the best post-fire measures to ensure the continued provision of ecosystem services.
The ecophysiology of beech suggests fire sensitivity due to its thin bark and reduced resprouting capability as it ages. However, surface fuels resulting from beech's compact litter layer support low-to-medium fire intensities, that in turn rarely cause stand-replacing events. Fire injured beech trees are more likely to undergo a progressive decaying process that eventually results in a delayed mortality. Therefore, predicting the timing and amount of tree mortality after a forest fire is of paramount importance for post-fire management decisions.
In order to study the mid-term post-fire process in beech forests, we selected and analyzed 36 stands burned between 1970 and 2012 (space for time approach) in Ticino (Switzerland) and Piedmont (Italy). Beech delayed mortality mostly occurred within the first 20 years post-fire in moderate and high- burn severity sites. Contrastingly, in low-severity sites, only small-sized trees died. Both small- and intermediate-sized individuals died in moderate severity burns, while mortality was ubiquitous throughout all diameter classes in high-severity burns.
Logistic regression models show that the survivability of an individual beech tree is a function of the amount of injured bark tissue and the likelihood of wood decaying fungi infecting exposed tissues. At higher elevation, beech trees are less vital and are more likely and more rapidly killed by fire. The delayed beech mortality itself contributes to post-fire beech regeneration by allowing the still surviving trees to produce enough seeds, especially during mast years. Additionally, delayed tree mortality opens the tree canopy gradually, favoring the germination and the growth of beech regeneration.
Consequently, in regards to forest management, seed-producing living trees, snags and logs should be left on the burns because they provide seeds, shade, moisture and nutrients for beech regeneration. In areas where beech forests serve as a protection forest, the accumulation of logs may additionally increase the danger of natural hazards. In such cases we recommend a timely directional felling of dying trees along the contour lines of the slopes before fungi compromise mechanical stability.

Keywords: European beech fire ecology, Fungal infestation, Southwestern European Alps

Bio: Janet Maringer studied Geoecology at the Karlsruhe Institute of Technology (Germany). During her studies she worked on fire ecology in the Insubric region for the Swiss Federal Research Institute for Forest, Snow and Landscape (WSL). During her PhD she investigated the fire ecology of European beech in the Southern Alps. Since 2010 she works as a guest scientist at the WSL and as a lecturer at the University of Stuttgart (Germany).

S21.11. Disease-wildfire interactions impact aboveground and belowground mechanisms of tree mortality

Presenter: Allison Simler, Graduate Student Researcher, University of California, Davis
Additional Authors: Metz, Margaret, Assistant Professor, Lewis and Clark College
Frangioso, Kerri, Researcher, University of California Davis
Meentemeyer, Ross, Professor, North Carolina State University
Rizzo, David, Professor, University of California Davis

Increasing severity and incidence of disturbances that impact forest fuel loads, such as emerging diseases, windstorms, or insect outbreaks, have raised concerns about how pre-fire tree mortality may influence subsequent fire behavior and forest resilience. Sudden oak death (SOD), an emerging exotic forest disease, has caused the mortality of millions of native oak and tanoak trees in the coastal redwood forests of California since the early 1990s, altering forest fuel profiles. These fire-prone forests are dominated by resprouting tree species. Therefore, the impacts of altered fire behavior on system recovery depends on both the processes determining aboveground mortality of individual stems, as well as those determining belowground mortality of entire genets. We established a long-term monitoring network to study the spread and ecological impacts of SOD, and in 2008, a large portion of these forest plots burned in the Basin Complex fires, which impacted both infested and disease-free study areas. This generated a unique natural experiment for investigating the impacts of compounded fire and disease-related disturbances on patterns of fire behavior, aboveground and belowground tree mortality, and subsequent forest recovery.

Our results suggest that SOD-altered fuel loads contribute to increased fire severity, but these effects vary, depending on the stage of disease progression and the structure of associated fuels. Disease-related changes in fire behavior impact patterns of aboveground and belowground tree mortality differently, with variation among species. Abundant standing dead fuels recently-killed by disease are associated with elevated canopy fire severity, which in turn, increases the likelihood of aboveground mortality for redwood stems. By contrast, patterns of belowground mortality for these resprouting species are predominantly determined by tree size and the accumulation of surface fuels in the later stages of disease, which contribute to increased soil heating. However, despite these altered patterns of mortality, in situ survival of resprouters can generate patterns of post-fire vegetative recruitment that are similar to those measured in areas not impacted by disease. Based on these results, we offer suggestions for fuel and disease management, as well as considerations for incorporating resprouting species into our understanding of post-fire tree mortality.

Keywords: Compounded disturbance, forest disease, wildfire, resprouting

Bio: Allison Simler is a PhD student at the University of California Davis. Her dissertation work examines forest pathology, tree physiology, and the impacts of changing forest disturbance regimes on forest regeneration.

S21.12. Fires following bark beetles: factors controlling severity and disturbance interactions in ponderosa pine

Presenter: Carolyn Sieg, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station
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Previous studies have suggested that bark beetles and fires can be interacting disturbances, whereby bark beetle-caused tree mortality can alter the risk and severity of subsequent wildland fires. We used a full factorial design across a range of factors thought to control bark beetle/fire interactions, including the temporal phase of the outbreak, level of mortality, and wind speed. We used a three-dimensional physics-based model, HIGRAD/FIRETEC, to simulate fire behavior in fuel beds representative of 60 field plots across five national forests in northern Arizona. The plots were dominated by ponderosa pine (Pinus ponderosa), and encompassed a gradient of bark beetle-caused mortality due to a mixture of both Ips and Dendroctonus species. Non-host species included two sprouting species, Gambel oak (Quercus gambelii) and alligator juniper (Juniperus deppeana), as well as other junipers and pinyon pine (P. edulis). The simulations explicitly accounted for the modifications of fuel mass and moisture distribution caused by bark beetle-caused mortality. We computed a metric based on live canopy fuel loss to characterize whether bark beetles and fire are linked disturbances, and if they are, if the linkage is antagonistic (net bark beetle and fire severity being less than if the two disturbances occurred independently) or synergistic (greater combined effects than independent disturbances). Both the severity of a subsequent fire and whether bark beetles and fire are linked disturbances depended on the outbreak phase of the bark beetle mortality and attack severity, as well as the fire weather (here wind). Greater fire severity and synergistic interactions were generally associated with the "red phase" (when dead needles remain on trees). In contrast, during the "gray phase" (when dead needles had fallen to the ground), fire severity was either similar to, or less than, green phase fires and interactions were generally antagonistic, but included both synergistic and neutral interactions. The simulations also revealed that the magnitude of the linkage between these two disturbances was smaller for fires occurring during high wind conditions, especially in the red phase. This complexity might be a reason for the contrasted/controversial perception of bark beetle-fire interactions reported in the literature, since both fire severity and the type and magnitude of the linkage can vary strongly among studies.

Keywords: interacting disturbances, bark beetles, Dendroctonus, Ips, Pinus ponderosa

Bio: Dr. Carolyn Sieg is a Research Ecologist with the Rocky Mountain Research Station in Flagstaff, Arizona. The main focus of her research is on the ecological effects of interacting disturbances such as wildland fire and bark beetle outbreaks, and she has been instrumental in supporting the development and application of detailed physics-based fire models such as HIGRAD/FIRETEC.

S21.13. The Effects of Tree, Clump, and Neighborhood Structure on Immediate and Delayed Fire Mortality

Presenter: Sean Jeronimo, PhD Candidate, University of Washington
Additional Authors: Lutz, James A., Assistant Professor, Utah State University
Kane, Van R., Research Assistant Professor, University of Washington

We studied the multi-scale effects of pre-fire forest structure and spatial pattern on immediate and delayed fire mortality in Sierra Nevada mixed conifer forests in California. We asked two questions about vertical and horizontal patterns of structure at individual tree, tree clump, and larger neighborhood scales: (1) What elements of structure at fine scales are good predictors of immediate and delayed tree mortality? (2) What mechanisms of death are related to the important structural predictors of tree mortality? We answered these questions using tree census data from the 25.6 ha Yosemite Forest Dynamics Plot and fifty-five 0.25 ha plots located across the footprint of the Rim Fire in Yosemite National Park, along with an airborne lidar flight of the entire Rim Fire. We mapped and measured trees on our plots and determined which trees died as a result of the fire within one year (immediate) or 2-4 years (delayed). We built a hierarchical Bayesian model using lidar measurements of forest structure and pattern at the scales of individual trees, tree clumps, and larger neighborhoods (~1 ha) to predict probability of survival, immediate mortality, and delayed mortality for each tree. We found that high fuel continuity, exemplified by conditions such as very large clumps and high vertical crown continuity, increased immediate tree mortality. Delayed mortality was related to neighborhood-level stresses such as high canopy cover and low canopy rugosity leading to reduced light use complementarity. Mechanisms of immediate mortality were crown damage related to vertical fuel continuity, and bole damage related to high foliage cover near the ground. Mechanisms of delayed mortality were drought stress related to high local density and bark beetle mortality related to high neighborhood-level density. This study identifies important spatially explicit linkages between pattern and process. Because the model was built using lidar data as the only predictors, it can be used to create contiguous maps of vulnerability to various agents of mortality across Sierra Nevada mixed conifer forests and inform restoration prioritization and objectives.

Keywords: Fire mortality, spatial pattern, lidar, Sierra Nevada

Bio: Sean Jeronimo is a PhD Candidate at the University of Washington and a consultant specializing in analyzing forest landscapes to identify restoration priorities and treatment options. His research focuses on applying airborne lidar data to applications in forest management, forest restoration, and silviculture.

S21.14. After the fire: cascading landscape changes caused by interactions between initial fire severity, forest cover type, bark beetles and climate

Presenter: Cameron Naficy, Post doctoral scientist, University of British Columbia
Additional Authors: Thomas T. Veblen, Professor, University of Colorado at Boulder

Since the mid 1980s, wildfires have burned a large percentage of the dry and mesic mixed-conifer forests of western Glacier National Park (GNP), Montana. One year post-fire remote sensing, aerial and field assessments in GNP document a diverse mosaic of burn severities for these fires, with more than 60% of burned forest area impacted by low to moderate severity effects. Yet recent field observations and preliminary investigation of aerial photo time series indicate that some areas burned at low to moderate severity have experienced significant ongoing mortality for many years following the initial post-fire assessments. Currently, however, the extent of delayed mortality and its causes are not well understood.

In this study, we quantify the spatio-temporal patterns and potential causes of delayed tree mortality for five fires in GNP that burned from 1999-2003 using a combination of remote sensing and field surveys. First, we developed and validated a remote sensing monitoring tool based on high-resolution color aerial imagery that produces tree- to stand-level maps of 6 vegetation types, including: green mature trees, post-fire tree regeneration, red phase trees, grey-phase trees, snags, and non-forest vegetation. Second, we used this tool to produce a time series of the spatial patterns of delayed tree mortality and forest structural change in all five fires from 2005-2013 (e.g. 2-14 years post-fire). Finally, to explore the potential causes of delayed mortality in GNP, we examined relationships between delayed mortality and three factors, including: delayed visual detection of tree mortality, bark beetles, and climatic stress at multiple time scales (both pre- and post-fire). Delayed mortality occurred throughout a substantial portion of GNP, but exhibited significant geographic variation in its magnitude and timing. In some cases, delayed mortality completely transformed landscape conditions since the initial post-fire assessments, while in others it had minimal effects. Lagged senescence of fire-damaged trees (caused by fire-girdling of trees), primary and secondary bark beetles, and climate all influenced the spatio-temporal patterns of delayed tree mortality that we documented. Forest cover composition was a key determinant of the magnitude of delayed mortality and its likely causal mechanisms. This research highlights the complexity of cascading ecological processes that are triggered by fire, provides unique tools for monitoring these changes, and presents novel insights about the mid-term consequences of feedbacks between initial burn severity, post-fire insect outbreaks and multi-temporal climatic stress.

Keywords: remote sensing, delayed post-fire tree mortality, bark beetles, aerial photography, climate stress, disturbance interactions

Bio: Cameron Naficy is a landscape ecologist that uses remote sensing, dendrochronology, and field data to study the response of temperate forest systems across scales (e.g. tree level physiology to large landscapes) to disturbances (especially fire and insect outbreaks), climate change, and human influences. He earned a MSc from the Division of Biological Sciences at the University of Montana and his PhD from the University of Colorado, Boulder. He is currently a post doctoral scientist at the University of British Columbia.

S21.15. Capturing Tropical Forests and Savannas with the Size-Structured Vegetation Model FATES-SPITFIRE

Presenter: Jacquelyn Shuman, Project Scientist, NCAR
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Mortality from fire is in part determined by tree size and species characteristics. This differential mortality has the capacity to impact forest size-structure, composition and succession dynamics, and biomass accumulation over time. Using the Functionally Assembled Terrestrial Ecosystem Simulator (FATES), a demographic size-structured vegetation model, embedded in the Community Land Model, we explore the impact of fire on forest structure and composition within the tropics. The SPITFIRE model, embedded in FATES, tracks fire ignition, spread, and impact based on fuel state and combustion. Mortality is based on the combined effects of cambial damage and crown scorch due to flame height and fire intensity. As a size-structured model, FATES allows for variable mortality based on the size of tree cohorts, with larger cohorts having a lower mortality compared to smaller trees for a fire of the same fire intensity. Variable bark thickness and time to cambial kill are represented and used to characterize the probability of vegetation mortality. Using FATES-SPITFIRE in an application across the tropics we explore the importance of the interaction between climate, vegetation structure and fire behavior within forest-savanna transition areas. Results for simulation scenarios where vegetation is represented by competing tropical trees and grass with variable initial states are compared to assess changes in biomass, fire regime and tree-grass coexistence. Within the forest-grass transition area, if trees are allowed to grow -in the absence of fire- tall enough to escape mortality, then a low-fire state is achieved. If fire is always allowed, grass is dominant in these bi-stable vegetation-fire-climate regimes. Use of a size-structured model, such as FATES, allows for improved representation of the effects of fire disturbance on biomass and vegetation composition in an area expected to be impacted by increased fire due to altered climate and fuel conditions.

Keywords: fire modeling, forest, savanna, tree mortality, size-structure

Bio: Dr. Shuman is motivated by an interest in the complex organization of vegetation and feedbacks between vegetation and the local, regional, and global system. Dr. Shuman's work focuses on the development and application of models for improved representation of vegetation response to altered climate and disturbance. Past research has focused on applications in the boreal forests of Russia and North America, including development of tree mortality due to fire based on tree size and species. Current research involves the development, testing and application of the SPITFIRE module embedded within the size-structured vegetation model FATES with initial application in the tropics.

S21.16. Outstanding Questions about Fire-induced Tree Mortality

Presenter: Sharon Hood, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Lab
Additional Authors: Cansler, C. Alina, Postdoctoral Research Forester, US Forest Service
van Mantgem, Phillip, Research Ecologist, US Geological Survey
Varner, Morgan, Research Scientist & Team Leader, US Forest Service

Each year wildland fires burn millions of forested hectares globally, affecting plant and animal biodiversity, carbon storage, hydrologic processes, and ecosystem services largely through fire-induced mortality of trees. The underlying mechanisms of fire-caused tree mortality remain poorly understood, however, limiting the ability to accurately predict mortality and develop robust modelling applications, especially under novel future climates. Virtually all applications use the same basic empirical modeling approach, developed from a limited number of species, stretching model assumptions beyond intended limits. In this special session on fire-induced tree mortality we reviewed modeling approaches from tree-to-biome scales and heard the latest research about the mechanisms of how fire kills trees and the indirect effects and consequences of mortality. This talk will provide a summary of the outstanding questions and knowledge gaps identified during the session and emerging themes for future research and technology transfer.

Keywords: tree mortality, first order fire effects, modeling, disturbance interactions

Bio: Sharon Hood is a Research Ecologist with the US Forest Service, Rocky Mountain Research Station at the Fire Sciences Laboratory in Missoula, MT. She studies the impact and role of fire in forested ecosystems and focuses primarily on fire-caused tree mortality and fire-bark beetle interactions. Sharon earned a PhD in Organismal Biology and Ecology from the University of Montana, a MS in Forestry from Virginia Tech, and a BS in Forestry from Mississippi State University. https://www.firelab.org/profile/hood-sharon